Getting Started with montaj Geophysics

This How-To Guide introduces you to the montaj Geophysics™ extension, which provides a range of filters, statistical tools and 2D and 3D section display tools for working with large-volume geophysical data. For more information on preparing data and applying filters, see the *Preparing Data and Applying Filters with montaj Geophysics* How-To Guide.

"Spatial" 1D Filters enable field geophysicists to process data by applying a variety of space (time) domain filters (linear and non-linear). The 1D FFT Filters enables you to apply a variety of Fourier domain filters to one-dimensional (line) potential field and other data.

A variety of geostatistical tools provide the ability to view summary and advanced statistics, including multivariate histogram analysis, scatter and triplot statistical analysis, and the ability to subset data interactively from maps based on text code, regions or map group classification.

You can also grid and display curved or crooked sections in 2D maps or 3D views. This provides a more accurate representation in 2D and 3D by ensuring that data are correctly positioned along the survey line. These sections support full data linking between all displays of the data including: plan maps, sections and 3D views.

System Capabilities and Concepts

The montaj Geophysics software extension provides a range of filters and statistical tools for working with large-volume geophysical data. Spatial 1D Filters enable field geophysicists to process data by applying a variety of space domain filters (linear and non-linear). The 1D FFT menu enables you to apply a variety of Fourier domain filters to one-dimensional (line) potential field and other data. A variety of geostatistical tools provide the ability to generate summary and advanced statistics, including histograms, scatter and triplots, and the ability to subset data based on code or map group classification.

This *How-To Guide* is targeted to Earth Science professionals who are familiar with geophysical data processing methods and who want to apply Fourier domain linear filters to process and interpret one-dimensional (line) potential field data from magnetic and gravity surveys.

To use this package effectively, you should be familiar with Fourier domain filtering concepts and methods including Fast Fourier Transforms. You should also have an appreciation of how to apply filters for numerical analysis and interpretation of line data.

Understanding 1-Dimensional Fast Fourier Transform Filtering

Fourier filtering techniques are an important tool to geophysicists who work with potential field (gravity and magnetic) data. Fourier filtering techniques provide an effective means of processing and interpreting data that is broadband in nature (i.e. each observation contains the effects from all magnetic or gravity sources that produce a response above the noise level at the point of observation).

By transforming data to the Fourier domain (through the use of a Fast Fourier Transform, or FFT), we can deal with the data as a function of wavenumber, or wavelength. In this form, there are a number of manipulations that can be applied to enhance information that is of interest, remove information that is not of interest, or transform the data (see Bhattacharya, 1966, and Spector and Grant, 1970).

For example, in the Fourier domain we might apply a Butterworth low-pass filter to data to remove short wavelength features that are not of interest. We might also upward continue or downward continue data to a new level that is more sensitive to the information of interest, or we might transform magnetic data from an observed geomagnetic latitude to the magnetic North pole. All of these procedures can be carried out using Fourier techniques.

The montaj Geophysics 1D- FFT menu includes a suite of Geosoft eXecutables (GX applications) that you can use to apply Fourier domain filters to one dimensional (line) data stored in a Geosoft database. Designed primarily for potential field data, montaj Geophysics provides you with the tools required to:

- Perform profile-based processing for interpretation and modeling purposes
- Interactively select filtering parameters, display power spectra and identify optimal filters for processing and interpretation
- Rapidly apply filters to one or more lines of data

Summary of Fourier Filtering Capabilities

Generally, you can think of Fourier filters as falling within one of the following groups:

1. Sharpening filters that enhance the shorter wavelength features in the data. These include high-pass filters, downward continuation and vertical and horizontal derivatives. Such filters are normally used to enhance information from shallow geological features.

2. Smoothing filters that enhance longer wavelength features in the data, normally by removing or attenuating shorter wavelength features. These include low-pass filters, upward continuation and integration. Smoothing filters are normally used to remove short-wavelength noise in the data or to remove the effects of shallow geological or cultural/anthropogenic features.

3. Geophysical transformations that convert data from one physical form to another. These include reduction to the pole for magnetic data and the calculation of apparent magnetic susceptibility or apparent density.

Smoothing and sharpening filters are often combined to meet the needs of a specific problem. For example, a vertical derivative (sharpening filter that enhances near-surface geology) might be combined with an upward continuation (smoothing filter that reduces the effect of noise in the data).

