

Gravity Data Corrections

in
QCTOOL



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info@qctool.ca

1. Importing Data

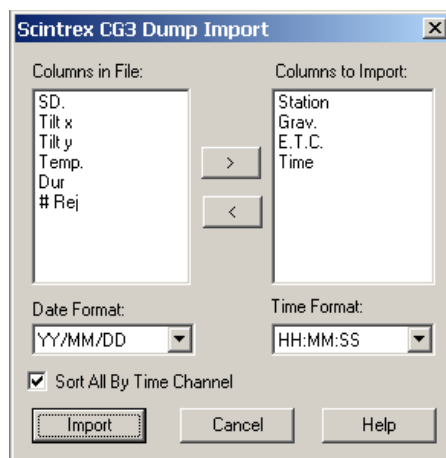
If your data is in Excel format, please export to .csv format for import.

1.1. Importing Gravity Survey Data Files

You can import data from gravity instrument dump files. Accepted file formats include Scintrex's CG3, CG5 and CG6 dump files, any ASCII columnar or .csv files, and Micro-g LaCoste Air-Sea gravimeter files – .DAT or .ENV formats.

1.1.1. Importing a gravity instrument dump file from a Scintrex CG3 gravimeter

- On the File menu select Import File, and then select Scintrex CG3 from a pop up list of Import Formats. Select the desired .dmp or .raw file to import and specify the output qct-file. Then, the Scintrex CG3 Dump Import window appears:



- Specify data columns to be imported. Add or remove columns from the “Columns to Import” list with buttons “>”, “<”.
- Specify ‘Date’ and ‘Time’ formats in the importing file.
- Leave *Sort All by Time Channel* checked to sort importing records by time automatically.
- Click on *Import* button.

N	A: Station	B: Grav.	C: E.T.C.	D: Time	E: Date
1	90002.	4604.65	0.01	05:18:29	94/06/15
2	5715.	4603.79	0.01	05:41:14	94/06/15
3	1605.	4600.01	0.01	06:09:13	94/06/15
4	1618.	4606.02	-0.03	09:47:23	94/06/15
5	1616.	4604.38	-0.03	09:58:21	94/06/15
6	1621.	4606.96	-0.03	10:10:44	94/06/15
7	1619.	4607.70	-0.03	10:25:23	94/06/15
8	1614	4603.79	-0.03	10:35:34	94/06/15

1.1.2. Importing a gravity instrument dump file from a Scintrex CG5 gravimeter

- On the *File* menu select *Import File*, and then select *Scintrex CG5* from a pop up list of Import Formats. Select desired ASCII file (.dmp, .dat, .xyz, .txt) to import and specify the name of the output qct-file.

Next, the ‘*Import: Set Channels*’ window appears.

- Specify header line and double-click to change the header selection, if needed.
- Check the format for columns and click on the '*Continue*' button to import the data.

1.1.3. Importing an instrument file from a Micro-g LaCoste Air-Sea gravimeter (.DAT)

- On the *File* menu select *Import File*, and then select *Micro-g LaCoste Air-Sea (DAT)* from a pop up list of Import Formats. Select the desired .DAT file to import and specify the output QCT-file.

Then, the '*Import: Set Channels*' window appears:

- Specify the 'channel' format and click on '*Continue*' to import the data.

1.1.4. Importing an instrument file from a Micro-g LaCoste Air-Sea gravimeter (.ENV)

- On the File menu, select *Import File*, and then select *Micro-g LaCoste Air-Sea (ENV)* from a pop-up list of Import Formats. Select the desired .ENV file to import and specify the output QCT-file.
- On the 'Set Channels' window, specify the format for columns.
- Click 'Continue' to import the data.

1.2. Importing Base Station Data

You can import data from CSV or any ASCII columnar file. The file should contain geographical coordinates, elevation and any absolute gravity readings for all base stations.

- On the *File* menu, select *Import File*.
- Then select either 'ASCII CSV' or 'ASCII XYZ' from a pop up list of Import Formats. Select desired base station data file to import and specify the output qct-file. Then, the 'Import: Set Channels' window appears:
-

Import: Set Channels

Select a column and set the Data Format

Skip first rows

Column Format

☐ General Text char. ☐ Date

☐ Float point (single precision)

☒ Float point (double precision) ☐ Time

☐ Short Integer (2 bytes)

☐ Long Integer (4 bytes)

☐ Use a Column as a Line Label ☐ Skip Column

Data Preview

Station	Gravity	Longitude	Latitude	Elevation
90001	979890.709	-0.57362644781	37.5529470596	201.7
90002	979903.209	-0.59235555556	37.571727778	191.4

File Header Double click on the single line to change the column labels

Station,Gravity,Longitude,Latitude,Elevation

Set Header Delimiters

Continue Cancel Help

- Specify header line, format of columns and click on the 'Continue' button.

1.3. Importing Location Data

The procedure is similar to the one described above in **Section 1.2**, *Importing Base Station Data*.

2. Merging survey data files with base station and location files

Comment: When surveying in areas with a long history of exploration, final results may be required in an older datum. Our recommendation is to perform the corrections in a modern datum such as WGS84 or NAD83 and upon completion of all corrections transform the coordinates to the older datum. In many cases, the accuracy of the corrections are much improved when using modern datums.

2.1. Creation of Latitude/Longitude coordinates from UTM XY data

Open qct-file with location information. On the *Tools/Coordinates* menu, select *Geographic* ↔ *Projected Coordinates* and then click '*Transverse Cylindrical Projections*' to see the following interface:

- Click the '*Easting/Northing*' option under *Input channels*.
 - Specify channels for *Easting* (UtmX), *Northing* (UtmY).
 - Select the axis direction between *W* and *E*, *N* and *S* in accordance with your data. Uncheck '*Standard sign convention*' to indicate that negative values are opposite to the selected direction. e.g. -106W is the same as 106E
 - Select '*All Lines*' to apply the conversion to the entire file or select '*One Line*' to process only the line the selection box immediately to the right
 - Modify the names of the '*Output Channels*' if desired
- Check the '*Insert after*' box to have the new columns inserted after the channel in the selection box directly beneath, otherwise the new columns will be inserted as the last columns.

Choose between '*UTM World*', '*Standard location projections*' and '*Custom Mercator*' tabs:

Select the ***UTM World*** tab to use the cylindrical projection formula defined in the document DMATM 8358.2 by the US Defense Mapping Agency. Choose the '***Source ellipsoid***' by clicking '***Select***'.

