

## GSadjust v1.0 User Guide

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U.S. Geological Survey  
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## 1. Overview

GSadjust is a cross-platform graphical user interface for least-squares network adjustment of combined absolute and relative gravity surveys. The software is a product of the [USGS Southwest Gravity Program](#). The purpose of GSadjust is to facilitate the efficient processing of field gravity surveys. The program is useful for both synoptic ("snapshot") gravity surveys or surveys of gravity change over time. The program does not perform gravity inversion or otherwise interpret gravity data.

The objective of network adjustment is to determine a single, best-fit gravity value at each station based on all available measurements and their respective uncertainty. Typically the measurements are relative-gravity differences between stations, observed with a relative-gravity meter, and absolute-gravity measurements at individual stations, observed with an absolute-gravity meter. The reason relative-gravity differences are used instead of individual relative-gravity meter observations has to do with the nature of the relative-gravity meter, which is subject to constant, random drift and occasional tares, or offsets. Usually there will be more relative-gravity observations than absolute-gravity observations, and there will be redundant data (that is, more than the minimum data necessary to determine a gravity value at each station).

Although various software packages exist for least-squares network adjustment of survey measurements, gravity networks present unique considerations not present in other methods. First, the primary instrument used in spatially-distributed measurements of the Earth's gravity field is the relative-gravity meter, the zero-point of which drifts randomly and unpredictably. Plotting relative-gravity meter drift over time is considered essential for an accurate accounting of the meter's behavior. Second, it is widely recognized that gravity measurements are susceptible to various errors and "outlier" measurements are not uncommon. Network adjustments often proceed iteratively, including or excluding observations based on the statistical properties of the network. For these reasons the gravity-specific graphical interface GSadjust was developed for network adjustment.

GSadjust builds on the software PyGrav (Hector and Hinderer, 2016). Compared to PyGrav, GSadjust offers enhanced plotting and analysis of relative-gravity meter drift, additional methods for drift correction (beyond inclusion as a parameter in the adjustment), and inclusion of absolute-gravity observations. GSadjust also offers additional functionality for network adjustment, including plotting results, enabling/disabling gravity differences, and calculating the change in gravity over time. GSadjust is written in Python 3 and the PyQt5 graphical user interface framework, and is public domain.

The software and related documentation on these web pages were developed in part by the U.S. Geological Survey (USGS) for use by the USGS in fulfilling its mission. The software can be used, copied, modified, and distributed without any fee or cost. Appropriate credit is requested. The USGS provides no warranty, expressed or implied, as to the correctness of the furnished software or the suitability for any purpose. The software has been tested, but as with any complex software, there could be undetected errors.

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## Installing GSadjust

GSadjust is provided as Python source code and an accompanying Python environment. The download is located at:

<https://code.usgs.gov/sgp/sgp-gsadjust>

On Windows, GSadjust is run by unzipping and running GSadjust\_launcher.bat.

On Mac and Linux platforms, a Python environment must first be created. A requirements.txt file is provided for use with pip for creating the environment. Alternatively, the Windows .zip download can be run inside a Windows virtual machine.

## Data Organization

Data in GSadjust are organized in a hierarchical tree. At the top-most level is the Campaign, which contains all of the data in a project, typically from a particular field area. The user does not generally interact with the Campaign object. Each Campaign has one or more surveys, which represent all of the data combined in a network adjustment. If more than one survey is present, gravity change over time can be calculated. Each survey has one or more loops; the drift correction is specified on a per-loop basis. Each loop has two or more (station) occupations. A station may be occupied one or more times in a Loop. Finally, each occupation has one or more samples. Typically during a relative-gravity measurement several samples are taken (often at a 5 second interval for the Burris meter, or 90 second interval for Scintrex meters).

**The content of the Drift tab is determined by the currently selected Loop, indicated by bold type. Similarly, the content of the Network Adjustment tab is determined by the currently selected Survey, also in bold. The selected Loop or Survey is changed by double-clicking on the Loop/Survey name.**

Name	Date
✓ 2016-06-19	
✓ 0	
✓ LC2 (1)	2016-06-19 13:0
✓ glc-5 (1)	2016-06-19 13:2
✓ glc-8 (1)	2016-06-19 13:4
✓ glc-7 (1)	2016-06-19 13:5
✓ GLC9 (1)	2016-06-19 14:0
✓ glc-10 (1)	2016-06-19 14:1
✓ usbr47 (1)	2016-06-19 14:2
✓ LC2 (2)	2016-06-19 14:5
✓ glc-5 (2)	2016-06-19 15:0
✓ glc-8 (2)	2016-06-19 15:1
✓ glc-7 (2)	2016-06-19 15:2
✓ GLC9 (2)	2016-06-19 15:3
✓ glc-10 (2)	2016-06-19 15:5
✓ usbr47 (2)	2016-06-19 16:0
✓ LC2 (3)	2016-06-19 16:2
✓ USBR48 (1)	2016-06-19 16:5
✓ usbr11 (1)	2016-06-19 17:0
✓ usbr12 (1)	2016-06-19 17:2
✓ usbr45 (1)	2016-06-19 17:3
✓ usbr16 (1)	2016-06-19 17:5
✓ USBR48 (2)	2016-06-19 18:1
✓ usbr11 (2)	2016-06-19 18:2
✓ usbr12 (2)	2016-06-19 18:4
✓ usbr45 (2)	2016-06-19 18:5
✓ usbr16 (2)	2016-06-19 19:0
✓ USBR48 (3)	2016-06-19 19:3
✓ AMTN (1)	2016-06-19 20:1
✓ USBR48 (4)	2016-06-19 20:5
✓ LC2 (4)	2016-06-19 21:1
✓ AMTN (2)	2016-06-19 21:4

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[Surveys](#)

[Loops](#)

[Occupations](#)



## Samples

A sample in GSadjust is a single observation (meter reading) at a station occupation. Usually any particular station occupation consists of several samples taken in relatively quick succession without moving the relative-gravity meter. For the Burris meter, the minimum interval between samples is 5 seconds if ambient noise is sufficiently low. For Scintrex meters, the interval is usually longer, about 60 seconds.

All of the samples at a station are displayed in the Data table, and plotted, on the [Data tab](#).

## Occupations

A (station) occupation includes all of the samples collected during one setup at a station. If a station is visited multiple times during a survey, each visit is a unique occupation. Occupations are shown in the left-hand tree view with the station name, average date/time, and average g. Immediately after the station name, the occupation number is shown in parenthesis. For example, if the station LC2 were visited 3 times during a loop, the entries LC2 (1), LC2 (2), and LC2 (3) would appear in the left-hand tree view:

<input checked="" type="checkbox"/>	LC2 (1)	2016-06-19 13:04:22 2588878.7
<input checked="" type="checkbox"/>	glc-5 (1)	2016-06-19 13:29:31 2589673.4
<input checked="" type="checkbox"/>	glc-8 (1)	2016-06-19 13:42:58 2591919.1
<input checked="" type="checkbox"/>	glc-7 (1)	2016-06-19 13:55:32 2590909.6
<input checked="" type="checkbox"/>	GLC9 (1)	2016-06-19 14:05:47 2593123.4
<input checked="" type="checkbox"/>	glc-10 (1)	2016-06-19 14:17:39 2599628.7
<input checked="" type="checkbox"/>	usbr47 (1)	2016-06-19 14:27:26 2601940.1
<input checked="" type="checkbox"/>	LC2 (2)	2016-06-19 14:50:13 2588898.1
<input checked="" type="checkbox"/>	glc-5 (2)	2016-06-19 15:08:17 2589700.3
<input checked="" type="checkbox"/>	glc-8 (2)	2016-06-19 15:17:54 2591916.4
<input checked="" type="checkbox"/>	glc-7 (2)	2016-06-19 15:28:33 2590910.6
<input checked="" type="checkbox"/>	GLC9 (2)	2016-06-19 15:38:27 2593120.0
<input checked="" type="checkbox"/>	glc-10 (2)	2016-06-19 15:53:10 2599627.9
<input checked="" type="checkbox"/>	usbr47 (2)	2016-06-19 16:02:20 2601939.5
<input checked="" type="checkbox"/>	LC2 (3)	2016-06-19 16:23:50 2588905.2

If samples are excluded by unchecking them in the main data view, the average date/time and g in the tree view is updated automatically, along with the corresponding gravity differences on the Drift and Network Adjustment tabs.

## Loops

A loop in GSadjust refers to all of the data for which a single drift-correction is applied. Traditionally, loops consist of a series of station occupations that start and finish at the same station (e.g., A-B-C-D-E-A). In the context of GSadjust, a loop may actually comprise two loops in the field, e.g. A-B-C-D-E-A-B-C-D-E-A (this double-loop approach is often used in high-precision surveys). Or, stations in a GSadjust loop need not be visited in any particular order; the survey A-B-C-B-A-C-D-E-C-A could also be defined as a single loop. Although often the same drift-correction method will be used throughout a campaign, the method could also vary by loop.

The following drift-correction methods are available:

[None](#)

[Network adjustment](#)

[Roman](#)

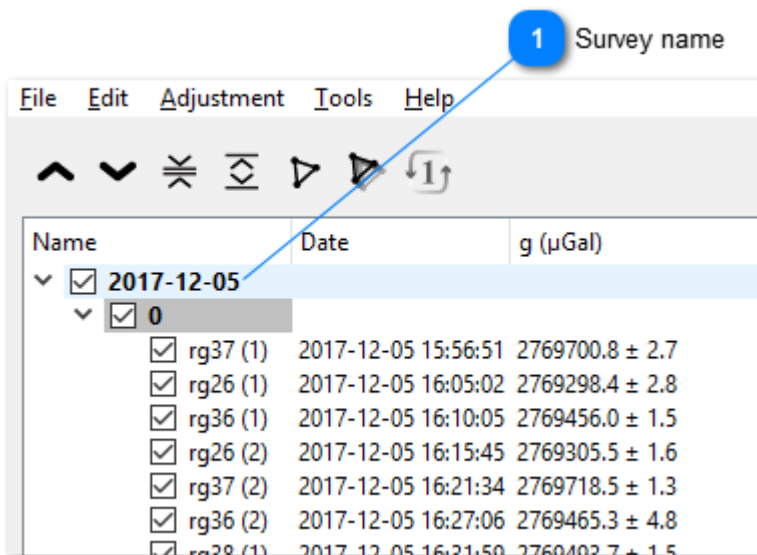
[Continuous model](#)

## Surveys

A survey in GSadjust includes all of the loops (and their respective occupations and samples) that are combined in a single network adjustment. The survey represents a single snapshot in time, although in practice, data may be collected over a period of days to weeks if the gravity field is changing slowly.

Surveys can be renamed using the F2 key. The survey name must be in the form of a date (YYYY-MM-DD), but need not be the same date as the data within the survey. Survey names don't need to be unique in order to carry out network adjustment, but they do if computing gravity change. The survey date is used when calculating [gravity change trends](#).

If results for more than one survey exist, the difference can be calculated using [Compute gravity change](#). This can be used to calculate change over time, or to compare processing styles. For example, The same dataset could be imported twice (first, using Load raw..., then using Append survey to campaign...), and different drift-correction styles assigned to the respective loop in each survey. Compute gravity change would then show the difference.



### Survey name

The name of a survey. Must be in YYYY-MM-DD format. Press F2 to rename.

## Campaign

A campaign in GSadjust includes all of the data in a project. Only one campaign can be opened or analyzed at a time. Campaigns consist of one or more surveys. If there are multiple surveys, gravity change over time can be calculated.

Campaign data, including checked/unchecked status, drift-correction method, and network adjustment options can be saved or loaded using the File > Save workspace... menu command. Campaign data are saved in \*.gsa files.

## Data Tree View

The Data Tree View, at the left side of the window, shows the overall organization of the relative-gravity data. This view allows surveys, loops, and occupations to be activated or deactivated (with check boxes), and for stations to be organized (and re-organized) into loops.

Stations may be deleted, duplicated, or moved to new loops using the [context menu](#), which opens when right-clicking on a station name. Several consecutive stations can be selected by holding down the shift key.

Stations can be renamed by pressing the F2 key when the station is selected in the tree view. A dialog is presented with the option to rename all of the stations in the Campaign, or only the stations in the same Survey or same Loop.

### Selecting surveys and loops

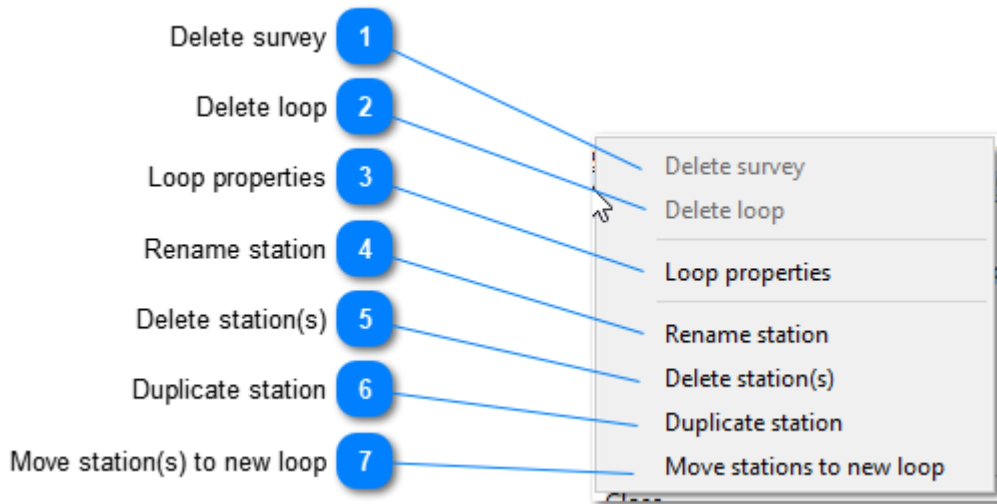
Certain actions and views in GSadjust act on, or show, the currently selected survey or loop. For example, when on the Drift tab, only the currently selected loop is shown, and the selected drift correction method applies only to that loop. On the Adjust tab, only the delta-g's and datum observations for the currently selected survey are shown, and the network adjustment is carried out on those observations.

A survey or loop is selected by double-clicking the respective name in the data tree view. The selected survey or loop is shown in bold. In addition, the selected loop has a shaded gray background.

Name	Date	Occupation
✓ 2016-06-19		
✓ 0		
✓ LC2 (1)	2016-06-19 13:0	
✓ glc-5 (1)	2016-06-19 13:2	
✓ glc-8 (1)	2016-06-19 13:4	
✓ glc-7 (1)	2016-06-19 13:5	
✓ GLC9 (1)	2016-06-19 14:0	
✓ glc-10 (1)	2016-06-19 14:1	
✓ usbr47 (1)	2016-06-19 14:2	
✓ LC2 (2)	2016-06-19 14:5	
✓ glc-5 (2)	2016-06-19 15:0	
✓ glc-8 (2)	2016-06-19 15:1	
✓ glc-7 (2)	2016-06-19 15:2	
✓ GLC9 (2)	2016-06-19 15:3	
✓ glc-10 (2)	2016-06-19 15:5	
✓ usbr47 (2)	2016-06-19 16:0	
✓ LC2 (3)	2016-06-19 16:2	
✓ USBR48 (1)	2016-06-19 16:5	
✓ usbr11 (1)	2016-06-19 17:0	
✓ usbr12 (1)	2016-06-19 17:2	
✓ usbr45 (1)	2016-06-19 17:3	
✓ usbr16 (1)	2016-06-19 17:5	
✓ USBR48 (2)	2016-06-19 18:1	
✓ usbr11 (2)	2016-06-19 18:2	
✓ usbr12 (2)	2016-06-19 18:4	
✓ usbr45 (2)	2016-06-19 18:5	
✓ usbr16 (2)	2016-06-19 19:0	
✓ USBR48 (3)	2016-06-19 19:3	
✓ AMTN (1)	2016-06-19 20:1	
✓ USBR48 (4)	2016-06-19 20:5	
✓ LC2 (4)	2016-06-19 21:1	
✓ AMTN (2)	2016-06-19 21:4	

## Tree view context menu

The Data Tree View has a right-click context menu from which stations can be deleted, duplicated, or moved to a new loop. Multiple stations can be selected by holding down the shift key (these operations won't work when non-adjacent stations are selected, as can be done by holding the control key).



1

### Delete survey

Delete survey

Deletes the currently survey (the highlighted survey; not necessarily the selected survey shown in bold).

2

### Delete loop

Delete loop

Deletes the currently loop (the highlighted loop; not necessarily the selected survey shown in bold).

3

### Loop properties

Loop properties

A text note can be added to each loop. This note is saved alongside the station data when the workspace is [saved](#).

4

### Rename station

Rename station

A station can be renamed by right-clicking it and selecting Rename station. Or, press the F2 key. A dialog is shown that gives the option to rename just the selected station occupation; all instances in the current loop; all instances in the current survey; or all instances throughout the campaign.



5

### Delete station(s)

Delete station(s)

Deletes one or more selected stations (stations must be adjacent in the tree view).  
To restore deleted stations, data must be reloaded from a text file.

6

### Duplicate station

Duplicate station

Duplicates the selected station. This feature is useful when [creating loops](#).

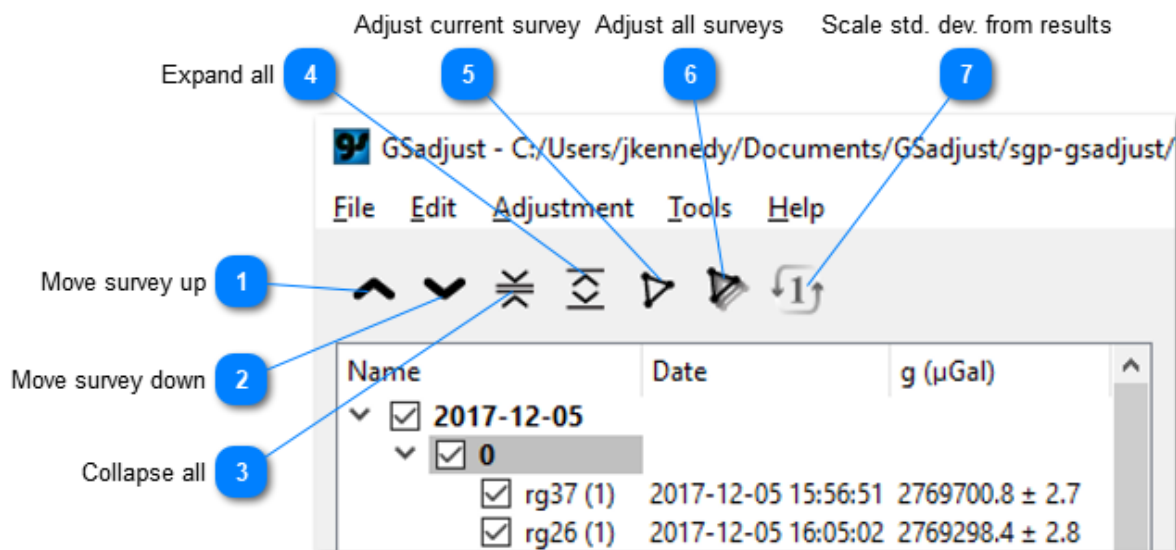
7

### Move station(s) to new loop

Move stations to new loop

[Creates a new loop](#) with the selected stations.

## Tree view toolbar



The tree view toolbar modifies the survey order, expands and collapses the view, and provides shortcuts for survey adjustment.

### 1 Move survey up



This button moves the currently selected survey upward (before the previous survey in the tree view).

### 2 Move survey down



This button moves the currently selected survey downward (after the next survey in the tree view).

### 3 Collapse all



This button collapses all surveys and loops.

### 4 Expand all



This button expands all surveys and loops.

### 5 Adjust current survey



This button adjusts the currently selected survey (also available on the Adjustment menu).

**6 Adjust all surveys**



This button adjusts all surveys (also available on the Adjustment menu).

**7 Scale std. dev. from results**



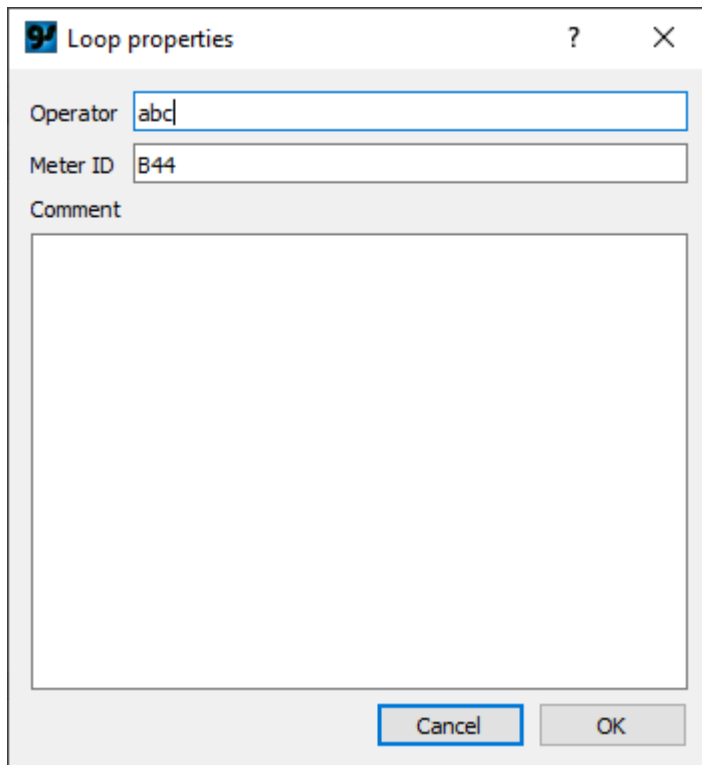
This button scales the standard deviation of the gravity differences (SD for adj. on the Network Adjustment tab) so that the standard deviation a posteriori approaches 1. Only the gravity-difference standard deviations are scaled; the datum observation standard deviations are not.

## Survey and Loop metadata

Information about each Survey and Loop can be displayed by hovering the mouse over the Survey or Loop name in the Tree view. For example,

Name	Date	g (μGal)
▼ <input checked="" type="checkbox"/> 2017-12-05		
▼ <input checked="" type="checkbox"/> 0		
<input checked="" type="checkbox"/> Loop: 0		2769698.4
<input checked="" type="checkbox"/> Drift method: none		2769296.0
<input checked="" type="checkbox"/> Meter: B44		2769453.6
<input checked="" type="checkbox"/> Operator: abc		2769303.8
<input checked="" type="checkbox"/> Comment:		2769716.4
<input checked="" type="checkbox"/> Source: B44_2017-12-05.txt		2769463.8
<input checked="" type="checkbox"/> rg38 (1)	2017-12-05 16:31:59	2769491.9
<input checked="" type="checkbox"/> rg39 (1)	2017-12-05 16:40:46	2769433.1
<input checked="" type="checkbox"/> rg38 (2)	2017-12-05 16:45:30	2769488.7

By right-clicking the loop name and selecting Loop properties, the operator, meter, and comment metadata can be edited:



Loop properties

Operator

Meter ID

Comment

Comments are saved with the workspace.

## Workflow

The GSadjust workflow generally proceeds in three steps:

1. Import and organize data ([Data tab](#))
2. Correct relative-gravity meter data for instrument drift ([Drift tab](#))
3. Network adjustment ([Network Adjustment tab](#))

In step 1, data are loaded from the text file output by the relative-gravity meter (Scintrex or Burris). For each station occupation, individual readings can be deselected as needed, using the time-series plot of gravity readings as a guide. For larger surveys, stations may be grouped into loops as needed ("loop" refers to the set of station occupations for which a common drift correction is applied).

In step 2, loops are corrected for drift. Drift-correction options are:

- None
- Include in network adjustment
- Roman method (interpolate)
- Continuous model

Each loop can be assigned a unique drift method.

In step 3, the drift-corrected gravity differences are adjusted using the least squares method. Datum observations ("fixed" stations, i.e., those with a known gravity value) are assigned and/or loaded from a text file. Adjustment statistics are evaluated and, if needed, gravity differences can be excluded as outliers.

For all but the simplest surveys, it is usually worthwhile to complete all 3 steps before deselecting individual samples in the [Data Table](#), or before spending much time on the drift correction. The reason is that errors in station name, tide correction, loop organization, etc. are not uncommon. It is more efficient to reveal these errors, by carrying out the network adjustment, before fine-tuning the individual occupations. For example, in the instance of station name errors, the imported data text file should be updated, and the file re-imported.