Filters can further be described as geophysical filters -- those whose outcome has a geophysical basis, or mathematical -- those that have a mathematical definition only. Since geophysical filters are based on the physics of potential fields, they are ideally suited to gravity and magnetic data whereas mathematical filters can be applied to any kind of data.

Examples of geophysical filters are vertical (i.e. upward and downward) continuation, vertical derivative or integration, reduction to the pole and apparent magnetic susceptibility or density. Mathematical filters include horizontal derivatives and the high and low pass filters --- Butterworth, Gaussian, Cosine and simple high and low pass cutoff filters.

In addition to filters, power spectra are often required. The montaj Geophysics system enables you to create a power spectrum of the data and to place the real and imaginary components of the Fourier transform into channels of the database. You may then apply your own mathematical algorithms to the data using the math functions of Oasis montaj.

Introduction to Filtering Concepts

For mathematical and computational efficiency, the montaj Geophysics system applies filters in the Fourier or wavenumber domain. If you are not already familiar with the application of filters to one-dimensional data using Fourier Domain techniques, you may want to read the following summary of filtering concepts.

Understanding the Mathematical Framework for Transforms

Mathematically, the Fourier transform of a space domain function f(x) is defined to be:

$$\bar{f}(\omega) = \int_{-\infty}^{\infty} f(x) \cdot e^{i\omega x} \, dx$$

The reciprocal relation is

$$f(x) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \bar{f}(\omega) \cdot e^{-i\omega x} \, d\omega$$

where w is an angular wavenumber in radians per ground_unit (for x in ground_units). The wavenumber in cycles per ground_unit (r) is simply $w/2p$.

A line of data in the space domain can be thought of as a sequence of magnetic or gravity values at points along a straight line, each point separated by a constant distance. Such a line can be transformed to and from the wavenumber domain by use of a discrete Fast Fourier Transform (FFT). The equivalent data set in the wavenumber domain is commonly called a Transform. A Transform of a line is consists of real and imaginary amplitude values as a function of wavenumber in cycles per original distance unit.

In addition to these basic mathematical concepts, there are a number of other generalized properties in Fourier domain processing, including:

❯ A given potential field function in the space domain has a single and unique wavenumber domain function, and vice-versa.

❯ The addition of two functions (anomalies) in the space domain is equivalent to the addition of their Transforms.

❯ The energy spectrum is a 1-D function of the energy relative to the wavenumber.

Relating Potential Fields to Transform Spectra

The Fourier transform of the potential field due to a prismatic body has a broad spectrum whose peak location is a function of the depth to the top and bottom surfaces and whose amplitude is determined by its density or magnetization. You can relate the peak wavenumber (w') to the geometry of the body according to the following expression:

$$\omega' = \frac{\ln\left(\frac{h_b}{h_t}\right)}{h_b - h_t}$$

where

w' is the peak wavenumber in radians / ground_unit
h_t is the depth to the top
h_b is the depth to the bottom

For a bottomless prism, the spectrum peaks at the zero wavenumber according to the expression:

$$f(\omega) = e^{-h\omega}$$

where w is the angular wavenumber in radians / ground_unit and h is the depth to the top of the prism. For more information, refer to Bhattacharia, 1966.

For a prism with top and bottom surfaces, the spectrum is:

$$\bar{f}(w) = e^{-h_t w} - e^{-h_b w}$$

where h_t and h_b are the depths to the top and bottom surfaces respectively. As the prism bottom moves closer to the observation point at surface, the peak moves to higher wavenumbers as illustrated in the following figure:
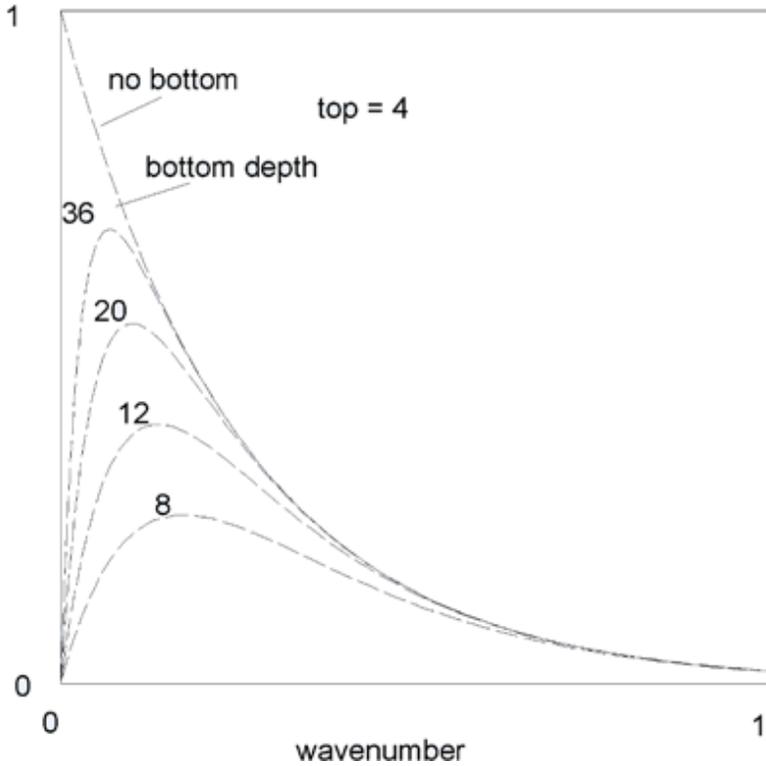
Considering the spectrum of a fixed size prism, as the prism depth increases, the peak of the spectrum shifts to lower wavenumbers (the space domain anomaly becomes broader) and the amplitude of the spectrum decreases:
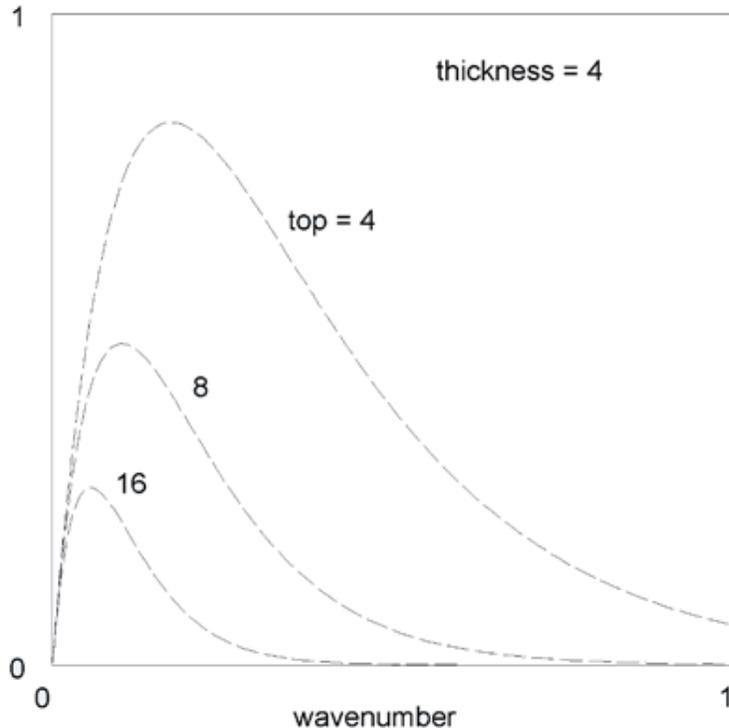
When looking at the spectrum above, it is important to note that the amplitude of a deep prism does not exceed the amplitude of the same prism at shallow depth at any wavenumber. The effect of increasing the depth is to shift the peak to lower wavenumbers. Because of this characteristic, there is no way to separate the effect of deep sources from shallow sources of the same type by using wavenumber filters. You can only distinguish sources if the deep sources have greater amplitude or if the shallow sources have less depth extent.

When considering a line that is long enough to include many sources, you can use the log spectrum of this data to determine the depth to the tops of a statistical ensemble of sources using the relationship (see Spector and Grant, 1970):

$\log E(k) = 4\pi hk$

where h is the depth in ground_units and k is the wavenumber in cycles / ground_unit.

You can determine the depth of an 'ensemble' of sources by measuring the slope of the energy (power) spectrum and dividing by 4p. A typical energy spectrum for magnetic data may exhibit three parts -- a deep source component, a shallow source component and a noise component.