Specify either the '*Pre-set Zone Number*' or the '*Pre-set Central Meridian*'.

Note: This is only required for reverse calculations from UTM to geographic (lat/long) coordinates. Otherwise, leave the 'Pre-set' values unchanged to -1.

Click '***Convert***' to create the '***Output Channels***'.

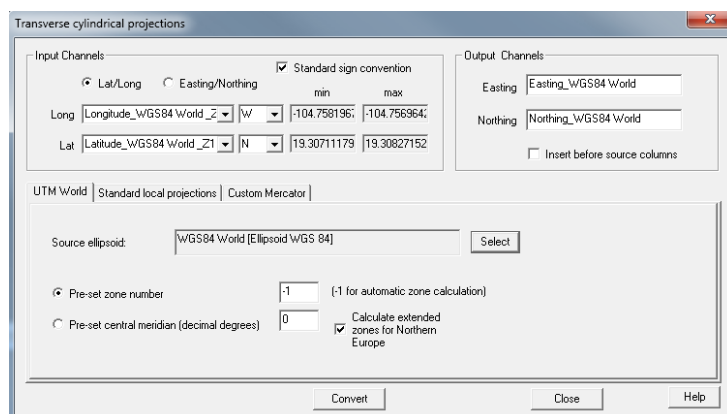
Standard local projections contains projections for specific locations in Europe, Africa and Asia yielding better results. Most European projections on the list are Gauss-Kruger projections. Otherwise, they are *Mercator* projections. Click the *See info* button for more information and map for each entry. You might be required to select the *Zone* for the projection you have selected. Click the '***Convert***' button to create the new channels.

Custom Mercator allows the user to select the location of the *natural origin* and *false origin* as well as the *Scale factor* at the natural origin. Generic Mercator USGS formulas are used to calculate the result. Choose the '*Source Ellipsoid*' by clicking '*Select*'. Specify *natural* and *false origin* values and the *Scale factor* before clicking '***Convert***' to finalize the procedure.

2.2. Creation of UTM XY coordinates from Lat/Long data

Open QCT-file with location information. On the *Tools/Coordinates* menu, select *Geographic* \longleftrightarrow *Projected Coordinates* and then click '*Transverse Cylindrical Projections*'.

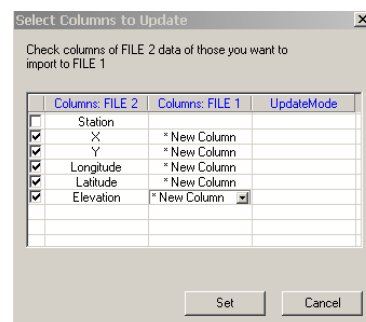
- On the 'Projections' dialog, click the '*Lat/Long*' option under '*Input channels*' (as shown below).



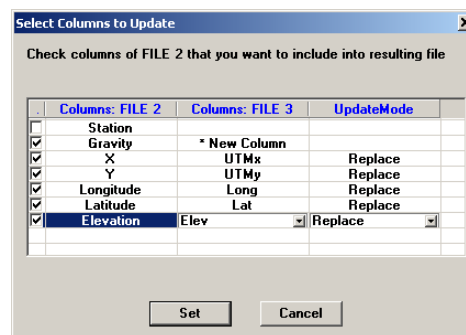
- Follow the rest of the procedure outlined in **Section 2.1** to create UTM XY coordinates channels in QCT-file with base station information.

2.3. Merging survey data files with base station and location files

- Close all qct-files. Select '*Merge Files*' from the '*Tools/Files*' menu.
- On the "*Merging Mode*" window, select *Update File Channels*. Then, the *Merge File* dialog appears.
- Specify the survey data file as File 1. Select Base Channel from Channel list (dropdown menu).
- Specify the location data file as File 2. Select Base Channel from Channel list (dropdown menu).
- Specify the merged file in the box labelled *Save Merged Data in File*
- Click on *Set Channels* button and select those columns from File 2 that would be used to import data into File 1. For example, *X*, *Y*, *Longitude*, *Latitude*, and *Elevation*. Leave *New Column* selection for updating mode.



- On the 'Merging File' dialog click on 'Merge' button.
- Restart the 'merge file' utility to merge the other files.
- Repeat merging procedure with survey data and base station files. On 'Select Columns to Update' dialog, specify columns of File 1 that you would like to be updated in the output file.



- Click 'Open the result file in Read/Write mode' to work with the new file.

3. Drift Correction

Now you have a qct-file with measured gravity data and coordinate information, all in one file. The purpose of 'Drift Correction' is to eliminate instrument error caused by various drifts caused by such things as temperature and pressure. Also you want to correct data for the "tide" effect. This may involve three steps. First, applying the *Meter Calibration Correction*, then, calculating and applying the *Tide Correction*, and finally, applying the *Instrument Drift Correction*. The tide correction is the only correction which is significantly dependent upon time and thus it should be done prior to the final drift corrections.

3.1. Meter Calibration Correction

For many older meters the manufacturers provided a single number for meter calibration. The number was the simple scale factor that converted the meter reading into milliGals by multiplying the reading by the factor. The scale factor was sometimes engraved into the meter nameplate. To apply this correction, simply use the 'QCTool calculator' and apply instrument scale factor to the readings, which have already been corrected for tide effect.

Modern meters use a more complete description of the relationship between meter reading (counter units) and milliGals. Over the extended range of these meters, the conversion from counter reading to milliGals is not perfectly linear; hence, a table rather than a constant is used. The table for the translation of instrument reading to milliGals is supplied by the manufacturer.

- Import this table to QCTool. Your qct-file should look like this:

N	A: Readings()	B: Calibration()
19	1800.00	1890.00
20	1900.00	1995.00
21	2000.00	2100.00
22	2100.00	2205.00
23	2200.00	2310.00
24	2300.00	2415.00
25	2400.00	2520.00
26	2500.00	2625.00
27	2600.00	2730.00

- To apply the Meter Calibration correction, use the *Merge Files* utility to 'update file channels'.
- Select your gravity survey file as a File 1. For the Base Station channel, select Instrument Readings Data.
- Select Instrument Calibration file as a File 2. For the Base Station channel, select Instrument Readings Data.
- On the 'Select Columns to Update' dialog, select channel with translation data in File 2. Leave 'New Column' mode selected for File 3.
IMPORTANT: Check the 'Interpolate if Value is not found' check box. The calibrated reading data will be calculated automatically.

