BEOWLF

Table of Contents - Beowlf

1 Program Description

Introduction

This documentation describes the BEOWLF program module that can be used in conjunction with the software program EM Vision. Time domain electromagnetic (TEM) modelling is best approached by applying relatively simple techniques and then refining the approach to gain more insight. It is important to initially understand the basic earth properties of resistivity and conductivity in the area being analysed. Following this, some idea of the target model that is consistent with known or expected geology should be formulated. With this knowledge forward models followed by more rigorous inversion modelling may be required.

EM Vision makes use of a number of modelling algorithms to accommodate different EM datasets and survey situations. Each algorithm can be purchased individually or collectively. The documentation available to describe and operate each module is presented individually and this manual relates only to the BEOWLF modelling program.

BEOWLF is implemented to operate remotely from EM Vision through the Modelling Control File interface (refer to *MCF Considerations*). Control and user feedback is provided to EM Vision while the program runs but the user can continue with other operations while the modelling executes in the background.

Program BEOWLF

Description

The BEOWLF program was written in the mid 1980's within CSIRO and sponsored by a group of companies under the Australian Mineral's Industry Research Association (AMIRA). The author of BEOWLF is Art Raiche largely using developments from previous EM routines developed during the research project.

BEOWLF is a transient EM modelling program that can operate in both forward or inversion modes. In joint inversion modelling mode BEOWLF fits a layered earth model to input data from one or more transmitter - receiver configurations. The receivers are vertical dipoles (db/dt) which may be inside or outside the loop perimeter.

The source(s) are assumed to be one or more rectangular loops lying on the surface of the earth and the transmitters may be of mixed types. The program computes the voltage (db/dt) response on the surface of a horizontally layered earth using a rectangular transmitter loop excited by a bi-polar square waveform with exponential rise-time and ramp turnoff.

BEOWLF can be used with either Cole-Cole or pure real resistivities. In the complex earth case, the program will attempt to adjust the top layer chargeability, whilst leaving the other parameters constant. It does this after the Marquardt inversion during each iteration by raising and lowering the top layer chargeability by 0.1 to see if this lowers the fitting error.

A second operational mode within BEOWLF is to use the forward solution from a user-supplied 'seed' model, to compare the theoretical responses with observed data. Variations to layer thickness and resistivity are applied and the response recomputed to minimise errors using the Jupp and Vozoff (1975) inversion technique. This inversion process is repeated until a maximum number of iterations are reached or the errors fall below a definable threshold.

The method used for the forward model uses the Gaver-Stehfest method of inverse Laplace transformation to convert the frequency domain expression for an isotropic, horizontally-layered earth into the time domain. The source is modelled using a circular loop of the same area as the source. The inverse Hankel transform is calculated using digital filter coefficients obtained from Walt Anderson (see Knight and Raiche, 1982).

BEOWLF Usage

For BEOWLF inversion efficiency, it is noted that computation times with a complex resistivity model, will much longer (a factor of about 3.5) compared to a real model inversion. One tactic to improve speed would be to do a real inversion of data (using about 5 iterations) to get an initial model of the resistivity and thickness - and then to refine this using a Cole-Cole inversion with about 4 iterations.

As BEOWLF is capable of operating in both a forward and inversion mode for layered models with receivers located inside or outside the transmitter loop, its capabilities extend to Turam, Slingram (separated loop) and in-loop modes of operation. Precision of response is determined internally but comparative studies (using the in and out of loop modes of operation between GRENDL and LAYER) give high accuracy and repeatability.

Limitations of BEOWLF

A number of limitations apply to the general operation of BEOWLF. These are:

- The program is compute intensive and therefore can be slow to resolve a complex sounding with a large number of layers. BEOWLF has been implemented using the Generic Model Interface to enable other operations to be undertaken while modelling continues.

- Although complex earth (Cole-Cole) parameters can be derived from BEOWLF, their computation will significantly (3-5 times) slow processing.

- In its implementation (as recommended), BEOWLF assumes a one dimensional earth and examines only the response of a single sounding at a time. In situations with rapidly changing lateral layering, BEOWLF can be unreliable or inaccurate in its solutions.

- BEOWLF cannot simulate downhole or coincident survey configurations.

- Only the vertical component (Z) can be computed.

MCF Considerations

As described, different MCF control files are required for the correct operation of BEOWLF under different operating systems. Refer to *MCF Files* for the purpose and usage of MCF control files.

Windows® 95 (and NT) Operation

BEOWLF will operate under EM Vision control in the Windows® 95, Windows® 98 and Windows NT™ multi-tasking environments,. An example of an appropriate MCF file is shown below:

```
[Interface]
Algorithm   = BEOWLF
Description = BEOWLF: Forward Multi-Layer Modelling
ModelClass  = Forward
DataType    = TEM
Executable  = c:\encom\emvision\BEOWLF32.exe
ExeType     = WIN32
StatusPoll  = 0.5
StatusAbort = 1200
```

Note that the Executable entry refers directly to the executable file.

Operation of BEOWLF
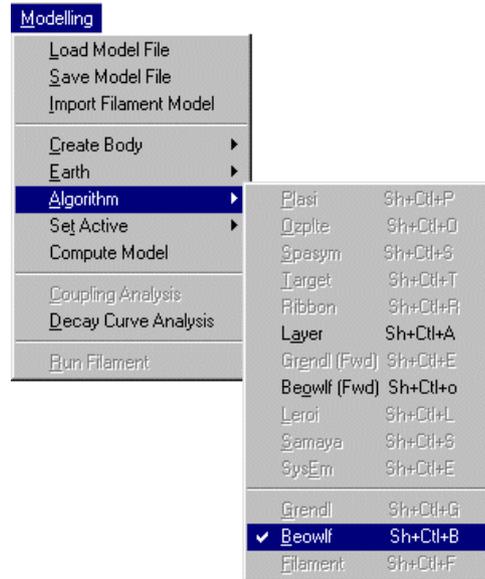
As for all modelling in EM Vision, a number of preparatory steps must be initially taken before a model response can be computed. These steps are sequentially listed in the Modelling menu. Initially, a modelling operation requires a display for the response and a profile (or station) for the reading locations, a representation of the earth structure and model, plus the assignment of channels and stations to compute response.

Earth Option

The Earth option of the EM Vision Modelling menu is used to define the Earth structure and assign its properties. The methodology of defining an Earth Type and then the Properties of the earth force a logical model definition on the user. For BEOWLF, only a layered earth model type can be applied.

Note

Unless the correct information is specified in terms of model type, Earth host and defining parameters, BEOWLF will not be accessible and will appear 'greyed' out in the Model/Algorithm menu option.

When selected, the Earth option provides two alternatives - Type and Properties. Initially, Type should be selected to define the specific Earth host type to be modelled.

Earth Type

Options available from the Earth Type option are as shown below:
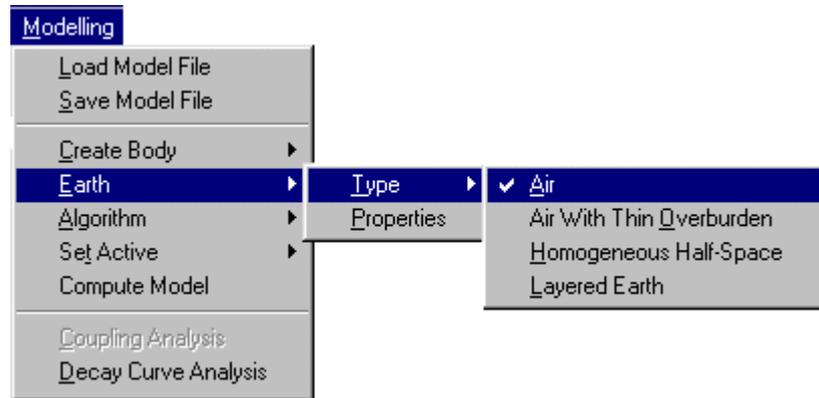
Only two Earth types can be used with BEOWLF. These are the Homogeneous (single layer) Half-space and the Layered Earth.