## 2. Quick-start tutorial

GSadjust is distributed with [sample data sets](#) for training purposes. Two fully-processed examples are available:

1. [Simple example](#): this synthetic dataset includes 5 stations, 11 relative-gravity observations, and no absolute-gravity observations.
2. [Complete example](#): this real-world dataset includes 38 stations, 271 relative-gravity observations, and 8 absolute-gravity observations.

## Simple example

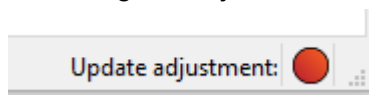
This synthetic dataset consists of a single survey with a single loop consisting of 5 stations, 11 relative-gravity observations, and no absolute-gravity observations. In GSadjust terminology, in which "loop" refers to all of the observations for which a single drift correction is applied, the loop consists of two visits to each station, with the first station visited 3 times. The station order is 1-2-3-4-5-1-2-3-4-5-1.

### 1. Import data

Select "Load raw Burris data..." from the File menu. Open Test1.txt in the test\_data/synthetic directory. Loop 0 is created.

In this synthetic example, there is only a single "observation" at each station. Therefore, the plots on the data tab show only a single point instead of a time series. Each station name can be selected in the tree view to show the associated data on the Data tab.

Note that the "Update adjustment" status indicator in the bottom right is highlighted, indicating the adjustment have not yet been performed:



### 2. Apply drift correction

Switch to the Drift tab by clicking "Drift". GSadjust displays a time series of the drift, with one line per station, starting at 0 for each station (see [Drift tab](#) for details).

In this example, drift is initially negative, as indicated by downward-sloping lines, but gradually becomes positive, as indicated by upward-sloping lines.

Four options are available for drift correction. The "None" and "Network adjustment" options do not change the plot. Selecting the "Roman" option updates the plot with vertical dashed lines to show the delta-g's, and a new table is shown in the bottom right with the average delta-g's. The "Continuous model" option displays an additional plot that shows the drift rate over time.

For now, proceed with the "Continuous model" option. Select "1st order polynomial" for the drift model type and "Constant" for the behavior at start/end.

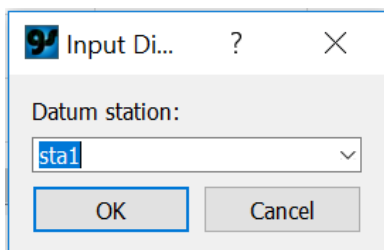
### 3. Populate delta table

Switch to the Network Adjustment tab. From the Adjustment menu, select "Populate delta table - all surveys" (because there is only one survey and one loop, the other Populate... options will have the same effect). The delta-g's from the Drift tab are copied to the table on the Network Adjustment tab.

### 4. Add datum observation

For this simple example, there are no absolute-gravity observations. Instead, an arbitrary datum is applied to one of the stations.

From the Adjustment menu, select "Add datum observation..." A dialog appears with a drop-down list of stations:



Select "OK" to select the default, sta1 (any other station is also acceptable, but will produce different results).

An arbitrary gravity value and standard deviation, 50,000 +/- 5  $\mu$ Gal, is applied to sta1 and shown in the datum observations table. This value can be changed by double-clicking it in the datum observations table, as can the standard deviation, measurement height, and gradient. The datum date is an arbitrary string and has no effect on the results.

## 5. Perform adjustment

From the adjustment menu, select "Adjust current survey" (because there is only one survey, "Adjust all surveys" will have the same effect). Alternatively, click the button on the [tree view toolbar](#), or use the keyboard shortcut Ctrl+2. The adjustment will proceed using the default [Numpy](#) method.

Adjustment results (a single, best-fit gravity value at each station) are shown in the adjusted station values table at the upper right. Adjustment statistics are shown in the table at the lower right. Note that the [Chi-test](#) was accepted, and the [a posteriori standard deviation](#) is near one. These indicate the adjustment was acceptable. The a posteriori standard deviation less than one indicates that the estimated standard deviation of the observations was higher than the adjustment results indicate. The delta-g standard deviations can be automatically scaled using the "Scale std. dev. from results" menu command or the corresponding button on the [Tree view toolbar](#). After doing so the "SD for adj." value shown on the delta-g table is lowered to 2.7  $\mu$ Gal, and the standard deviation a posteriori is 1.0

Note that the "Update adjustment" status indicator in the bottom right is no longer highlighted.

For this simple example, the tools for evaluating results are limited. A histogram of delta-g residuals ("Plot residual histogram", or Ctrl-H) is uninformative owing to the small number of observations. Because there is only one datum observation, the adjusted value matches the observed value exactly and the "Plot adjusted datum vs. measured" plots only a single value of zero.



## 6. Export results

From the Tools menu, select "Write tabular data". A comma-separated value (.csv) file with the filename "GSadjust\_TabularData\_..." followed by the date is written to disk with the values shown in the adjusted station values table. Optionally, the results table can be highlighted by clicking in the upper-leftmost cell, then right-clicking and selecting Copy to clipboard. Data can be pasted into Excel or a text file.

From the Tools menu, select "Write metadata text". A text file (.txt) with the filename "GSadjust\_MetadataText\_..." is written to disk with a narrative summary of the adjustment. This text can be used in a [metadata file](#).

From the Tools menu, select "Write adjustment summary". A text file (.txt) with the filename "GSadjust\_Summary\_..." is written to disk showing the observations used in the adjustment and the results of the adjustment. This file includes all of the information necessary to re-create the adjustment results.

## 7. Save the workspace

To facilitate future re-processing or evaluation, the workspace should be saved by selecting "Save workspace as..." from the File menu. A file save dialog is shown; save with an appropriate filename. A ".gsa" extension is added if not specified. The workspace is written to file in JSON format. This file can be re-loaded into GSadjust using the "Open workspace..." command on the File menu. It should not be edited outside of GSadjust.

## Complete example

This real-world dataset includes 38 stations and 8 absolute-gravity measurements. Two surveys were carried out, each with two relative-gravity meters.

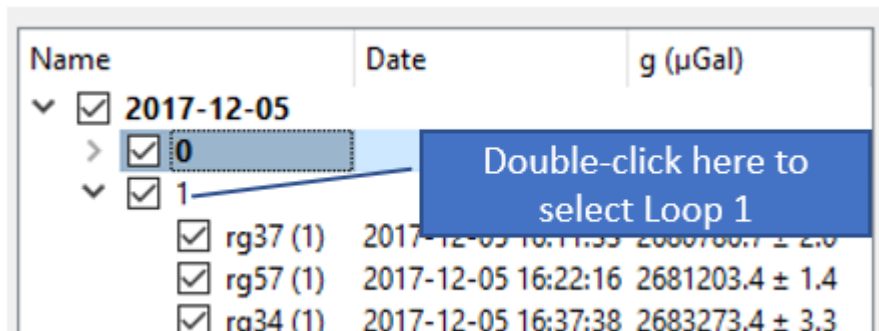
Two saved workspaces are provided. The file `gsadjust\test_data\field\Burris\complete_workspace1.gsa` is worked through step 4 below (Earth tide correction). The file `gsadjust\test_data\field\Burris\complete_workspace2.gsa` is worked through step 7 below. These files can be loaded to skip ahead in the tutorial.

### 1. Import relative-gravity data

First, [load data](#) from the first meter (serial number B44) used on the first survey. Select "Load raw Burris data..." from the File menu. Open `B44_2017-12-05.txt` in the `test_data/field/Burris` directory. Survey 2017-12-05 and Loop 0 are created and selected.

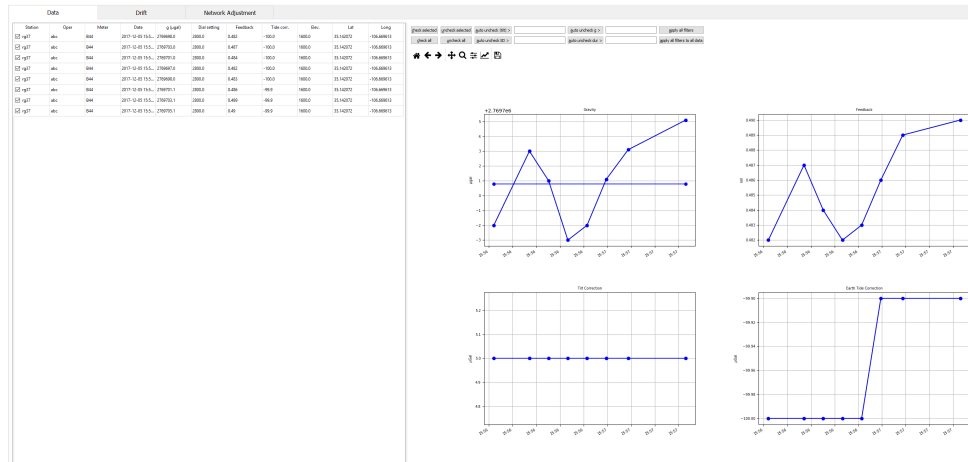
In this real-world example, each station occupation consists of several samples. The gravity time series (and feedback, tilt correction, and Earth tide correction time series) are shown in the table and plots on the Data tab. The respective data for each station can be shown by selecting the station in the left-side tree view.

Next, load data from the second meter (B108) used on the first survey. Select "Append loop to current survey..." from the File menu. Open `B108_2017-12-05.txt` in the `test_data/field/Burris` directory. A dialog appears to select the meter type; choose "Burris". Loop 1 is created *but not selected*. Double-clicking "1" will update the contents of the Drift tab.



Load the data from the second survey in a similar manner. First, add the data from meter B44 (`B44_2018-02-27.txt`) using "Append survey to campaign...". A dialog appears to select the meter type; choose "Burris". Survey 2018-02-27 and Loop 0 are created *but not selected* (you may need to click the "expand" arrow next to the survey name to show the loops). **Double-click Survey 2018-02-27 to select it.** Finally, append the data from meter B108 (`B108_2018-02-27.txt`) using "Append loop to current survey...". A dialog appears to select the meter type; choose "Burris". Loop 1 is created but not selected.

The samples collected at each station occupation are displayed on the table and plots on the Data tab:

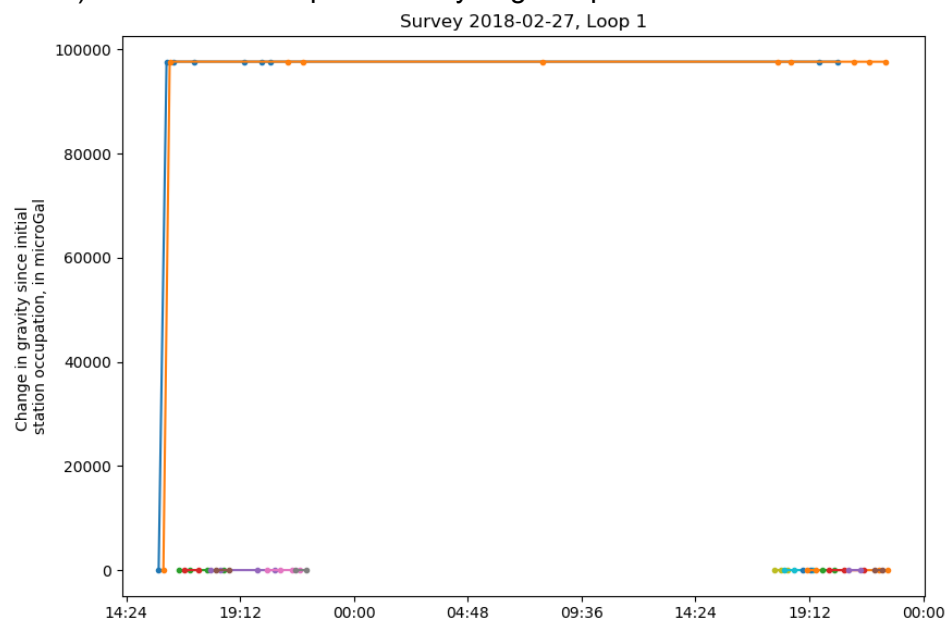


For now, don't worry about which samples are included at each station (controlled by the check boxes in the table). These can be fine-tuned after successful adjustment results are obtained.

## 2. Edit data

Two items need correcting in the raw data before loading: two stations were collected on the wrong dial setting, and one station must be duplicated so it can be included in two different loops.

The stations collected with the wrong dial setting are obvious from the drift plot. With the Drift tab displayed, double click 2018-02-27 Loop 1 to select it (data from meter B108). Note in the drift plot the very large step in the drift:

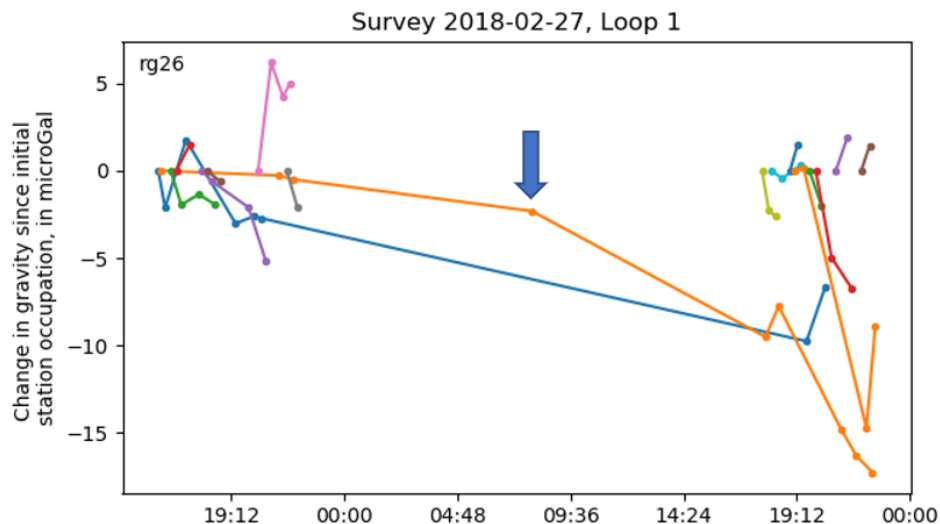


This is caused by an incorrect dial setting for the first two stations. Its also apparent by the large difference in gravity for the first two occupations at rg37 and rg26 in the data tree view:

✓	1	
✓	rg37 (1)	2018-02-27 15:46:13 2582098.9 ± 2.3
✓	rg26 (1)	2018-02-27 15:58:12 2581688.9 ± 3.8
✓	rg37 (2)	2018-02-27 16:06:10 2679777.6 ± 1.8
✓	rg26 (2)	2018-02-27 16:14:08 2679363.4 ± 2.3
✓	rg37 (3)	2018-02-27 16:23:49 2679775.5 ± 3.0
✓	rg57 (1)	2018-02-27 16:38:03 2680191.2 ± 1.4
✓	rg34 (1)	2018-02-27 16:52:12 2682268.4 ± 3.2

In this case, these first two station occupations should be deleted. Select them (with rg37 highlighted, hold down the shift key and click rg26) and right-click to bring up the [context menu](#). Select Delete station(s). The drift plot is updated.

Now, on the updated drift plot, note the single occupation at station rg26 in the center of the survey, at about 8:00 (click on the orange line to show the station):



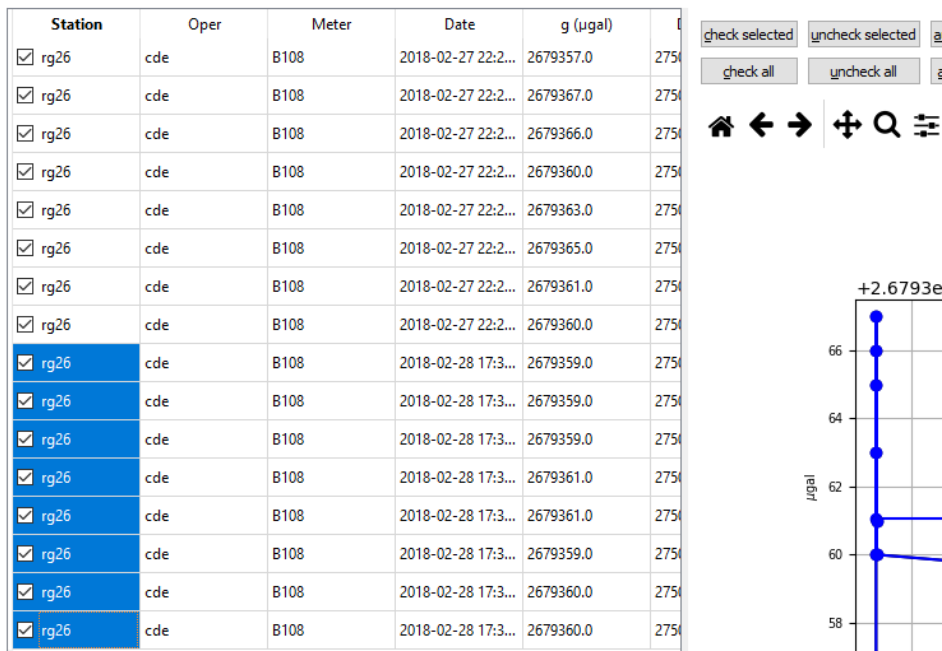
This happens in the common situation when the last station of the day is observed as the first station the following day. Station rg26 was occupied last on 2018-02-27, and first on 2018-02-28. The point on the plot represents the average time midway between these occupations. To see this, display the Data tab and select the rg26 occupation at 7:57:

✓	rg26 (4)	2018-02-27 21:50:50 2679362.9 ± 1.0
✓	rg43 (2)	2018-02-27 22:00:11 2680940.6 ± 1.8
✓	rg26 (5)	2018-02-28 07:57:57 2679361.1 ± 2.7
✓	rg52 (1)	2018-02-28 17:43:27 2680086.2 ± 1.6
✓	rg26 (6)	2018-02-28 17:51:59 2679353.9 ± 3.9

First, we'll [duplicate](#) rg26 by right-clicking and selecting Duplicate station. Now there are two identical rg26 occupations in the data tree view:

☒ rg43 (2) 2018-02-27 22:00:11 2680940.6 ± 1.8  
☒ rg26 (5) 2018-02-28 07:57:57 2679361.1 ± 2.7  
☒ rg26 (5.1) 2018-02-28 07:57:57 2679361.1 ± 2.7  
☒ rg52 (1) 2018-02-28 17:43:27 2680086.2 ± 1.6

Select the first one, "rg26 (5)". With the Data tab displayed, select (by shift-clicking) all of the samples on 2018-02-28:



Next, click the "uncheck selected" button at right. The plot and mean gravity value are updated. In this example, the two occupations have very similar gravity values but that is not always the case. Repeat with the "rg25 (5.1)" occupation, unchecking the samples from 2018-02-27. The contents of the tree view are updated to reflect the checked samples:

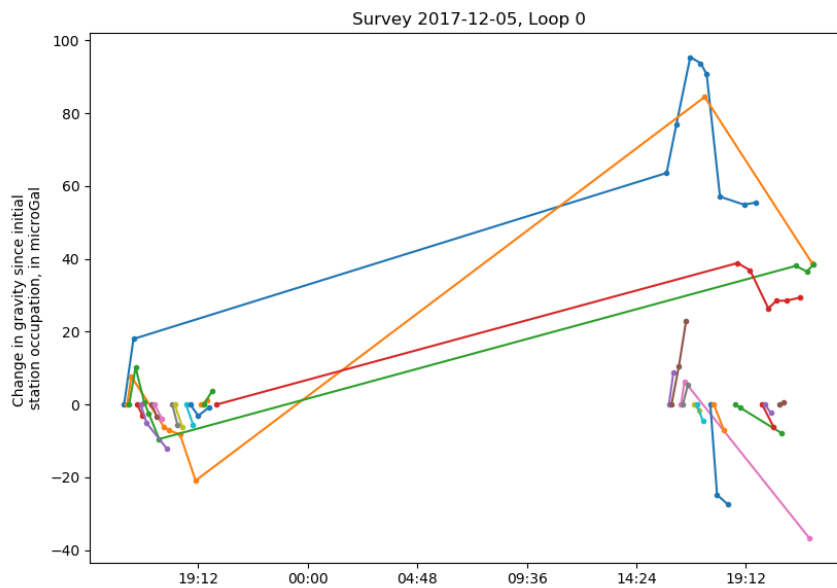
☒ rg43 (2) 2018-02-27 22:00:11 2680940.6 ± 1.8  
☒ rg26 (5) 2018-02-27 22:21:01 2679362.4 ± 3.2  
☒ rg26 (5.1) 2018-02-28 17:34:57 2679359.9 ± 0.8  
☒ rg52 (1) 2018-02-28 17:43:27 2680086.2 ± 1.6

Now, on the Drift tab, the central point has been replaced by two points on 2017-02-27 and 2018-02-28.

### 3. Organize data

Next, each loop needs to be [subdivided](#) into smaller loops. Viewing the Drift tab shows a long gap in the data for each of the surveys (double-click the loop name to show drift for that loop).

For example, Survey 2017-12-05 Loop 0 shows two groups of data separated by an overnight period without data:



Because these two periods, representing two consecutive days of field work, have unique drift behavior, they should be divided into separate loops (a loop denotes the group of stations for which a single drift correction is applied). The loops can be separated in one of two ways. Generally the easiest is to apply a time-based threshold, by which gaps in data greater than a specified value are moved to a new loop. Do this using the "Divide selected loop..." option on the Edit menu. A dialog is shown where the time threshold can be specified; the default value of 8 hours works well to divide surveys on successive days.

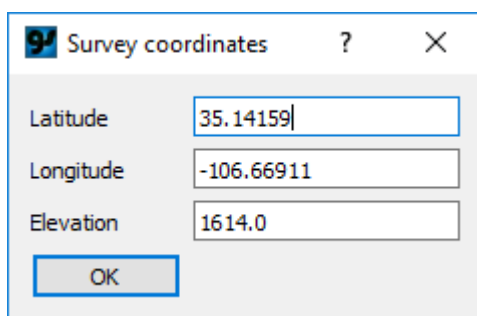
After clicking OK in the threshold dialog, a new loop (Loop 2) is created under the 2017-12-05 survey. Select each loop in the 2017-12-05 survey (by double-clicking the loop name) with the Drift tab visible to see how the new loops were created

An alternate way to divide loops is to select the stations in the tree view (by shift-clicking or dragging across a group of stations) to be moved to a new loop and selecting the "Move station(s) to new loop" command on the [right-click context menu](#).

Divide all of the remaining loops using the same time-based threshold. Before dividing, each loop must be selected by double-clicking the loop name.

#### 4. Update tide correction

Although the Burris relative-gravity meter (and Scintrex meters) apply a tide correction, for this study the Agnew model provides a more accurate correction. To [update the tide corrections](#), from the Edit menu select Tide correction, then choose the "Agnew" option. A dialog is displayed to enter coordinates:



A dialog box titled "Survey coordinates" with a question mark icon and a close button. It contains three input fields: "Latitude" with the value "35.14159", "Longitude" with the value "-106.66911", and "Elevation" with the value "1614.0". An "OK" button is at the bottom.

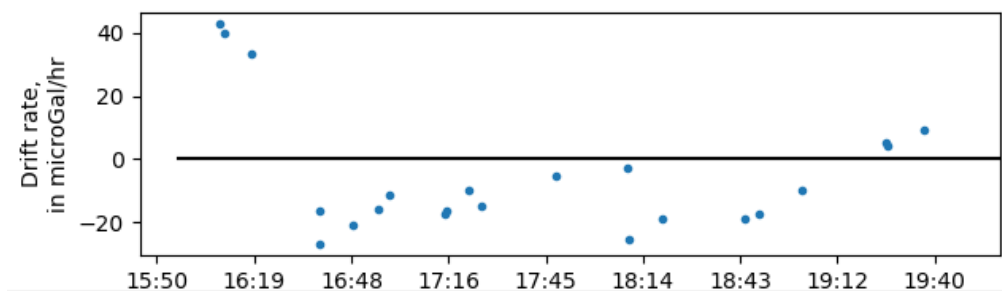
The dialog is pre-populated with the mean latitude and mean longitude of the observations. After selecting OK, the meter-supplied tide correction is removed and the new tide correction applied. To revert to the meter-supplied tide correction, select Tide correction from the Edit menu, then "Meter-supplied".

