EKKO_View Enhanced
&
EKKO_View Deluxe

User's Guide

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s u b s u r f a c e   i m a g i n g   s o l u t i o n s

Sensors & Software Inc.
1040 Stacey Court
Mississauga, ON L4W 2X8 Canada

Tel: (905) 624-8909
Fax: (905) 624-9365

E-mail: sales@sensoft.ca
Website: www.sensoft.ca

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Sensors & Software Inc.
1040 Stacey Court
Mississauga, Ontario
Canada L4W 2X8
Tel:(905) 624-8909
Fax:(905) 624-9365
E-mail: sales@sensoft.ca

Table of Contents

1 Overview

The EKKO_View family of software is the next generation editing, processing and plotting software package for Sensors & Software GPR data.

This software package comes in three different versions:

1. EKKO_View is used for data plotting of GPR data,
2. EKKO_View Enhanced allows for data plotting as well as data editing and simple data processing of the GPR data,
3. EKKO_View Deluxe is the professional version that allows for data plotting, editing and full processing routines including spatial and temporal filters, migration, instantaneous attributes, amplitude spectra, CMP velocity analysis and more.

The EKKO_View family of software was designed for the demanding user, who needs to edit, process and plot large volumes of GPR data quickly and efficiently. It is also possible to convert the GPR data to other formats for export.

EKKO_View Enhanced and EKKO_View Deluxe use a simple to understand spreadsheet approach to display all the GPR data in a project (see Figure 1-1). All the data file names in the project are listed in a column. As well, the survey parameters such as the Start Position, Number of Traces, Time Window length, etc. are listed in columns on the spreadsheet. This format allows users to quickly spot errors in the data that need to be edited.

Editing and processing can be done to any or all the data files in a project. Often used or “favourite” processing streams can be saved as “recipes” to use on other data sets.

The original data is always saved in the primary folder. Edited and processed files are saved to sub-folders. This means that the original data cannot be changed. It is always available to try a new processing stream.

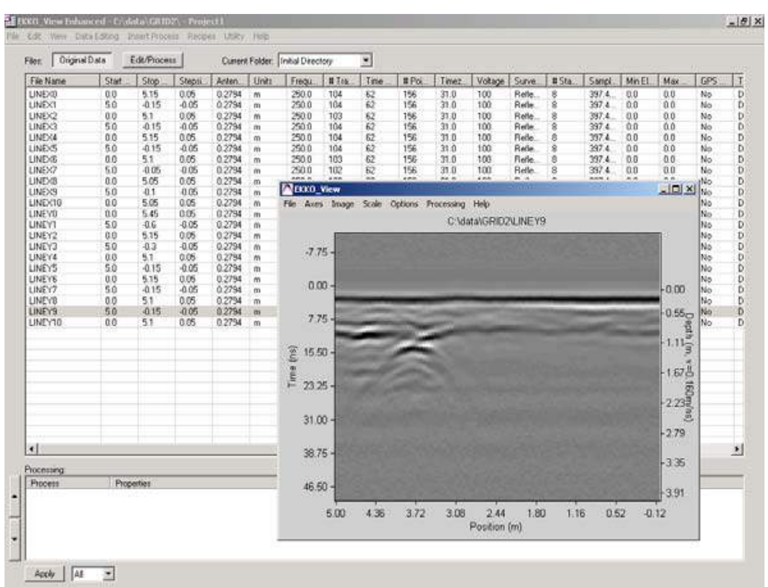


Figure: 1-1 The EKKO_View Enhanced screen in the background with the EKKO_View program in the foreground displaying a data image.

2 Installation and Startup

2.1 System Requirements

The complete EKKO_View Enhanced (or EKKO_View Deluxe) software consists of two parts:

1. The EKKO_View Enhanced (or EKKO_View Deluxe) program and,
2. The EKKO_View program.

EKKO_View Enhanced (or EKKO_View Deluxe) is used for data editing and processing data while the EKKO_View program is used for plotting the data images.