Homogeneous Half-Space

This Earth type assumes a single, conductive earth volume lying beneath the survey area. The earth host has a definable resistivity but this earth type does not enable complex resistivity parameters. The extent of the half-space is assumed infinite horizontally as well as vertically (depth) and the top of the half-space lies at the surface of the earth.
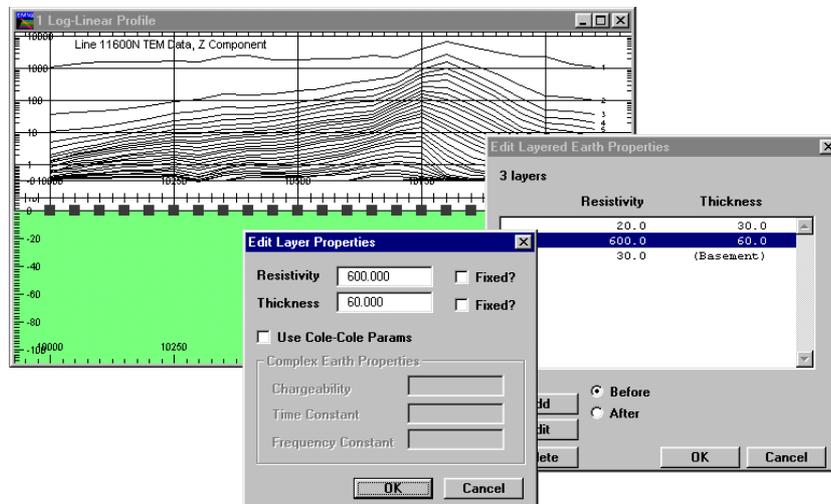
Layered Earth

A Layered Earth model is comprised of a series of horizontal, stratified layers each of definable thickness and electrical property. The layered earth model can simulate a homogeneous half-space if only one layer is specified but usually more than one is defined. The extent of the layers is infinite laterally and defined by the thickness parameter vertically. The bottom layer is assumed to represent basement and so has resistivity properties but no thickness definition.

Any number of layers can be defined in EM Vision although the number is limited for BEOWLF applications to 10. Individual layers can be defined by thickness (which cumulatively represents depths to the top and bottom surfaces) and resistivity. Complex earth (Cole-Cole) properties can be used as BEOWLF can model these.

Earth Properties

The Properties option is available from the Earth item of the Modelling main menu. This feature is used to define the properties used by the various Earth Types (see *Earth Type*). The dialog to control the various parameters of a layered earth will be displayed after selecting the Properties item.

For defining a **Layered Earth** model, two dialogs controls the entry, editing and properties of the individual layers.

Editing the Layered Earth model

When the dialog is initially displayed, EM Vision will create a single layer that it refers to as basement. Note that no Thickness property is assigned to the bottom, basement layer of the list.
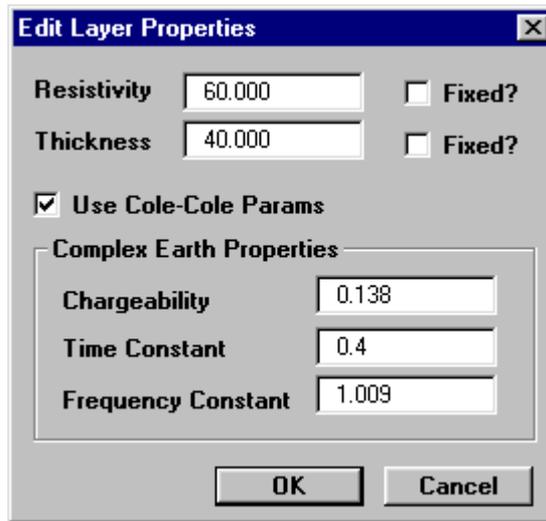
At the base of the dialog are three buttons that control the creation, deletion and editing of layers. Associated with the **Add** push button are two options for **Before** and **After**. These options enable creation of a new layer before (shallower) or after (deeper) than the layer highlighted.

Note

It is not possible to create a layer after or below the basement layer.

Any layer that is highlighted can be edited by selecting the **Edit** push button while the required layer is highlighted. An alternative means of directly selecting and editing a layer, is to position the cursor over the layer and double click with

the left mouse button. By this method or by using the **Edit** push button, an editing dialog for the selected layer will be presented.

Editing dialog for layers

The resistivity and thickness can be edited on this dialog. Some modelling algorithms used for inversion can force parameters to remain unchanged (set the **Fixed** option) while the inversion process is being undertaken. This situation arises where for example, drilling evidence or resistivity soundings indicate a particular layer thickness or resistivity.

The **Use Cole-Cole Params** option is available for BEOWLF. Complex resistivity Cole-Cole parameters are optional and in most cases are not applicable unless specific information relating to the complex resistivity and frequency dependence of the defined layers is known. This information is typically made available from IP surveys or laboratory sample analyses. Refer to *Complex Resistivity* for additional information.

Note

Access to the **Use Cole-Cole Params** option in the Properties dialog is only available after BEOWLF has been selected as the required algorithm. Refer to the *Algorithm Option* for this.


The use of Cole-Cole parameters relates to the frequency dependence of rocks. Frequency dependence of EM soundings is typically evidenced by the presence of negative values being recorded in field data. Rock conductivities are often weakly frequency dependent between excitation frequencies of 0.1 and 10,000 Hz. Rocks

with this dependence are referred to as 'dispersive' (Smith, 1988). Qualitatively, the strength of the frequency dependence is the 'polarizability', a quantity that can be given a number of quantitative definitions. Commonly the polarizable dependency is measured over a frequency range of 0.1 to 10 Hz by the frequency domain induced polarization (IP) technique.

Setting Individual Station Properties

In many layered earth modelling programs it is possible to set the properties of each station independently. Consequently, when the cross-section is displayed beneath a profile, the locations of the reading positions is displayed as an 'X' marker symbol. The purpose of this is to enable individual graphical selection of readings so their associated properties can be defined.

To set individual reading properties, display the profile and cross-section (see Cross-*Section Displays*). An example of this is shown below:
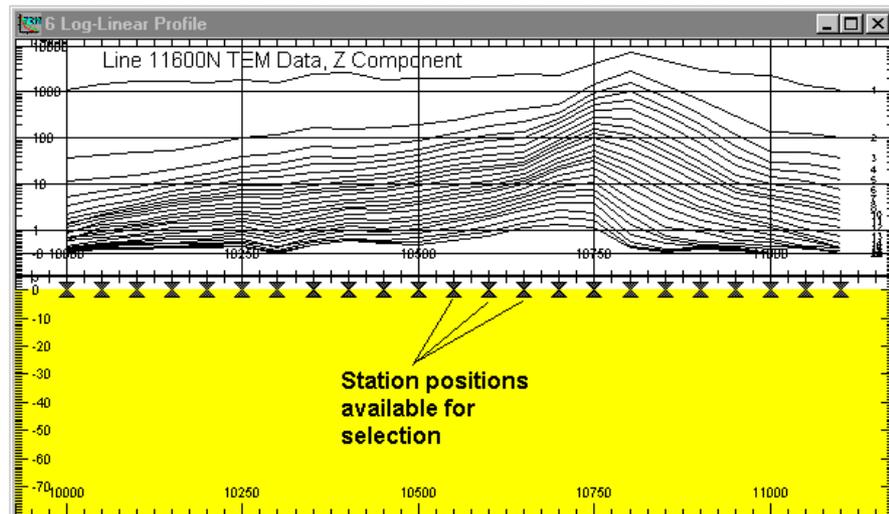

Example cross-section initial layered earth model

Select individual readings by positioning the cursor over the marker symbol and clicking the left mouse button. If more than one reading location is to be selected, press the SHIFT key while positioning and selecting. Refer to the section *Individual Station Symbols* to control and reconfigure the station markers. To define the earth properties of the selected layers, select the **Properties** button or icon on the toolbar or position the cursor over the layer and double click the left mouse button. When this is done, the Edit Layer Properties dialog is displayed.

If difficulties are experienced in selecting the marker symbols, press CTRL key and the left mouse button to locate the symbol. The CTRL key can also be used with the SHIFT key for multiple selections.