Note that the Agnew tide correction is reported to 0.1  $\mu\text{Gal}$ , compared to the Burris internal tide correction which is reported to 1  $\mu\text{Gal}$ .

## 5. Apply drift correction

Next, click on the [Drift tab](#). The plot title should show Survey 2017-12-05, Loop 0. If a different survey is shown, double-click "0" under the 2017-12-05 survey to select Loop 0:

The drift plot shows a short period of positive drift (upward-sloping lines) followed by generally negative drift (downward-sloping lines). This change in drift rate is visible when the "Continuous model" drift correction method is [selected](#):



For now, select the Roman drift correction method. The plot is updated with vertical dashed lines to indicate how the gravity differences (delta-g's) are calculated. The Roman method is a good all-purpose method that accommodates periods of inconsistent drift.

Also apply the Roman drift correction method to the remaining loops by double-clicking each loop in turn and selecting the Roman method.

## 6. Populate delta table

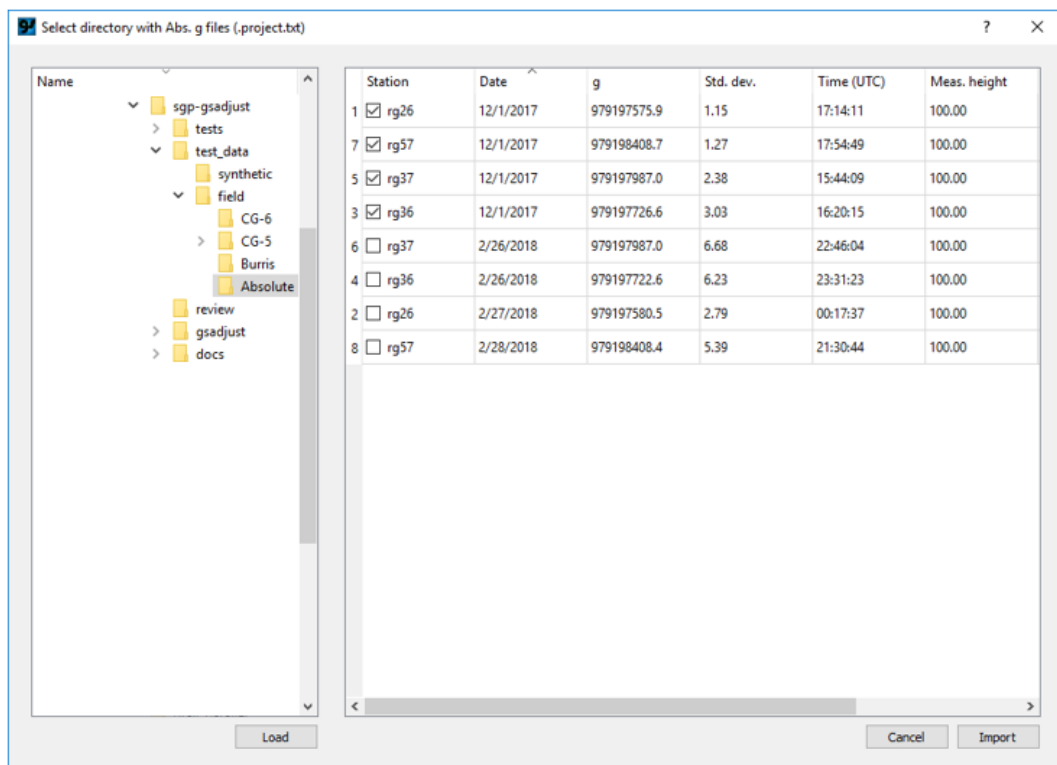
Next, show the [Network Adjustment tab](#), which should be empty. First we want to copy the gravity differences (delta-g's) from the Drift tab to the Network Adjustment

tab. When the delta-g's are copied, they retain their link to the data in the tree view, but not to the delta-g's on the Drift tab. That is, if the gravity value at a station occupation changes (for example, if samples are unchecked on the Data tab), the delta-g(s) that include those stations are automatically updated on the Network Adjustment tab. Any changes on the Drift tab (for example, changing the drift correction method) are not reflected on the Network Adjustment tab until the delta table is [updated](#).

To populate the delta table for all surveys, select the "Populate delta table - all surveys" command on the Adjustment menu. Later, when iteratively updating the observations used in the adjustment (for example, testing a single loop), the other "Populate delta table" commands are useful.

## 7. Import datum observations

The [datum observations](#) can be absolute-gravity measurements stored in \*.project.txt files generated by 'g' software used with Micro-g Lacoste absolute-gravity meters. First, make sure the 2017-12-05 survey is selected (if not, double-click on it to select). Select "Import abs. g from project files..." from the Adjustment menu. In the dialog, navigate to the gsadjust\test\_data\field\absolute directory. Click the "Load" button at bottom left. The relevant details from the .project.txt files in the absolute directory are shown:



	Station	Date	g	Std. dev.	Time (UTC)	Meas. height
1	<input checked="" type="checkbox"/> rg26	12/1/2017	979197575.9	1.15	17:14:11	100.00
7	<input checked="" type="checkbox"/> rg57	12/1/2017	979198408.7	1.27	17:54:49	100.00
5	<input checked="" type="checkbox"/> rg37	12/1/2017	979197987.0	2.38	15:44:09	100.00
3	<input checked="" type="checkbox"/> rg36	12/1/2017	979197726.6	3.03	16:20:15	100.00
6	<input type="checkbox"/> rg37	2/26/2018	979197987.0	6.68	22:46:04	100.00
4	<input type="checkbox"/> rg36	2/26/2018	979197722.6	6.23	23:31:23	100.00
2	<input type="checkbox"/> rg26	2/27/2018	979197580.5	2.79	00:17:37	100.00
8	<input type="checkbox"/> rg57	2/28/2018	979198408.4	5.39	21:30:44	100.00

Sort by Date (click on the column header), then check the 4 observations from 2017-12-01. Click import and the observations will appear on the datum table.

Select the 2018-02-28 survey and import the absolute-gravity observations from February 2018.

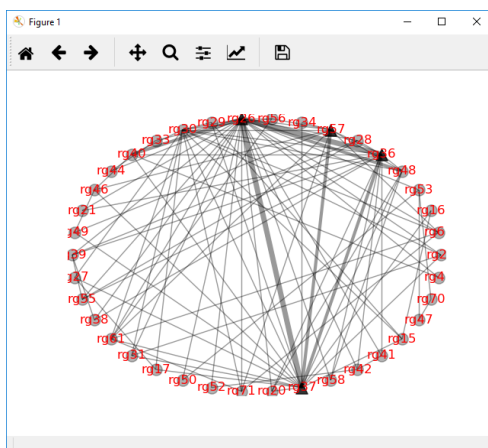


*Shortcut: The saved workspace complete\_example2.gsa is saved at this point.*

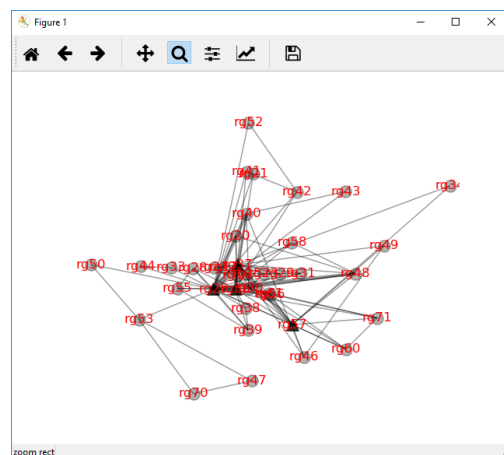
## 8. Perform adjustment

Now, sufficient data are present to perform the network adjustment. Network graphs can be viewed in circular or map-view layout using the two commands on the Tools menu:


Tools menu > Network graph - circular



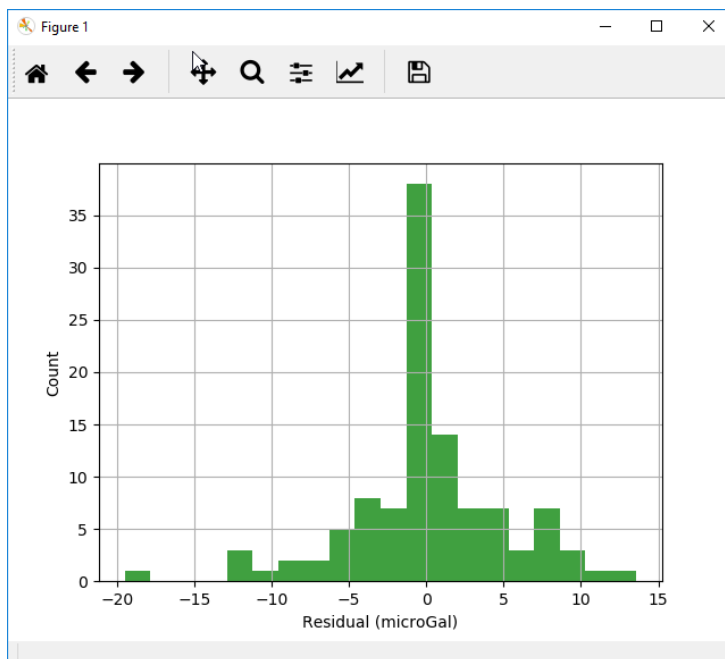
Tools menu > Network graph - map view



In the network graphs datum (or absolute-gravity) stations are shown as black triangles and relative-only stations are shown as red circles.

To perform the network adjustment, select "Adjust all surveys" from the Adjustment menu, or click the corresponding button on the tree-view toolbar: . The Adjusted station values and Least-squares statistics tables on the Network Adjustment tab will update. These tables are unique to each Survey; by changing the selected survey (double-clicking in the tree view) the tables will update.

View the adjustment residuals using the "Plot residual histogram command" on the Adjustment menu (close the network graph window first if it is still open):



## 9. Change adjustment options

Although the network adjustment was successful and results were obtained, note in the statistics window (bottom right) that the Chi-test was rejected for both surveys and the "SD a posteriori" statistic is greater than 1, meaning that the uncertainty (standard deviation) of the input observations was underestimated (that is, the observations don't fit together as well as the measurement uncertainty suggests). Several steps can improve the results:

First, note that the standard deviation of many of the delta-g's is very low (sort the Relative-gravity differences table by clicking on the "Residual" column heading). The standard deviation will be zero when using the Roman drift correction method if only one delta-g exists between a particular station pair. Low standard deviations cause these measurements to be matched nearly exactly (residuals are close to zero), while measurements with high standard deviation are weighted much less.

When surveying with relative-gravity meters, there is a practical lower limit on how accurately delta-g's can be observed. The delta-g uncertainty includes the uncertainty from both station occupations, uncertainty from the drift corrections, and uncertainty from unaccounted tares. A minimum lower limit for delta-g standard deviation can be specified in the [Adjustment options](#) dialog on the Adjustment menu:

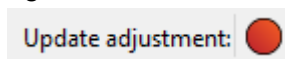
**9 Network adjustment options** ? X


☐ Standard deviation multiplier: pre-minimum 1.0000  
☐ Standard deviation multiplier: post-minimum 1.0000  
☐ Add to standard deviation: pre-minimum 0.0  
☒ Minimum standard deviation 3.0  
☐ Calculate relative meter calibration coefficient  
☐ Specify calibration coefficient

	Meter	Calibration factor
1	B44	1.0
2	B108	1.0

Significance level for global model test 0.05

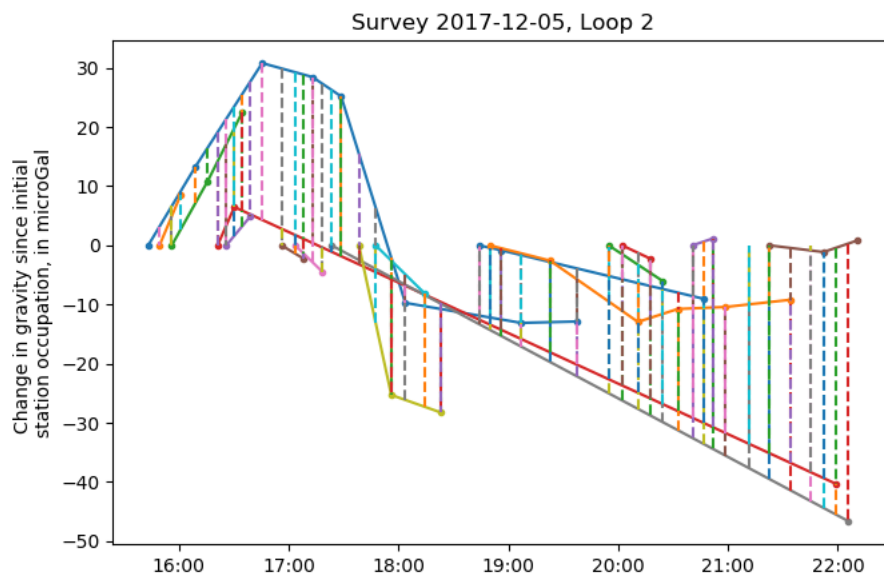
Check the box next to "Minimum standard deviation", keep the default value of 3.0, and click "Apply to all surveys". Now in the Relative-gravity differences table the "SD for adj." column shows the larger of 3 or the uncertainty determined from the drift adjustment. Note that the input data for the adjustment has changed and the adjustment results are now outdated, as shown by the status indicator in the bottom right:



Repeat the adjustment (  ) to update results and clear the status indicator.

## 10. Update drift correction

After the adjustment the Chi-test was still rejected for the 2017-12-05 survey, but accepted for the 2018-02-27 survey. While viewing the 2017-12-05 survey on the network adjustment tab, note that several of the residuals are fairly large: less than -10 or greater than 10. Sorting the Relative-gravity differences table by Loop shows that most of the large residuals are associated with Loop 2. Double-click on loop 2 to select it and display the Drift tab:




Note the two long segments (red and grey) that stretch across nearly the entire survey, corresponding to stations rg30 and rg26 (click the line to show the station name at the top left of the plot). Using the Roman method, relative-gravity differences are calculated between these two stations and nearly every other station, with the drift rate interpolated over the 5+ hour period between repeat occupations. Based on repeat occupations at the other stations, it appears during this 5+ hour period there was only a short period of high drift (around 17:30 to 18:00), or possibly a tare, and much lower drift during the remainder of the period.

To remove this spurious drift estimate, a maximum time threshold between stations can be specified by checking the box to the right:

☒ Max. time between repeats (hh:mm)

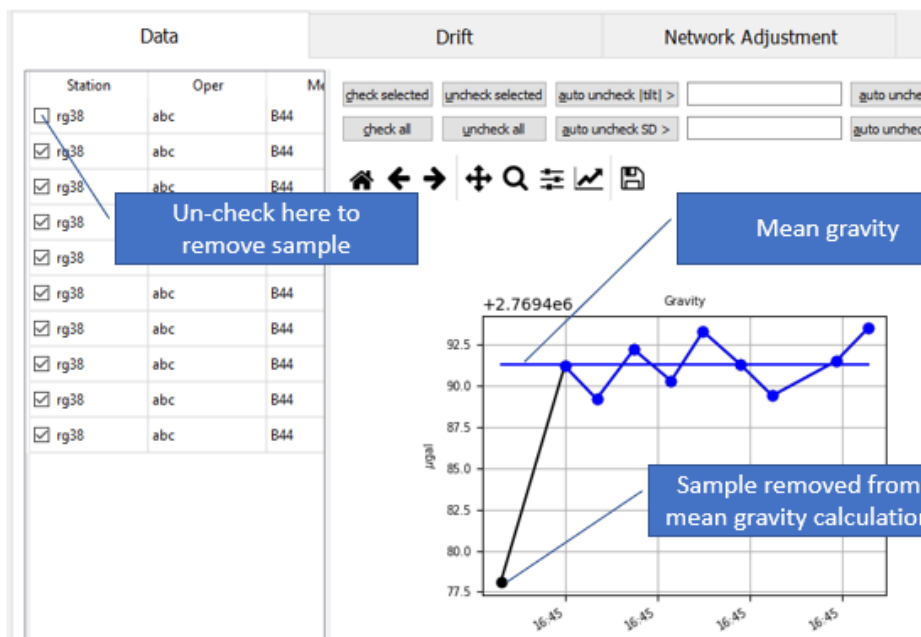
Now, any station occupations separated by the specified threshold will be ignored in the drift calculation (for either the Roman or Continuous drift-correction options).

The delta-g's on the Network Adjustment tab are automatically updated.

Repeat the adjustment (  ) to update results and clear the status indicator. Now the Chi-test is accepted for both surveys and the SD a posteriori statistic is close to 1, indicating the standard deviation estimated from the observations is close to the standard deviation estimated by the network adjustment.

## 12. Fine-tune the individual station values

Next, the estimate of the average gravity reading at each station occupation can be improved by deactivating samples as needed. With the Data tab displayed, go through each station in the left-hand tree view and deselect samples as needed by unchecking them in the table on the Data tab. For example, with the Burris meter often the first 1 or 2 readings appear to be outliers:



As samples are checked or unchecked, changing the mean gravity value, the gravity differences on the Drift tab and the Network adjustment tab are updated automatically. However, the network is not automatically re-adjusted.

After improving the estimate of mean gravity at all of the stations, repeat the adjustment for all surveys ( ). You can also experiment with changing the [drift correction method](#) or [adjustment options](#).

### 13. Update adjustment results

Once final station values are determined, appropriate drift corrections made for each loop, and an initial adjustment performed, the standard deviations should be scaled so that the standard deviation a posteriori statistic is close to one. This can be accomplished by the "Scale std. dev. from results" command on the Adjustment

menu, or the button on the [Tree View toolbar](#). This scales the standard deviation of each delta-g ("SD for adj." column in the [relative-gravity differences](#) table). See the [network adjustment options](#) page for more information about how the scaling is applied.

### 14. Calculate gravity change over time

If more than one survey exists, the change in gravity over time can be calculated with the [Compute gravity change](#) command on the Tools menu. This shows a table of gravity change over time in the first n-1 columns, and cumulative change in gravity since the first survey in the next n-1 columns (where n is the number of surveys). If a station is not present in a survey the null value -999 is shown.

Three options are available for further analysis. First, a time-series of gravity change relative to the first observation at each station can be shown by clicking the Plot button in the gravity change table. Second, if station coordinates are available, a map view of gravity change can be shown by clicking the Map button. Finally, a more complete table of results which includes gravity values, uncertainties, coordinates, and gravity change converted to meters of water using the 1-d horizontal-infinite slab approximation ( $41.9 \mu\text{Gal} = 1 \text{ m}$  of free-standing water) can be shown by clicking the Show full table button.

## 15. Export results

Finally, results can be [exported](#) in several ways:

- 1) The adjusted station values on the network adjustment tab can be highlighted (clicking the upper left corner highlights all cells), copied by right-clicking on the table, and pasted into Excel or a text file as tab-delimited data. Similarly, results can be copied and pasted from the [gravity change table](#).
- 2) Adjusted station values can be exported to a comma-delimited text file using Write tabular data on the Tools menu.
- 3) A narrative summary of the adjustment, including statistics and the number of observations, can be written to a text file using [Write metadata text](#) on the Tools command. The resultant text is suitable for describing the data-processing steps in a metadata file to accompany the adjustment results.
- 4) A complete list of all data used in the adjustment can be written to a text file using Write adjustment summary on the Tools menu.

## Data sets included with GSadjust

Several example data sets, both synthetic data and real-world field data, are included with GSadjust. The synthetic data are generated from known station gravity values with random noise, drift, and calibration error added. These data are useful for testing whether different processing methods are capable of recovering the known station gravity values. The field data were collected using different relative and absolute gravity meters. The "true" station gravity values are unknown.

### Synthetic data

Five synthetic datasets are provided with GSadjust in the `sgp-gsadjust\test_data\synthetic` directory. These test datasets include a range of drift types, number of relative-gravity meters, calibration errors, and survey designs. The details of each are shown in the table below. Random error is applied to the synthetic data, which can be used to test whether GSadjust recovers the known station gravity values through network adjustment. The parameters defining these datasets (drift rate, calibration error, observation error) can be modified in the Excel file `GSadjust_TestData.xlsx`, and the GSadjust input data regenerated. For example, two test datasets could be generated for an expected level of relative-gravity meter precision, and evaluated as to whether the adjustment can resolve the simulated gravity change. Additional test datasets (for example, with tide error) could also be generated from the examples provided.

The synthetic data are simulated as one sample per station. Therefore, when viewed in GSadjust the plots on the [Data tab](#) will only show a single point rather than a time series.

Test case one is used in the [simple example](#).

Test case	Drift	Number of relative-gravity meters	Calibration error	Survey type
1	None	1	no	Loop
2	Linear	1	no	Loop
3	Linear	1	yes	Loop
4	Linear	2	yes	Loop
5	Nonlinear	1	yes	Dense-network

### Field data

Field data are provided from ZLS Corporation Burris relative-gravity meters and from Scintrex CG-5 and CG-5 relative-gravity meters.

#### Burris data

These data were collected using two ZLS Corporation Burris meters. Two surveys were carried out, one in December 2017 and one in February 2018. The coordinates have been changed randomly by about 0.15 degree, so if the tide model is updated it will not

correspond to the exact study area. There is corresponding absolute-gravity data for this data in the field\Absolute directory. These data are used in the [complete example](#).

#### Scintrex CG-5 data

These data were distributed with the original release of PyGrav (Hector and Hinderer, 2016).

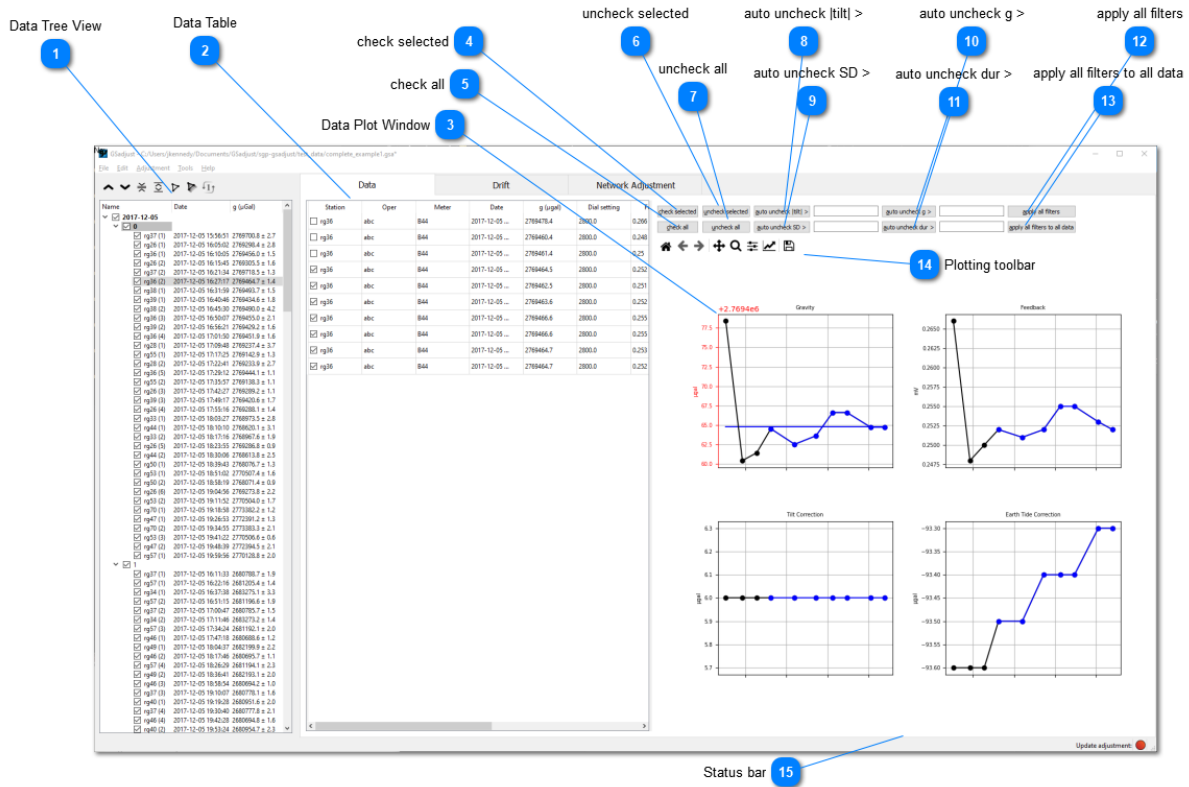
#### Absolute data

These data were collected using a Micro-g Lacoste, Inc. A-10 absolute-gravity meter. Data were collected in conjunction with the relative-gravity data in the Burris directory. Four stations were occupied with the A-10 during each of the relative-gravity surveys. The gradient was measured at each station and is used to transfer the gravity value from the A-10 measurement height (about 71 cm) to the land surface.