Note that while EKKO_View is a part of the EKKO_View Enhanced and EKKO_View Deluxe programs, it is a separate program that can be run independently of EKKO_View Enhanced and EKKO_View Deluxe. So, if you just want to plot a data file, it can be done by running the EKKO_View program. It is not necessary to run the EKKO_View Enhanced or EKKO_View Deluxe program.

The minimum system requirements for running the EKKO_View Enhanced (or EKKO_View Deluxe) program are:

- Pentium, Pentium Pro, Pentium II, Pentium III, Pentium IV, Intel Xeon, AMD Athlon or Athlon XP based personal computer
- Microsoft Windows 98 (original and Second Edition), Windows Millennium Edition (ME), Windows NT 4.0 (with Service Pack 5 for Y2K compliancy or Service Pack 6a), Windows 2000, or Windows XP.
- CD-ROM drive (for installation from CD)
- 128 MB RAM minimum, 256 MB RAM recommended
- 25 MB free hard disk space
- 8-bit graphics adapter and display (for 256 simultaneous colors). A 16, 24 or 32-bit OpenGL capable graphics adapter is strongly recommended.

Other recommended items include:

- Microsoft Windows supported graphics accelerator card and printer

2.2 Installing EKKO_View Enhanced or EKKO_View Deluxe

For the latest information about installing EKKO_View Enhanced (or EKKO_View Deluxe), see the Software Installation information sheets accompanying the Sensors & Software CD-ROM or the Software Installation PDF file on the CD-ROM.

To install EKKO_View Enhanced, insert the Sensors & Software CD into the CD drive. Click the **START** button and select **RUN**. Choose the correct disk drive and move to the **EKKO_View Enhanced** folder and run the **SETUP.EXE** program.

To install EKKO_View Deluxe, insert the Sensors & Software CD into the CD drive. Click the **START** button and select **RUN**. Choose the correct disk drive and move to the **EKKO_View Deluxe** folder and run the **SETUP.EXE** program.

The CD-ROM has a folder called **Samples** that contains sub-folders of GPR data.

The \SAMPLES\GPR_DATA, \SAMPLES\PIPES and \SAMPLES\WATERTNK folders contain surveys where a number of parallel GPR data lines were collected. These data can edited, processed and plotted using EKKO_View Enhanced or EKKO_View Deluxe.

Any of the sample data can be copied from the CD-ROM. Note that these GPR data may have the Read-Only attribute set if they are copied directly from the CD. If this is true, these files can be plotted with the Sensors & Software programs but cannot be edited, unless the Read-Only attribute is removed (this can be done in Windows by changing the Properties of the file).

2.3 Installing EKKO_View

The EKKO_View program is automatically installed when EKKO_View Enhanced and EKKO_View Deluxe are installed. EKKO_View can, if necessary, be installed by running the **SETUP.EXE** program in the **EKKO_View** folder on the CD.

The manual for EKKO_View is available under the Help menu when the EKKO_View program is run. It is possible to print a copy of the manual from the Help files.

2.4 Running EKKO_View Enhanced or EKKO_View Deluxe

After installing EKKO_View Enhanced or EKKO_View Deluxe, the program can be run by:

a) Double-clicking the EKKO_View Enhanced or EKKO_View Deluxe icon on the Desktop.

b) Clicking **Start**, selecting **Programs**, **Sensors & Software GPR** and **EKKO_View Enhanced** or **EKKO_View Deluxe**.