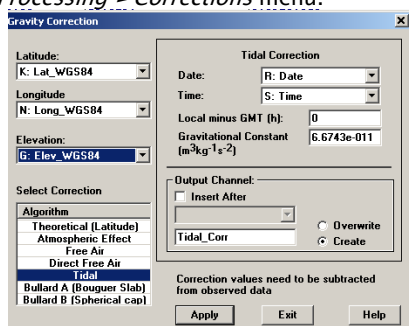
3.2. Tide Correction

The very first correction to be done is the tidal correction as this is the only temporal corrections in this group of corrections apart from the drift corrections. To properly correct for drift, the tide should first be applied. The datum, presently, for this correction is based on Longman (1959) which utilizes the Hayford ellipsoid model of 1910. The choice of datum for the coordinates is not considered relevant as any errors are less than 1 μ gal.

References: LONGMAN I.M., Formulas for computing the tidal accelerations due to the moon and the sun. Journal of Geophysical Research, 64(12):2351–2355, 1959

Open your gravity survey file and correct data for the 'tide' effect.

- Select *Latitude, Free Air, Tide, Bouguer, Atmospheric Effect* from the *Processing/Gravity Data Processing* ► *Corrections* menu.



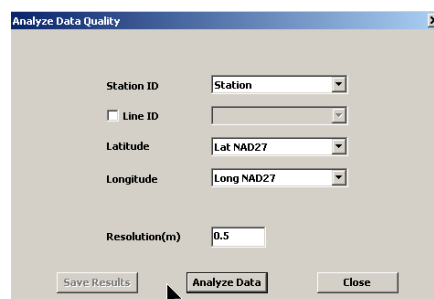
- Specify *Latitude, Longitude, Elevation* channels using the respective dropdown menus. Select '*Tidal*' algorithm in the correction algorithm list box. Specify '*Date*' and '*Time*' channels and GMT time difference. If desired, alter the default value for *G*. Set the name of '*Output Channel*'. Click on the '*Apply*' button to '*create*' or '*overwrite*' the specified channel. Ensure that the time zone of the time channel in your file is set correctly in the interface.
- The new channel with the 'tide correction' will be created in your QCT file.
- Apply this correction to the channel with instrument readings by using the calculator. (Insert a new channel then apply formula *new channel = instrument reading + tide correction* (e.g. $M = B + L$) for all lines and all rows).

3.3. Check Station ID and Repeat Station coordinates

The Station ID Channel is a key channel to accurate drift corrections and accurate drift corrections are key to accurately processed data. During surveying, measurements should be repeated at critical stations both for daily loops and across days. Sometimes, repeat measurements are identified as being performed at the same station but the measurement was not repeated sufficiently close to the other repeats. Also, sometimes repeats are made but the Station ID was recorded incorrectly. When there are a large number of measuring stations in the survey, it can be difficult to make all the necessary corrections prior to performing the drift corrections.

Processing/Gravity Data Processing ► *Analyze Data Quality*.

- Select Station ID channel as well as Latitude/Longitude and the desired resolution for repeat station proximity.
- If the StationID's are unique within the file, Line ID need not be defined. But, if StationID labels are repeated between lines, the Line ID must be selected
- Analyze Data. If the message is that the Station ID locations are not valid. Then, save your results and analyze the information to make corrections.



3.4. Instrument Drift Correction

Characterizing the Drift

Meter drift is often assumed to be a linear phenomenon. If it were truly linear, the drift rate could be determined from only two readings. You could take a base station reading at the beginning of the survey and another at the same station at the end of the survey. This is called a loop tie. From this, you could solve for the constant drift rate and use this to compute the drift and use it to remove from any observation as a function of time.

Rather than making a single loop tie, you could make several loop ties as the survey progresses. Within each loop tie, you might assume a linear drift but because you have many different drift segments, you can reasonably approximate a more complex drift. Once the drift curve is established, you can compute what drift to remove from any observation as a function of time.

Each line (spreadsheet) in the file must be sorted by time in ascending order.

Sorting is performed by selecting *Tools/DataChannels/Sort all by Channel*. Select to sort by your time channel, select *Ascending* and *select for all lines*

The Station ID Channel and the Time channel are the key channels to calculation the drift. Stations which are repeated either during a single day or across days should have the same Station ID.

Select *Processing/Drift Correction* from the menu. Next, the *Instrument Drift Correction* dialog appears.

- Be sure to select the *Station ID channel* (channel containing station label) as well as *Data channel*, which in our case will be the channel with data already calibrated and corrected for the tide effect. Set the *Reference Channels* (Time and Date). Specify the *Output Channel*.
- The Line Channel is required if the same station label is used at different locations on different lines
- **Process days separately** if a sheet has multiple days and the drift correction should be calculated using the first reading on each day. Normally each day's data will be contained in a different sheet within the file
- Select **Correction Across Days** to apply a least squares approximation so that the difference between base station data values for each day is reduced. Normally, a fixed StationID is used a base station reading on each day.
- Now apply the drift correction to the data channel by using the calculator's 'addition' function. You will get the 'corrected' observed gravity values.

N: Grav_Obs	O: DriftCorr	P: Grav_Ob...
4834.865522	0.000000	4834.865522
4833.965497	-0.000352	4833.965145
4830.036361	-0.000785	4830.035576
4836.409874	-0.004162	4836.405712
4834.682339	-0.004332	4834.678007
4837.377858	-0.004524	4837.373334
4838.154712	-0.004751	4838.149961
4833.529221	-0.004908	4833.524313
4835.854897	-0.005167	4835.849730
4832.816510	-0.005298	4832.811212
4834.872262	-0.006740	4834.865522

4. Absolute Gravity Calculation

The absolute gravity can be calculated for all stations in the survey file. This assumes that you have reference or base stations which have been measured at Absolute Gravity stations. Not all countries have such stations installed.

Select *Absolute Gravity Calculation* from the '*Processing/Gravity Data Processing/Corrections*'

Then, the *Absolute Gravity Calculation* interface appears.

The screenshot shows a dialog box titled "Absolute Gravity Calculation". It has several input fields and buttons. The "Reference Station Channel" is set to "Station". The "Reference Station" is set to "90002". The "Absolute Gravity" is set to "979903.19". The "Gravity Reading Channel" is set to "Grav_Obs_Final". Under "Output Channel", the "Overwrite" radio button is selected, and the "Gravity" dropdown is visible. At the bottom, there are "Process" and "Cancel" buttons.