### 3. Data tab

The data tab provides functions for viewing samples at each station occupation and tools for selecting/deselecting samples based on quality criteria.



#### 1 Data Tree View

The [Data Tree View](#) shows the hierarchical structure of the data set, and is common to all tabs.

#### 2 Data Table

- The Data Table shows all of the samples for a particular station occupation. The columns vary depending on the meter type:

Burris	Scintrex
Station name	Station
Operator	Gravity (g)
Meter number	Standard deviation
Date/time	Tilt x
Gravity (g)	Tilt y
Dial setting	Temp
Feedback	Duration
Tide correction	Rejected
Elevation	Elapsed time

Latitude                      Date/time  
Longitude

### 3 Data Plot Window

The Data Plot window shows graphically the gravity value and accompanying data for a particular station occupation. For the Burris meter, the plots shown are gravity, feedback, tilt correction, and Earth tide correction. For the Scintrex meter, the plots shown are gravity, Tilt X, Tilt Y, and standard deviation.

On the gravity plot, if the y-axis range exceeds 20  $\mu\text{Gal}$ , the axis is shown in red. Otherwise the y-axis range is 20  $\mu\text{Gal}$  and the axis is shown in black.

### 4 check selected

check selected

Rows in the Data Table can be selected using the mouse; multiple rows can be selected by holding down the shift or control keys. If unchecked rows are selected, this button checks them.

### 5 check all

check all

Checks all rows in the Data Table.

### 6 uncheck selected

uncheck selected

Rows in the Data Table can be selected using the mouse; multiple rows can be selected by holding down the shift or control keys. If checked rows are selected, this button unchecks them.

### 7 uncheck all

uncheck all

Unchecks all rows in the Data Table.

### 8 auto uncheck [tilt] >

auto uncheck [tilt] >

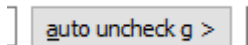
Unchecks observations with  $\text{abs}(\text{tilt})$  (X or Y) greater than the specified value. Used only for Scintrex data.

9

**auto unchecked SD >**

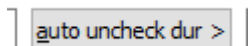
Unchecks observations with standard deviations greater than the specified value. Used only for Scintrex data.

10

**auto unchecked g >**

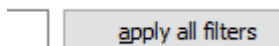
Unchecks observations with g values that differ from the mean by more than the specified value.

11

**auto unchecked dur >**

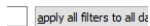
Unchecks observations with durations longer than the specified value. Used only for Scintrex data.

12

**apply all filters**

Applies any thresholds for tilt, g, standard deviation, or duration to all samples of the current station occupation.

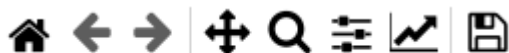
13

**apply all filters to all data**

Applies any thresholds for tilt, g, standard deviation, or duration to all stations in the Campaign.

WARNING: This can be very slow for large datasets.

14

**Plotting toolbar**

This is the standard Matplotlib (plotting utility for Python) tool bar. More info is under the [Plot toolbar](#) heading.

15

**Status bar**

The [status bar](#) at the bottom of the window shows messages about the current processing status.

## Loading data

Burriss or Scintrex data can be loaded with the respective "Load raw..." menu commands on the File menu (see [Data Formats](#) for details on each file type.). These open a standard file open dialog, allowing the user to select a file. The file to be opened is the raw data file output by the gravity meter software.

For both meter types, the corrected gravity reading and the tide correction are read from the input file. If [a different tide correction is applied](#), the meter tide correction is removed from the corrected gravity reading and the new correction applied.

In a campaign (workspace) with existing data, surveys can also be created by [appending a data file](#) to create a new survey.

## Data Formats

GSadjust can import data exported by ZLS (Burris) and Scintrex (CG-3, CG-5, CG-6) relative-gravity meters. Data from each of these meters is written in a space delimited text format.

When a data file is initially loaded, the appropriate menu option should be selected ("Load raw CG-3/CG-5 data", "Load CG-6 data", or "Load raw Burris data"). If additional data are loaded using the "Append survey to campaign" or "Append loop to survey" menu options, a dialog will be shown allowing the user to specify the data format.

### ZLS (Burris)

Burris data is a space- or comma-delimited output file from the ZPARSE.exe program run on a Windows computer (if using the Palm field computer), or output from UltraGrav2 software (if using the Android field computer). The file read by GSadjust is the "single mode data" file.

The Burris file may be hand-edited to, for example, remove data from previous surveys. Care should be taken if the file is edited in Excel, which will typically result in a change in the date format (from YYYY-MM-DD to MM/DD/YYYY). The date format must be changed back to the original format if this is the case.

### Scintrex (CG-3 and CG-5)

Scintrex data files are space delimited. The Scintrex file will typically have a header with information such as the meter operator and the serial number.

### Scintrex (CG-6)

Scintrex CG-6 data can be logged internally in a format similar to CG-3/CG-5 data, or logged to a handheld field computer in [Tsoft](#) format. There is a specific menu import command for each format.

### CSV

In addition to the meter-specific formats described above, generic data can be imported from a comma-delimited file. The columns must be in the following order:

STATION, LAT, LON, ALT, GRAV, SD, TILTX, TILTY, TEMP, TIDE, DUR, REJ, TIME, DEC.TIME, TERRAIN, DATE

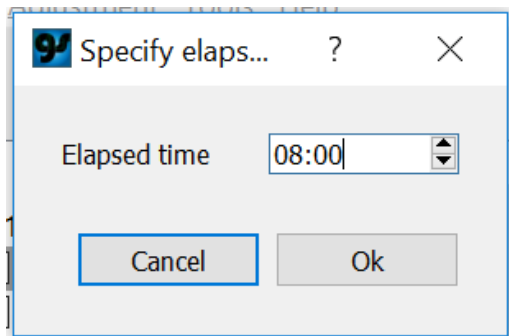
### Absolute gravity data

Absolute gravity data can be imported from [text files](#) or directly from the [\\*.project.txt files](#) written by the 'g' processing software used by Micro-g Lacoste, Inc. gravity meters.

## Creating loops

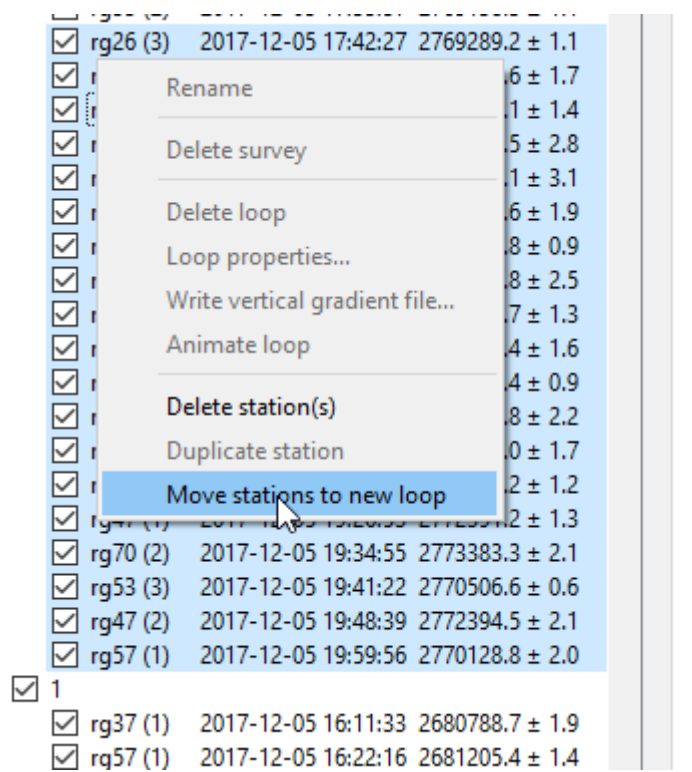
[Loops](#) in GSadjust (the group of stations for which a single drift correction is applied) are created after a file is loaded. Alternatively, in a campaign (workspace) with existing data loops can be appended from individual data files using the "Append loop to current survey..." command on the File menu.

Loops can be created based on a time-based threshold or by selecting the stations to move to a new loop. To use a time-based threshold, use the "Divide selected loop..." command on the Edit menu. A dialog appears where one can specify the time threshold:



If there is a gap between stations longer than the elapsed time specified, the data before the gap will retain the original loop name and data after the gap will be put in a new loop. If there are multiple gaps longer than the threshold (for example, if data were collected over several days with gaps each night) multiple loops will be created.

To create a new loop within the current Survey from selected stations, select the first station, hold down shift, then select the last station. Then, right click to show the [Data Tree View Popup menu](#), and select Move stations to new loop. A new loop is created.



## Duplicate stations

If the same station is occupied as the last station on one day, and the first station the following day, all of the samples are grouped into a single station occupation. This results in a station with an assigned time midway between the two individual setups, and an averaged g value. To more accurately represent the survey, the occupation should be duplicated (by selecting it and using the right-click [context menu](#)). Then, the original occupation (observed first) should have all of the samples collected on the second day unchecked in the [Data Table](#), and the duplicate station should have all of the samples collected on the first day unchecked. This should be done prior to using the "Divide selected loop into subloops..." command.



## Appending data

After a data have been loaded, either by importing data or loading a previously saved workspace, additional data can be appended. This is useful for ongoing projects where intermediate analysis takes place before data collection is complete; as additional data are collected they can be appended as a new loop or survey.

There are three append options on the File menu: either a new loop can be appended to the currently selected survey, a new survey can be appended to the campaign, or an entire workspace saved from a previous GSadjust session can be appended. The first option is useful primarily for adding a new day's data for a survey currently in progress. The second option is useful primarily for appending data after a repeat gravity survey has been carried out. After appending a new survey to a campaign, data can be separated into loops as needed.

## Selecting data

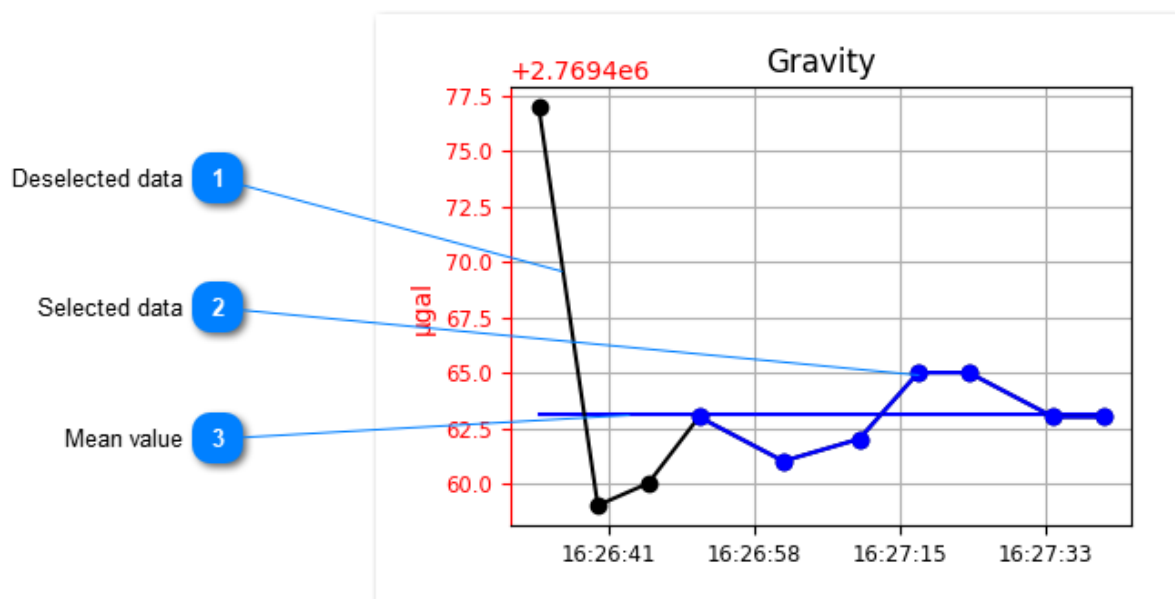
Data are selected or deselected using checkboxes. In the Data tree view, surveys, loops, or stations may be selected or deselected. In the station table, individual samples may be selected or deselected. By default, all of the samples, stations, loops, and surveys are selected after importing.

Individual samples at a station occupation may also be selected/deselected using the criteria described on the [Data tab](#) page.

### Data plots

In the station data view, the currently selected samples are shown with blue markers. Deselected samples are shown with black markers. The mean value of the selected data is shown as a horizontal solid blue line.

On the Gravity plot only, the y-axis color is changed to red if the range is larger than  $\mu\text{Gal}$ . Otherwise, the range is 20  $\mu\text{Gal}$  and the axis is shown in black.



1

### Deselected data

Data are deselected by unchecking the text box in the Station table. Deselected data are shown in black.

2

### Selected data

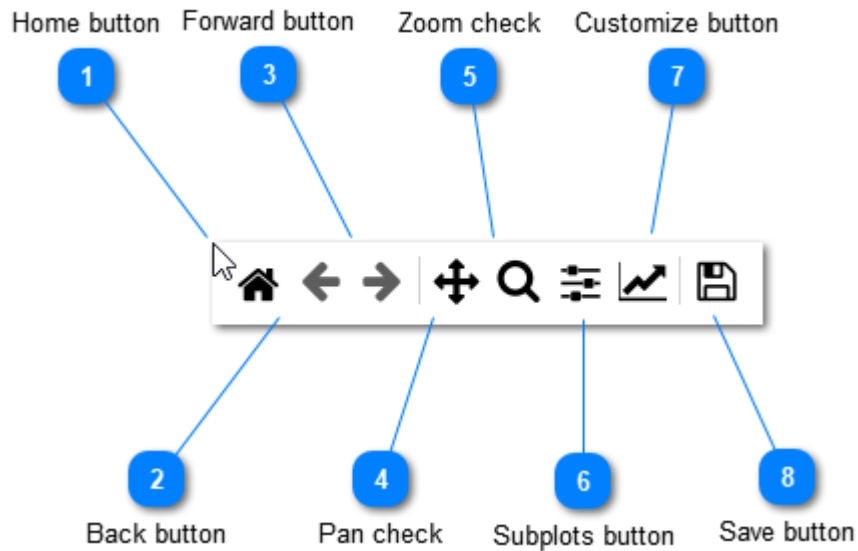
Data are selected by default. Selected (checked) data are shown in blue.


### **3 Mean value**


The mean (average) of the selected data is shown as a horizontal solid blue line.

## Plot toolbar


This is the standard Matplotlib (plotting utility for Python) tool bar.



**1 Home button**  
  
Reset original view

**2 Back button**  
  
Back to previous view

**3 Forward button**  
  
Forward to next view

**4 Pan check**  
  
Pan axes with left mouse, zoom with right

**5 Zoom check**



Zoom to rectangle

6

#### Subplots button



Configure subplots

7

#### Customize button



Edit curves line and axes parameters

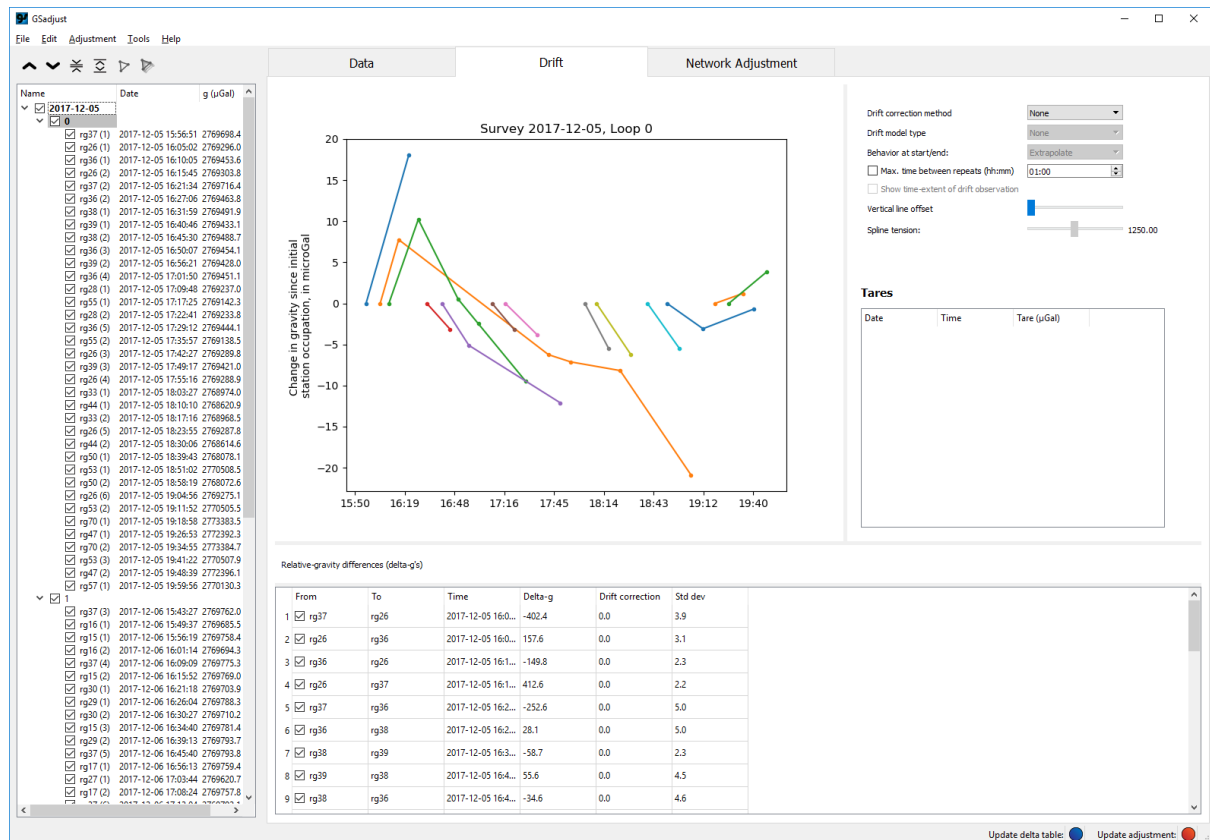
8

#### Save button



Save the figure

## 4. Drift tab



The drift tab provides functions for plotting drift and applying drift corrections. Four options exist:

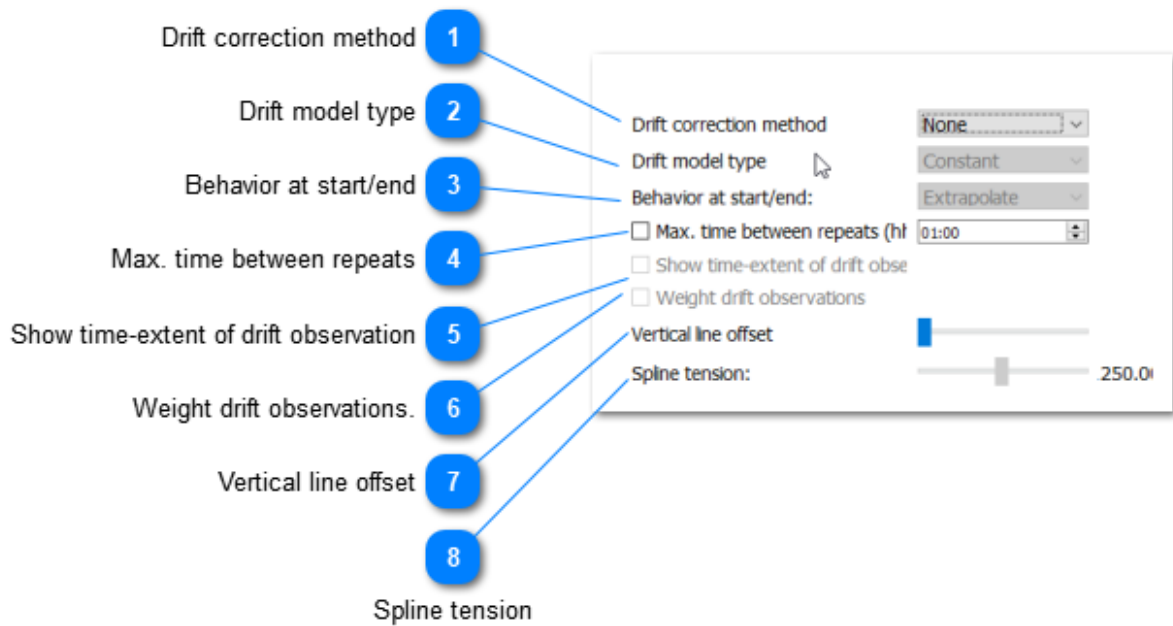
- [No drift correction](#)
- [Network-adjustment drift correction](#)
- [Roman method](#)
- [Continuous method](#)

The drift correction method is selected in a dropdown box on the right side of the drift window. The plots and tables shown on the drift tab can vary depending on the drift correction method. For the no correction, network-adjustment, and Roman method options, a plot of gravity change vs. time at each station is shown. For the continuous method option, an additional plot of drift observations vs. time is shown. For the no correction, network-adjustment, and continuous method options, a single table of gravity differences (Delta-g's) is shown, along with relevant details. Delta-g's are only calculated between successive stations. For the Roman method option, two tables are shown: one with all possible Delta-g's, and another with average Delta-g's (where more than one Delta-g exists between two stations).

## Plotting options

Several options exist on the right-hand side of the drift tab for controlling the drift method used and the appearance of the drift plots. Some of the options (drift model type, behavior at start/end, show time-extent of drift observation, and spline tension) are only available when the [Continuous method correction](#) is used.

Clicking on a line in the main plot window will show the station name at the top left of the plot.



### 1 Drift correction method

Drift correction method

Drop down box to specify drift correction method: none, network adjustment, Roman, or continuous. This option is set per survey and can affect the calculated delta-g values.

### 2 Drift model type

Drift model type

Continuous drift model only: Specify either a polynomial or spline model of continuous drift. This option is set per survey and can affect the calculated delta-g values.

### 3 Behavior at start/end

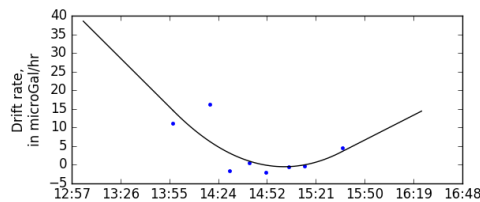
Behavior at start/end:

Continuous drift model only: The model only extends to the first and last drift observation, which is a smaller time-span than the first and last station occupation

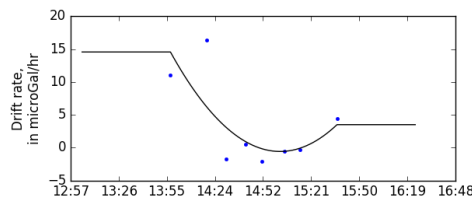
(the drift observation is plotted at the midpoint in time between the two occupations that comprise the drift observation). The drift model can be extrapolated, or extended at a constant value. If extrapolated, a straight line is extended with the same slope as the drift model; in some cases this can lead to extreme drift corrections for the first and/or last occupations, and a constant value is preferable.

This option is set per survey and can affect the calculated delta-g values.

#### Extrapolate:



#### Constant:



4

#### Max. time between repeats

☐ Max. time between repeats (hr)

For some surveys, a large amount of time may elapse between repeated station occupations, and these may not be reliable measurements of drift. This option allows drift observations to be excluded based on the time between station repeats. Note: the minimum counter value is 00:10. If the counter is above this, but will not decrease when the down arrow is clicked, it may be necessary to place the cursor (by clicking the mouse) on either the hour or minutes field.

This option is set per survey and can affect the calculated delta-g values.

5

#### Show time-extent of drift observation

☐ Show time-extent of drift obse

Continuous drift model only: When checked, the lower plot of drift rate vs. time includes horizontal lines that extend to the time of the two station occupations that comprise the drift observation. This option can be useful in determining whether drift observations are useful for determining the drift model (repeated stations with long elapsed times can be unreliable for estimating drift). This option only affects plotting, not the delta-g values.