The following figure illustrates the interpretation of an energy spectrum into these three components:
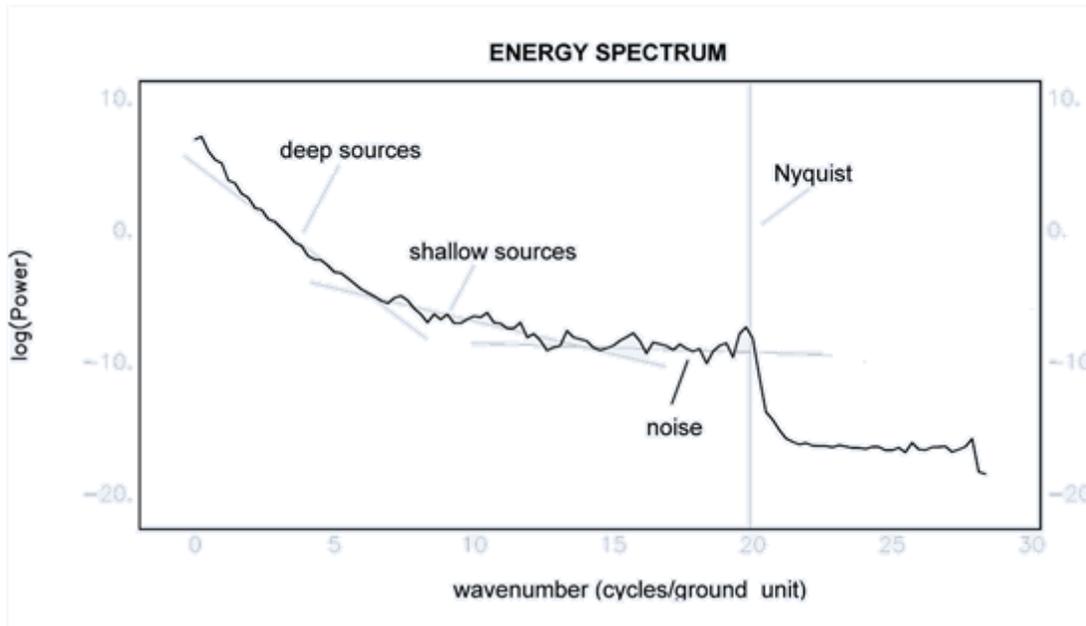
Understanding the 1D-FFT Filtering Process

When applying Fourier domain filters to a line of data the following steps are typically applied:

1	Trend Removal	A first order trend is calculated by least-square fitting a straight sloping line to the data. This trend is removed and the trend coefficients are saved as part of the zero wavenumber component of the transform. This means that changes to the zero wavenumber in the Transform will also effect the first order trend.
2	Line Extension	The line length is extended by a minimum of 10% up to the next power of two, which is required by the FFT process used in Oasis. The minimum 10% is to provide a minimum extension length within which the predicted data function is periodic.
3	Prediction	The line extension and any missing data within the line are filled in by predicting data using either Maximum Entropy Prediction (MEP; Burg, 1975) or Constrained Linear Prediction (CLP; Press et al, 1992). MEP determines the spectral content of the preceeding real data segment and then predicts a data function that has the same spectral signature as the original data. CLP calculates a series of linear prediction coefficients based on a segment of real data and then uses these coefficients to recursively extrapolate the data. CLP is useful in minimizing edge effects when working with data containing systematic high frequency interference.
4	FFT	The data is that transformed from the space domain to the wavenumber domain using an FFT. The wavenumber increment of the resulting transform will be 1/(line_length). For example, if the extended line length is 4096 points, and the data fiducial increment is 10 ground_units, the wavenumber increment in the Fourier domain will be 1/(4096 * 10) or 0.00002441 cycles/ground_unit. The maximum wavenumber will be at the Nyquist frequency, which is 1/(2*data increment). In the previous example, this would be 1/20, or 0.05 cycles/ground_unit. The FFTOUT GX will place the real and imaginary components of the transform into channels of the database. The FFTPSPEC GX will calculate the power spectrum and place the result in a power spectrum channel. The other filters will carry on to the next step.
5	Filter Application	The user-specified filter(s) are applied to the data in the Fourier domain.
6	Inverse FFT	The filtered wavenumber data is transformed back to the space domain using an inverse FFT.
7	Trend Replacement	The zero wavenumber amplitude is used to determine the trend to replace in the data. Many filters will set the zero wavenumber to 0.0, which results in no trend being replaced in the data.
8	Masking	The original data channel is used as a mask to return the filtered data to the same length and to place dummies in the final filtered data. The result is placed in the output channel specified by the GX

The Fourier domain filtering process (as outlined above) is built into every 1D-FFT filter.