You may also need to increase the height in the track of the symbols. To increase the height above the symbols by setting the vertical axis distance (Max) in the Drawing Configuration dialog (while ensuring the Earth Section is displayed in the Drawing list).
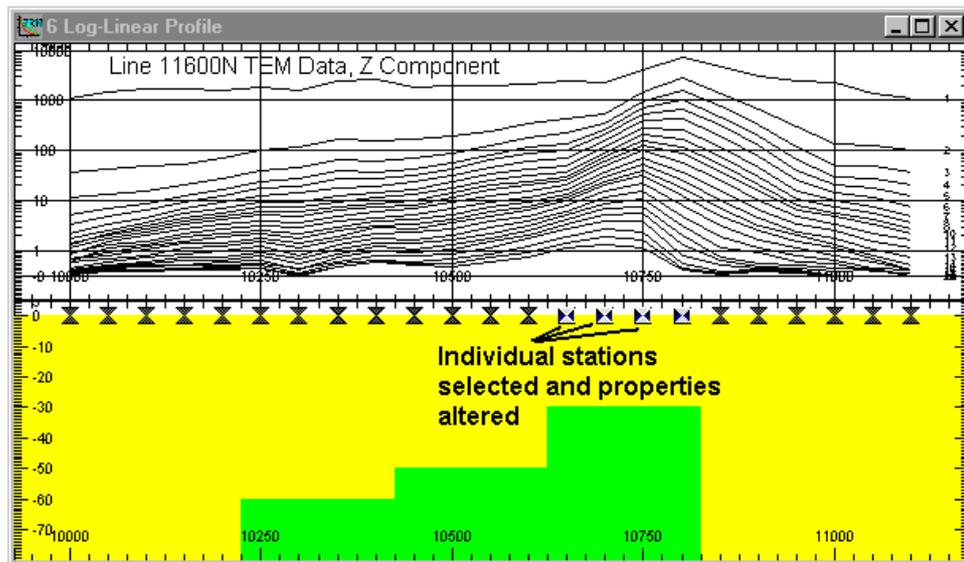
Cross-section with modified individual reading properties

Edit the layer properties as required for the various stations. When this is completed, modelling of programs (such as BEOWLF) will treat each station computation independently and therefore use the individual station properties to compute the theoretical response. Refer to *Setting Individual Station Properties* for additional information. The pull-down menu (as shown above) is obtained by positioning the cursor over selected stations and double left mouse clicking.

If modelling a reading taken at only one station location, it is not possible to display a profile of the data. The response can be viewed in a Decay display format if required. The initial creation of a layered earth model is done by creating the layers within the Earth Properties option without a display of the earth cross-section.

Controlling the Presentation of Layers

The section on *Earth Properties* and *Setting Individual Station Properties*
describes the method of specifying a layer's thickness and resistivity properties.
The appearance of layers, both on the screen and in hardcopy can also be
controlled by allocating colours to specific resistivities.

To graphically alter the properties or colour of a layer, move the cursor over the
desired layer and while positioned there, double click the left mouse button. A
dialog indicating the layer colour and the properties is displayed. The properties
can be altered by editing the values displayed.

The colour of a layer is indicated in the central indication box of the dialog and
within this are Red:Green:Blue colour values indicating the mix of primary
colours used to display the layer. This Default Colour can be altered by selecting
the **Use Specified Colour** button. When activated, this button causes the **Edit
Specified Colour** push button to be available. Selecting this button provides a
dialog enabling you to modify the layer colour as required.
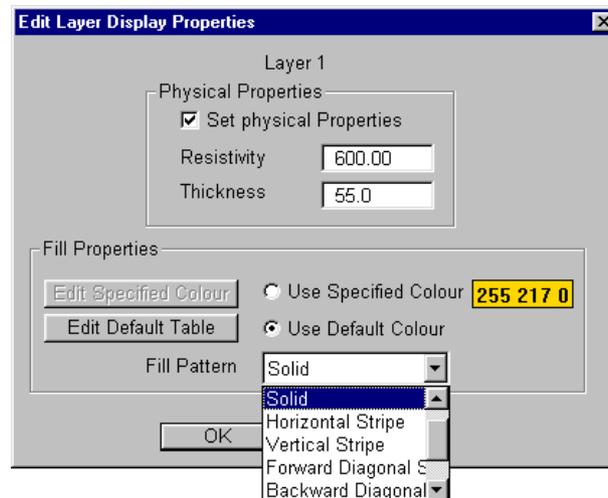
Editing the property or display attributes of layers

Control of the palette and the range of resistivities that can be presented is made
available by the **Edit Default Palette** push button. This button is activated by
selecting the **Use Default Colour** option. When the activated palette button is
pressed a dialog that enables the mapping of resistivities to various colours is
displayed:

Algorithm Option

The Algorithm option in the Modelling menu is used to select BEOWLF in either a forward or inversion mode. The two occurrences of BEOWLF in the Algorithm menu item appear as shown. The upper BEOWLF entry is for forward modelling as indicated.
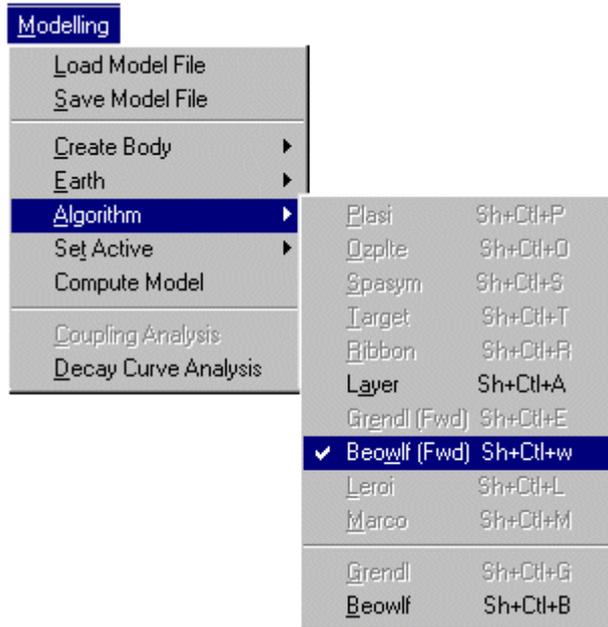

All implemented modelling programs are contained in the displayed menu list but not all algorithms has been made accessible. When a program is not available or is not correctly configured, its entry on the Algorithm menu list is not highlighted.

Even if a program is installed, access may be denied by EM Vision if an incorrect survey configuration or instrument combination has been set. For example, if coincident loop survey data is imported, both forward and inversion BEOWLF options are not available since it is unable to operate on coincident loop data.

Note

In the event that **NO** algorithm option, or the algorithm required is **not** available for selection when you think it should be, refer to *Non- Accessible Programs*.

Once the BEOWLF algorithm is chosen, a dialog confirms its selection. In the case of BEOWLF Forward operation, a message dialog appears. In the case of BEOWLF Inversion, an additional dialog is presented.
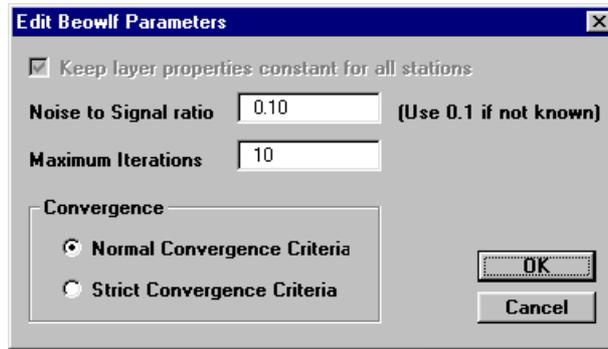
Dialog to control BEOWLF parameters

Options available enable the user to define the noise to signal ratio and the maximum number of iterations for each sounding. The noise to signal ratio is used within BEOWLF to control the relative eigenvalue threshold used in the critical 'ridge' regression of the inversion. The ratio supplied is the minimum allowed value for this threshold. If a larger noise to signal ratio is specified, faster but less accurate solutions to the inversion is derived. For precise results where a solution can be reached, use a smaller noise to signal ratio.

The number of iterations determines the upper number of iterative steps that BEOWLF will perform in determining an inversion solution. Usually about 10 iterations is satisfactory, but up to 20 may be specified.

Two convergence criteria are also available for BEOWLF. Both these refer to the changes that are computed in a forward model operation for each iteration of the inversion process. For normal operation, where a 1% error change is noted in computation of the forward solution (compared with the previously computed solution), the program will continue to converge. If the strict option is selected, only a 0.1% change will cause BEOWLF to continue iterating.

Set Active Option

The modelling process involves creation of a model, data and survey definition and selection of an algorithm. The only remaining step prior to initiating BEOWLF is to define which delay channels and readings are to be modelling. This is done by the Set Active option of the Modelling menu.

Modelling computations can be restricted to user defined delay channels and data readings. Channels and readings available for modelling are referred to as active.

By default, EM Vision makes all data initially active.