6

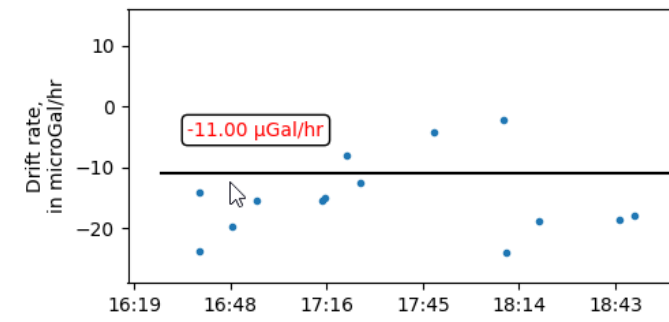
#### Weight drift observations.

☐ Weight drift observations



Gravity and time observations are weighted in the drift calculation. Only implemented for constant drift rate.

If drift rate is insignificant (according to  $p=0.05$  t-test), the drift equation shown when hovering the mouse over the line in the plot will be shown in red:



## 7 Vertical line offset

Vertical line offset



This slider controls the (arbitrary) vertical offset between lines in the station drift plot. Varying the slider may be useful to visualize the data, and helps the user understand the arbitrary nature of the vertical position of each line. This option only affects plotting, not the delta-g values.

## 8 Spline tension

Spline tension:

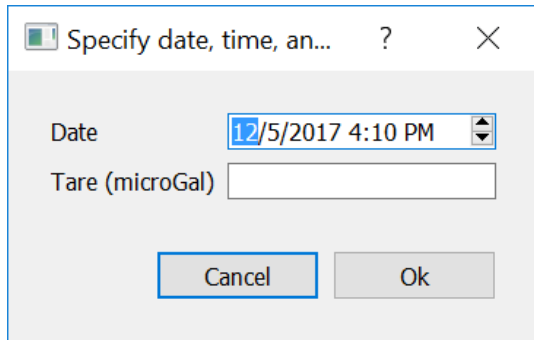


Continuous drift model only: When using a spline as the drift model, this slider controls the spline tension. Greater values, to the right, result in a smoother spline and possibly a poorer match to the drift observations. Smaller values, to the left, result in a wavier spline and drift observations are more likely to be matched exactly.

This option is set per-survey and can affect the calculated delta-g values.

## Tares and the tare table

Tares, or offsets, occur when the relative-gravity meter reading "jumps" during a survey; a tare affects all subsequent observations, but does not affect observations recorded prior to the tare. Tares may be added using the "Process > Add tare..." menu item, which brings up the dialog:



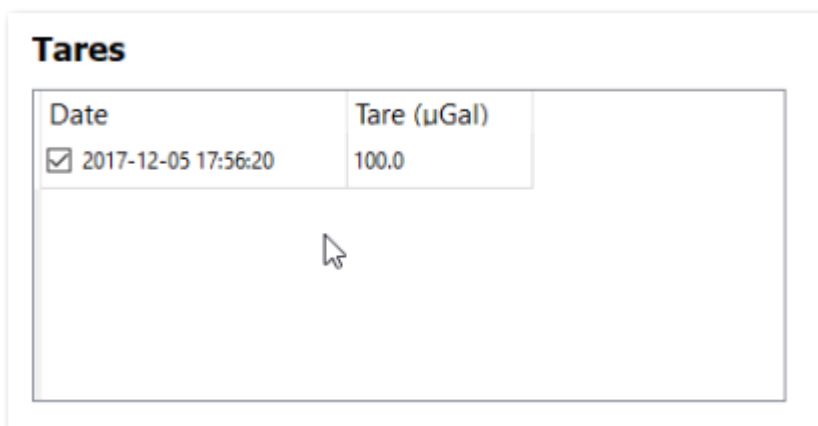
A dialog box titled "Specify date, time, an..." with a question mark icon and a close button. It contains two input fields: "Date" with a date/time picker showing "12/5/2017 4:10 PM" and "Tare (microGal)" with an empty text box. At the bottom are "Cancel" and "Ok" buttons.

Here, the user may specify a date and magnitude of a tare. The tare value is simply subtracted (or added, if negative) to all relative-gravity observations within the currently-active loop that are recorded after the specified time.

The tare table, shown on the [Drift tab](#), shows tares that have been added. More than one tare can be applied simultaneously, and tares are cumulative. That is, if a 10  $\mu\text{Gal}$  tare occurs one hour into a survey, and a 20  $\mu\text{Gal}$  tare two hours into a survey, after two hours a 30  $\mu\text{Gal}$  tare will be subtracted from all subsequent observations.

Tares shown in the tare table can be temporarily disabled by unchecking the respective check box. The delta-g observations shown on the Drift tab are updated immediately.

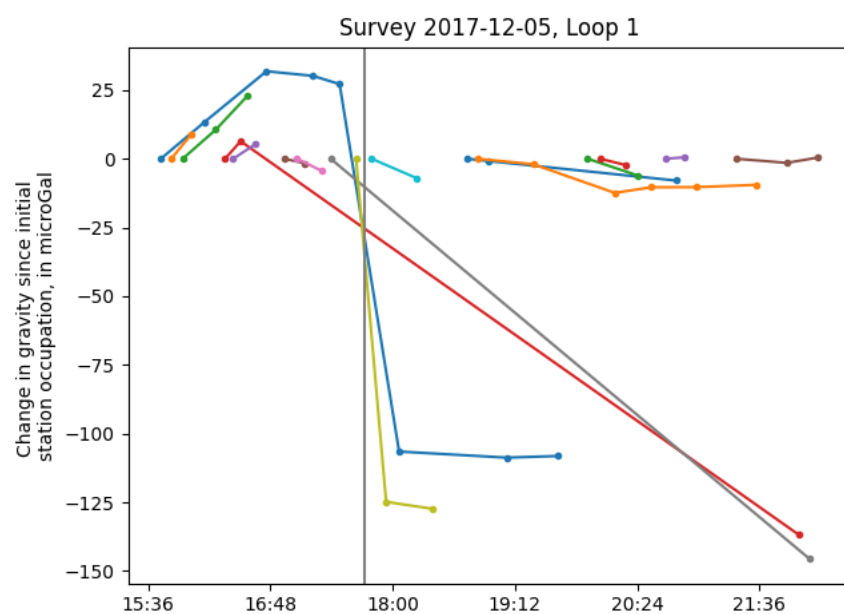
Tares may also be permanently removed by right-clicking on the tare in the Tare table and selecting "Delete tare."



A table titled "Tares" with two columns: "Date" and "Tare ( $\mu\text{Gal}$ )". The first row contains a checked checkbox, the date "2017-12-05 17:56:20", and the value "100.0". A mouse cursor is pointing at the row.

Date	Tare ( $\mu\text{Gal}$ )
<input checked="" type="checkbox"/> 2017-12-05 17:56:20	100.0

The time at which a tare occurred is shown by a solid vertical line in the drift window:



Note that the tare only affects delta-g's that span the time of the tare. Repeat observations that both take place before the tare, or both after the tare, are unaffected.

## **Drift correction**

Drift correction is a fundamental processing step for relative-gravity meter surveys. Even when a drift-correction is applied internally in the meter data-collection computer, there may be a residual nonlinear drift component that requires further correction. Four options for drift correction exist in GSadjust:

[No drift correction](#)

[Network-adjustment drift correction](#)

[Roman method drift correction](#)

[Continuous-model correction](#)

## No drift correction

The "None" drift correction method calculates delta-g's between measured values at successive stations, without further correction. Although not generally used, the method may be useful for evaluating the magnitude of the drift correction, relative to the uncorrected delta-g's. The default standard deviation when using the "None" method is 3.0  $\mu\text{Gal}$  (the standard deviation used in the adjustment can be modified in the [Network adjustment options dialog](#) or edited in the [delta table](#)).

## Network-adjustment drift correction

Network-adjustment drift correction includes polynomial coefficients of a time-dependent function for drift in the network adjustment solution. With this method, a linear model (1st, 2nd, or 3rd order) is fit to the data:

$$D(t) = \sum_{p=1}^a d_p (t - t_0)^p$$

where  $D(t)$  is the cumulative drift at time  $t$ ,  $(t-t_0)$  is elapsed time,  $d_p$  are the model coefficients, and  $a$  is the degree of the polynomial. The coefficients  $d_p$  are parameters in the network adjustment, determined as part of the least-square solution.

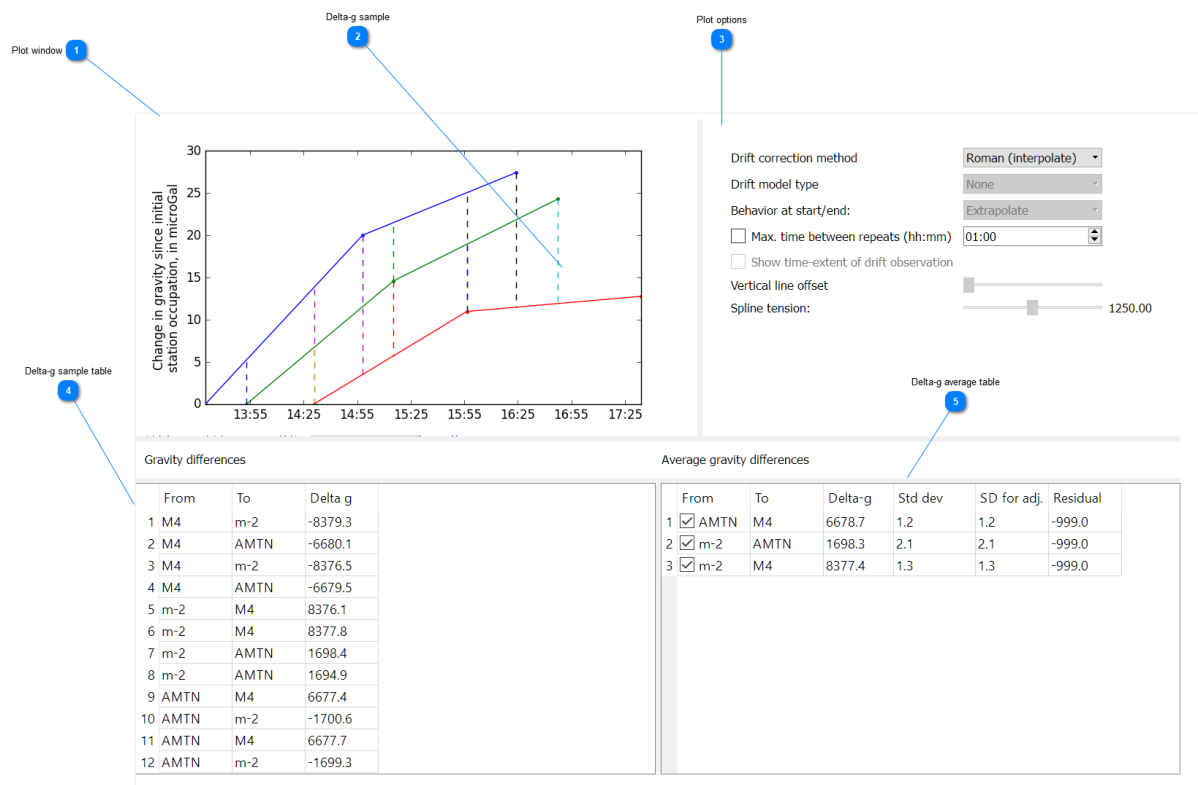
Linear drift models can be used with either the network-adjustment drift correction option, or the continuous model option. When a linear model is suitable, the network-adjustment drift correction may be preferable, because uncertainty in the drift-model parameters is propagated into the uncertainty estimate of the final station values. One advantage of the continuous model, however, is the possibility to extend the drift model as a constant value, as opposed to extrapolating the linear model, at the beginning and end of the loop (see "Behavior at start/end" under [Plotting options](#)). The suitability of a linear drift model can be evaluated using the continuous model option, after which the drift method can be changed to the network-adjustment option before adjusting the network.

## Roman method drift correction

The Roman (1942) method interpolates a gravity value when there is more than one gravity observation at a station. A total of three station occupations—two at one station, and one at an additional station—are used to calculate a delta-g sample [Item (2) below]. An interpolated value is calculated for the station with two occupations, and differenced with the measured value at the other station, to calculate delta-g.

In the window below, delta-g's are shown as vertical dashed line. Each measurement is shown relative to the first measurement at that station (in other words, if the measured values were plotted, the solid lines would have a vertical separation equal to the gravity difference between the stations). For the survey shown, which consists of two complete loops at three stations, there are a total of 12 delta-g's, shown on the Delta-g sample table (4).

As part of the Roman method drift correction, the redundant delta-g's (12 observations are possible, but only 3 are required to identify a gravity value at each station) are averaged. The averaging process is a simple form of network adjustment, with equal weight given to all observations. For surveys and/or campaigns with only a single loop (including [vertical gradients](#)), the values in the Delta-g average table (5) can serve as final results.



### 1 Plot window

The main plot window shows the relative-gravity observations at each station, relative to the first occupation at that station.

- 2 Delta-g sample**  
Each vertical dashed line represents a delta-g calculated using the Roman method. There is a corresponding entry in the Delta-g sample table for each dashed line.
- 3 Plot options**  
See [Plotting options](#)
- 4 Delta-g sample table**  
This table displays all of the possible delta-g's calculated using the Roman method.
- 5 Delta-g average table**  
This table displays the average delta-g between any two stations in the Delta-g sample table. If there is only one delta-g between two stations, it will also be included in the average table.

Roman, I. (1946). An observational method to overcome zero drift error in field instruments. *Geophysics*, 11(4), 466–490. <https://doi.org/10.1190/1.1437276>



## Continuous-model correction

The continuous-model drift correction treats model drift as a continuous function. The main advantage over the [network-adjustment drift correction](#) is that it allows a non-linear spline model, which is often the best fit for survey data recorded using a ZLS Inc. Burris relative-gravity meter (in contrast, Scintrex meters typically have higher, more linear drift rates).

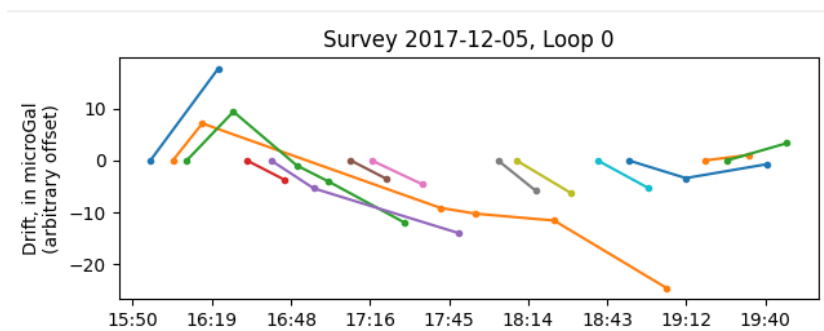
The continuous drift model is developed from repeated station occupations (that is, when a station is visited more than once, with other stations occupied in between). Each station-repeat provides one observation of relative-meter drift. Ideally, repeats will occur with relatively little elapsed time between, over a period when the drift is nearly linear. As the length of time between station repeats increases, drift is likely to become increasingly non-linear, and the drift estimate less suitable for forming the continuous drift model. The elapsed time can be visualized on the continuous-drift plot with the "Show time extent of drift observation" option under [Plotting options](#).

Successful application of the continuous-model drift correction depends on accurate observations of gravity-meter drift, which in turn depends on repeat occupations with minimal elapsed time in between. To accomplish that, it may be necessary to adapt the survey design. In particular, observing stations in loops (i.e., visiting 5 or 6 stations before returning to the initial station) may allow too much time to elapse for a representative drift estimate to be obtained.



### 1 Drift plot

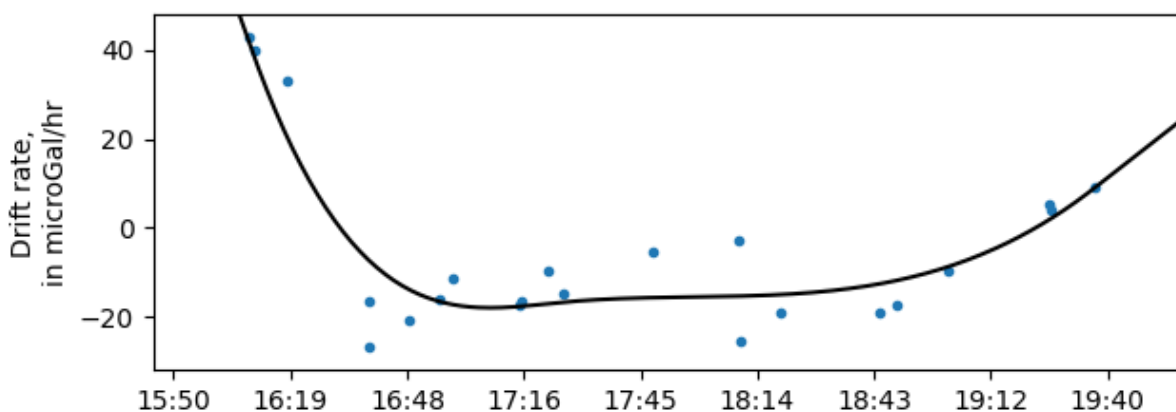
This plot shows the change in gravity at each station, relative to the initial occupation at that station. Each line depicts a unique station. Steeper lines (positive or negative) indicate a larger drift rate. The points that make up each line can be filtered using the "Max. time between repeats" option. A vertical offset between each line can be added with the "Vertical line offset" slider control.



2

## Drift rate plot

This plot shows the drift rate, calculated each time a station is repeated. Each point in this plot represents the slope (i.e., the drift rate) of the line directly above in the drift plot.



3

## Relative-gravity differences table

Relative-gravity differences (delta-g's)

From	To	Time	Delta-g	Drift corr.	Std. dev.
<input checked="" type="checkbox"/> rg37	rg26	2017-12-05 ...	-410.9	8.5	3.9
<input checked="" type="checkbox"/> rg26	rg36	2017-12-05 ...	153.9	3.7	3.1
<input checked="" type="checkbox"/> rg36	rg26	2017-12-05 ...	-153.5	3.0	2.2
<input checked="" type="checkbox"/> rg26	rg37	2017-12-05 ...	410.9	2.0	2.1
<input checked="" type="checkbox"/> rg37	rg36	2017-12-05 ...	-254.0	0.8	4.9
<input checked="" type="checkbox"/> rg36	rg38	2017-12-05 ...	28.2	0.1	5.0
<input checked="" type="checkbox"/> rg38	rg39	2017-12-05 ...	-58.3	-0.8	2.3
<input checked="" type="checkbox"/> rg39	rg38	2017-12-05 ...	56.3	-0.9	4.6
<input checked="" type="checkbox"/> rg38	rg36	2017-12-05 ...	-33.9	-1.1	4.7

4

## Plot controls

See [Plotting options](#) for more information.

## Tare table

Date	Tare ( $\mu$ Gal)
------	-------------------

## 5. Network adjustment tab

The network adjustment tab provides information about the least-squares network adjustment. The basic workflow is to:

1. [Populate the delta table with relative-gravity differences](#)
2. [Add datum observations manually or from a file](#)
3. [Perform the network adjustment](#)
4. [Evaluate the adjustment statistics](#)
5. [Revise by removing outliers and/or adjusting the standard deviations](#)
6. [Export results](#)

The parts of the network adjustment tab are:

The screenshot shows the Network Adjustment tab interface with four numbered callouts:

- 1 Delta table**: Points to the 'Relative-gravity differences (delta-g's)' table.
- 2 Datum table**: Points to the 'Datum observations' table.
- 3 Adjustment results**: Points to the 'Adjusted station values' table.
- 4 Adjustment statistics**: Points to the 'Least-squares statistics' table.

**Relative-gravity differences (delta-g's)**

From	To	Loop	Time	Delta-g	Drift corr.	Std. dev.
<input checked="" type="checkbox"/> rg71	rg57	1	2017-12-06 20:28:29	-1089.5	0.0	3.0
<input checked="" type="checkbox"/> rg71	rg60	1	2017-12-06 19:58:29	-952.8	0.0	3.1
<input checked="" type="checkbox"/> rg70	rg47	0	2017-12-05 19:22:56	-991.3	0.0	1.7
<input checked="" type="checkbox"/> rg70	rg53	0	2017-12-05 19:38:08	-2877.9	1.1	1.9
<input checked="" type="checkbox"/> rg61	rg56	1	2017-12-06 20:49:08	84.8	0.0	4.3
<input checked="" type="checkbox"/> rg61	rg37	1	2017-12-06 19:01:33	-19.7	0.0	4.2
<input checked="" type="checkbox"/> rg61	rg57	1	2017-12-06 18:47:00	395.4	0.0	1.3
<input checked="" type="checkbox"/> rg60	rg71	1	2017-12-06 20:20:51	949.0	0.0	2.8
<input checked="" type="checkbox"/> rg60	rg57	1	2017-12-06 20:06:29	-144.9	0.0	2.9

**Adjusted station values**

Station	g	Std. dev.
rg71	51514.3	40.8
rg70	53701.3	41.4
rg61	50031.1	39.9
rg60	50566.6	40.5
rg57	50424.9	39.4
rg56	50116.5	40.8
rg55	49449.2	40.1
rg53	50825.0	40.8
rg50	48392.6	40.8
rg48	50984.4	39.8

**Datum observations**

Station	Date	g	Std. dev.	# sets	Meas. height	Gradient
<input checked="" type="checkbox"/> rg15	1/1/2000	50000.0	5.00		0.00	-3.00

**Least-squares statistics**

1	Number of unknowns	29
2	Number of relative observations	84
3	Number of absolute observations	1
4	Degrees of freedom (nobs-nunknowns)	56
5	SD a posteriori	56.945058
6	chi square value	3188.92
7	critical chi square value	74.47
8	Chi-test rejected	
9	Average standard deviation	40.22
10	Maximum delta residual	85.41

### 1 Delta table

Relative-gravity differences (delta-g's)

From	To	Loop	Time	Delta-g	Drift corr.	Std. dev.
<input checked="" type="checkbox"/> rg71	rg57	1	2017-12-06 20:28:29	-1089.5	0.0	3.0
<input checked="" type="checkbox"/> rg71	rg60	1	2017-12-06 19:58:29	-952.8	0.0	3.1
<input checked="" type="checkbox"/> rg70	rg47	0	2017-12-05 19:22:56	-991.3	0.0	1.7
<input checked="" type="checkbox"/> rg70	rg53	0	2017-12-05 19:38:08	-2877.9	1.1	1.9
<input checked="" type="checkbox"/> rg61	rg56	1	2017-12-06 20:49:08	84.8	0.0	4.3
<input checked="" type="checkbox"/> rg61	rg37	1	2017-12-06 19:01:33	-19.7	0.0	4.2
<input checked="" type="checkbox"/> rg61	rg57	1	2017-12-06 18:47:00	395.4	0.0	1.3
<input checked="" type="checkbox"/> rg60	rg71	1	2017-12-06 20:20:51	949.0	0.0	2.8
<input checked="" type="checkbox"/> rg60	rg57	1	2017-12-06 20:06:29	-144.9	0.0	2.9
<input checked="" type="checkbox"/> rg57	rg40	1	2017-12-06 21:20:43	241.0	0.0	2.6

Datum observations

Station	Date	g	Std. dev.	# sets	Meas. height	Gradient
---------	------	---	-----------	--------	--------------	----------

The delta table shows the relative-gravity differences and associated information. See [delta-g observations](#) for more information.

2

## Datum table

Datum observations

Station	Date	g	Std. dev.	# sets	Meas. height	Gradient
<input checked="" type="checkbox"/> rg15	1/1/2000	50000.0	5.00		0.00	-3.00

The datum table shows the "reference" values for the network adjustment. They can be observed values from an absolute gravity meter, or arbitrary value. At least one datum is required for network adjustment.

3

## Adjustment results

Station	g	Std. dev.
rg71	51514.3	40.8
rg70	53701.3	41.4
rg61	50031.1	39.9
rg60	50566.6	40.5
rg57	50424.9	39.4
rg56	50116.5	40.8
rg55	49449.2	40.1
rg53	50825.0	40.8
rg50	48392.6	40.8
rg48	50984.4	39.8

The adjusted station values are shown in the adjustment results table at top right. This table can be selected by clicking in the top left and copied by right-clicking.