⚠️   *You can use the "FFT1D|Advanced Usage" menu items to go through the step-by-step Fourier domain filtering process. This step-by-step method enables you to apply a user defined filter formula or math expression.*

Create a Project

In order to access the menus in Oasis montaj, you must have an open Project. An Oasis montaj "Project" encompasses every item in your working project; from the data files in your project (databases, maps, and grids), to the tools used (including auxiliary tools such as histograms, scatter plots etc.), to the project setup including the menus you have displayed and whether you are working on a map or profile and the state in which you left it the last time you used it.

The project also controls your working folder. Projects are saved as (*.gpf) files. If you open an existing project from a folder, the system assumes that all your project files are located in the same folder. To streamline your work, as well as keep it organized, you may wish to make sure that your project file is in the same folder as the other files you want to use. We recommend that each project you work on have its own project (*.gpf) file. If you use a number of extensions in Oasis montaj that have different menus, you can use the project to display only the menus you require.

The Project Explorer tool enables you to browse as well as open any project item. The Project Explorer has two tab windows, the *Data* window that includes all data files included in the project and the *Tools* window that organizes and maintains the project tools. To access the Tools window click the **Tools** bar on the bottom of the Project Explorer. To return to the Data window, click the **Data** bar on the top the Project Explorer.

To Create a Project:

1. Start Oasis montaj.

2. On the *File* menu click *Project* and then click**New**.
   The *New Project* dialog is displayed.
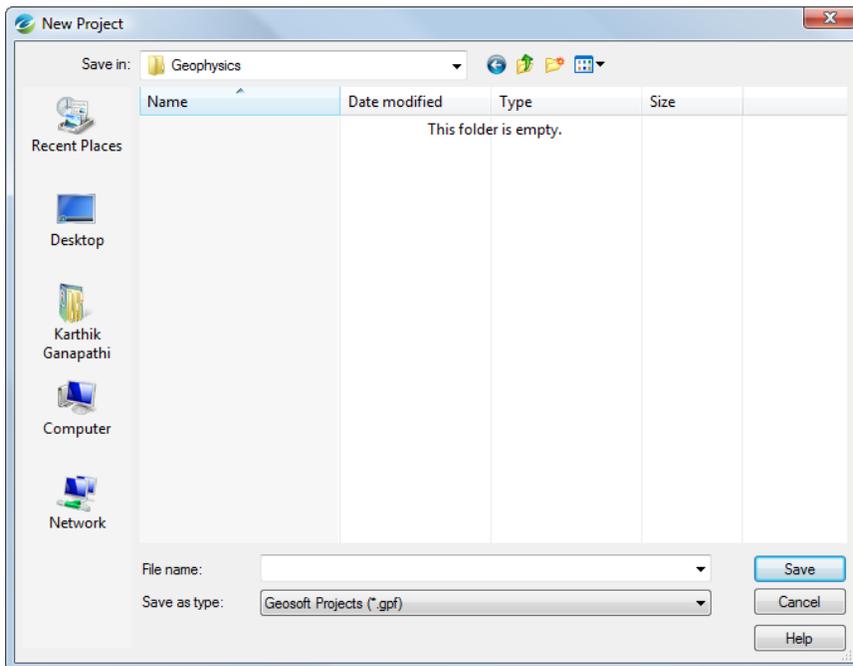
3. Specify a name and folder for the project. Oasis montaj will automatically look for your data in the folder containing this project.

⚠️ *You are strongly discouraged from processing the data in the Oasis montaj folder. Always make a copy of the data in a working folder.*

4. Click the **Save** button. The system saves the project and indicates it is open by opening the Project Explorer window, enabling the buttons on the Main toolbar and adding menus to the menu bar. These are visual clues indicating that you are ready to start working with the system.

Locate the Geophysics menus

Once you have installed your Geosoft License to include the montaj Geophysics system the *FFT1D* and the *Section Tools* menus will become accessible to you by selecting **Load Menu** from the *GX* menu or by clicking the Load Menu (▤) icon on the Standard tools bar.

