

MAGNETIC BASE STATION CORRECTIONS IN QCTOOL

Background:

In addition to spatial variations in the magnetic field as measured by the rover magnetometer, there are temporal variations in the magnetic field. Historically, one base station was used to remove what was termed the diurnal variation from the rover data. However, misunderstanding of the term “diurnal” compounded by dramatic improvements in the sensitivity and accuracy of modern instruments requires more complex processing of these temporal variations. QCTOOL provides the capabilities to remove most temporal variations from your data in order to more fully utilize the increased capability of modern systems.

Diurnal Variation:

As the name implies, these are variations having a period of a day but they comprise data of two periods, the solar day and the lunar day. These variations are suggested to be due to variations in solar radiation during the day. These variations can be as much as 5% (on average) of the total field and thus must be removed from the rover data. These temporal variations have a long wavelength (slow) temporal variation and only comprise part of the total temporal variations. With care, these variations can be removed from the rover data with the use of only one basestation as these variations are approximately uniform over large distances. But, there are magnetic observatories all around the world and this data is normally available for download. Although, these measurements are generally done at a very low sample rate, these rates are generally sufficient for correction the diurnal variation.

Other Temporal Variations:

There are many sources of other **temporal** variations but in our experience, there are 3 significant variations that must be considered: 1) Repeating man-made noise such as would occur from noisy power lines, factories, pumping stations, etc, 2) one time man-made noise such as the effects of vehicles, trains, etc and 3) complex external electromagnetic waves. These latter fields are the fields that are typically measured when doing magnetotelluric experiments. These fields originate above the earth within or below the ionosphere. Although, these latter fields can have periods ranging over a vast frequency range, for magnetic measurements, we are principally interested in those which the magnetometer measures. New instrumentation is increasing the sample rate significantly from the historical systems and thus a much bigger bandwidth may have to be considered.

Very low frequencies can be observed by comparison of base station data from multiple days while the signals from the upper frequencies are determined by the data collection procedures of the magnetometer data acquisition components. However, it is very common to have such data of up to 10nT and more affecting your data.

There are two basic approaches to dealing with these other temporal variations. The first is to attempt removal. Removal of these effects must be removed from both the base station and the rover data before applying corrections as they are not spatially uniform. With care the effects of 1) and 2) can be corrected with one basestation while the removal of 3) requires at least 2 base stations. Removal could be accomplished by simple windowed filtering such a mean or median or in QCTOOL a very useful filter is the Gaussian filter. The other approach if the timing of the data is accurate is to apply low pass filters. We suggest in this case using the DFT filters in QCTOOL which are extremely accurate.

The second approach is to use two or more base stations of which one may be an observatory data but the other must be proximate to the survey. If the survey is spatially large additional base stations will be required. First, the remote base station is used to determine the long wavelength diurnal variation during the survey times. Observatory data by its very nature is generally already free of high frequency noise but some sort of smooth filter may be applied. Then, the daily diurnal variation is computed by differencing the daily mean of the raw or filtered data from the same channel. This variation is then imported into local base station(s) and removed. Then, the idea is to compute the variation of local noise (temporal variation). Thus, the remote variation is removed from the local data after removal of any obvious outliers. The mean of this channel is computed and the new variation is computed. The total correction for removal from the survey data is then the sum of the remote variation and the local variation.

Two local base stations can be used to identify noise which is not to be expected in the survey data. For example, instrument noise, very local, small amplitude man-made sources and local 3D telluric effects. There are various means to remove such noise depending upon their nature. The wide range of processing tools in QCTOOL allows for a great deal of ingenuity and flexibility here.

One very classic and very large problem is the use of a very remote base station. For example, in many aeromagnetic surveys, the survey area is some distance from the lodgings of the crew. For simplicity, the base station is often located close to the lodgings but far from the survey area. Thus, the external noise signals (atmospheric and cultural) at the base station will not represent those at the survey area. To deal with this, the base station data is highly smoothed to remove all but long wave length data and now the base station data serves the same purpose as the observatory data. To deal with the remaining short wavelength noise in the survey data, the data is often low passed. However, the danger is that the signal from smaller targets or sharp boundary contacts are lost.