- Select the *Reference Station Channel* (channel with the station label), *Reference Station* (station for which absolute gravity data is known) and *Gravity Reading Channel* (your 'corrected' channel from **Section 3.3**) from the respective dropdown menus.
- Set the *Absolute Gravity* for the specified reference station.
- Specify the *Output Channel*.
- Click on the *Process* button to obtain the '*Absolute Gravity*' values.

Note: If you have more than one raw file with gravimeter readings, import all of them into QCTool first. Then merge all files into one using the '*Append Files*' utility. Once you have a merged file with all the measured data, repeat **Sections (steps) 2 to 4** described in this manual.

Gravity Corrections > Processing

5. Latitude, Free Air, Bouguer, Atmospheric corrections

- Select *Latitude, Free Air, Tide, Bouguer, Atmospheric* (from *Processing > Gravity Data Processing > Corrections*). The tide corrections having normally been done before this stage. The order of corrections now is normally Theoretical (latitude), atmospheric, and then free air.

The Theoretical often termed the Latitude correction is the principle gravity response due to the theoretical ellipsoid and calculated for a station on the surface of the ellipsoid. This accounts for the majority of the absolute gravity observed data. It is important that the chosen latitude is consistent with the geoid used in the formula that you chose. For example, if your stations are in NAD27 then you would not choose the 1980 (GRS 80) international gravity formula because the ellipsoids are not consistent.

We believe that if the user requires the final results to be in old geoid model such as NAD27 then the coordinates should first be transformed to more modern coordinates both horizontal as well as vertical such as NAD83, NAVD88 or WGS84. Then the processing may be done using the modern ellipsoid models. The results may be stored with the original coordinates. This allows the use of more modern and accurate datums and formulae for these corrections. It is also important that once the corrections are begun with the stations and elevations in specific datums that the following corrections are performed with consistent formula for all corrections. For example, if the stations are in NAD83 and you perform the theoretical correction in GRS80 then free air should also be done with GRS80.

It is also important to realize that the theoretical calculation removes the response of an ellipsoid model of the earth with uniform density (normally 2.67 g/cc). Thus, from this calculation going forward, the

resulting data is residual data and all anomalies are relative the response of the theoretical ellipsoid model. This is simply the fundamental principle of the gravitational potential. Note also, that the theoretical response removes the gravitation effects of the rotating ellipse at the surface.

Additionally, the historical approach to calculating the Free Air results is a little awkward given modern computers. The free air correction is to account for the variation in the gravity field of the model ellipsoid at the station elevation versus the strength of this response on the geoid surface. Remember that the field due to a uniform ellipsoid is a function of distance from the ellipsoid's center and the latitude of the measurement. The end result after performing the theoretical and adding back in the excess due to the elevation is merely the observed measurement minus the theoretical field at the station. This is why we provide a Direct Free Space calculation which provides as an output the final Free Space field without need for the common intermediate calculation. The gravitational effects of the earth's rotation are included in these calculations.

In the standard historical processing steps, the intermediate Free Air calculation outputs the theoretical response at the station minus the theoretical response at the geoid and thus in the present processing, the intermediate free air calculation channel is to be subtracted.

- Select Theoretical, Free Air, Atmospheric, Bouguer algorithm from the Correction Algorithm list.
- Specify Latitude, Longitude and Elevation channels from the respective dropdown menus as required

- Set the additional parameters for the selected algorithm:
Theoretical Gravity correction Select the formula for Latitude, Atmospheric and Free Air correction
Density value for the Bouguer corrections
- Verify 'Output Channel' for the selected algorithm.
- Click the Apply button. The new channel with correction data will be created.
- Repeat the above steps for each desired correction
- Use formula: $Corrected\ Gravity = [Gravity_Observation_Final] - [Gravity_Theoretical] - [Free\ Air\ correction] - [Atmospheric\ Effect] - [Bouguer\ correction]$ to calculate the reduced gravity value with simple Bouguer correction.
- Use formula: $Corrected_Gravity = [Gravity_Observation_Final] - [Gravity_Theoretical] - [Free\ Air\ correction] - [Bouguer\ correction] - [Spherical\ Cap\ Bouguer\ correction] + [Regional\ Terrain\ Correction] + [Local\ Terrain\ Correction]$ to calculate the reduced gravity value with complete Bouguer correction.

Note: More information about the spherical cap Bouguer algorithm can be found in An exact solution for the gravity curvature (Bullard B) correction. T.R. LaFehr. Geophysics. Vol. 56. No.8(August 1991);p1179-1184.

6. Isostatic Correction

In addition to the aforementioned corrections, the Isostatic correction is to compensate for density variations in the crust and mantle caused by effective weight of the topography (or variations in the surface of the earth from the ellipsoid model). This is an extremely important correction which is often overlooked. The strength of this correction is comparable to the Bouguer corrections. The weight or lack of weight caused by variations in the surface of the earth from the ellipsoid surface creates changes in the thickness of the earth's crust as the mantle can be described as a type of fluid. This correction offsets the Bouguer corrections and is generally similar in magnitude but of opposite sign to the Bouguer corrections.

Select *Create a Regional Grid for Isostatic Gravity Correction*
(from *Processing > Gravity Data Processing > Corrections > Isostatic Correction*)

6.1. Creating a Regional Grid from NOAA's Global Relief Model (ETOPO1)

This application is designed to create a Regional Grid in order to apply the Isostatic Correction. The wizard obtains a Global Relief Model (in ETOPO1 format) of the current survey area (as specified by the .qct file) with an overlap of 166.7km on each side and then saves it as a smaller grid. The advantage of the ETOPO1 grid is that it includes bathymetry data.

You may download a suitable relief model from NOAA at

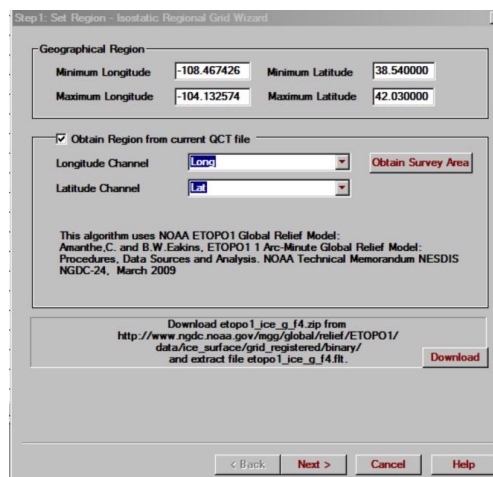
https://www.ngdc.noaa.gov/mgg/global/relief/ETOPO1/data/ice_surface/grid_registered/binary/

and chose "etopo1_ice_g_f4.zip" to download and then unpack.