The *1D-FFT* filters enable you to apply a variety of Fourier domain filters to one-dimensional (line) potential field and other data.

The *Section Tools* enable you to define and create crooked sections in 2D or 3D views as either grids or pixel plots.

FFT1D Menu

Butterworth...	Butterworth Filter (FFTBUTTW GX)
Gaussian...	Gaussian Filter (FFTGAUSS.GX)
Cosine...	Cosine Roll-off Filter, (FFTCOSN GX)
Low Pass...	Lowpass Filter (FFTLOWP.GX)
High Pass...	Highpass Filter (FFTHIGHP.GX)
Band Pass...	Bandpass Filter (FFTBANDP.GX)
Vertical Derivative...	Vertical Derivative (FFTVDRV.GX)
Vertical Integration...	Vertical Integration (FFTVINT.GX)
Horizontal Derivative...	Horizontal Derivative (FFTHZDRV.GX)
Horizontal Integration...	Horizontal Integration (FFTHZINT GX)
Continuation...	Downward/Upward Continuation (FFTCONT.GX)
Reduce to Pole...	Magnetic Pole Reduction (FFTRPOLE.GX)
Susceptibility...	Magnetic Susceptibility (FFTSUSC.GX)
Density...	Density for Gravity Data (FFTDENS.GX)
Multiple Filters...	Multiple Filters (FILT1MULT.GX)
Analytic Signal...	Analytic Signal (FFTAS.GX)
Hilbert Transform...	Hilbert Transform (HILBERT.GX)
Power Spectrum...	Power Spectrum (FFTPSPEC.GX)
Advanced Usage ▶	

Advanced Usage Menu

Set Expansion Method...	Set expansion method (FFTSETEXTMD GX)
Preprocess...	Preprocessing previewer (FFTPREP.GX)
Re-Fid to Distance...	Re-fid channel to distance base (DISTFID.GX)
FFT Space -> Fourier...	Transform from space to wavenumber domain (FFTIN.GX)
FFT Fourier -> Space...	Transform from wavenumber to space domain (FFTOUT.GX)
Re-Fid Back to Fiducial...	Re-fid channel to fiducial base (REFID.GX)

Open a Database

You must have a database open in your working folder to apply the 1D-FFT filters to a data channel.

To Open a Database:

1. On the *Database* menu, click **Open Database**.
   The *Open Database* dialog appears.

2. Select the database file and click **Open**.

3. The database will be displayed in the spreadsheet window.

Apply FFT Filter to Data Channel

You must have a database open in your working folder to apply any 1D-FFT filters to a data channel. In this example, we will use a Butterworth filter to illustrate the procedure.

⚠ *The entire Fourier domain filtering process is built in to every 1D-FFT filter.*

⚠ *All 1D-FFT options (utilities and filters) have their own dialog boxes with unique parameters specific to each. To find out detailed information on each dialog, click the dialog **Help** button.*

To Apply Filter to Data Channel:

1. On the *FFT1D* menu, select **Butterworth**.
   The *FFT Butterworth Filter* dialog appears.
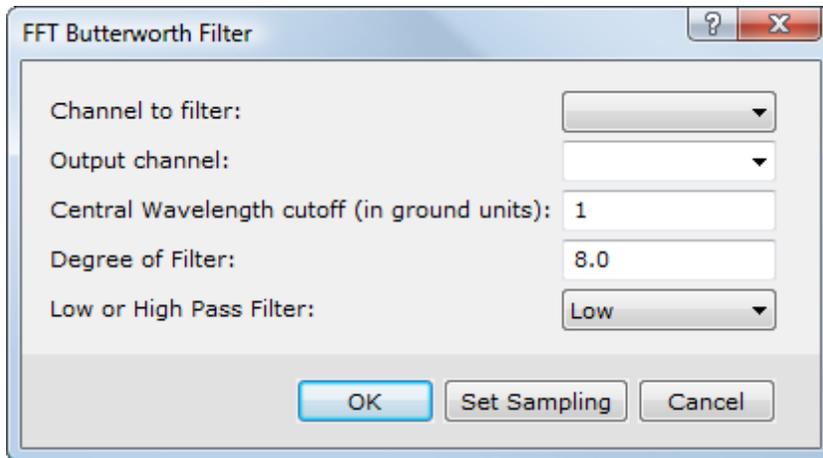
2. Select the channel to filter from the dropdown list. Specify the name of the output channel. You can specify values for central wavelength cutoff, and degree of filter and select either a low or high pass filter. For more information on these parameters click the **Help** button.