Setting Channel Activity

The Set Active option for channels will present the Channel Selection dialog as below. Nominate the channels to be modelled by taking into account any early time noise or response behaviour which is uncharacteristic of expected decays. Similarly, late time noise can be derived from instrumentation, geological and cultural sources.
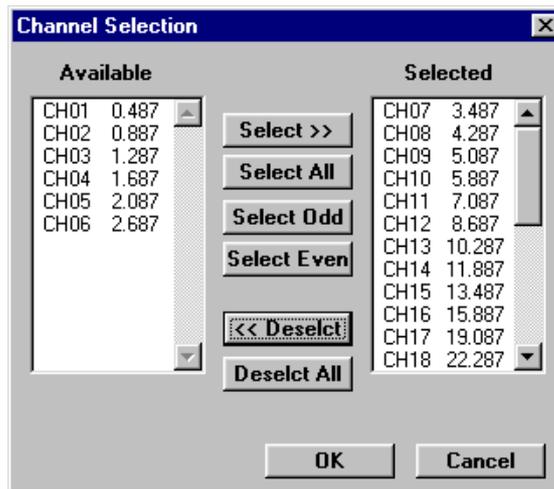
Channel selection dialog

The channels on the right scroll list are regarded as active for the applied modelling.

Setting Station Activity

Defining which data readings are to be modelled is controlled by the **Set Active>Stations** option. When selected a dialog accompanied by a survey map of the available station locations are displayed. Initially all readings are highlighted indicating their active state. Within the dialog you can **Select All** or **Deselect All** readings. Also within the dialog you can choose to use the cursor to **Select** or **Deselect** stations. To use this method, choose one of the two options

and then move the cursor to the survey map. When the left mouse button is pressed and the cursor moved a dashed rectangle is drawn.
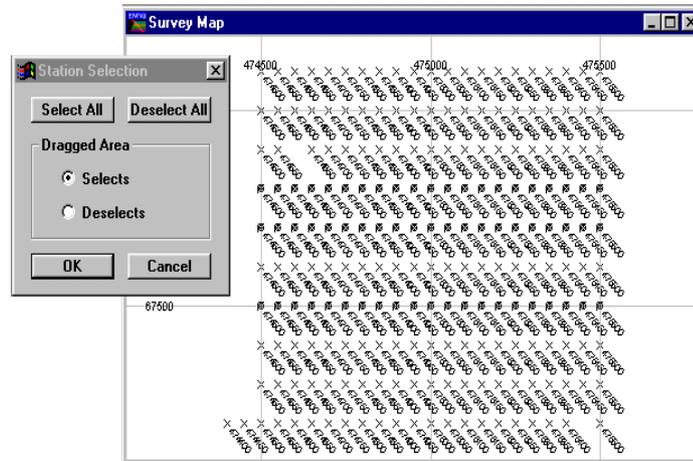
Station selection for modelling

When the mouse button is released, all the readings enclosed within the rectangle alters their activity state to match that set in the dialog.

To reverse the activity of individual stations, despite the **Dragged Area** selection, you can position the cursor over a reading and then click the left mouse button. This technique will toggle the activity state of the station.

Compute Model

Once the data, survey, algorithm and model have been defined and the desired channels and data readings made active, BEOWLF can be initiated. EM Vision can execute the program by selecting the Compute Model option of the Modelling menu, or by pressing the **Compute** button or icon on the toolbar.

BEOWLF uses the Generic Modelling Interface to operate and so is executed externally from EM Vision. In these cases, an icon will appear in the Windows status bar that indicates that EM Vision has initiated the program in an external portion of memory. This icon should not be selected while the program is running. For additional information on the icon settings and its operation, refer to *Controlling Algorithm Access*.

Progress of modelling is indicated by a slider bar with a percentage of completion. In cases where BEOWLF is to be halted during execution, the

progress bar has a **Cancel** push button. If you select this button, the program will abort. After the program has been aborted, status files and results to that point will be available for examination. These files along with control and model files resides in the project directory as defined by the import data.

Once a program has been halted, modifications to the model, channel and station activity can be made and the program re-initiated. Halting and re-executing the program can be undertaken any number of times.

Running BEOWLF in Forward Mode

If the algorithm selected (see *Algorithm Option*) is BEOWLF (FWD - Forward), the progress bar will move as computation of the response is calculated. As BEOWLF operates, it creates text result files which, can be viewed when execution is completed. At completion, a dialog enabling access to the text results is presented as shown. If you select **Yes** to browse the report, the text editor as specified in the EM Vision defaults file (see *The Defaults File* in the Reference Manual) is initiated and it automatically loads and display the BEOWLF results.
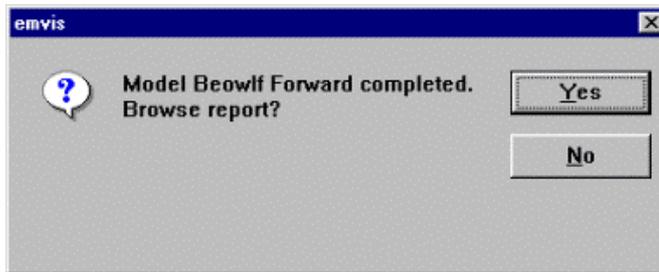
*Message displayed at the conclusion of BEOWLF*

After browsing the results, or after selecting **No** in the dialog above, EM Vision displays the modelled responses in any displayed profile window that has the Model Display option enabled (refer to *Profile Selection*).

Running BEOWLF in Inversion Mode

The inversion operation of BEOWLF is markedly different from the forward operation since user feedback and display of inversion convergence are important aspects of the operation.

After definition of the data, model, reading and channel activity, initiation of BEOWLF Inversion will result in three new objects appearing on the screen. These objects include:

1. An icon in the Windows status bar. This icon indicates the execution of BEOWLF externally to EM Vision under Generic Model Interface control.

2. A progress bar which contains not only an indication of computation progress, but also a **Cancel** button and an indication of the Standard Error between the computed and observed results for the station being modelled. The iteration number of the processing for each station is also displayed along with the station number and location (easting/northing).
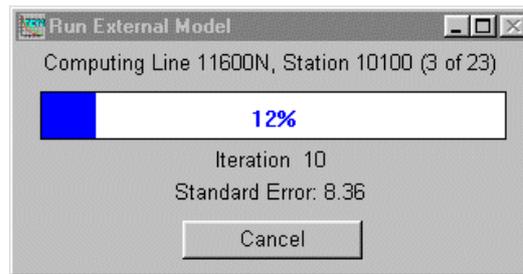
3. Comparative decay results between observed and computed TEM voltages. These displayed results gives an indication of the accuracy of the initial 'seed' model between the computed and observed responses. If the results are widely separated, you may wish to halt the inversion, modify the layered earth properties, and then recompute the response.

As BEOWLF progresses across a displayed profile it also displays the modelled response and resultant layered earth model in addition to the observed profile data. Refer to the *BEOWLF Tutorial* for further explanation.

As BEOWLF operates, it creates text result files that, when completed can be viewed. At completion, a dialog enabling access to the text results is presented as shown. If you select **Yes** to browse the report, the text editor specified in the EM Vision defaults file (see *The Defaults Files* in the Reference Manual) is initiated and automatically loads and displays the BEOWLF results.
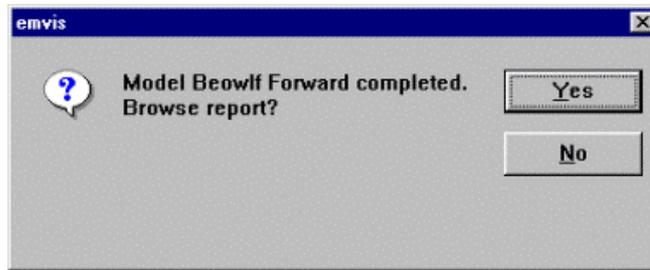
For an example of the text file results and an analysis of the file contents, refer to the *BEOWLF Tutorial*.

After browsing the results, or after selecting **No** in the dialog above, EM Vision will display the modelled results in any displayed profile window that has the Model Display option enabled (refer to *Profile Selection*).

Display of Errors from Inversion

At the conclusion of inversion modelling programs (e.g. BEOWLF), a report is produced. The errors reported in the BEOWLF output report are useful, (see *BEOWLF Operating Manual*) but a more graphical method of examining errors and inversion accuracy can be gained by displaying the computed errors of a BEOWLF inversion in conjunction with the model and profile results. Note in the Layer Configuration dialog (see below) that a Data Channel called STDERR is present.
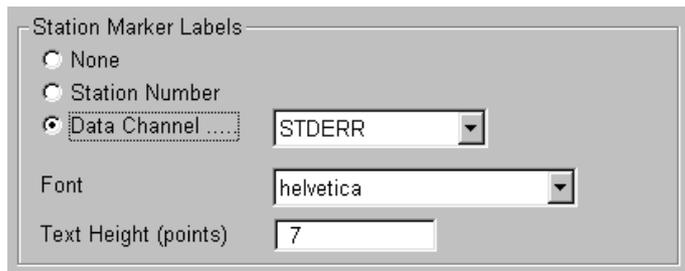
Error display dialog portion.