Then proceed to the Isostatic corrections via the main Gravity Corrections link on the main page. Note, the grid coordinates for this model are in WGS84 and thus you must have WGS84 Lat/Long (NAD83 is reasonably close for most applications) in your data file. Note: our application allows for the coordinates to stored in as many datums as desired.

First Page

- If you wish, you may specify the geographical region by setting the Minimum and Maximum values for the Latitude and Longitude.
- Otherwise, if you wish to cover the survey area, check the 'Obtain Region from current QCT file' box and select the NAD83 or WGS84 latitude and longitude channels. Then, click Obtain Survey Area to update the minimum and maximum channel values.
- If you have already not done so, Click the 'Download' button to save the required file from NOAA's website: etopo1_ice_g_f4. Zip. Choose a location to 'Save' the file to your computer.
- Note: To create the grid, the algorithm uses the grid-registered, binary ice surface version of the NOAA ETOPO1 Global Relief Model. This grid is not included with QCTool SETUP due to the significantly large size of the file.



Second Page

Specify the location of the Digital Topography file by clicking the  button

Note: Since the ETOPO1 grid does not distinguish between negative elevations on land and sea, MODIS water mask maps are used for this purpose. If a point is located in the ocean, 50 km must be subtracted from its value for correct Isostatic calculations. Click MODIS for more information.

- Choose Use water mask maps to differentiate between negative elevations on land and water. In which case, the correction mentioned above is performed automatically. Otherwise, select No negative inland elevations.

When using the 'water mask maps' option, each point is checked against MODIS maps to determine if the location is under water. If that's the case, then a value of -50 km is used for that location only. Conversely, if 'no negative inland elevations' is selected, the -50km value is used for ALL negative elevations, by default.

- Load the elevation data by clicking the **Load Data** button. Alternatively, to reset the 'loaded data', click the **Discharge** button.

*Note: The **DEM File Info** section is not applicable for the Isostatic Correction.*

- Click **Next** to proceed to the third page.

Third Page


This page allows for the creation of a grid in a QCTool format (.isgr) using the extracted elevation data. This grid is then used to apply the Isostatic Correction. The data is in WGS 84 format and specify the 'Zone' to convert latitude and longitude to UTM X and Y coordinates. Check the Polar Projection box if the survey area is within the polar region. Please note that Add UTM coordinates box must be checked in order to use the grid with the Isostatic Gravity Correction tool.

- Click **Save Imported Data** to specify a name for the output file. Click **Finish** to create the grid file.
- *Note: the .isgr format is a standard QCTOOL grid format. It can be opened in QCTOOL and the Ellipsoid Datum transformed and saved as a .qdem file and used for corrections for stations using the different datum.*

6.2. Applying the Isostatic Correction

- Select 'Isostatic Correction' from the Processing > Gravity Data Processing > Corrections > Isostatic Corrections menu.

- On the window that appears, load the **Isostatic correction grid file (.isgr)** created in the previous step by

clicking the  button.

Note: The ISGR file *MUST* have been created using *QCTool's Isostatic Regional Grid Wizard* particularly when you have negative elevations (e.g. bathymetry data). However, if the .isgr file has been created in the wizard, it can be opened in *QCTOOL*, changes made and re-saved as a .qdem file. If elevations are available from other sources with a suitable grid, they can be gridded in *QCTOOL* and saved as a .qdem file.

- Select *UTM X* and *UTM Y* channels from the dropdown menus.
- Specify the *Output Channel*.
- Set Parameters: *Densities*, *Inner Radius* and *Outer Radius*. The suggested value for the *Inner Radius* is the resolution of the grid. i.e. 1000 for a grid with cells measuring 1 km. *Outer Radius* should be less than the distance between the outer edge of the grid and the outer edge of the survey area.
- ECM models: <https://www.earthcrustmodel1.com/> Can provide crustal thicknesses and densities
- Choose between three models: *Airy-Heiskanen*, *Pratt Model* or *Extended Heiskanen*
- The chosen '*Compensation depth*' value will be the assumed thickness of the crust
- For the *Airy-Heiskanen Model*, specify the *Crust*, *Mantle* and *Water densities* as well as the *Inner* and *Outer Radii* and the *Compensation depth*.
- For the *Pratt Model*, specify ONLY the *Crust* and *Water densities* in addition to the *Inner* and *Outer Radii* and the *Compensation depth*.
- For the *Extended Heiskanen* model, set the estimated Oceanic Crust thickness as well as the continental crust thickness and *Crust*, *Mantle* and *Water densities*. The ECM models will provide you thicknesses and density estimates

Note: The *Airy-Heiskanen Model* assumes a constant density of the crust and accommodates for changes in topography by changes in crustal thickness, whereas the *Pratt Model* uses lateral changes in the rock density to accommodate for changes in topography.

- Click on the '*Calculate Correction*' button to create a channel with local Isostatic correction values. These values must be subtracted from your instrument readings to apply the correction.

FEATURES – This procedure can now utilize topography and bathymetry data from all over the world using the *ETOPO1* format. Furthermore, using the *MODIS* water mask tiles, the accuracy of the procedure is further enhanced by determining whether a given point is on land or under water. The algorithm has been modified to utilize non-regular grids and ALL the grid points of the Isostatic Grid except at the specified boundaries for inner and outer radii, where the elevation is computed using interpolation.

7. Terrain or Topographic Correction

<https://www.petroseikon.com/download/abstracts/TopoCorrectionSAGEEP2009.pdf>

Introduction:

The Bouguer corrections overestimate the effects of the topography as the assumed elevations have no lateral boundaries. The Bouguer slab was introduced as a correction prior to the existence of computers as a general tool since the slab corrections can be made by hand on paper. The topographic corrections are designed to add back in the overestimates. Thus, the topographic corrections are to be added to your results after the Bouguer corrections are made. But, it should be noted that this procedure to make Bouguer and topographic features appears to be seeing the end of its usefulness. Even with accurate full Bouguer and Isostatic corrections, the resulting data still will almost certainly have a DC shift without the use of absolute meter readings.