3. Click the **Set Sampling** button.
   The *Set FFT Sampling Parameters* dialog box appears.
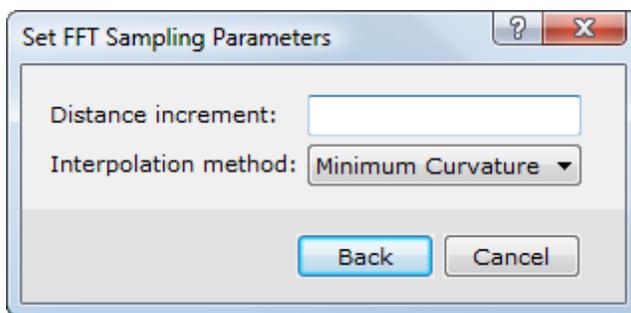
4. Here you can specify the required distance increment and the interpolation method to use. If the distance increment is not specified the nominal data spacing will be used.

5. Click **Back** to return to the *FFT Butterworth Filter* menu. Click **OK** to apply the Butterworth filter and display the output channel in the current database.

Set Expansion Method

Use the *Set Expansion Method* option, found on the *FFT1D|Advanced Usage|Set Expansion Method* menu, to set the extension fill method.

There are two methods to choose from, the default *Maximum Entropy* and the *Constrained Linear Prediction (LP)* extrapolation method. The latter method is useful in minimizing edge effects when working with data containing systematic high frequency interference.
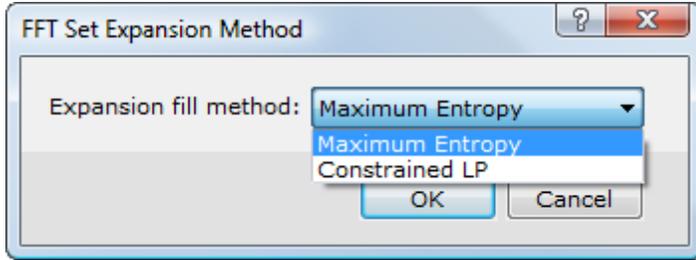
New Section Tools

To access the new Section Tools you must load the *Section Tools* menu (SectionTools.omn).
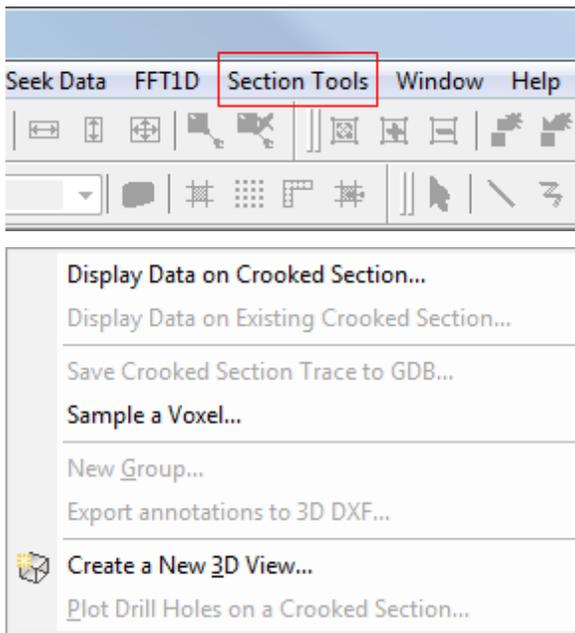

Display Data on a Crooked Section

You can use this tool to create sections from an array database that contain survey lines that bend or curve. You can grid and display these curved or crooked sections in 2D maps or 3D views. This new section support provides a more accurate representation in 2D and 3D by ensuring that data are correctly positioned along the survey line. These sections support full data linking between all displays of the data including: plan maps, sections and 3D views.