3 Using EKKO_View Enhanced & EKKO_View Deluxe

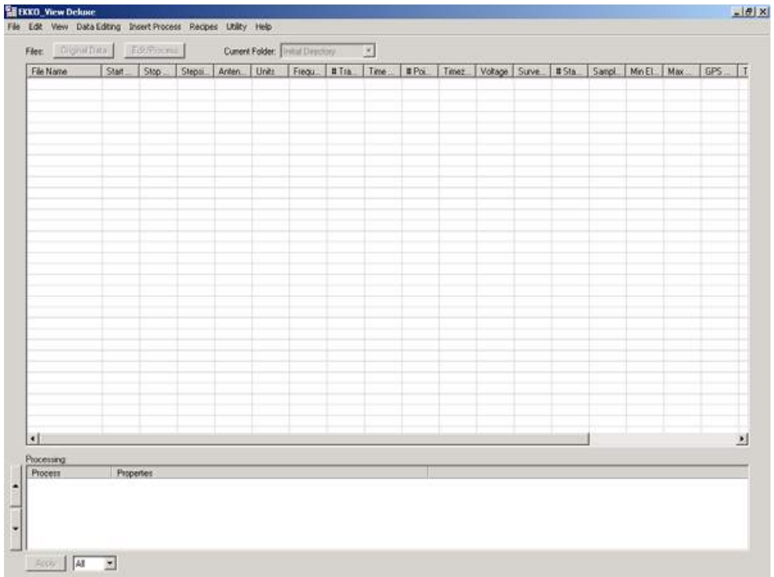


Figure: 3-1 The EKKO_View Deluxe main window.

3.1 Opening a Project

A project in EKKO_View Enhanced and EKKO_View Deluxe is defined as all the GPR data in a folder. If data files are in different folders they must all be copied to one folder to be included in the project. Microsoft Windows Explorer can be used to copy or move files to the same folder.

Note that each survey line of Sensors & Software GPR data consists of two files, an ASCII header file with a .HD extension and a binary data file with a .DT1 extension. Both files must be present to have complete data. See Appendix B for more details about the Sensors & Software File format.

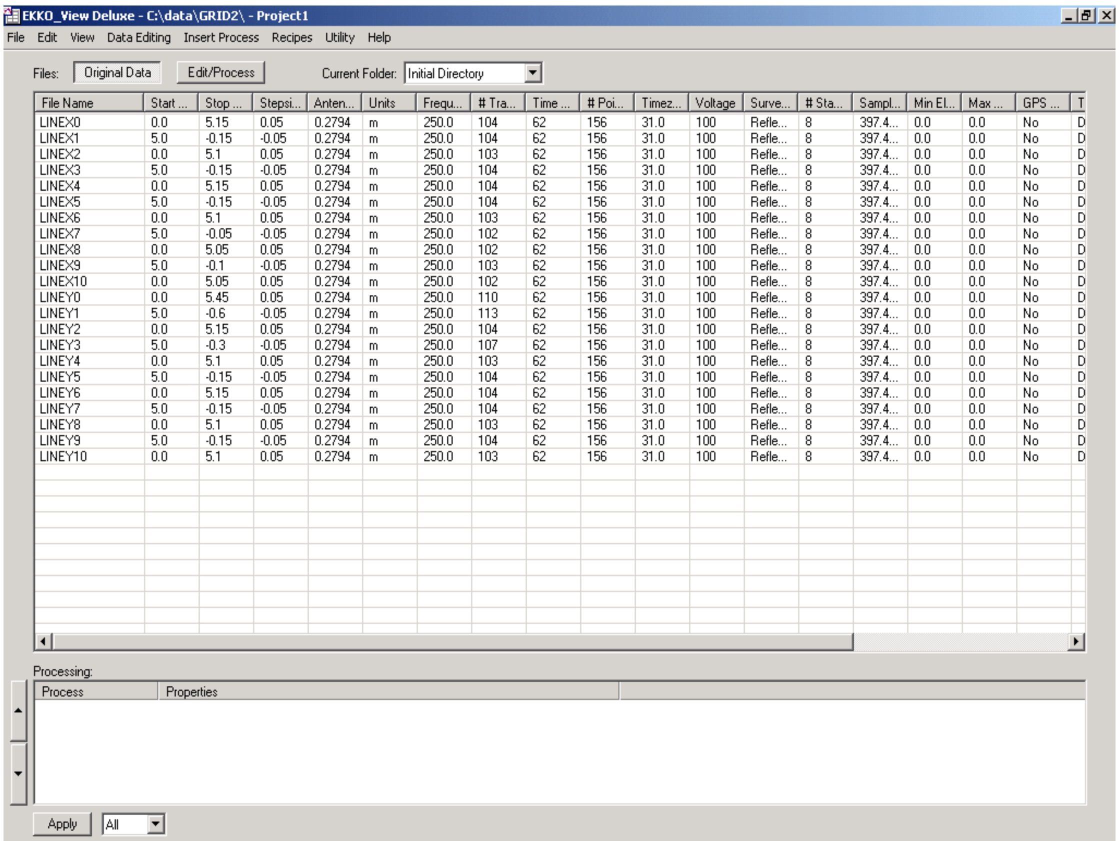
EKKO_View Enhanced and EKKO_View Deluxe project files have a .prj extension.