If the Data Channel (STDERR) option is enabled and the channel selected, it is possible to display the earth section with RMS errors (as percentages) for each station.
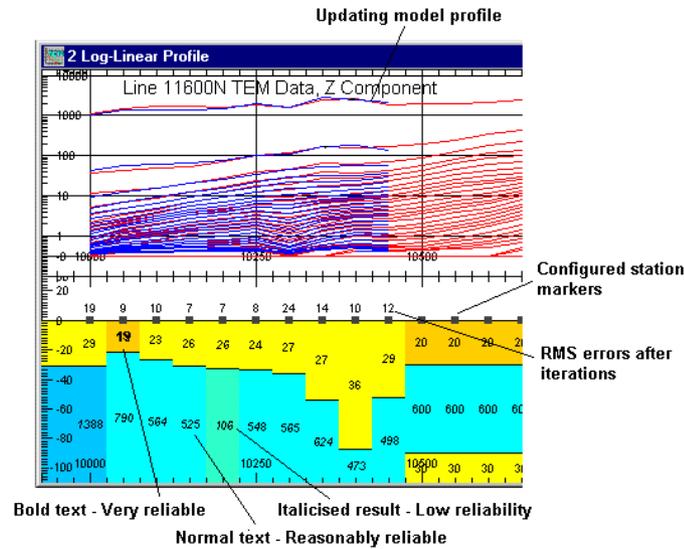
*Plotting of errors along the top of a BEOWLF inversion section.*

If there is insufficient space between the base of the data track and the top of the model, you can adjust the size of this space by allowing a greater distance (depth) above the model. Use the Min/Max vertical axis settings of the Drawing Configuration dialog to do this. Ensure the Earth Section track is the selected entry in the Drawings list at the top of the dialog before altering the depth values.

2   Beowlf Tutorial

The following section is a brief tutorial to explain the normal methods of operating BEOWLF. The dataset to be used for this exercise is supplied with EM Vision and is called EMV1_FXD.TEM. The file is read into the EXAMPLES subdirectory during installation of EM Vision. The tutorial is presented as a number of critical steps. Within each step where applicable, some additional information will be provided to assist you in understanding alternative analysis or display options.

Step 1 - Import the data

Import the EMV1_FXD.TEM data file using the **Data>Open Field Data** option (or the TEM import icon) as shown below:
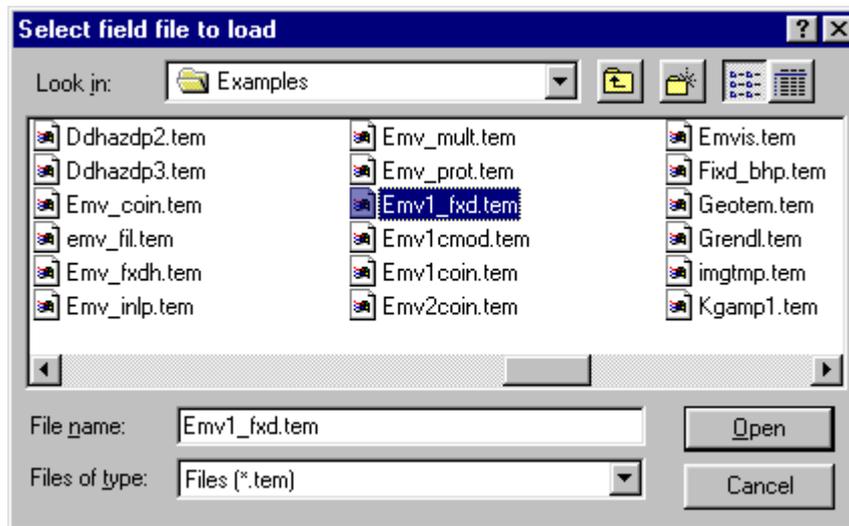
Data file selection dialog for tutorial input file.

The data is read (indicated by a progress bar) and then an explanatory dialog describing the data is presented. The data file has been acquired using composite time channels on a Sirotem Mk3 with a 300 x 600 metre rectangular transmitter loop in Fixed Loop survey configuration. A single line of data is contained in the file.

Step 2 - Examine the data by profile display

The data needs to be displayed as a profile to create layers for modelling with BEOWLF. Select the **Display>Profile>Linear-Linear** or Log-Linear option. Note that to present the profile with a section area beneath, the **Show Model Section** check box needs to be enabled. Note that three data components have been acquired. Although all three can be displayed (in a Log-Linear profile display), only one component (Z) can be modelled using BEOWLF.
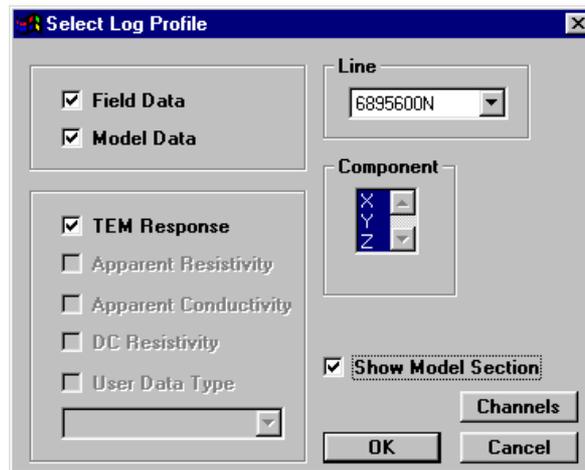
Log-linear profile selection dialog with Model Section enabled.

It is also advisable to enable the **Model Data** check box, as BEOWLF displays the theoretical responses automatically as it executes.

Once these items have been selected and **OK** pressed, the display is presented.
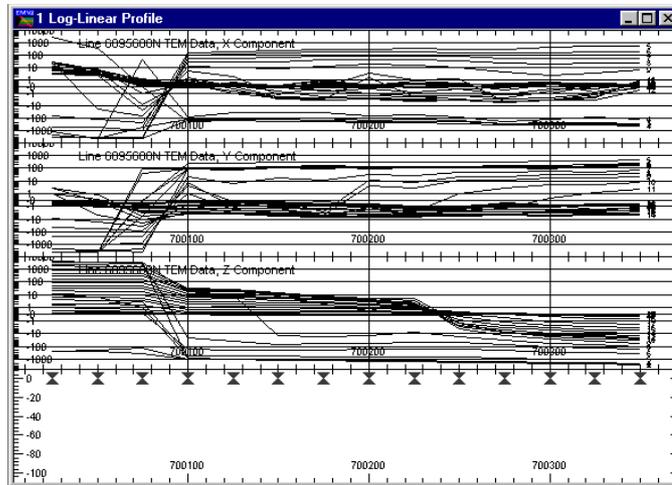
Three component log-linear profile with earth section beneath.

In the above display, an empty section beneath the data is provided, but at the top of this, small open crosses (**X** – marker symbols) appear at the site of each data reading. In this display, a Log-linear profile has been used, but linear-linear or predefined style could also be used.

Step 3 - Define the Earth Type

In some circumstances, you have some idea of the earth resistivity and how many layers adequately represent the electric section. This information may be known from IP studies, DC soundings or a general knowledge of the regional resistivity. Often these ideas are satisfactory to develop a suitable initial 'seed' model.

The Earth option of the Modelling menu is used to define the Earth Type and assign its properties. Various Earth types are available to satisfy the many host environments which can be modelled but in the case of BEOWLF, the only Earth Type available is the Layered Earth.

Note

Unless the correct information is specified in terms of model type, Earth host and defining parameters, the BEOWLF algorithm will not be accessible and will appear 'greyed' out in the Model/Algorithm menu option.