#### 4 Adjustment statistics

1	Number of unknowns	29
2	Number of relative observations	84
3	Number of absolute observations	1
4	Degrees of freedom (nobs-nunknowns)	56
5	SD a posteriori	56.945058
6	chi square value	3188.92
7	critical chi square value	74.47
8	Chi-test rejected	
9	Average standard deviation	40.22
10	Maximum delta residual	85.41

The adjustment statistics are shown in the table at bottom right. If Gravnet inversion is used, the results are taken directly from the Gravnet output.

## Delta-g observations

Delta-g observations are shown in the Delta table on the network adjustment tab:

From	To	Loop	Time	Delta-g	Drift corr.	Std. dev.	SD for adj.	Residual
<input checked="" type="checkbox"/> rg71	rg57	1	2017-12-06 20:28:29	-1089.5	0.0	3.0	3.0	0.1
<input checked="" type="checkbox"/> rg71	rg60	1	2017-12-06 19:58:29	-952.8	0.0	3.1	3.1	5.1
<input checked="" type="checkbox"/> rg70	rg47	0	2017-12-05 19:22:56	-991.3	0.0	1.7	1.7	-1.9
<input checked="" type="checkbox"/> rg70	rg53	0	2017-12-05 19:38:08	-2877.9	1.1	1.9	1.9	1.7
<input checked="" type="checkbox"/> rg61	rg56	1	2017-12-06 20:49:08	84.8	0.0	4.3	4.3	0.5
<input checked="" type="checkbox"/> rg61	rg37	1	2017-12-06 19:01:33	-19.7	0.0	4.2	4.2	-2.0
<input checked="" type="checkbox"/> rg61	rg57	1	2017-12-06 18:47:00	395.4	0.0	1.3	1.3	-1.6
<input checked="" type="checkbox"/> rg60	rg71	1	2017-12-06 20:20:51	949.0	0.0	2.8	2.8	-1.3
<input checked="" type="checkbox"/> rg60	rg57	1	2017-12-06 20:06:29	-144.9	0.0	2.9	2.9	3.2
<input checked="" type="checkbox"/> rg57	rg40	1	2017-12-06 21:39:43	-241.0	0.0	2.6	2.6	0.0

Delta-g observations (also called relative-gravity differences) must be populated (that is, copied from their respective loops to the Network Adjustment tab) using menu commands on the Adjustment menu. Delta-g's for all surveys can be populated at once, or individual surveys, or individual loops. The latter options are useful to verify that individual loops can be adjusted correctly before adjusting the entire survey or campaign.

Delta-g's can be unchecked to exclude them from the network adjustment. For the "none", "adjustment", or "continuous" drift methods, the start/end times, and duration between them are shown. For the Roman method, the time at which the delta-g is calculated is shown.

Two columns for standard deviation are shown: that calculated from the station observations and/or drift method ("Std. dev." column), and the standard deviation used in the network adjustment ("SD for adj." column). The latter can be adjusted if needed by specifying a minimum value, or multiplier (see [Network adjustment options](#)). This is helpful to avoid giving too much weight to delta-g's with very small standard deviations.

The standard deviation for the network adjustment ("SD for adj." column) can also be manually edited. Care should be taken with this option because the fact that the standard deviation was modified may not be obvious. The modified standard deviation will be saved with the workspace, and a record of the modification is stored in the [log file](#). If the standard deviations are [scaled](#) after the initial adjustment, the user-modified standard deviations are also scaled.

If the drift-correction type is none, network adjustment, or continuous, the delta-g value can also be modified. This can be useful when troubleshooting bad observations, or hand-entering datasets. If modified, the delta-g value is shown in red.

The other items in the table cannot be modified. However, stations can be [renamed](#) in the tree view.

Before network adjustment, the Residual column shows the default value -999. After network adjustment this column shows the difference between the adjusted delta-g and the measured delta-g. Clicking the column header sorts by residual magnitude.

Delta-g observations are linked to their respective values on the drift tab. If the drift method for a loop is changed, all of the delta-g's for that loop on the Network Adjustment tab are cleared and replaced with the new delta-g's (any modified delta-g's or standard deviations will be lost). Also, if the station values are changed (by selecting/deselecting samples), the respective delta-g's will automatically update.



## Datum observations

Datum observations are shown in the Datum table on the network adjustment tab:

Datum observations

	Station	g	Std. dev.	Date	Meas. height	Gradient	Residual
4	<input checked="" type="checkbox"/> rg57	979198408.4	5.39	02/28/18	100.00	-3.00	-4.5
1	<input checked="" type="checkbox"/> rg37	979197987.0	6.68	02/26/18	100.00	-3.00	3.3
2	<input checked="" type="checkbox"/> rg36	979197722.6	6.23	02/26/18	100.00	-3.00	10.2
3	<input checked="" type="checkbox"/> rg26	979197580.5	2.79	02/27/18	100.00	-3.00	-1.4

Datum observations are the "known" values from which delta-g's are observed. At least one datum observation must be present for each survey to perform an adjustment. A datum observation can be an arbitrary value, such as 0 or 50,000, or it can be a measured absolute-gravity value. There are three options for adding datum observations:

1. [Adding manually](#)
2. [Importing from text file](#)
3. [Importing from g files](#)

When datum observations are added, they are associated with the currently selected survey. Datum observations can be excluded from the network adjustment by unchecking their respective checkbox.

Datum observations, as shown in the Datum table, include the following fields:

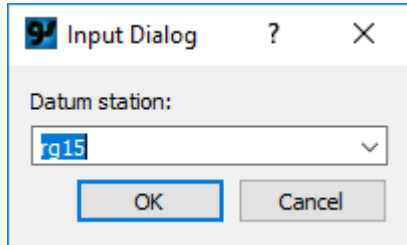
- Station name
- Gravity ( $\mu\text{Gal}$ )
- Standard deviation ( $\mu\text{Gal}$ )
- Date
- Measurement height (centimeters)
- Gradient ( $\mu\text{Gal/m}$ )
- Residual ( $\mu\text{Gal}$ )

The first three (name, gravity, standard deviation) are required. The station name must match exactly at least one station with a delta-g observation (names are case sensitive). The date is not used (datums are associated with the selected survey when they are added). The measurement height and gradient are used to transfer an absolute-gravity measurement from the measured height (about 71 cm or 131 cm for the A-10 and FG-5 absolute-gravity meters, respectively) to the land surface (i.e., the height of the relative-gravity meter). The gravity value for the respective datum measurement is increased by the amount  $[\text{measurement height}] * \text{abs}([\text{gradient}])$  (the gradient shown in the Datum table is negative to indicate gravity decreases with elevation). Finally, the residual column in the Datum table shows the difference between the specified absolute-gravity value and the network adjusted value. If only one Datum observation is specified, the residual will be zero.

The date, g, standard deviation, measurement height, and gradient fields can be changed by double-clicking on the respective cell.

## Adding manually

Datum observations are added manually using the menu option Adjustment > Add datum observation..., which brings up the following dialog:



The dropdown list shows all of the current stations in the Delta-g table. After clicking OK, the selected station is added to the Datum table with a default value of 50,000 +/- 5  $\mu$ Gal.

## Importing from text file

Datum observations are added from a text file using one of two menu options: Adjustment > Import abs. g (simple)..., or Adjustment > Import abs. g (complete)... Either choice opens a standard file open dialog. The file formats are:

Simple format - a space-delimited file with no header and the columns  
*STATION GRAVITY STDEV*

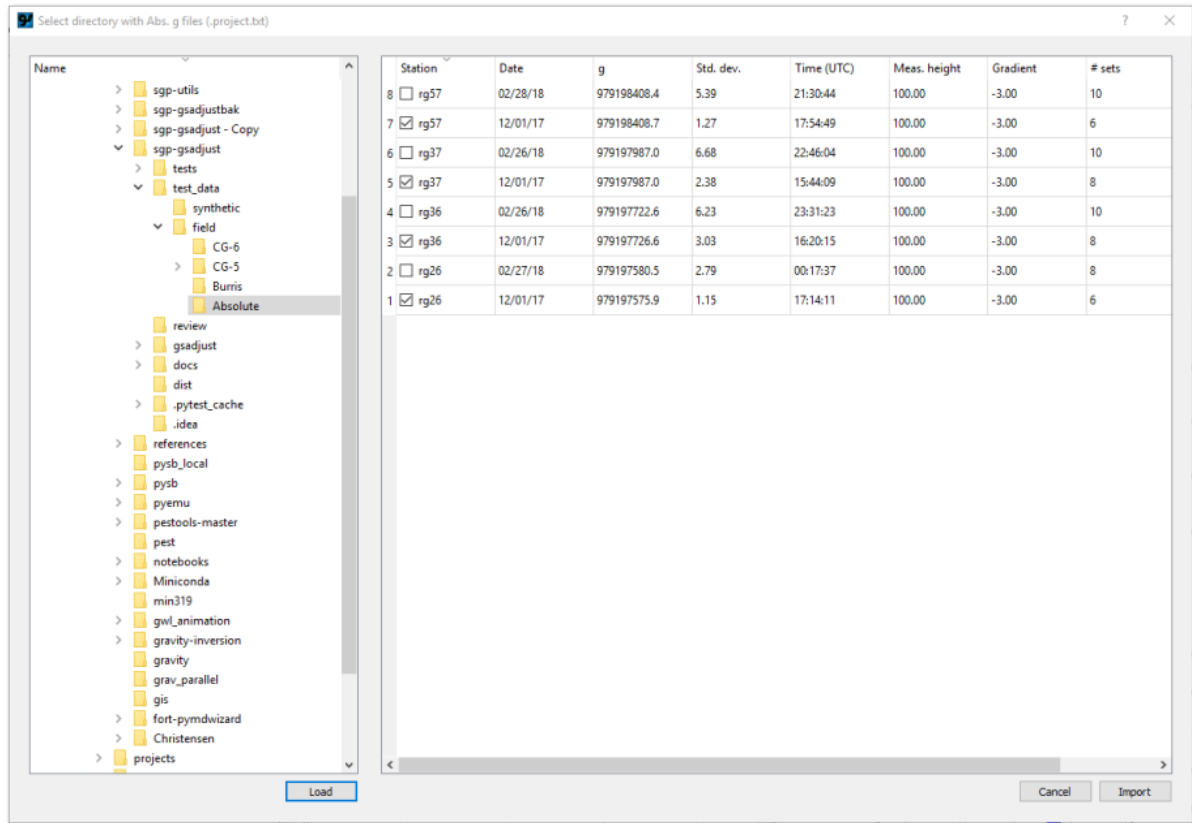
Complete format - a comma-delimited file with one header line. GSadjust will import data from the following columns (case-sensitive)

*Gravity, Station Name, Set Scatter, Date, Transfer Height, Gradient*

The columns may be in any order, and other columns may also be present.

## Importing from g files

Datum observations can be added directly from \*.project.txt files generated by 'g' software (Micro-g Lacoste, Inc.) using the menu option Adjustment > Import abs. g from database, which brings up the following dialog:



First, navigate to the directory with \*.project.txt files. The Load button scans the chosen directory and subdirectories. Metadata for each observation is shown in the table. Check the observations to import and select the Import button.

## Network adjustment

Least-squares network adjustment is the process for solving the system of equations that represent all of the survey observations (relative-gravity differences, and absolute-gravity observations), along with any additional parameters that describe relative-gravity meter drift and calibration.

In brief, network adjustment solves the system of equations, represented in matrix form as:

$$\mathbf{L} + \mathbf{V} = \mathbf{AX}$$

where  $\mathbf{L}$  is an  $n \times 1$  vector of relative-gravity (delta-g's) and absolute-gravity measurements,  $\mathbf{V}$  is a  $n \times 1$  vector of residuals,  $\mathbf{A}$  is the  $n \times m$  design matrix, and  $\mathbf{X}$  is a  $m \times 1$  vector of unknowns, that is, the gravity value at each station and relative-gravity meter parameters that describe drift and meter calibration. The value  $n$  is the total number of observations (both delta-g's and absolute-gravity), and  $m$  is the number of unknowns (number of gravity stations plus the number of gravity-meter parameters).

GSadjust can solve the system of equations using the least squares routine in the Python Numpy package (using the `linalg.inv` method), or using the program Gravnet. The solution to use is selected with the Adjustment > Adjustment type... menu. Prior to adjustment, adjustment options, including whether to include a calibration coefficient, are set using the [Network adjustment options dialog](#).

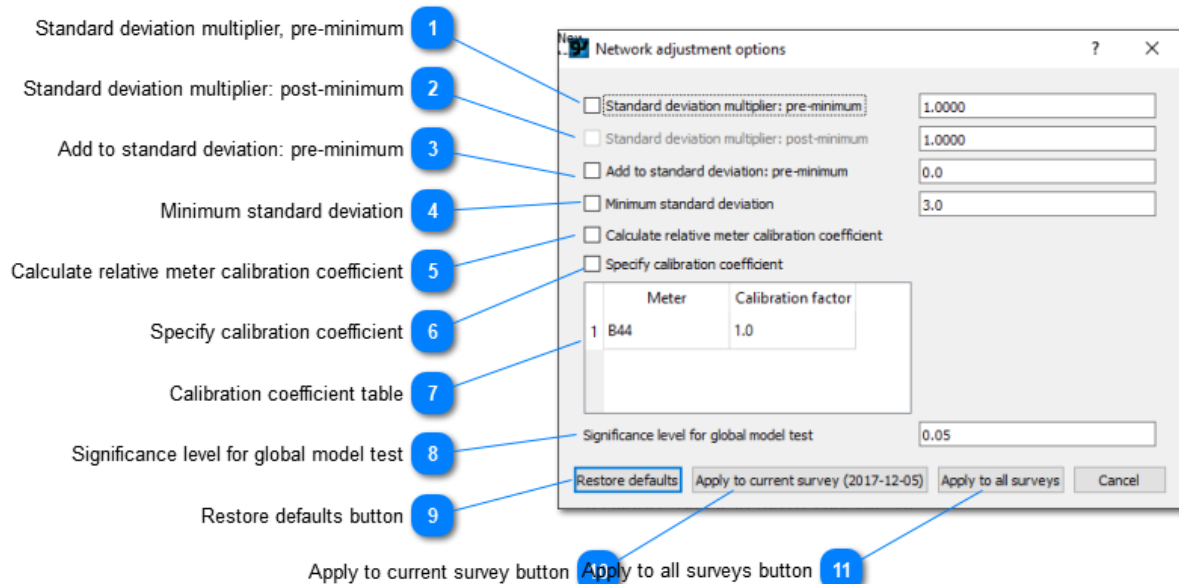
After successful adjustment, station values are shown in the Adjustment results table in the upper right part of the Network adjustment tab. Statistics about the adjustment results and meter parameters (drift and calibration, if included in the adjustment) is shown in the lower right part.

Note that the delta-g's shown in the Delta table on the Network adjustment tab are effectively static once the Delta table is populated. If changes are made to the samples that comprise each station occupation, or the drift method, the Delta table must be cleared (Adjustment menu > Clear delta table) and repopulated.

Oftentimes it is helpful to adjust the network in pieces (individual loops or surveys) prior to adjusting the campaign (or a survey) as a whole. This can be accomplished using the "Populate delta table - selected survey" and (or) "Populate delta table - selected loop" options on the Adjust menu.

## Network adjustment options dialog

This dialog provides options for performing the network adjustment. Options 1-4 are used to calculate the value shown in the "SD for adj." column of the Delta Table, which is the standard deviation used in the network adjustment.



1

### Standard deviation multiplier, pre-minimum

When checked, multiplies the delta-g standard deviation (determined from the data and/or drift-correction method) by the specified value *prior* to enforcing the minimum standard deviation (if checked). May be used in conjunction with "Add to std. dev." (multiplier is applied first).

If the minimum standard deviation box is not checked, this value is modified when [scaling the standard deviation after an adjustment](#).

2

### Standard deviation multiplier: post-minimum

When checked, multiplies the delta-g standard deviation (determined from the data and/or drift-correction method) by the specified value *after* enforcing the minimum standard deviation (if checked). May be used in conjunction with "Add to std. dev." (multiplier is applied first).

If the minimum standard deviation box is checked, this value is modified when [scaling the standard deviation after an adjustment](#).

3

### Add to standard deviation: pre-minimum

When checked, adds the specified value to the delta-g standard deviation (determined from the data and/or drift-correction method) prior to enforcing the minimum standard deviation. May be used in conjunction with "Add to std. dev." (multiplier is applied first).

- 4 Minimum standard deviation**  
When checked, the delta-g standard deviation used in the adjustment is the greater of the specified value, or the standard deviation determined from the data and/or drift-correction method.
- 5 Calculate relative meter calibration coefficient**  
When checked, a relative-meter calibration coefficient (scale factor) is calculated during the network adjustment. The calibration coefficient is a multiplier applied to all relative-gravity observations. It is calculated from the datum observations in a network, and 2 or more datum observations are required. If more than one relative-gravity meter is used on a survey, the calibration coefficient must be calculated or specified for all meters (if not specified, it is set to 1.0).
- 6 Specify calibration coefficient**  
When checked, the specified relative-meter calibration coefficient is applied during the network adjustment. The calibration coefficient is a multiplier applied to all relative-gravity observations. A coefficient for each meter must be provided in the calibration coefficient table.
- 7 Calibration coefficient table**  
If the Specify calibration coefficient checkbox is checked, each delta-g is multiplied by the gravity-meter specific coefficient in the calibration coefficient table.
- 8 Significance level for global model test**  
Significance level for the chi-square test used to evaluate adjustment residuals.
- 9 Restore defaults button**  
Restores default values in dialog box. One of the "Apply..." buttons must be selected to apply values.
- 10 Apply to current survey button**  
Applies the network-adjustment options to the survey currently selected in the data tree view at the left side of the window (The current survey is highlighted in bold).
- 11 Apply to all surveys button**  
Applies the network-adjustment options to all surveys in the campaign.



## Evaluating the adjustment

The network adjustment summary and statistics are shown in the bottom right of the [Network adjustment tab](#). If using Gravnet for adjustment, the adjustment results are taken from the \*.gra file written by Gravnet. If using Numpy for adjustment, similar output is shown.

In either case, the primary metrics for evaluating the adjustment is the Chi-square goodness of fit test, the reference factor, and the observation residuals.

### Chi-square test


The Chi-square test is a standard metric when adjusting survey observations of all types. The test involves calculating the Chi-square statistic:

$$\chi^2 = \sum_{i=1}^m v_i^2 p_i^2$$

from the residuals ( $v_i$ , the difference between observed and adjusted delta-g's and datum values) and their respective weights ( $p_i$ ). The statistic is compared to a critical value, calculated for the network degrees of freedom (number of observations) and the significance level. The default significance level is 0.05 (5 percent) but can be changed in the [Network adjustment options dialog](#).

The result of the Chi-square test ('accept' or 'reject') is shown in the bottom right of the [Network adjustment tab](#).

### Scaling the standard deviation

For network adjustment statistics to be accurate, the estimated standard deviations of the input data must be accurate. This can be evaluated with the standard deviation a posteriori statistic ("SD a posteriori") in the least-squares statistics in the bottom right of the Network Adjustment tab. A value less than 1 indicates input standard deviation is too high; greater than one indicates input standard deviation is too low. Using the Adjustment menu > Scale standard deviation from results command (or the  button on the [Tree View toolbar](#)), the standard deviation of the delta-g's is scaled automatically so that the standard deviation a posteriori statistic approaches one. See [adjustment options](#) for more information on how the scaling is applied.

Only the gravity-difference standard deviations are scaled; the datum observation standard deviations are not.

### Plots

Two plots are useful for evaluating the adjustment. The first, shown when the "Adjustment > Plot residual histogram" menu item is selected, is a histogram of the delta-g residuals (i.e., the difference between each observed delta-g and the adjusted delta-g). This plot

should approximately follow a normal distribution, with no large outliers. The second plot, "Adjustment > Plot adjusted datum vs. measured", shows a bar plot of the difference between the datum observations (e.g., absolute-gravity measurements) and the adjusted values. The closer these residuals are to zero, the better the adjustment.

For campaigns with several surveys, a time series version of the "adjusted datum vs. measured" plot is available. Rather than columns, this plot shows the adjusted value and measured values as separate time-series for each station.

## Outliers and standard deviation

Outliers and the standard deviation of the observations can both have a significant impact on the adjustment results. The relative-gravity meter—both metal and quartz-spring versions—is suspect to periodically recording a "bad" measurement. At times these may be tares (offsets that persist across subsequent measurements) or extreme drift, but at other times, only a single reading seems to be bad (based on repeat observations at that station). The ability to quickly and iteratively remove potential bad measurements is an important function of GSadjust.

Similarly, the standard deviation of the observations may need updating when adjusting a network. The weight of each observation is proportional to 1 over the variance (standard-deviation squared). For example, an observation (delta-g or datum) with standard deviation of 5  $\mu\text{Gal}$  would have 1/25 the weight of an observation with a standard deviation of 1  $\mu\text{Gal}$ . This range of standard deviations (or greater) is not uncommon for field surveys.

### Outliers

Observations can be removed from the adjustment by unchecking the appropriate checkbox. If the checkbox next to a station in the [Data tree view](#) is unchecked, the respective delta-g table on the [Drift tab](#) will be updated. In this case, the delta-g table on the [Network adjustment tab](#) will need to be updated using one of the "[Populate delta table...](#)" commands (the delta-g tables also need to be updated after changing the drift method).

In addition to unchecking individual station occupations, delta-g's can be unchecked on the [Network adjustment tab](#). The delta-g table does not need to be updated, but the "Adjust network" command must be run to update the adjustment results. After the initial adjustment, by sorting the delta-g table by the adjustment residual (by clicking the column header), the worst observations can be identified and potentially removed. By cross-referencing the residuals with stations and occupation times, it may be possible to identify problem stations, or periods of bad data.

Datum observations can also be removed from the adjustment by unchecking the respective checkbox. The "Adjust network" command must be run to update the adjustment results.

### Standard deviation

The standard deviation of the observations may need updating based on the adjustment results. As noted, it may be undesirable to have a wide range of standard deviations, thus giving some undue weight. A second reason to update the standard deviation of the observations is to meet the Chi-square test criteria. If the *a priori* standard deviations are too low (that is, the observations are worse than estimated), the Chi-square test will be rejected.

Standard deviations of delta-g's and datums can be edited directly by double-clicking the respective cells on the [Network adjustment tab](#). More efficiently, a minimum standard deviation, additive term, or multiplier can be applied to all of the delta-g's in a survey or campaign in the [Network adjustment options dialog](#).

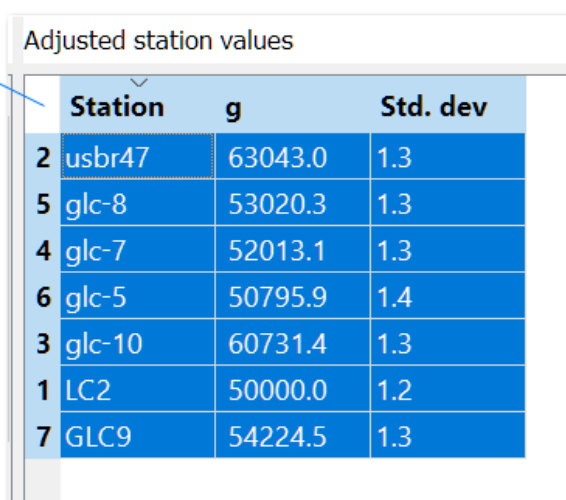
## Exporting results

After performing the network adjustment, results can be obtained by copy-paste or exporting to a tabular text file. In addition, if the "Write output files" option is checked in the [Network adjustment options window](#), station gravity values (and other information) are written to disk.

To copy adjusted gravity values to the clipboard, click the upper-left corner of the Results table. This will highlight the table. Next, right-click on the table and select "Copy to clipboard". The table can now be pasted into a text editor or spreadsheet program (the keyboard shortcut Ctrl-C cannot be used to copy in this context).

Click here to select table

1



	Station	g	Std. dev
2	usbr47	63043.0	1.3
5	glc-8	53020.3	1.3
4	glc-7	52013.1	1.3
6	glc-5	50795.9	1.4
3	glc-10	60731.4	1.3
1	LC2	50000.0	1.2
7	GLC9	54224.5	1.3

### Click here to select table

To export results to a tabular (.csv) text file, select the command "Write tabular data" on the Tools menu. This will write a file named GSadjust\_TabularDataYYYYMMDD-HHMM.csv, with the date and time the file was written. The file will have the columns station name, latitude, longitude, and elevation, and for each survey, g and the standard deviation of g from the network adjustment.