To open a new project, select **File – New Project**. Use the **Browse** button to find the folder holding the GPR data. Then type in the **Project Name** (or use the default name provided) and click **OK**.

Figure 3-2: Select File - New to open a new project. Use Browse to find the data folder and then give the project a name or use the default name provided.

To open an existing project, select **File – Open Project**. Use the **Open** dialog box to find and select the project (.prj) file name and click **Open**.

After a new or existing project file has been selected, all the files in the folder are listed to the spreadsheet as shown below (see Figure 3-3). The spreadsheet lists more than 20 columns of parameters associated with the file including the file name, start position, end position, stepsize and number of points per trace.



File Name	Start ...	Stop ...	Stepsi...	Anten...	Units	Frequ...	# Tra...	Time ...	# Poi...	Timez...	Voltage	Surve...	# Sta...	Sampl...	Min El...	Max ...	GPS ...	T
LINEX0	0.0	5.15	0.05	0.2794	m	250.0	104	62	156	31.0	100	Refle...	8	397.4...	0.0	0.0	No	D
LINEX1	5.0	-0.15	-0.05	0.2794	m	250.0	104	62	156	31.0	100	Refle...	8	397.4...	0.0	0.0	No	D
LINEX2	0.0	5.1	0.05	0.2794	m	250.0	103	62	156	31.0	100	Refle...	8	397.4...	0.0	0.0	No	D
LINEX3	5.0	-0.15	-0.05	0.2794	m	250.0	104	62	156	31.0	100	Refle...	8	397.4...	0.0	0.0	No	D
LINEX4	0.0	5.15	0.05	0.2794	m	250.0	104	62	156	31.0	100	Refle...	8	397.4...	0.0	0.0	No	D
LINEX5	5.0	-0.15	-0.05	0.2794	m	250.0	104	62	156	31.0	100	Refle...	8	397.4...	0.0	0.0	No	D
LINEX6	0.0	5.1	0.05	0.2794	m	250.0	103	62	156	31.0	100	Refle...	8	397.4...	0.0	0.0	No	D
LINEX7	5.0	-0.05	-0.05	0.2794	m	250.0	102	62	156	31.0	100	Refle...	8	397.4...	0.0	0.0	No	D
LINEX8	0.0	5.05	0.05	0.2794	m	250.0	102	62	156	31.0	100	Refle...	8	397.4...	0.0	0.0	No	D
LINEX9	5.0	-0.1	-0.05	0.2794	m	250.0	103	62	156	31.0	100	Refle...	8	397.4...	0.0	0.0	No	D
LINEX10	0.0	5.05	0.05	0.2794	m	250.0	102	62	156	31.0	100	Refle...	8	397.4...	0.0	0.0	No	D
LINEY0	0.0	5.45	0.05	0.2794	m	250.0	110	62	156	31.0	100	Refle...	8	397.4...	0.0	0.0	No	D
LINEY1	5.0	-0.6	-0.05	0.2794	m	250.0	113	62	156	31.0	100	Refle...	8	397.4...	0.0	0.0	No	D
LINEY2	0.0	5.15	0.05	0.2794	m	250.0	104	62	156	31.0	100	Refle...	8	397.4...	0.0	0.0	No	D
LINEY3	5.0	-0.3	-0.05	0.2794	m	250.0	107	62	156	31.0	100	Refle...	8	397.4...	0.0	0.0	No	D
LINEY4	0.0	5.1	0.05	0.2794	m	250.0	103	62	156	31.0	100	Refle...	8	397.4...	0.0	0.0	No	D
LINEY5	5.0	-0.15	-0.05	0.2794	m	250.0	104	62	156	31.0	100	Refle...	8	397.4...	0.0	0.0	No	D
LINEY6	0.0	5.15	0.05	0.2794	m	250.0	104	62	156	31.0	100	Refle...	8	397.4...	0.0	0.0	No	D
LINEY7	5.0	-0.15	-0.05	0.2794	m	250.0	104	62	156	31.0	100	Refle...	8	397.4...	0.0	0.0	No	D
LINEY8	0.0	5.1	0.05	0.2794	m	250.0	103	62	156	31.0	100	Refle...	8	397.4...	0.0	0.0	No	D
LINEY9	5.0	-0.15	-0.05	0.2794	m	250.0	104	62	156	31.0	100	Refle...	8	397.4...	0.0	0.0	No	D
LINEY10	0.0	5.1	0.05	0.2794	m	250.0	103	62	156	31.0	100	Refle...	8	397.4...	0.0	0.0	No	D