When selected, the Earth option provides two alternatives - Type and Properties. Type should be set to Layered Earth for BEOWLF.
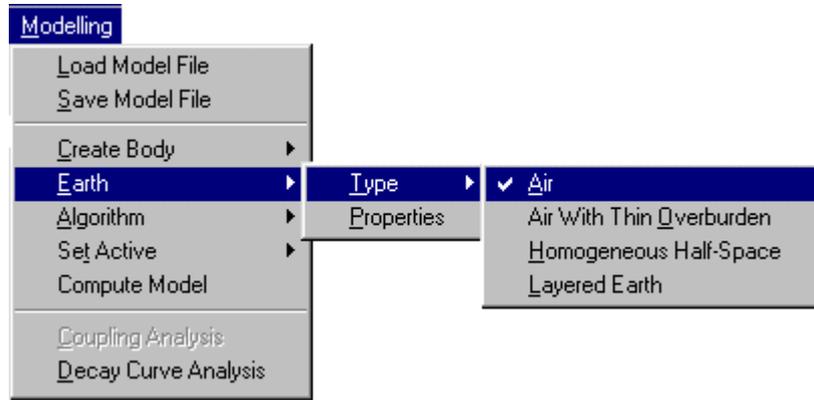
When the Layered Earth option is initially selected, if a profile with cross-section is displayed, the station locations and a single basement 'half-space' layer is drawn.

Step 4 - Defining the Layer Properties

A single basement 'half-space' for the displayed profile will have been created by selecting a Layered Earth model type. Additional layers with individual resistivity properties can be added by selecting the Modelling>Earth>Properties menu option. When this is done, a dialog is presented that describes the existing layer properties of Thickness and Resistivity (initially for only the Basement layer).
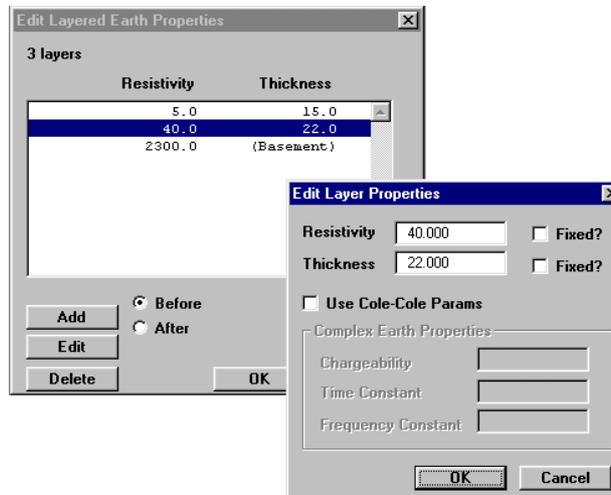
Adding and editing Layered Earth properties

To add layers, select the **Add** button and enter new resistivity and thickness properties. When adding a layer, it is added either before or after the highlighted layer depending on the **Before** or **After** button selected.

After a layer has been created, it can be edited by either highlighting it in the Edit Layered Earth Properties dialog and selecting the **Edit** push button, or, alternatively, positioning the cursor over the desired layer and double clicking with the left mouse button.

A layer can be removed by highlighting it and then pressing the **Delete** push button. For the model and data being simulated here, use a three layer case. As an initial 'seed' model, use a 1 or 2 ohm.metre resistivity of 5-10 metres thickness over a 550-600 ohm.metre layer of 80-100 metres thickness. A conductive basement of 80-100 ohm.metres should complete a suitable initial model.

Step 5 - Modifying Layer Properties and Colour

After defining the layers, the properties and appearance of each layer can be altered graphically. In the diagram below, three layers with different resistivity and thickness properties are shown. Note that the bottom layer represents the basement and so has infinite thickness.
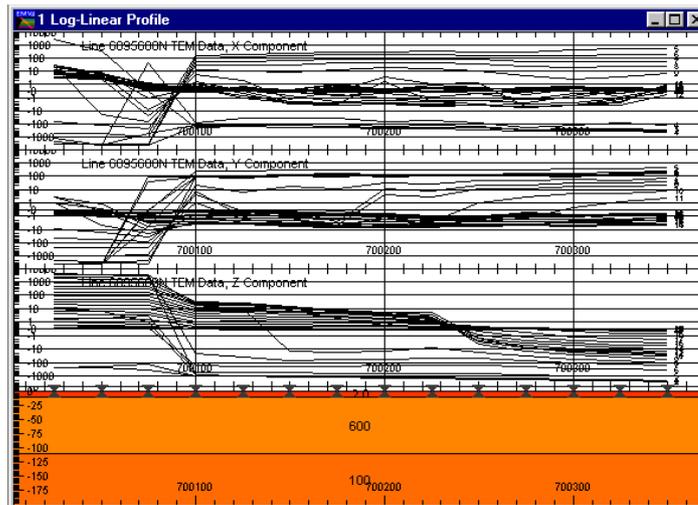
Three layers of different resistivity and thickness properties

To graphically alter the properties or colour of a layer, move the cursor over the desired layer and while positioned there, double click the left mouse button. A

dialog indicating the layer colour and the properties is displayed. The properties can be altered by editing the values displayed.

Refer to *Controlling the Presentation of Layers* for further information.

Step 6 - Controlling Layers of Individual Stations

BEOWLF operates on single TEM soundings and computes or inverts their response before moving to the next active reading. This means that EM Vision can supply BEOWLF with individual station models. The individual sounding models will act as different layered earths in a BEOWLF forward modelling operation but serves as different 'seed' models in the case of an inversion BEOWLF run.

To set the properties of a single sounding independently of surrounding stations, the '**X**' marker symbols that appear along the top surface of the uppermost layer are used. The marker symbols can be configured to be any size or symbol type (refer to *Setting Properties of Individual Stations*). Position the cursor over the symbol for the required station and click the left mouse button. The symbol will be highlighted when selected. If difficulty is experienced in selecting the symbol, press the CTRL key at the same time as the left mouse click.

Once selected, the standard Earth Properties dialog can be displayed by either positioning the cursor over the selected station symbol and double clicking the left mouse button, or pressing the **Properties** push button on the Toolbar.

Note

If a grouping of stations are to be modelled with different layer properties from other readings, these station marker symbols can be grouped by positioning the cursor above the first reading required and then, with the SHIFT key held down, select the other required stations in the group. Using this technique, it is not necessary that adjacent readings are selected. They can be selected from any location on the profile. As before, if difficulty is experienced in selecting individual station marker symbols, use the CTRL key as well as the SHIFT key.

Further assistance in selecting marker symbols can be achieved by providing greater space in the track above the symbols. To control this, reduce the minimum Earth Section setting (see *Profile Window Configuration*).
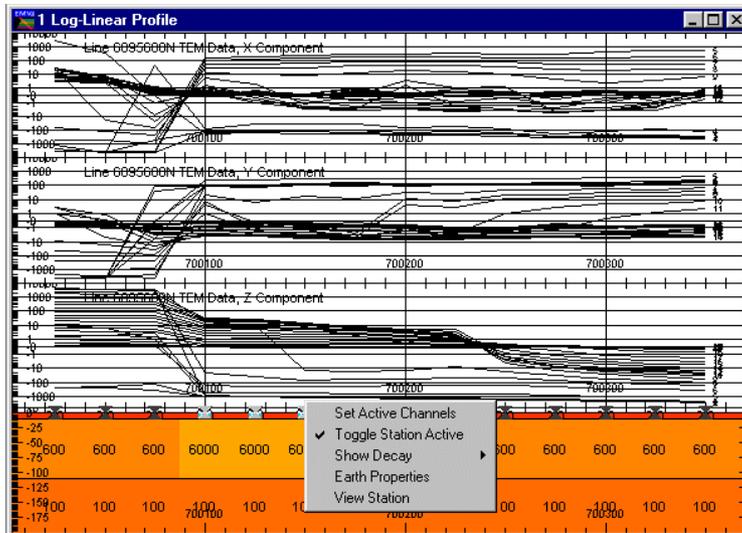
Cross-section with modified individual reading properties

WARNING

When a group of readings are selected for individual layer property control, do not double click to display the Earth Properties dialog as this resets your station selections. To set the properties, use the **Properties** push button located on the Toolbar.

Note

When only a single TEM sounding is available, it is not possible to display the data in profile form. In this case you can display the data as a single station decay and then create a layer model from the menu option of **Modelling>Earth>Properties**.

Step 7 - Define the Algorithm

Once the earth model is defined (see Steps 5-7), you must decide whether to model using BEOWLF in either forward or inverse mode. To set the algorithm, select from the menu **Modelling>Algorithm**. The menu appears as shown below.