To Display Data on a Crooked Section:

1. Open a database and display a Line with current X and Y channels, which define the path.

2. On the *Section Tools* menu, select **Display Data on a Crooked Section**.
   The *Display Data on a Crooked Section* dialog is displayed.
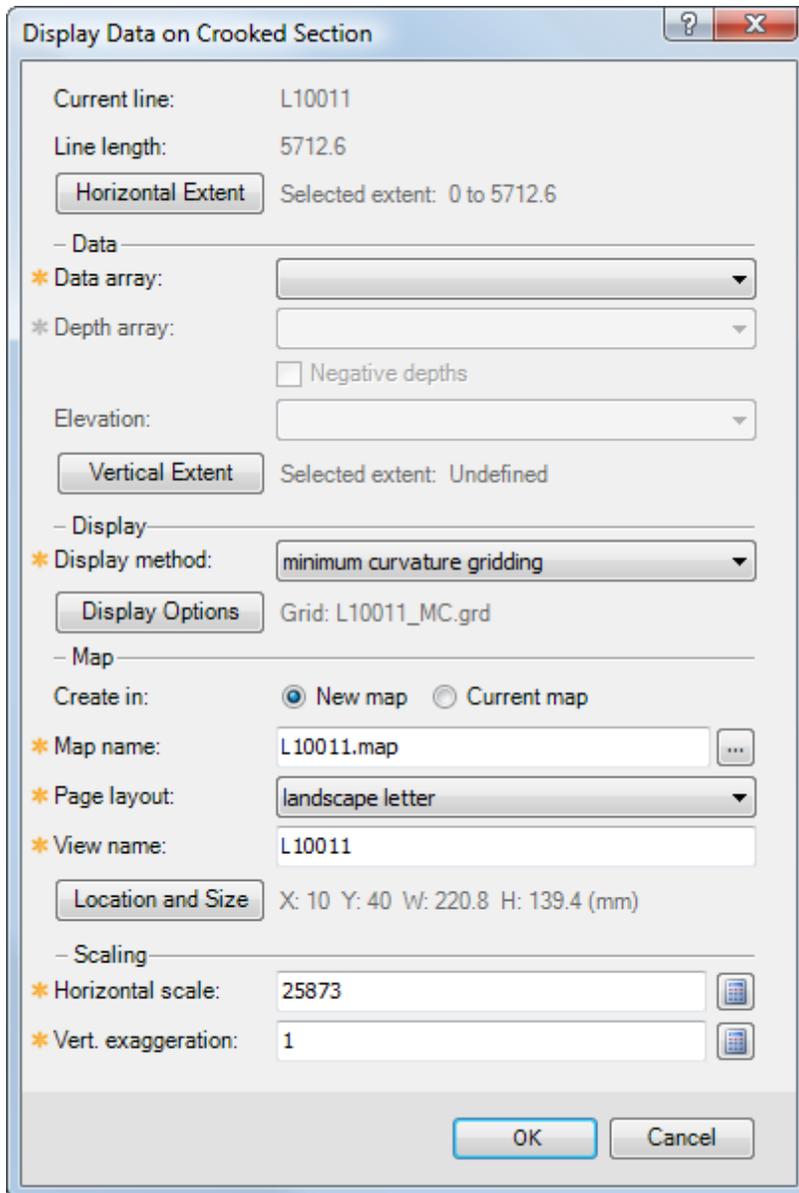
💡 *A crooked section view is based on a single line, the Current line, in the current database. The Line length is the full length of the current line, measured between the line locations.*

3. Specify the parameters for each section of the dialog. Use the **Horizontal Extent** button to display and/or modify the Horizontal extents for the new crooked section view. The horizontal extents are defined using the distance along the line, and must be in the range 0 to the line length.

4. View or specify the *Data* to be plotted, the channels used to define the depths in the section, and the *Vertical Extents* to be displayed in the crooked section. Note that, your database must contain both the data and depths in array channels.

5. Select how to *Display* the data. You have five options to choose from, you can *Create empty section*, *Minimum Curvature Gridding*, *Inverse Distance Weighting*, and *Direct Gridding* (click the **Help** button for more information). In addition, the *Pixel Plot* produces a grid-like output, but builds a discreet rectangular cell around each data point and does not interpolate outside of this cell, and so, unlike gridding, preserves both the original location and data values.

6. Specify the *Map* parameters, including whether you are plotting to a *New* or *Current* (existing) map, as well as specifying the map and view names.

7. Finally specify the *Scaling* parameters, *Horizontal scale* and *Vertical exaggeration* values. Once you are satisfied with your selections, click the **OK** button and the crooked section will be created and plotted to your map.

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