Figure: 3-3 The display of the data files in the EKKO_View Deluxe spreadsheet.

Scroll bars can be used to see all the columns and all the files in the list. The width of the columns can be changed by clicking on the border between two column titles and widening or narrowing the column. Widening the column allows the whole column name to be displayed.

It is possible to edit which columns appear on the display by selecting **Edit – Columns** or right clicking on any of the column titles. This action will bring up a list of column titles that can be checked or unchecked depending on which columns are to appear on the list (see Section 5.1: Columns on page 19).

There are two buttons located above the spreadsheet:

1. Original Data
2. Edit/Process

In Original Data mode, properties and plots of the data file(s) can be displayed but the data cannot be edited or processed.

In Edit/Process mode, copies of the data files can be edited and/or processed.

3.2 Original Data Mode

When a project is opened for the first time, the **Original Data** button is on.

Highlighting a file name and then selecting the **View** menu item (or right-clicking on the file name) allows:

1. Data files to be displayed as a **Section** plot (see Section 6.1: Section on page 21) or
2. Data files to be displayed as individual **Traces** (see Section 6.2: Traces on page 23),
3. The current **Processing History** of the file can be viewed (see Section 6.3: Processing History on page 24).
4. Information in the **Trace Headers** of the data file can be viewed (see Section 6.4: Trace Header on page 24).
5. **Trace Comments** added to the data during data acquisition can be displayed (see Section 6.5: Trace Comments on page 25).

As well, the EKKO_View Deluxe version allows two special plots can be made. The **Average Time – Amplitude Plot** shows signal strength versus time (see Section 6.6: Average Time-Amplitude Plot on page 26) and the **Average Amplitude Spectrum Plot** shows the frequency content of the data (see Section 6.7: Average Amplitude Spectrum Plot on page 26).

The EKKO_View Deluxe version also allows CMP data files to have a **CMP Analysis** done on them to extract velocity information (see Section 6.8: CMP Analysis on page 27).

In **Original Data** mode, data files can be removed from the list by highlighting them and then pressing the **Delete** key or selecting **Edit - Delete**. Remember that this only removes the data file name from the list, it does not actually delete the files from the folder.

The GPR data files can be converted to other formats by right-clicking on the file name and then selecting **Convert** (see Section 7.1.4: Convert on page 31).

3.3 Edit/Process Mode - Editing Data

The original GPR data files in the folder cannot be edited or processed. When data files are to be edited or processed, a sub-folder is created and copies of the data files are written to the sub-folder i.e. \data\edit1. It is the copies of the data files in the sub-folders that are edited and or processed.