Today, with rapid computation abilities at our fingertips with the advent of multi-core rapid processors installed in every computer, the need to perform any corrections beyond free air is likely not necessary. Modern interpretation software (e.g. EMIGMA, Intrepid) can include the topography into our gravity models. Thus, there is no need to assume a uniform density for the topography and we can also look for structure within the topography. This, latter issue is extremely important for so called micro-gravity where we are attempting to resolve shallow structures. But, even if the full Bouguer is performed plus Isostatic corrections, it may still be useful to include the local topography in the inversion models.

Clearly, the importance of topographic corrections is based upon the accurate knowledge of the local topography and the distance extent of the more coarsely defined regional topography. The effect of the distance topography can be significant and it is important to ensure that the corrections carried out to a sufficient distance depending upon your exploration objectives.

Early numerical techniques were based upon surveying near each station to derive a local 3D model and correct utilizing simple trigonometry. This technique became known as the Hammer Correction and is included in QCTool. It is, of course, useful as a check if the surveying has been performed. However, satellite data cannot resolve areas of high terrain variation and may not reach into crevices nor resolve canyons well or provide sufficient accuracy for sites at the tops of steep mountains.

In 2014, we introduced an approach to utilize digital elevation grids combined with local surveying of GPS elevations. This also allowed the use of high resolution GPS survey in the survey area and coarse GPS surveying in a region outside the survey area. At this time, what DEM grids that were available for example in Australia, Canada, Mexico and the United States were coarse grids normally for a size 1km by 1km. In such cases, the DEM resolution is inadequate to represent the topography over and near the survey area and thus a tighter resolution GPS elevation survey was required. This was termed in our software, the Local and Regional terrain corrections.

Today, with the advent of several choices for high resolution DEM models, different approaches can be made with our software. One choice is the Shuttle Radar Topography Mission (SRTM) land elevation data. This is available from several sources but can easily be acquired via USGS Earth Explorer ([/earthexplorer.usgs.gov](http://earthexplorer.usgs.gov)) for almost everywhere on the earth. Nevertheless, even with the higher resolution many surveyors perform their own elevation survey at higher spatial resolutions. In this case, the terrain correction can be applied twice or more to cover areas of different spatial resolution.

There is not one single method to perform these corrections but the software is intended to allow each user their own procedures.

Algorithms: Discrete vs. Continuous

The computation of the gravitation effect of terrain at a survey station is with simplicity,

$$g_z(r_0) = G \int \frac{\rho(r)}{|r-r_0|^2} dr$$

where the integral is over the entire topography. In early days, with slower computers, this integral was performed via a simple numerical technique where the topography was constructed as a suite of rectilinear prisms with the base the DEM grid cell and its height the elevation. The strength of G_z at the survey site for each prism was then simply calculated as its density multiplied by its volume and multiplied by inverse distance squared to the center of mass of the prism. If you recall your high school or university calculus, this method is called a Riemann sum and utilizing just the center of mass is equivalent to the midpoint rule with no attempt to check convergence. This approach is, of course, extremely inaccurate and unfortunately still used in some well-known commercial software. Of course, the numerical integral could easily be improved. However, the use of rectilinear prisms of this sort proves numerically inefficient when accurate solutions are required. Additionally, the use of “flat tops” on the prisms does not very accurately represent the true surface when the stations are sitting on a strong slope. The problem is thus more relevant in areas of high topographic variance.

Another approach is to represent the surface as continuous and use an appropriate gridding technique to closely approximate a continuous surface with flat surfaces but orientated to closely approximate the true surface. The entire topography must then be split into grid cells which necessarily are not rectilinear. Our approach is proprietary gridding technique which attempts to subdivide the volume into cells of uniform volume. The integration then is performed over this collection of cells utilizing “sample points” inside each grid cell to accomplish desired convergence requirements.

In this application, the user can request which type of topographic gridding they desire.

NOTE: The user must keep in mind that DEM files are compiled in a certain datum (geoid model) which may be different from the datum they wish to use for their survey coordinates. This can be particularly important if you are working on a historical problem where data and maps have been compiled in older datums. If the datums of the DEM and survey coordinates differ then you must convert the topography to the correct datum before proceeding with topographic corrections or it may be simpler to convert your survey to the topographic datum (normally WGS84), process in this datum and then convert the final data back to your desired datum. Latitude and Longitude are normally provided in the DEM and so the datum can be transformed to the desired datum and the Eastings and Northing projected. All of these processes can be accomplished in QCTool.

The following are some examples of procedures that can be followed.

7.1. Creating a Regional Topography grid from USGS (GTOPO) or Canadian (CDED) files

This is only one approach that you may take in QCTOOL for terrain corrections. The application has been designed to create a regional topography grid from the DEM files in GTOPO, CDED and .BIL formats. The grid produced is then used to apply the Terrain Correction. The GTOPO digital elevation grids are 30 arc second grids which are approximately 1km x 1km and have been available worldwide since 1996. Because of this coarse resolution, these grids are very suitable for the regional topography correction. In this description, we are assuming the use of the coarse DEM grid for the regional topographic corrections and then later some other source for the finer, local corrections. The CDED DEM is either 30m or 90m resolution. The SRTM .bil files are approximately 30m x 30m.

GTOPO30, SRTM .bil files are available at the USGS *EarthExplorer* site, <https://earthexplorer.usgs.gov/> as well other sites. Note that these grids do not contain bathymetry data.

Band Interleaved by Line format (.BIL)

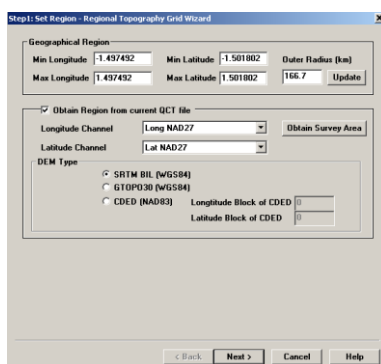
These are raster formats with geographic information in WGS84 Latitude/Longitude Coordinate system. DEM data in the .bil format are also available from the Mexican government website, INEGI (*National Institute of Statistics, Geography and Computer Science*) and from the WWF HydroSHEDS website. The elevations are with respect to the geoid. CDED files may also be used which are NAD83.

From the **Terrain Corrections** menu (*Processing ► Gravity Data Processing ► Corrections*), select *Create Grid from DEM Data*. *Note: It is not necessary to use this tool. All the formats may be imported to QCTOOL, multiple files merged and then the data is gridded and the resulting grid saved for use in the next section.*

The first page of a wizard to create such a grid appears.