Instrument Drift Variations

Just as in gravity data, there are instrument drifts which vary with each particular instrument. These effects can be significant when compared to the basic accuracy of the instruments and so the use of drift measurements is recommended both within one day and between days. Such corrections require measuring with another magnetometer near the base station at the beginning of the day and at intervals through the data. The procedures are very similar to gravity drift corrections although typically drifts in magnetic instruments are less severe than can be experienced with gravity data.

Summary of Base Station Corrections in QCTool:

1. Obtain and Process Remote Base data

- remove any obvious outliers or impulsive type responses
- apply suitable low pass filter
- compute mean of low pass data (*Statistics* tool in QCTOOL)
- compute variation (*low pass – mean*)



2. Merge Variation Channel

- merge the variation channel from Stage 1 from the local base station file linked by time of day
- remove remote variation from the local base station data – [*remote base residual*]
- check spikes or impulsive type responses against survey data. If these noise instances do not exist in the data then they should be removed from the data at this stage.
- find the mean of the resulting channel and remove producing the *local base residual*



3. Determine Compound Variation Data

- the remote base residual is added to the local base residual to create the final channel to correct the survey data.

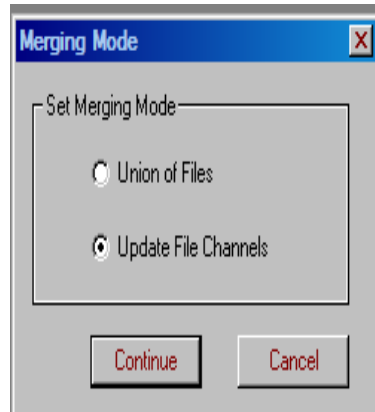
First, all base station data and observatory data are imported to different QCTOOL files. Then, spikes and obvious transitory noise are removed from the remote or observatory data. Then the remote base station or observatory data is processed for the *diurnal* variation by removing the mean over the times used for that day's surveying. Local base stations are checked for drift and corrected. If there are multiple local base stations, processing is applied to remove noise that is not correlated between the two base stations. This means correlated in time and/or frequency and not amplitude. Then the diurnal variation is imported into the resulting local base station data and the total variation computed as described above.

Then, the rover data is imported to another QCTool file and spikes and other transitory noise not correlated with the local base station are removed. It is easier to describe the following processes if the survey data is corrected daily but it is possible to have the entire survey data in one file and each day's total variation in another QCTOOL file with each day in a different spreadsheet in the one .qct file. But, it is useful to import both the total variation from the base station data as well as the daily means.

The procedures from this stage are dependent on the preference of the user. However, one procedure would be to merge the rover and base station data using the timing as the reference channel for merging. Plotting the base station data and the rover data as a function of time allows the user to identify if there are noise signals in the total variation data which do not appear in the rover data. This noise should be

removed from the base station data. The resulting corrected channel may then be removed from the rover data. In this way, we are removing the long wavelength variations from the data caused by the so called diurnal variations as well as common noise to both rover and base station data. At this point, the user may remove from the corrected data any other high frequency noise by the use of the various filters provided. After this, if the survey is large, the IGRF should be removed.

Merging Base Station Data with Survey Data



This tool is found through **Tools**

Base Data

Survey Data

Select Update Channels

Pair Lines (spreadsheets)

Lines: FILE 1	Lines: FILE 2
LINE1	LINE1

Examples

Correcting magnetic data using data from base stations

Two sets of examples are referenced below. The files are found in the folders /Example1 and /Example2

Example 1: Base station correction of ground magnetic data with 1 base station. (small survey)

Example 2: Processing of data from two (2) base stations into a single magnetic correction channel. Two basestations are required if you wish to remove the magnetotelluric signal.

1) Import base station data into QCTool using the appropriate import for the raw data file.

Example 1: [mar20_base_orig.qct](#).

Contains 2 channels: a) **time** and b) **base** (magnetic field measured at base station)

→ If you had multiple base stations measuring at the same time, or have access to data at a magnetic observatory in addition to the base station, then import these files separately, and merge as follows:

- Select **Merge Files** under Tools -> Files.
- Select **Update File Channels** as the merging mode.
- Select one base station file as the first file, and the other as the second file.
- Choose time as the base channel.
- Click **Merge**.