The first step is to select the data files to be copied to the sub-folder. This is done by highlighting one or more data file names in the spreadsheet list. To highlight a single file name, click on it. To highlight a series of file names, click on the first file name, hold down the Shift key and then click on the last file name. This will highlight all the file names between the first and last file names. To highlight selected file names, hold down the Control (Ctrl) key while clicking on the desired file names. **If no file names are highlighted, ALL the data files in the original data folder will be copied to the edit/process sub-folder.**

After highlighting the file names, click on the **Edit/Process** button. The user is prompted to input the name of a new sub-folder or select an existing sub-folder. Once OK is selected, all the highlighted data files are copied to the sub-folder and listed to the spreadsheet. These files can now be edited and/or processed.

Note that sub-folders do not have to be just from the original data folder. It is possible to make a sub-folder from an existing sub-folder. For example, if you are in Edit/Process mode in a sub-folder, you can create a new sub-folder by clicking on the Edit/Process button again. In this way it is possible to create whole chains of sub-folders like \data\edit1\edit1\process1.

Once the data files are listed in the sub-folder, the next step is to select the data files to be edited and/or processed. Again, highlight the data file names using the method described above.

To edit the highlighted data files, find the desired editing operation under **Data Editing** (see Section 7: Data Editing on page 29), fill in any necessary parameters and select **Run**. The editing operation will be performed on the file or files selected.

Another way of selecting an editing operation is called the Spreadsheet approach (see Section 3.3.2: Spreadsheet Editing on page 10). Again, highlight the file or files to be edited and now simply right-click in the column that relates to what you want to edit. This will display a menu with all the editing operations available for that column. For example, to edit the position values of a data file, right click in the **Start Position** column and list of position-related editing options comes up. Choose one editing operation, fill in any parameters, select **Run** and the edit is done.

If, during editing and/or processing you make a mistake, highlight the file name and simply right-click and select Reset to get a “fresh” copy of the original data file. The data file in the sub-folder is over-written by a new copy from the main folder. This is the ultimate “undo” tool.

As well, the **Reset All Files** option under the **Edit** menu item overwrites all the files in the sub-folder with the original files from the main folder.

Note that at any time during data editing or processing, the data file can quickly be viewed. Simply select **View – Section** to display the data file with all the current editing and/or processing.

After data have been edited or processed, other Sensors & Software programs like EKKO_3D, EKKO_Pointer and EKKO_Mapper can be run.

3.3.1 Editing Data Summary

Data editing includes about 25 different operations. These operations are available under the Data Editing menu under the headings listed below. These operations can also be accessed by right-clicking in the appropriate parameter column on the spreadsheet (see Section 3.3.2: Spreadsheet Editing on page 10).

All the headings and editing operations are listed below with a brief description. Detailed descriptions of each operation are given in Section 7: Data Editing on page 29. Operations prefixed with a * indicate that these operations are only available in the advanced version, EKKO_View Deluxe, and not the basic version of the software, EKKO_View Enhanced.

FILE:

MERGE	merge two or more GPR data files together horizontally.
STACK	merge two or more data files together vertically.
RUBBERBAND	rubberband the data to known positions of fiducial markers added during data acquisition.

ADD_TOPO	add topographic data to a GPR data file using a user defined Topo file.
*ADD_TOPO-GPS	add topographic data to a GPR data file using GPS Z data.
SHIFT_TOPO	shift data to compensate for topography.
*ADD_GPS	add GPS X, Y and Z positions to a GPR data file.

DATA CONVERSION:

SEGY	convert pulseEKKO data to SEG-Y format.
EAVESDROPPER	convert pulseEKKO data to Eavesdropper format.
ASCII1	convert the binary pulseEKKO data to ASCII format.
ASCII2	convert the binary pulseEKKO data to a columnar ASCII format that can be read by spreadsheet and 2D data visualization programs.
CSV	convert the binary pulseEKKO data to CSV format.
EXPORT TIME SLICE	export average amplitude data in a time range from a pulseEKKO data to CSV format.