First Page:


- On the first page of the wizard, specify 'Geographical region' by setting of minimum and maximum values for the latitude and longitude. If you wish to cover the region of your survey data, simply check the *Obtain Region from current QCT file* check box, specify channels for *Latitude* and *Longitude* and click on *Obtain Survey Area* button.
- Select the type of DEM file (GTOPO, BIL or CDED) Click *Next*.

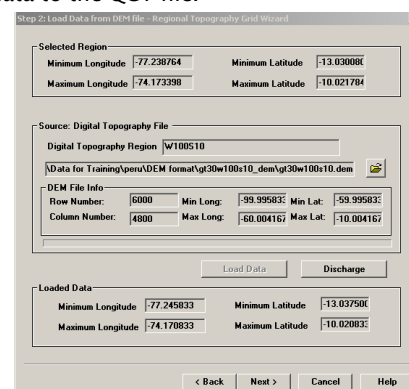


Second Page:

For GTOPO or BIL Files

- On the second page of the wizard, specify the appropriate digital topography file either in .BIL or .DEM (GTOPO30) formats.
- For .BIL files, click the *File Browser* button to change the file type to .BIL using the dropdown menu. Then, select the file and click *Load Data* to load the elevation data to the QCT file.
- For GTOPO30 files, the directory of the DEM file should also have a header file containing size and coordinate information for the DEM. This file is expected to have the same name as the DEM file and a .hdr extension.
- Click the *Load Data* button to load the elevation data to the qct-file.
- You can append data to the existing topography file if your survey area is covered by more than one DEM-file. Select the second DEM file by clicking the

File Browser  button and then clicking the *Load Data* button again. Click *Next* to proceed to the third page.



Note: If selected area covers more than one geographical zone you will get a warning. The suggestion is to split measured area into parts according to the geographical zone bounds.

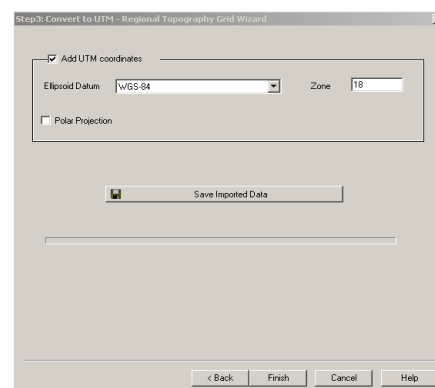
- You can reset the *Loaded Data* section by clicking the *Discharge* button.

For CDED files:

- Depending on the size of the area you selected in Step 1, you may need to load up to four files. Select the relevant files before clicking *Next*.

Third Page:

- On the third page, you will create a grid using the topography data files in the QCTOOL grid format (.qdem). This will be done in two steps.
- First, the latitude/longitude coordinates are converted to the appropriate GRID X and GRID Y. Ensure that the correct *Ellipsoid Datum* is selected. This application will not transform from the original DEM datum. Check the *Polar Projection* box if the survey area is within the polar region. Please note that *Add UTM/Grid coordinate's* box must be checked in order to use the grid with the *Terrain Correction from DEM* tool.
- Second, the regional grid is created. Click *Save Imported Data* to specify a name for the output file. Click *Finish* to create the grid file.



7.2. Building a Grid from User Elevation Data

If you have your own elevation data, you may use it to build a grid and use this grid to perform a terrain correction or part of the correction.

- Import your data into QCTool. To do this, you must have UTM X and UTM Y channels in addition to elevation data. In this case, ensure the datum for the grid UTM coordinates is the same as that for the data coordinates.
- First map the elevation channel in QCGrid . When you click QCGrid, a *Set Channels* dialog appears. Ensure that the correct channels are selected for X, Y, and data.
- Interpolate the data using . You can set the appropriate sizes for a grid cell.
- Click the *Grid Mesh* button , and then click to save the grid as an .EGR file.

7.3. Terrain Corrections from grids.

Select *Continuous Surface Topography* from the *Terrain Correction* menu
Processing ► Gravity Data Processing ► Corrections

Note: The Discontinuous Prismatic Topography selection will use the archaic technique of rectangular prisms as discussed above.

- Once the dialog appears, specify the Regional DEM Grid file either the .qdem file (you built using the Regional Topography grid wizard) or the .egr file created using the *Save Grid* button on the *Grid Mesh* tab of the *Tools* window from another source of DEM.
- You must now select/check that the X, Y and Elevation channels are selected correctly from your DEM grid and that the X and Y grid channels are selected correctly from your data file. The grid and the data file are now allowed to have multiple grid coordinates and elevations. The station elevation may be determined from your instrument or from another instrument but you have the choice to use the data file elevations or the grid elevations to perform the calculations.
- Select the correct channels from the grid file for grid X and grid Y in the respective dropdown menus as well as the Elevation channel
- Select the correct grid channels in your data file in the respective dropdown menus.

- Now select whether the elevations in the DEM grid or the data file are to be used for the topographic correction. If the DEM elevation is used, the app will estimate the elevation at the station from the DEM grid.
- Specify **Output Channels**. The DEM Elevation channel will contain the interpolated elevation as each station derived from the DEM grid. This is to perform checks.

- Full Terrain or Terrain Residual:**

The traditional approach as this stage is to calculate the overestimate of the Bouguer slab correction termed the 'Terrain Residual'. This will not fully correct for the overestimate for the slab because this computation assumes an infinite slab in the horizontal dimensions. The *Full Terrain* utilizes the DEM grid to calculate the entire response of the digitized topography. This *Full Terrain* channel is then used rather than the [Bouguer – Terrain residual] to obtain the Full Bouguer correction. One can also select to use the older approach of using rectangular prisms to estimate the topographic effect whether Full or Residual.

- Set Parameters:** Density, Inner Radius and Outer Radius.

The suggested value for *Inner Radius* is the resolution of the grid. (e.g. Enter 1000 for grid with cells measuring approximately 1km or 30m if the grid cells are approximately 30m). *Outer Radius* should be less than the distance between the outer edge of the DEM and the outer edge of the survey area. If you wish a different value for the gravitational constant, enter it here.

- Click the 'Calculate Correction' button to perform the correction and add the resultant channel (with regional terrain correction values) to the file.

Note: You may create a .qdem file without using the wizard; create a QCTOOL file with your Grid X, Grid Y and ELEVATION channels and then simply change the file extension from .qct to .qdem or interpolate and save as an .egr.