Select BEOWLF to operate in either the forward or inversion mode. If forward mode is requested, EM Vision will display a dialog to report that this mode has been selected. If BEOWLF inversion mode is chosen a dialog to control the number of iterations and noise-to-signal ratio is displayed.
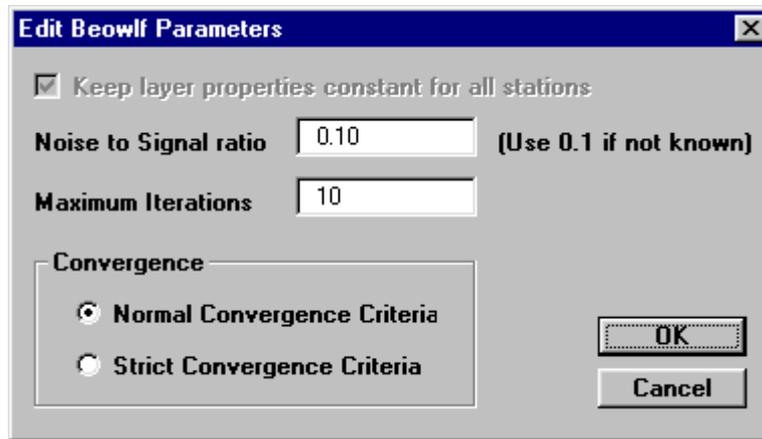
BEOWLF inversion control parameters

Initially set the Algorithm to BEOWLF FORWARD (see *Step 11*) and then set the Algorithm option to BEOWLF Inversion (see *Step 12*).

For most TEM datasets the maximum number of iterations should be approximately 10-15. For rapid (but inaccurate) results, a model can be derived with 3-4 iterations. Select the Normal Convergence criteria option.

Step 8 - Controlling Which Channels to Model

By default, BEOWLF models all data channels available. If early or late time noise is present in the data being modelled it is often a good idea not to model the noisy channels. Using the **Modelling>Set Active>Channels** option it is possible to 'turn off' certain channels which are not to be computed by BEOWLF.

When the option is selected the standard channel selection dialog as shown below is presented.
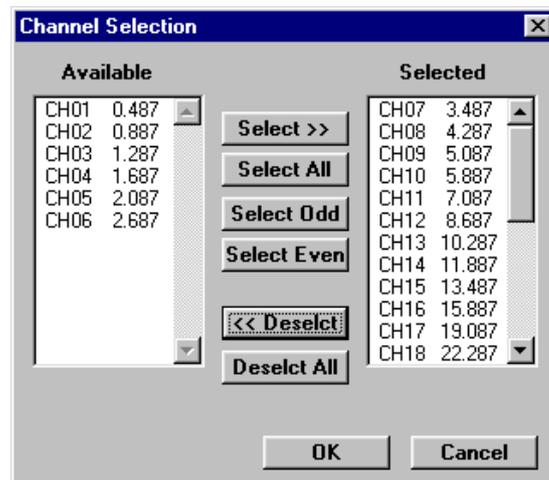
Channel selection dialog for channel activity

Refer to the section on *Standard Operations* for details on selecting and deselecting channels.

Step 9 - Controlling Which Stations to Model

The BEOWLF program models station responses individually. This means that you can control on which stations you wish BEOWLF to calculate responses. This control is provided by the **Modelling>Set Active>Stations** option. When selected the option presents a dialog accompanied by a survey map of the data loaded as shown below. Using the dialog options, individual or groups of stations can be selected as being 'active'. Stations that are highlighted are deemed to be active.
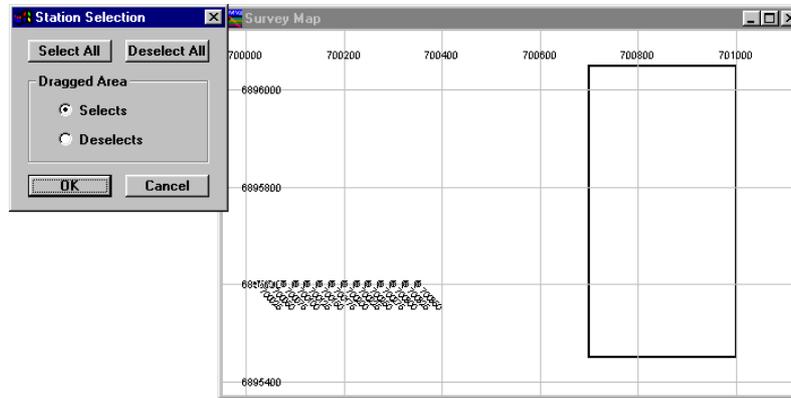
Setting stations to be active for modelling

It is possible to drag a rectangle over one or more stations and select them as active or inactive, depending on the setting of the dialog. To do this, position the cursor where appropriate and then press the left mouse button while moving the mouse. A rectangle is created and all stations contained in this is selected.

Step 10 - Computing a Forward BEOWLF Model

After creating a model and setting the activity and algorithm appropriately, you can initiate a forward BEOWLF model in one of two ways:

- Press the **Compute** push button or icon on the Toolbar.

- Select the **Modelling>Compute Model** option from the menu.

As responses are derived, the progress bar is updated but also the model response will be displayed (assuming the Model Response option was enabled during the profile display).
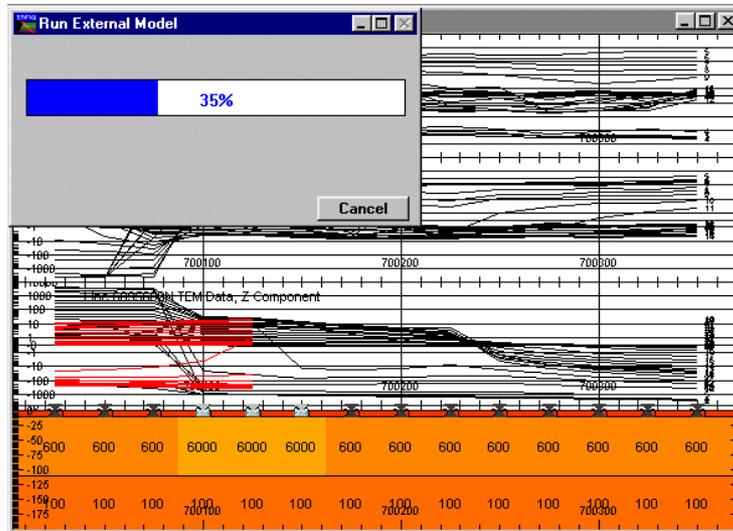
Forward model with modelled and observed responses

The program will continue executing until all stations and channels are completed. If you require, you can terminate a program run early by selecting the **Cancel** button. On normal termination of the program, a file is written that contains computed results for each station. A dialog will appear which enables you to examine this results file (see below). Not in the results that are displayed above, only the Z component data is computed by BEOWLF. Other programs, such as LAYER can produce three component data for the various survey configurations.

Step 11 - Computing an Inversion BEOWLF Run

When a BEOWLF inversion is initiated (using the **Modelling>Compute Model** option or Toolbar **Compute** push button or icon), operation is different to that of forward operation. As inversion is an iterative operation, it is useful for the user to see results and model parameters change as the inversion progresses. Consequently, after BEOWLF is initiated, three new display windows are presented.

These are:

- A progress bar which displays not only the station number, iteration and incremental progress, but also the Root Mean Square error between the computed and observed responses.

- A decay display (for the computed station) comparing the measured and computed model TEM voltage responses.

- A decay display (for the computed station) comparing the calculated and computed model apparent resistivities. This display is especially diagnostic in determining if the initial 'seed' model is appropriate for the data being modelled.

An example of these three displays follows.
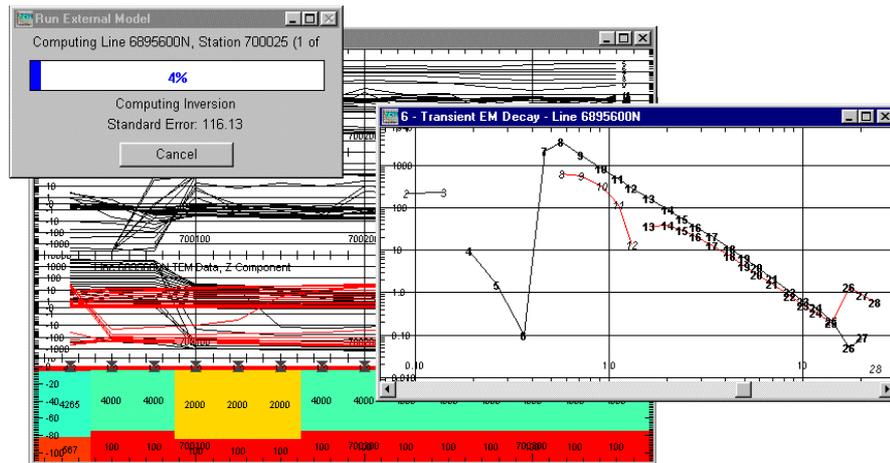
Progress bar, and decay comparisons of voltage and apparent resistivities

As the inversion progresses across the active stations, a model response curve can be seen to display with the observed response. Note that only the Z component is used with BEOWLF inversions. The modified 'seed' models reflects the re-modelled layer properties derived from the BEOWLF inversions.