In addition, a table of gravity change between surveys can be exported from the [Compute gravity change](#) window.

## 6. Other tools

GSadjust includes other tools for evaluating and publishing gravity results:

[Network visualization](#) - plots gravity differences between stations.

[Metadata export](#) - text summary of adjustment results for creating metadata.

[Vertical gradient calculation](#) - for calculating the vertical gradient when a specific gradient survey is done.

[Tide correction](#) - an alternative to the meter-supplied tide model.

[Show/edit station coordinates](#) - dialog for editing station coordinates, for map-view plots.

[Calculate gravity change over time](#) - tools for showing and plotting gravity differences between surveys.

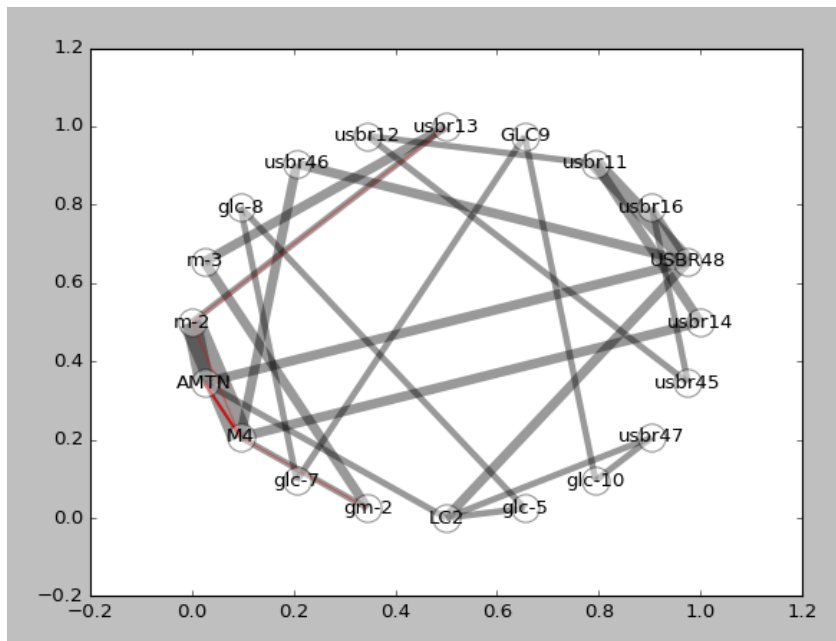
[Logging](#) - logging window for record keeping and troubleshooting.

[Loop animation](#) - shows the sequence of station observations in a survey.

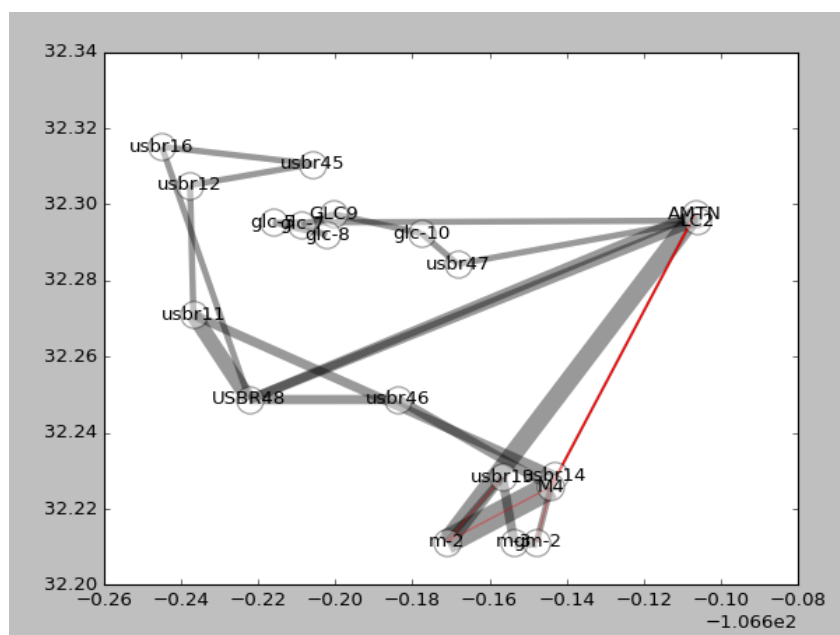
## Network visualization

Network graphs of the relative-gravity observations are available using the menu options Network graph - circular and Network graph - map view, on the Tools menu. The first option plots stations equally spaced around a circle, whereas the latter plots stations according to their spatial location (in Cartesian coordinates; map projections are not supported). For either option, line weight is proportional to the number of delta-g's between any two stations. Enabled delta-g's (unchecked in the Delta Table) are plotted as gray lines. Disabled delta-g's are plotted as red lines.

### Network graph - circular



### Network graph - map view (Latitude/Longitude coordinates)



## Metadata export

When publishing network-adjusted gravity data, it should be accompanied by a description of the processing. Complete geospatial metadata, typically provided in XML format, meets the [FGDC](#) or [ISO 19115](#) standard. [Many tools](#) exist to prepare such metadata, and typically a specialized editor is required to meet the specific format and fields required by the standards.

To assist in the preparation of metadata, the Tools > Write metadata text menu command will write narrative text to a file in the data directory with details of the network adjustment, including:

- Minimum and maximum delta-g residuals
- Minimum and maximum datum observation residuals
- Average standard deviation of the adjusted gravity values
- Number of delta-g's included in the adjustment
- Number of excluded delta-g's
- Number of datum observations included in the adjustment
- Number of excluded datum observations

Typically this metadata text would be included in the [Attribute Accuracy Report](#) section of FGDC metadata.



## Vertical gradient calculation

Vertical gradients (the change in gravity with vertical position, in units of microGal/m) are typically measured by moving a relative-gravity meter between the land surface and (or) two or more positions on a tripod. Typical tripod heights are 71 cm (the height of the A-10 absolute-gravity meter) and 131 cm (the height of the FG-5 absolute-gravity meter).

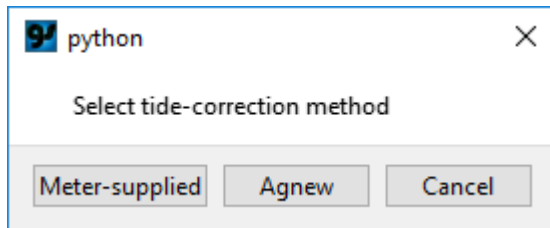
If data are collected at two heights (typically, one at the land surface and one elevated, but any two heights are possible) GSadjust can calculate the vertical gradient by dividing the gravity difference by the height interval. This process requires the Roman drift method be used. The height interval is specified by the menu option Process > Vertical gradient interval... The default value is 64.2 cm; if the tripod is set to this height the sensor of a LaCoste and Romberg D or G relative-gravity meter is located at approximately the measurement height of the A-10 absolute-gravity meter.

Vertical gradients are calculated with the menu option Process > Write vertical gradient file... This opens a file save dialog. The resultant file, a text file with the extension .grd, has a single value and uncertainty (in units of  $\mu\text{Gal}/\text{cm}$ ).

At this time GSadjust will only calculate a two-point, first-order linear gradient.

## Tide correction

Although most modern relative-gravity meters provide real-time tide correction based on station location, GSadjust provides the option to replace the meter-provided tide correction with calculated tides using the Agnew model, from the software Predict, or from a Tsoft-format text file. The tide correction is changed using the Process > Tide correction menu item. This shows a dialog box in which the method can be selected:



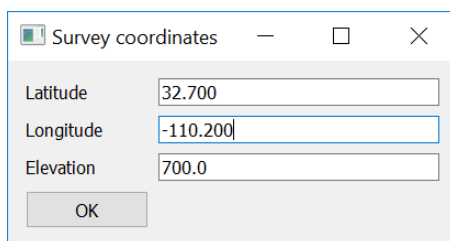
**Note:** The Agnew code was originally developed for PyGrav (Hector and Hinderer, 2016). The accuracy of this code has not been independently verified.

### Meter-supplied

If the tide model has been changed after loading a data file (using one of the options below), selecting Meter-supplied in the dialog will restore the original meter tide correction. If the tide model has not been changed, this option will have no effect.

### Agnew

The Agnew correction calculates a theoretical solid-Earth tide based on station and time (Agnew 2007, Agnew 2012). The station occupation times must be recorded in UTC. The tide is calculated for a single location. When the Agnew option is selected, the user is prompted to enter coordinates:



The default coordinates are calculated as the average of the station locations.

Agnew, D.C., 2007, 3.06 - Earth Tides, in Schubert, G. ed., Treatise on Geophysics, Amsterdam, Elsevier, p. 163–195.

Agnew, D.C., 2012, SPOTL: Some Programs for Ocean-Tide Loading

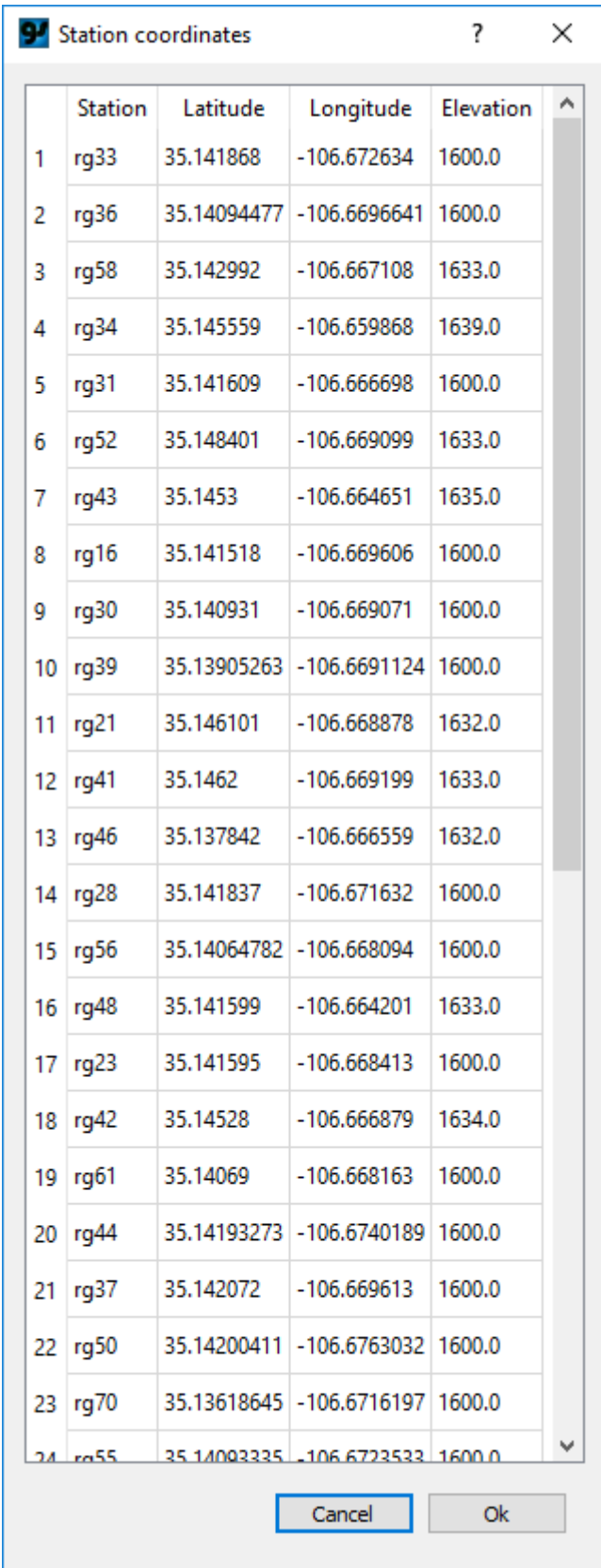
Hector, B., & Hinderer, J. (2016). pyGrav, a Python-based program for handling and processing relative gravity data. *Computers & Geosciences*, 91, 90–97. <https://doi.org/10.1016/j.cageo.2016.03.010>

Van Camp, M., & Vauterin, P. (2005). Tsoft: graphical and interactive software for the analysis of time series and Earth tides. *Computers & Geosciences*, 31(5), 631–640. <https://doi.org/10.1016/j.cageo.2004.11.015>

## Show/edit station coordinates

Station coordinates are used to [plot the network graph in map view](#), and to [plot gravity-change results](#). They are not used directly for the [tide-correction model](#); those coordinates are specified in a dialog box when a tide correction is run.

Station coordinates are populated when a data file is read. Station coordinates may be viewed or updated using the Show station coordinates... command on the Edit menu. The table shown in the popup can be copied and pasted. For example, the table could be copied to Excel, updated with post-processed GPS coordinates, and pasted back into GSadjust.

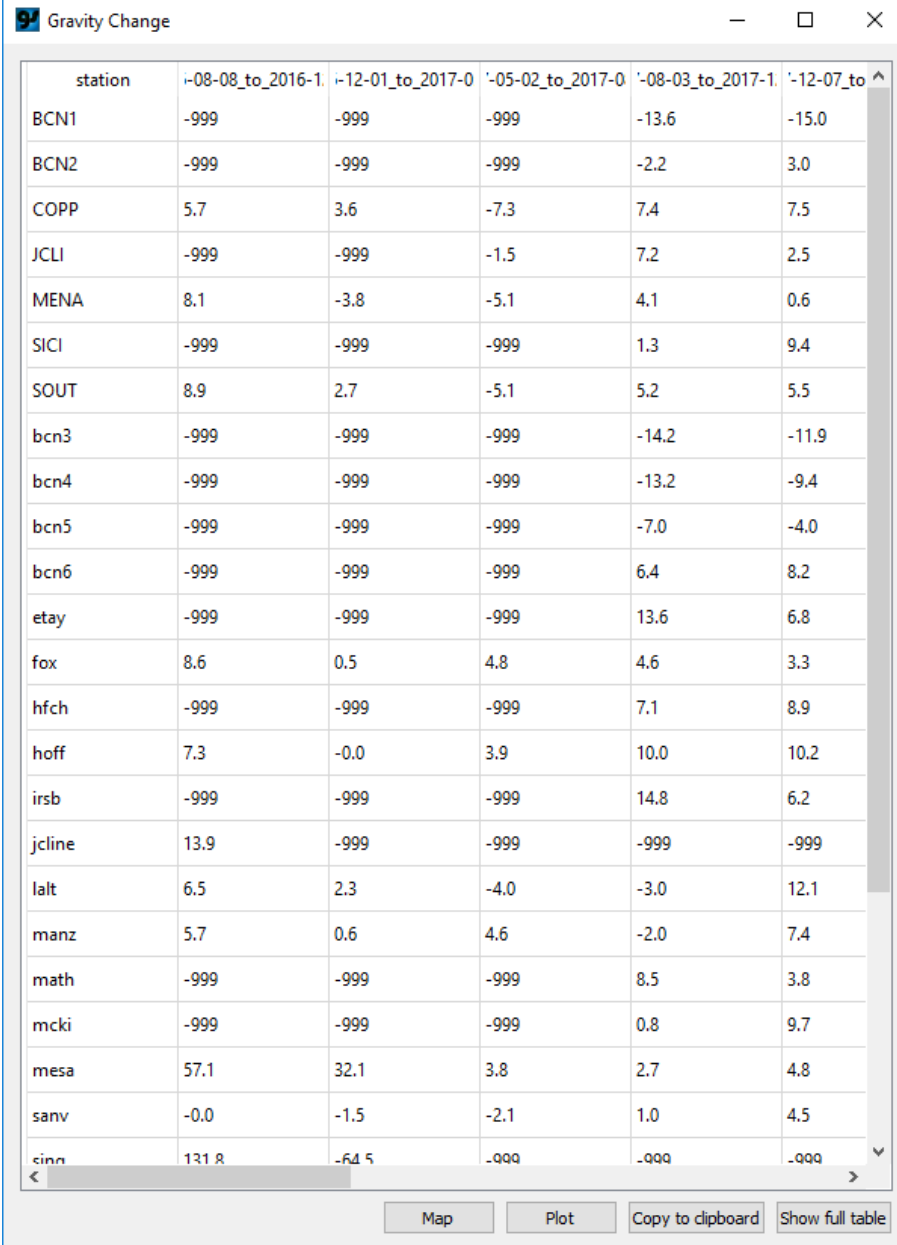


The dialog box is titled "Station coordinates" and contains a table with 5 columns: Station, Latitude, Longitude, and Elevation. The table lists 24 stations, each with a unique ID (rg33, rg36, etc.), latitude, longitude, and elevation values. The dialog has "Cancel" and "Ok" buttons at the bottom.

	Station	Latitude	Longitude	Elevation
1	rg33	35.141868	-106.672634	1600.0
2	rg36	35.14094477	-106.6696641	1600.0
3	rg58	35.142992	-106.667108	1633.0
4	rg34	35.145559	-106.659868	1639.0
5	rg31	35.141609	-106.666698	1600.0
6	rg52	35.148401	-106.669099	1633.0
7	rg43	35.1453	-106.664651	1635.0
8	rg16	35.141518	-106.669606	1600.0
9	rg30	35.140931	-106.669071	1600.0
10	rg39	35.13905263	-106.6691124	1600.0
11	rg21	35.146101	-106.668878	1632.0
12	rg41	35.1462	-106.669199	1633.0
13	rg46	35.137842	-106.666559	1632.0
14	rg28	35.141837	-106.671632	1600.0
15	rg56	35.14064782	-106.668094	1600.0
16	rg48	35.141599	-106.664201	1633.0
17	rg23	35.141595	-106.668413	1600.0
18	rg42	35.14528	-106.666879	1634.0
19	rg61	35.14069	-106.668163	1600.0
20	rg44	35.14193273	-106.6740189	1600.0
21	rg37	35.142072	-106.669613	1600.0
22	rg50	35.14200411	-106.6763032	1600.0
23	rg70	35.13618645	-106.6716197	1600.0
24	rg55	35.14093335	-106.6723533	1600.0

## Calculating gravity change over time

If two or more Surveys are present in a Campaign, GSadjust can calculate the change in gravity over time using the Process > Compute gravity change menu option. This opens a new window that displays a table of gravity change:



The screenshot shows a window titled "Gravity Change" with a table of data. The table has columns for station names and five time intervals. The data is as follows:

station	-08-08_to_2016-1	-12-01_to_2017-0	-05-02_to_2017-0	-08-03_to_2017-1	-12-07_to_2017-1
BCN1	-999	-999	-999	-13.6	-15.0
BCN2	-999	-999	-999	-2.2	3.0
COPP	5.7	3.6	-7.3	7.4	7.5
JCLI	-999	-999	-1.5	7.2	2.5
MENA	8.1	-3.8	-5.1	4.1	0.6
SICI	-999	-999	-999	1.3	9.4
SOUT	8.9	2.7	-5.1	5.2	5.5
bcn3	-999	-999	-999	-14.2	-11.9
bcn4	-999	-999	-999	-13.2	-9.4
bcn5	-999	-999	-999	-7.0	-4.0
bcn6	-999	-999	-999	6.4	8.2
etay	-999	-999	-999	13.6	6.8
fox	8.6	0.5	4.8	4.6	3.3
hfch	-999	-999	-999	7.1	8.9
hoff	7.3	-0.0	3.9	10.0	10.2
irsb	-999	-999	-999	14.8	6.2
jcline	13.9	-999	-999	-999	-999
lalt	6.5	2.3	-4.0	-3.0	12.1
manz	5.7	0.6	4.6	-2.0	7.4
math	-999	-999	-999	8.5	3.8
mcki	-999	-999	-999	0.8	9.7
mesa	57.1	32.1	3.8	2.7	4.8
sanv	-0.0	-1.5	-2.1	1.0	4.5
sinn	131.8	-64.5	-999	-999	-999

At the bottom of the window, there are four buttons: "Map", "Plot", "Copy to clipboard", and "Show full table".

Three table formats are selectable from the drop-down list:

**Simple:** Includes gravity change is calculated between each successive survey, and cumulative change is calculated from the first survey. One row per station.

**Full:** Includes station coordinates, adjusted gravity values and standard deviation, and gravity change converted to meters of water. One row per station.

**List:** Includes station name, date, adjusted gravity value, and standard deviation. One row per station per survey.

To export results, select cells in the table (Ctrl-a to select all), and select the "Copy to clipboard" button at the bottom of the table.

The complete table can also be exported by selecting the Tools > Write tabular data menu option.

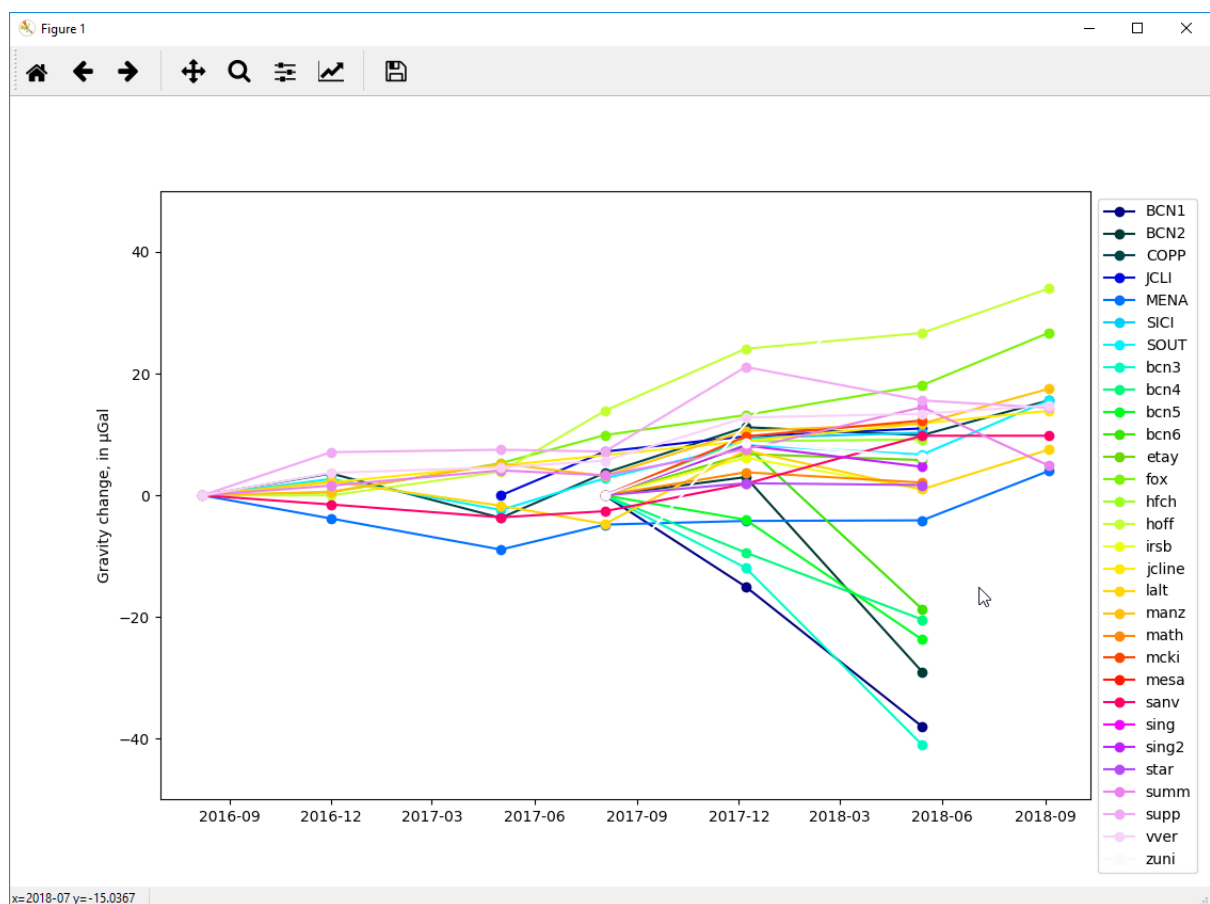
Gravity-change time series can be plotted with the [Plot](#) and [Map](#) buttons.

## Plotting gravity time-series

The gravity-change time series can be plotted with the Plot button on the gravity change table. Gravity change is plotted relative to the first occupation at each station. The plot can be saved as an .svg file from the Matplotlib toolbar for further editing in Illustrator or other graphics packages.