You will now have a file with two base station magnetic channels. Rename if needed.

Example 2: [merge_baseAB.qct](#), created by merging [baseA.qct](#) and [baseB.qct](#).

2) Process base station data

a) *For 1 base station:*

Example 1: [mar20_base_processed.qct](#).

- Plot the base station data.
- Remove any data outside the time during which the survey data was collected. Right click on the time channel, select **Processing**, then **Outlier Removal**. Use this tool to remove data outside a specific time window.

- Remove any bad data manually, such as spikes caused by instrument malfunction, by clicking the **Delete Points** button. Should you have many spikes from drop-outs, for example, you might use the **Outlier Removal** tool to do this automatically. See channel: [base_spikeremoval](#).
 - Following careful examination of the data, you may wish to filter the data to remove instrument noise or noise signals which do not seem to appear in the rover data. Note: If the basestation data contains a noise signal not contained in the rover data and you not remove this noise signal from your basestation data, then it will appear with opposite sign in the final processed survey data.
 -
 - **Digital filters** are located under **Processing**. Two filters were applied in the example. See channels: [base_spikeremoval_Median9](#) and [base_spikeremoval_Median9_Mean35](#).
 - Now get the Mean of the above channel. Use Statistics select Mean for each line and the Save Survey lines should be separated at this stage and each day done separately.
 - Subtract the mean channel from the processed base station data to obtain the base correction. If this data is at a very low frequency and filtered, it should be an estimate of the diurnal (internal) variation.. See channel: [base_correction](#).
- If desired, save a new file (**Save As**) with only the time and final diurnal correction channel to simplify merging with the survey data.

Now update the survey data with your desired channels. Some channels may be extra but provide checks to ensure everything is done correctly at this stage. [mar20_sureyline_variation.qct](#).

Final results in [mar20_surveyline_variation_FINAL.qct](#).

b) For 2 base stations:

Although ultimately you want a single base station correction channel, having multiple base stations allows more accurate processing and removal of noise signals not present in the rover data.

Example 2: merge_baseAB.qct

i) Remove bad data

- Plot both base station data channels. (Channels in example: **A_base_mag** and **B_base_mag**.)
- Remove any data outside the time during which the survey data was collected. Right click on the time channel, select **Processing**, then **Outlier Removal**. Use this tool to remove data outside a specific time window.
- Carefully examine the plot and remove non-coherent events. This is an advantage of having multiple base stations. In the example, there is excellent agreement between the two bases. *Note: In this example there is a DC shift in response between the two magnetometers of about 30 nT. Base A data has been shifted to the level of the Base B data (see channel: shift_A) before proceeding with the next step.*

ii) Average and Filter

Note: If one base station has much better quality data than the other, you may wish to use only that one for the diurnal correction. If this is the case, do not average.

- **Interpolate** both data channels with respect to time. (Right click on data channel, select **Processing** then **Interpolate Channels**.)
- Select the channel beside which you would like to create a new channel for the averaged base station data. Right click, and select **Insert Channel**.
- Enter the name of the new channel, and select the format and whether the channel will be placed before or after the current channel. Click **Insert**. (Channel: **mean_base**)
- In the spreadsheet toolbar, click **Transform Data** (the calculator).
- Enter the formula to average the two base station channels, and select the rows to which you wish to apply the formula. Click **Apply**.
- If desired, filter to reduce instrument noise and other small amplitude non-coherent signals. **Digital filters** are located under **Processing**. Filtered data will be in a new channel; compare with the original averaged data until you are happy with the result of the filtering. (Channel: **mean_base_filter**.)
- Compute the MEAN of the above channel using the STATISTICS tool

iii) Create variationl correction channel

- Insert a new channel as described above. Subtract the last MEAN computation of the processed data obtain the variation correction. (Channel: **base_correction**.)
- You may wish to save a new file (**Save As**) with only the time and final diurnal correction channel for ease of merging with the survey data.