Similar to a forward BEOWLF program run, when an inversion is terminated, a report file is generated. The report will contain the initial and final model details, control parameters plus response and apparent resistivity results.

Step 12 - Analysing the BEOWLF Results File

To graphically assess the errors derived from a BEOWLF inversion, see *Display of Errors from Inversion*.

In the report created by a BEOWLF inversion, a number of diagnostic analyses on the results are provided. In the examples provided below, a three layer model has been used for the BEOWLF model (therefore three resistivities and two layer thicknesses are analysed). An eigenvalue and a correlation matrix analysis is performed for each station inverted. These analyses provide excellent assessment of the results obtained for inversions using BEOWLF.

Eigenparameter Matrix Analysis

The performance of inversions by BEOWLF can be assessed from a combination of the damping factors, the **V** matrix (the Eigenparameter matrix) and the calculated error bounds. An example of this analysis is provided below for a model with three layers as detailed in Hohmann and Raiche (1987). This model used a 1.0 ohm.metre overburden, resistive intermediate layer (4,000 ohm.metres) and moderately resistive basement (500 ohm.metres).

The columns of the **V** matrix correspond to the eigenparameters (EP) and the rows to the logarithms of the physical parameters resistivity and thickness. A damping factor above 0.9 indicates that the associated eigenparameter is well resolved. Damping factors less than 0.8 imply that the resolution of the eigenparameter is less well resolved. Damping factors less than 0.1 imply that the eigenparameter is completely unresolved.

```
    **************************************************
    * LAYER THICKNESS PARAMETER SENSITIVITY ANALYSIS *
    **************************************************

    THE NUMBER OF EFFECTIVE PARAMETERS IS     1.139

    PARAMETER SPACE EIGENVECTORS (V MATRIX)
                  EP1     EP2     EP3     EP4     EP5

    LOG(RES1)   .699   -.656    .285   0.000   -.009

    LOG(RES2)   .006   -.007   0.000    .054    .999

    LOG(RES3)   .094   -.310   -.946   -.030   -.001

      LOG(H1)   .708    .687   -.156    .047   -.002

      LOG(H2)  -.031   -.041   -.021    .997   -.054

Damping Factors  1.0     1.0   0.961   0.094   0.028
```

As shown in the example above, only EP3 and EP5 are well resolved. EP1, EP2 and EP4 are poorly resolved or not resolved. Since each of these eigenparameters is a linear combination of logarithms of physical parameters, we can estimate the resolution of different aspects of the final model.

For example, EP1 and EP5 consist of the third layer resistivity-thickness quotient and product respectively, so the resistivity and thickness of the basement layer are each well resolved. EP5 shows that the depth to the resistive layer is well resolved. EP4 and EP5 have very low damping factors. Consequently basement and overburden resistivity are not at all resolved. These assessments are also

supported by the statistics provided in the 68 percent confidence intervals as
shown below:

```
************************************
* ERROR BOUNDS FOR LAYER THICKNESS *
************************************

LAYER RESISTIVITIES  68 % CONFIDENCE INTERVAL
(UNDAMPED)

 LAYER    RES(I)      BOUND(1)    BOUND(2)
    IMPORTANCE

1   5.066 .7475 34.33 .71
2   4269. UNBOUNDED        .01
3   574.0 160.420     54.   .10

LAYER THICKNESSES   68 % CONFIDENCE INTERVAL (UNDAMPED)

LAYER     THICK(I)    BOUND(1)    BOUND(2)
    IMPORTANCE

1   7.674 2.016 29.21 .71
2   74.56 UNBOUNDED        .03
```

In addition to the above error analyses, Standard Error and Jacobian sensitivities
are provided.

Step 13 - Saving (or Loading) a Computed Model

Prior to, or after running BEOWLF, it is a wise policy to save the created model.
Use the **Modelling>Save Model File** (or Load Model File) option to write or
retrieve a model file. By default, EM Vision model files have the file extension
.MOD. Once saved, these ASCII files become a valuable resource.

3   References

Barnett, C.T.   1984   Simple inversion of time-domain electromagnetic data. Geophysics, v 49, pp 925-933

Bulgakov, Yu. I   1971   Interpreting surveyed results by the single loop transient process method. *In* Fokin,A.F.,ed *The Method of Transient Process in the Search for Sulphide Ore Deposits*. USSR Ministry of Geology, Leningrad.

Eaton, P.A. & Hohmann, G.W.   1986   A technique for rapidly estimating the resistivity of the earth from transient electromagnetic soundings. Expanded Abstracts, 56th Ann. Internat. Soc. Explor. Geophys. Mtg.

Eaton, P.A. & Hohmann, G.W.   1989   A rapid inversion technique for transient electromagnetic soundings. Physics of the Earth and Planetary Interiors, v. 53 pp 384-404.

Flood, N.   1990   CSIRO EM Modelling Suite. TEM Data file format. AMIRA CSIRO Research document.

Hohmann, G.W. & Raiche, A.P.   1987   Inversion of controlled source electromagnetic data. Ch. 8, in Electromagnetic Methods in Applied Geophysics. Vol. 1, Soc. of Explor Geophysicists, pp 469-503.

Knight, J.H. & Raiche, A.P.   1982   Transient electromagnetic calculations from the Gaver-Stehfast inverse Laplace transform method. Geophysics v.47, pp 47-50.

McAllister, K. & Raiche, A.P.   1986   Program BEOWLF- Manual prepared for AMIRA by the

		Mathematical Geophysics Group, CSIRO division of Exploration Geoscience.
Nabighian, M.N. & Macnae, J.C.	1991	Time domain EM prospecting methods in Electromagnetic Methods in Applied Geophysics. Vol 2A, Ch 6, pp 430-446.
Oristaglio, M.L. & Hohmann, G.W.	1984	Diffusion of EM fields into a two-dimensional earth. Geophysics, v.49 pp 870-894.
Smith, R.S. & West, G.F.	1988	Inductive interaction between polarizable conductors: an explanation of a negative coincident-loop transient electromagnetic response. Geophysics, v.53, pp 677-690.
Raiche, A.P.	1981	Coincident loop transient electromagnetic master curves for interpretation of two-layer earths. Geophysics, v.46, pp 53-64.
Raiche, A.P.	1983	Comparison of apparent resistivity functions for TEM methods. Geophysics, v.48 pp 787-789.
Raiche, A.P.,	1983	Negative transient voltage and magnetic field responses for a half-space with a Cole-Cole impedance. Geophysics, v.48, pp 790-791.
Raiche, A.P., Bennett, L.A., Clark, P.J. & Smith, R.J.	1985	The use of Cole-Cole impedances to interpret the TEM response of layered earths. Bull. Aust. Soc. Explor. Geophys., 16(2/3), pp 271-272.
Raiche, A.P., Jupp, D.L.B.,	1985	The joint use of coincident loop transient electromagnetic and

Rutter, H. &
Vozoff, K.
Schlumberger sounding to resolve
layered structures. Geophysics, v.50,
pp 1618-1627.

Raiche, A.P. &   1985   Apparent resistivity and diffusion
Gallagher, R.G.   velocity. Geophysics, v.50, pp 1628-
                                 1633.

Raiche, A.P.   1987   Transient electromagnetic field
                                 computations for polygonal loops
                                 on layered earths. Geophysics, v.52,
                                 pp 785-793.

Raiche, A.P.,   1989   Manual for the EM/IP modelling
Sugeng, F. &   and inversion workshop - A
Flood, N.   workshop description and guide.
                                 August 1989. CSIRO Div.
                                 Explor. Geoscience. AMIRA Project
                                 P223. Restricted Report 54R.

Vozoff, K. &   1975   Joint inversion of geophysical data.
Jupp, D.L.B.   Geophys. J. Roy. Astr. Soc.
                                 v.42 pp 997-991

4 Index