HEADER FILE:

ANTENNA_SEPARATION	edit antenna separation.
SURVEY_MODE	edit survey mode (Reflection, CMP or Transillumination).
TITLES	edit title1 and title2 fields in the header file.
UNITS	edit the units used for measurement (metres or feet).
FREQUENCY	edit antenna frequency.
PULSER VOLTAGE	edit pulser voltage.

POSITIONS:

REPOSITION	reposition all the traces in a data file
REVERSE	reverse data file direction.
NEW_STEPSIZE	resample the data spatially, either at a finer or coarser stepsize.
CHOPDATA-TIME	used to take a smaller portion of a data set in the time direction.
CHOPDATA-POS	used to take a smaller portion of a data set in the position direction.
MUTEDATA	zero a range of data.
DELETE_TRACES	delete bad traces from a data file.
INSERT_TRACES	insert blank traces into a data file.
POLARITY	reverses the polarity of some or all the traces in a data file.
FILL_DATA_GAPS	interpolate traces into gaps caused by data collection with the odometer and moving too fast.

TIME WINDOW:

NEW TIME WINDOW	increases or decreases the time window length.

POINTS/TRACE:

RESAMPLE	resample the data in time, either at a finer or coarser sampling interval.
DECIMATE	reduce the number of points in the data file to a fraction of the original number.

TIMEZERO:

RE-PICK TIMEZERO	a routine to re-pick the timezero point number in the header file.
DATUM TIMEZERO	find the first break based on a percentage of peak amplitude and then shift all the traces to this new first break.
EDIT TIMEZERO	allows the user edit the timezero point number in the header file.

TRACE COMMENTS:

TRACE COMMENTS	list and edit comments written to specific traces during data acquisition.

UTILITY:

Utility program to create and edit:

TOPOGRAPHY FILE	
USERGAIN FILE	
RUBBERBAND FILE	
*USER GPS FILE	
*GPS TOOLS	to View and Reformat a raw GPS file.

3.3.2 Spreadsheet Editing

Editing operations can always be selected from the operations under the Data Editing menu option (see Section 3.3: Edit/Process Mode - Editing Data on page 7). However, another, perhaps more intuitive, way of editing data files is to highlight the file names to be edited and then simply right-click in the column that relates to what you want to edit. This displays a menu with all the edit operations available for that column. Choose one editing operation, fill in any parameters, select Run and the edit is done.