Discontinuous Prismatic Topography – Historically, topography corrections were made by assuming a rectangular prism with the base the size of the DEM cell and the height the elevation given for the grid cell. The effect of the grid cell was normally computed only as the volume at the center of the cell times the density. This older method still used in several commercial software apps has been replaced by a more accurate continuous surface. But it is also implemented here. <https://www.petroseikon.com/download/abstracts/TopoCorrectionSAGEEP2009.pdf>

NEW FEATURES – The algorithm has been modified to utilize all the grid points of the DEM except at the specified boundaries for inner and outer radii, where the elevation is computed using interpolation. The interface can now utilize non-regular DEM grids as well as grids created entirely from QCTool (.EGR).

Suggestions for Using Multiple Grids: - If we were to assume, as an example, that we had a DEM from the SRTM data which normally has a resolution of 30m as well as a 5km x 5km surveyed DEM grid with a resolution of 5m carried out over a gravity survey of 2km x 2km. Then, the surveyed grid would be applied with an inner radius of 5m and an outer radius of 3km. Following this, the larger SRTM DEM would be applied with an inner radius of 3km and an outer radius equal to the minimum distance between the outside of the gravity survey and the outside of the regional DEM grid. The distance between any point in the gravity survey plus the outer radius must be within the larger DEM grid.

7.4. Local Terrain Correction (Stations)

This technique is the original terrain technique used by surveying elevations around a gravity survey point.

Select **Local Terrain Correction (Stations)** from

Processing > Gravity Data Processing > Corrections menu.

There are two methods by which you may obtain these corrections. In one case, the user has a .qct file which contains a set of local elevations surrounding each gravity station such as the example shown below.

N	A: StationID	B: X	C: Y	D: Z
1	A	380669.88	4439796.51	2000.50
2	A	380667.58	4439794.51	2001.00
3	A	380666.88	4439790.00	2000.00
4	A	380670.00	4439795.00	2000.40
5	A	380669.00	4439795.51	2000.30
6	B	374649.08	4436562.84	1900.50
7	B	374648.08	4436560.84	1900.00
8	B	374647.58	4436561.34	1901.00
9	B	374647.28	4436561.24	1900.80

In this case, select '*Local Terrain Correction*' and the dialog appears:

- Select the QCTOOL file with correction points. This file should already have *Station ID*, *UTM X*, *UTM Y*, and *Elevation* channels. Of course, these need not be UTM grids but grid coordinates consistent with your data coordinates. There should be at least 3 correction station points around each gravity station of the original file. The file should look like the one above.
- Specify channels for *Station ID*, *UTM X*, *UTM Y*, and *Elevation* using the respective dropdown menus.
- Specify *the Output Channel* and the average *Density* (of crustal rocks).
- Click the '*Calculate Correction*' button to apply the Local Terrain correction.

If you have traditional **Hammer correction points**, you will have about each gravity station a series of points where you have the azimuth, inclination and distance from the gravity station to the correction point. In this case, select "Create Hammer Correction file" with your gravity data file open.

Ensure, the Station ID, and coordinate channels of your gravity data are selected in the above interface. Click OK and a Hammer correction file will be created in QCTOOL format for which the formulas for each channel are stored (*see below*).

Create Hammer Correction File

Output

M:\Product\QCtool\Hammer Corrections\local_terrain_files\gravity_surve

Browse

Input Channels

Station ID A: STATIONID Y E: UTM

X D: UTMX Elevation F: ELEV

OK Cancel Help

Record	A:Station ID	B:X	C:Y	D:Z	E:Azimuth(deg)	F:Inclination(deg)	G:Distance(m)	H:X_Cor	I:Y_Cor	J:Z_Cor
1	999	422500.00	8725700.00	4150.00	*	*	+	+	+	+
2	999	422500.00	8725700.00	4150.00	*	*	+	+	+	+
3	999	422500.00	8725700.00	4150.00	*	*	+	+	+	+
4	999	422500.00	8725700.00	4150.00	*	*	+	+	+	+
5	999	422500.00	8725700.00	4150.00	*	*	+	+	+	+

Populate at least 3 locations about each station with Station ID, Azimuth, Inclination and Distance. Then, select '**X_Cor**' channel and proceed to the calculator button. , click *Load channel formula* and select *All records, All Lines* and then *Apply*. '**X_cor**' will be populated with the coordinates of the correction station. Repeat for the channels, '**Y_cor**' and '**Z_cor**'. You may then load this file into the first process (Local Terrain Correction, Stations) and perform the gravity corrections.

Formula Calculator

Result: = Formula:

☐ Autobold formula

Current Line: 999

Formula result:

Records:

☒ All Records ☒ All Lines From: To:

Functions

sin	asin	x/2	ln	row
cos	acotan	x/3	log	row
tan	acotan	10^x	cotg	PI
atan(x/y)	abs	exp		
Rie	ln	complex(i)		
<input type="button" value="random"/>				

☐ Degrees ☐ Radians

Numeric

7	8	9	.	=
4	5	6	+	-
1	2	3	*	/
0	-	+	A	
<input type="button" value="."/>				

Columns:

A	B	C	D	E	F	G	H	I	J	K	L	M
N	O	P	Q	R	S	T	U	V	W	X	Y	Z

8. Eötvös Correction (for Marine and Airborne surveys) - *NEW*

This correction is applied when the gravimeter is on a moving platform (e.g. marine, airborne survey).

Three algorithms are available. **Glicken**, (Glicken, M. 1962) is the standard Eotvos including the vertical component of the Coriolis as well as the second, centrifugal term. This assumes a constant elevation above the ellipsoid and low velocities and thus suitable for marine gravity. **Harlan** (Harlan, R.B. 1968) is an improvement to account for higher velocities and incorporates the effects of the earth's flattening. It does not account for accelerations due to variations in the vehicle altitude above the ellipsoid surface. **Accurate**, is our modification of Harlan which are improvements in his approach to his approximations in the terms which are dependent upon the ellipticity.

- Select *Eotvos Correction* from the 'Processing > Gravity Data Processing > Corrections' menu.

- Select the *Latitude* channel from the dropdown menu.
- Specify the '*Speed*' and '*Heading*' channels. Speed is the total speed along the surface and heading provides the vector direction.
- Glicken does not require an elevation.
- Specify the *Output Channel* either by overwriting an existing channel or by creating a new one.
- Click Process to calculate the 'Eötvös effect' correction and create the specified Output Channel.
- The output channel by our convention is to be removed from the processed gravity channel to be consistent with the other corrections.



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