Individual lines can be removed from the plot by clicking the line in the legend. All lines can be deleted by clicking the right button, or restored by clicking the middle button.

More extensive plotting requires saving the gravity-change table by copy and pasting it or saving as a text file with the Tools > Write tabular data menu option.

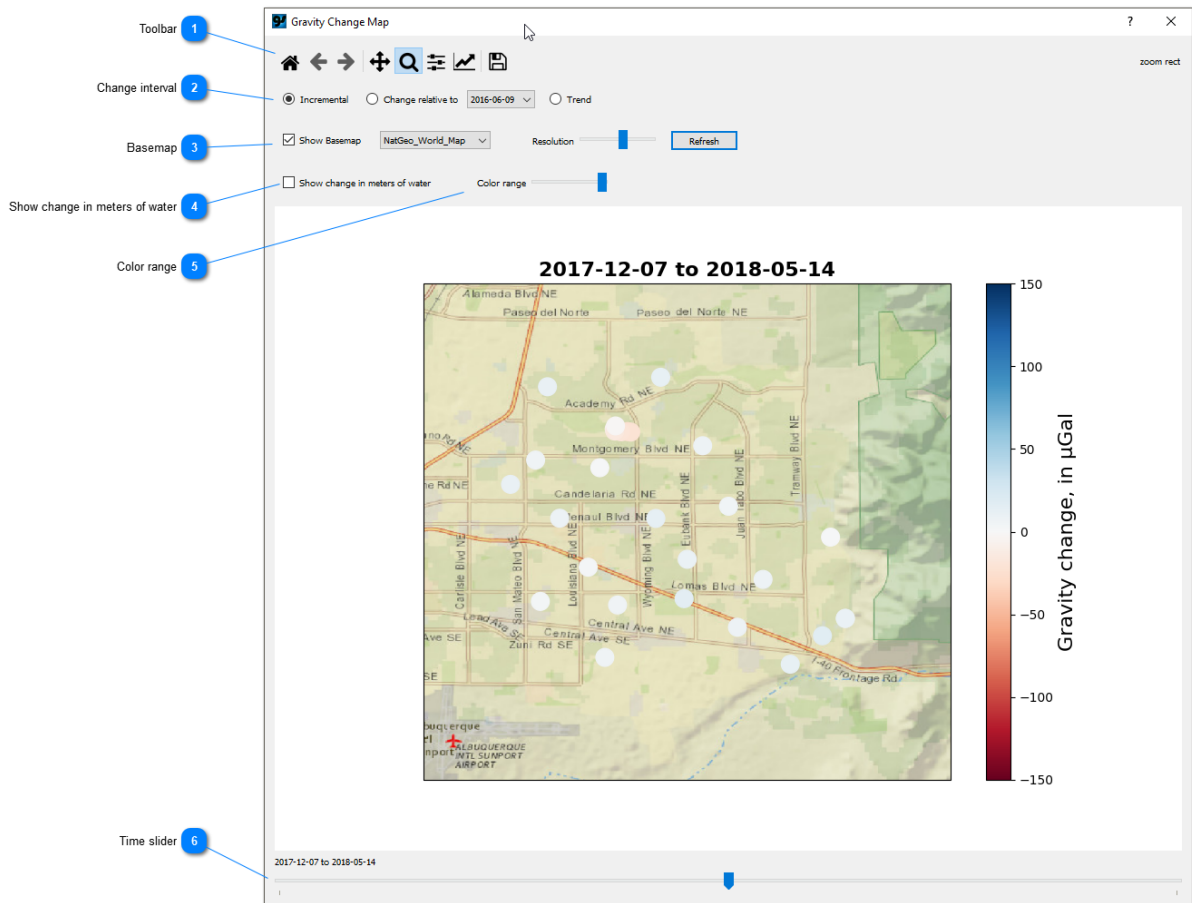




## Map-view gravity change

This window shows a presentation-style view of gravity change with an optional basemap. Station coordinates must be present in the input file.

**Note:** Using the basemap option requires an internet connection. GSadjust can become unresponsive while downloading a basemap; at the default resolution 10-30 seconds is usually required. .

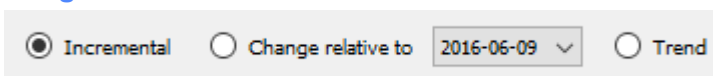


### 1 Toolbar



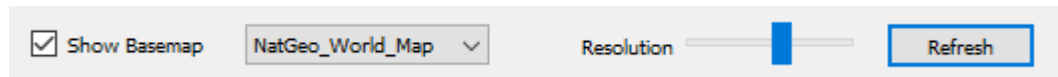
The standard Matplotlib toolbar. Use the magnifying glass to zoom in; right-click zooms out.

### 2 Change interval



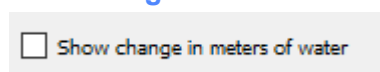
Gravity change can be plotted between successive surveys (the Incremental option), or relative to a particular survey (such as the first survey). Also, a linear gravity trend in  $\mu\text{Gal}/\text{yr}$  can be calculated at each station.

### 3 Basemap

The interface for the basemap control includes a checked checkbox labeled 'Show Basemap', a dropdown menu currently set to 'NatGeo\_World\_Map', a slider labeled 'Resolution' with a blue marker, and a 'Refresh' button.

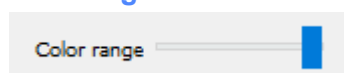
An optional basemap can be shown. Several options are available in the dropdown. Basemap resolution can be changed using the slider (uncheck/check to refresh). High-resolution basemaps can result in slow loading times.

### 4 Show change in meters of water

The control consists of an unchecked checkbox followed by the text 'Show change in meters of water'.

Gravity change can be converted to meters of water using the Bouguer slab approximation ( $41.9 \text{ microGal} = 1 \text{ meter of free-standing water}$ )

### 5 Color range

The control features a slider labeled 'Color range' with a blue marker positioned towards the right end.

This slider controls the color range. If extreme values are present, they may mask small changes. The color range can be reduced by moving the slider leftward.

### 6 Time slider

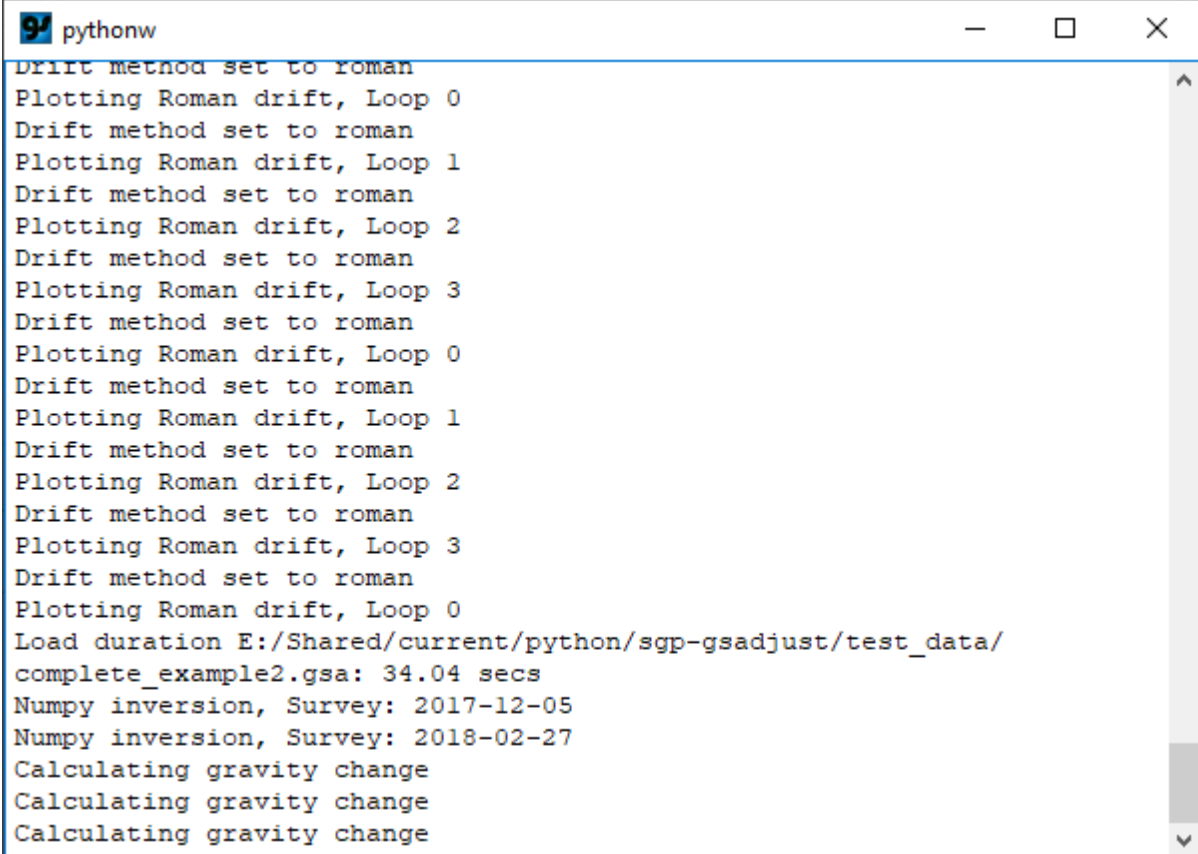
The time slider shows a date range from '2017-12-07 to 2018-05-14' at the top. Below is a horizontal track with a blue arrow marker pointing to the right.

Controls the date range shown in the plot.

## Logging

Actions undertaken and error messages are logged to file to assist in troubleshooting errors and showing the steps taken to arrive at a given workspace. The log file is saved in the GSadjust main directory with the filename GSadjustLog\_YYYYMMDD-hhmm.txt.

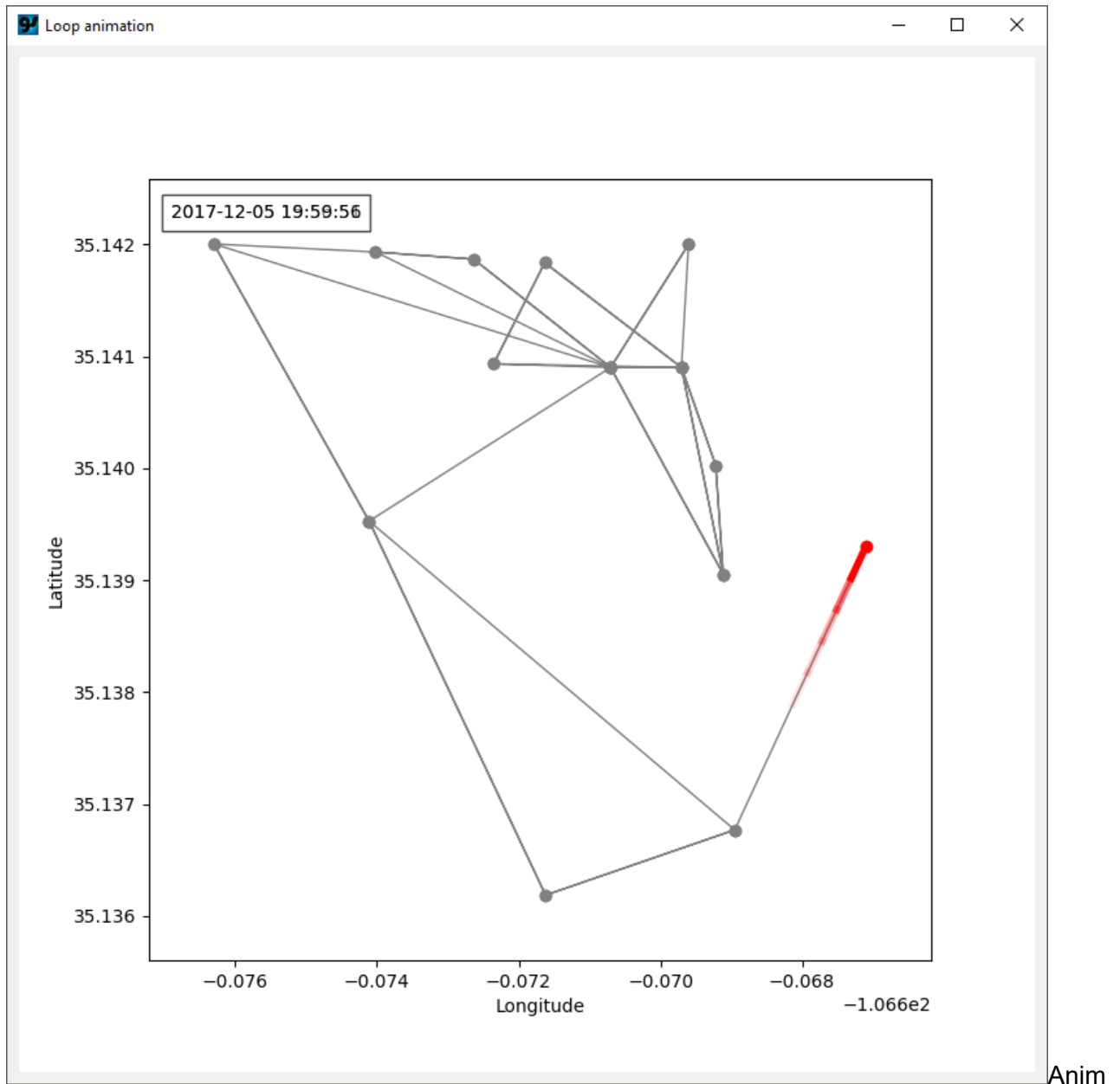
The log file can be shown by selecting "Log window" from the help menu.



```
pythonw
Drift method set to roman
Plotting Roman drift, Loop 0
Drift method set to roman
Plotting Roman drift, Loop 1
Drift method set to roman
Plotting Roman drift, Loop 2
Drift method set to roman
Plotting Roman drift, Loop 3
Drift method set to roman
Plotting Roman drift, Loop 0
Drift method set to roman
Plotting Roman drift, Loop 1
Drift method set to roman
Plotting Roman drift, Loop 2
Drift method set to roman
Plotting Roman drift, Loop 3
Drift method set to roman
Plotting Roman drift, Loop 0
Load duration E:/Shared/current/python/sgp-gsadjust/test_data/
complete_example2.gsa: 34.04 secs
Numpy inversion, Survey: 2017-12-05
Numpy inversion, Survey: 2018-02-27
Calculating gravity change
Calculating gravity change
Calculating gravity change
```

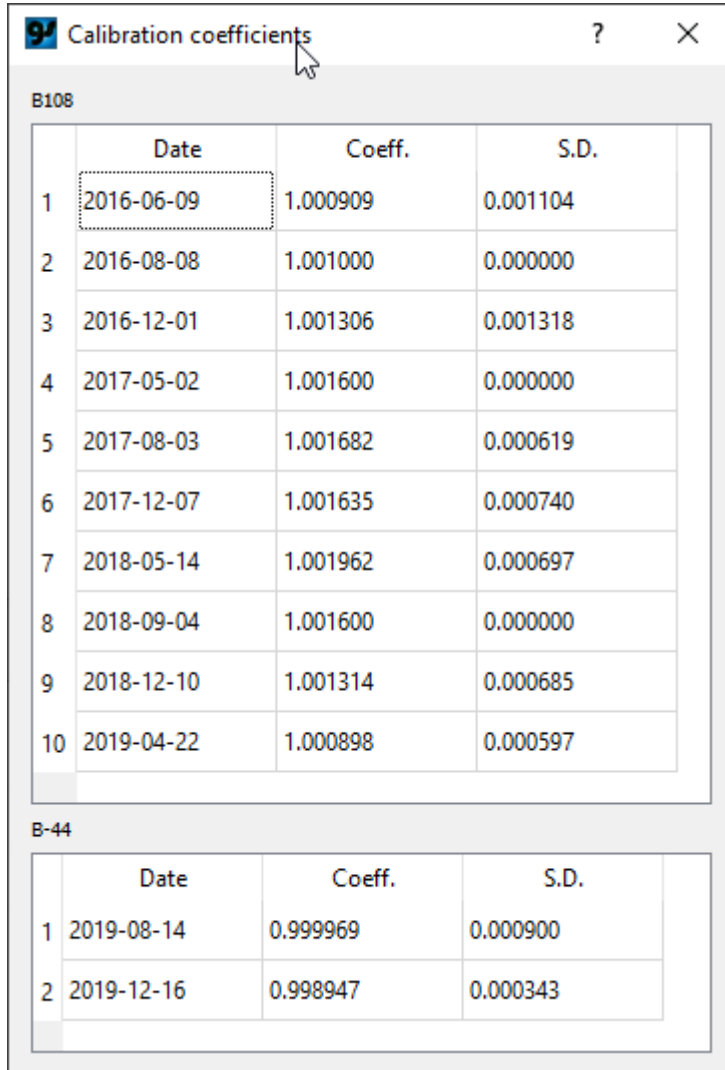
## Loop animation

When reviewing data, especially when the reviewer did not collect the data, it can be helpful to visualize the survey progression in map view. To do so, right-click on a loop in the tree view and select **Animate loop**. This will open a new window with an animated line proceeding from the first to last station occupation, after which the animation repeats.



## Show calibration coefficients

For campaigns with several surveys, it can be useful to see how the calibration coefficients compare. The Tools > Show calibration coefficients shows the following table:



The screenshot shows a window titled "Calibration coefficients" with a question mark icon and a close button. It contains two tables of calibration data.

**B108**

	Date	Coeff.	S.D.
1	2016-06-09	1.000909	0.001104
2	2016-08-08	1.001000	0.000000
3	2016-12-01	1.001306	0.001318
4	2017-05-02	1.001600	0.000000
5	2017-08-03	1.001682	0.000619
6	2017-12-07	1.001635	0.000740
7	2018-05-14	1.001962	0.000697
8	2018-09-04	1.001600	0.000000
9	2018-12-10	1.001314	0.000685
10	2019-04-22	1.000898	0.000597

**B-44**

	Date	Coeff.	S.D.
1	2019-08-14	0.999969	0.000900
2	2019-12-16	0.998947	0.000343

Standard deviation equal to 0 indicates a specified calibration coefficient.

## 7. Considerations

## Dynamic data links between tabs and status indicators

GSadjust links data across the data, drift, and network adjustment tabs. If station gravity values change (by unchecking samples in the Data Table on the Data tab), the respective gravity differences relative to that station on the Drift and Network Adjustment tabs are immediately updated. This facilitates an [iterative workflow](#).

Although the gravity differences are updated, the network adjustment is *not* automatically repeated if station gravity values change. The user must repeat the "Adjust network" command on the Adjustment menu. If station gravity values have changed since the previous adjustment, a circular red indicator in the bottom right of the GSadjust window is shown. The indicator is cleared after performing the adjustment.

When changes are made to the current loop drift correction method (for example, changing the type from None to Continuous, or enabling the maximum time between repeats threshold, the respective delta-g's for that loop on the Network Adjustment tab are updated immediately and the adjustment results are invalidated. If the delta-g's for that loop aren't included on the Network Adjustment tab (for example, if the delta table has not yet been populated, or was populated with only a subset of loops, not including the current loop), changing the drift correction method won't affect the deltas on the Network Adjustment tab.

In addition to the station gravity values, the check status of each station in the left-hand tree view affects the data to be analyzed. When a station is unchecked, the delta-g's that include the station are immediately removed from the Drift and Network Adjustment tabs.

By disabling relative-gravity differences through unchecking one of the constituent stations, the influence of potentially bad station occupations can be rapidly assessed.

## Numpy vs Gravnet inversion

Two options exist for the least-squares solution of the network adjustment, Numpy or Gravnet (Hwang et al., 2002). Gravnet is a Fortran program, and a compiled executable for Windows is provided with GSadjust. Gravnet uses Cholesky decomposition to invert the design matrix and solve the network adjustment system of equations. The numpy inverse solution (using `numpy.linalg.inv`) uses the [LAPACK](#) linear algebra package's Gaussian elimination routine.

For most network adjustment solutions the Numpy and Gravnet solutions will be identical, and run equally fast. There are three main differences in functionality:

- Gravnet only accommodates a single relative-gravity meter when calculating a calibration coefficient; the Numpy solution will calculate a unique calibration coefficient for each relative-gravity meter.
- When drift is included as a polynomial to be solved for in the least squares solution, Gravnet is limited to a single polynomial for all observations in a Survey. That is, if the drift method on the Drift tab is set to "Network adjustment", all Loops in the same Survey must also be set to "Network adjustment", all with identical polynomial degrees. With the Numpy solution, the drift method can be set independently for each loop. If necessary, the "Network adjustment" method may be used for some loops, and an alternative method used for other loops within the same survey.
- Gravnet includes Pope's t-test method to test for outliers; Numpy inversion does not perform outlier tests.

Gravnet can also solve for circular (screw) error, but this option is not currently implemented in GSadjust.

Gravnet is provided as a Windows executable; it will not run on non-Windows computers unless the Fortran source code is compiled for the specific platform.

Hwang, C., C. Wang, and L. Lee (2002), Adjustment of relative gravity measurements using weighted and datum-free constraints, *Comput. Geosci.*, 28, 1005–1015.



## Vertical gradients

The vertical gravity gradient, expressed in  $\mu\text{Gal}/\text{cm}$ , has two functions in combined absolute/relative gravity surveys. First, the gradient is used in the absolute gravity data-collection software ('g', by Micro-g LaCoste) to calculate g, because gravity varies over the height of the free-fall. Especially for the A-10 meter, having a relatively short free-fall, the vertical gradient has only a minor effect on g and a standard value (-3 or -3.086  $\mu\text{Gal}/\text{cm}$ ) is often used. Second, and more importantly, the vertical gradient is used to calculate g at the transfer height at which it is reported. Typically the transfer height is 100 cm, whereas the A-10 measures at about 71 cm, and the FG-5 at about 131 cm.

The latter application of the vertical gradient is important when combining relative and absolute measurements, which are typically made at different measurement heights. Generally the absolute-gravity measurement is transferred from the transfer height to the land surface (or, the measurement height of the relative-gravity meter). GSadjust uses the transfer height and gradients shown for each datum in the Datum Table to transfer the absolute-gravity value to the land surface (these are imported from the \*.project.txt files output by 'g' if the "Import abs. g - complete" menu option is selected). An offset equal to [transfer height] \* [gradient] is added to each datum. If the imported/specified absolute-gravity value (or datum) should be used as-is, the transfer height should be set to zero. If the gradient is the same for every datum, it will have no effect; a constant offset will be added to each datum.

The adjusted gravity value at each station in the Results Table has the transfer offset applied (that is, it is the gravity value at the land surface). When comparing adjusted to measured values at datum stations, the offset is taken into account.

Vertical gradients are typically measured over a discrete interval using a relative-gravity meter and a tripod or similar stand. A mini loop is measured between the ground and the measurement height of the A-10 or FG-5 meter; typically the ground is occupied 3 or 4 times, and the tripod 2 or 3 times (additional occupations may improve accuracy). If this type of survey, with only two stations, is processed with GSadjust, the menu option "Write vertical gradient file..." can be used to calculate a vertical gradient, in  $\mu\text{Gal}/\text{cm}$ , and write it to file. The gradient is calculated over the interval specified in the dialog opened by the "Vertical gradient interval..." menu command.

## Saving and loading the workspace

At any point the current workspace can be saved using the "Save workspace..." menu command. This writes the stations, loops, and surveys of the campaign, along with their checkbox states, drift method(s), delta-g's, and datums, to a file with a \*.gsa extension. The file is written in JSON format and can be read using a text editor. Hand-editing the file, however, will likely lead to errors. Adjustment results are *not* saved. Saved workspaces can be imported using the "Load workspace..." menu command.

## Multiple meters

GSadjust can accommodate data from more than one relative-gravity meter, and, if absolute-gravity observations are present, determine the calibration coefficient for each meter during the least-squares network adjustment. The presence of multiple meters is determined automatically based on the serial numbers read from the raw data files. The calibration coefficient option must be selected in the [Network adjustment options dialog](#) on the Adjust menu. If this option is selected, a calibration coefficient will be determined for all meters (there is no option to calculate a coefficient for some meters and not others used on the same Campaign). If the calibration coefficient is to be determined for multiple relative-gravity meters, the Numpy adjustment option must be selected; Gravnet cannot accommodate more than one meter.