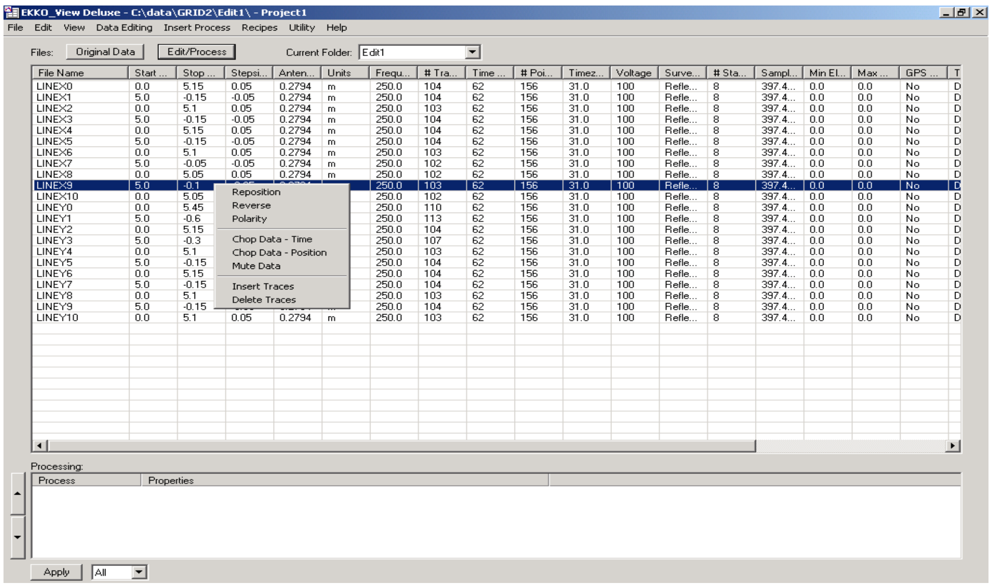


Figure 3-4: In Edit/Process mode right-clicking in any column in the spreadsheet brings up a menu of related editing operations.The editing options available for each column are listed below.

If you RIGHT click in:Available editing operations are:

File Name	Rubberband View: Section, Traces, Processing History, Trace Headers, Trace Comments, Average Time Amplitude Plot, Average Amplitude Spectrum Plot Convert to SEG-Y, EAVESDROPPER, ASCII 1, ASCII 2, CSV, Export Time Slice. If two or more data file names highlighted, Merge and Stack. Reset or Delete data file
Start Position	Reposition, Reverse, Polarity, Chop Data-Time, Chop Data-Pos, Mute Data, Insert Traces, Delete Traces
Stop Position	Reposition, Reverse, Polarity, Chop Data-Time, Chop Data-Pos,, Mute Data, Insert Traces, Delete Traces
Stepsize	Reposition, Reverse, New Stepsize
Antenna Separation	Edit to a new value
Units	metres or feet
Frequency	Edit to 12.5, 25, 50, 100, 110, 200, 225, 450, 900, 1200 or OTHER.
#Traces	Informational only. Cannot be edited.

Time Window	New Time Window
#Points/Trace	Resample, Decimate
Timezero	Re-pick Timezero Point, Datum Timezero, Edit
Voltage	Informational (not used in any calculations) but can be edited to 200, 400 or 1000 Volts
Survey Mode	Reflection, CMP or Transillumination survey modes (ZOP, MOP, CAL) For a CMP file, CMP Analysis
Stacks	Informational only. Cannot be edited.
Sampling Interval	Resample
Min Elevation	Add Topography, Add Topography-GPS Z ,Shift Topography
Max Elevation	Add Topography, Add Topography-GPS Z, Shift Topography
Title 1, Title 2	Edit text in Title1 and Title2
Date	Informational only. Cannot be edited.
Comments	YES or NO. If YES, option to view and edit trace comments.
Data Gaps	Fill Gaps

3.4 Edit/Process Mode - Processing Data

The original GPR data files in the folder cannot be edited or processed. When data files are to be edited or processed, a sub-folder is created and copies of the data files are written to the sub-folder i.e. \data\edit1. It is the copies of the data files in the sub-folders that are edited and or processed.

The first step is to select the data files to be copied to the sub-folder. This is done by highlighting one or more data file names in the spreadsheet list. To highlight a single file name, click on it. To highlight a series of file names, click on the first file name, hold down the Shift key and then click on the last file name. This will highlight all the file names between the first and last file names. To highlight selected file names, hold down the Control (Ctrl) key while clicking on the desired file names. **If no file names are highlighted, ALL the data files in the original data folder will be copied to the edit/process sub-folder.**

After highlighting the file names, click on the **Edit/Process** button. The user is prompted to input the name of a new sub-folder or select an existing sub-folder. Once OK is selected, all the highlighted data files are copied to the sub-folder and listed to the spreadsheet. These files can now be edited and/or processed.

Note that sub-folders do not have to be just from the original data folder. It is possible to make a sub-folder from an existing sub-folder. For example, if you are in Edit/Process mode in a sub-folder, you can create a new sub-folder by clicking on the Edit/Process button again. In this way it is possible to create whole chains of sub-folders like \data\edit1\edit1\process1.

Once the data files are listed in the sub-folder, the next step is to select the data files to be edited and/or processed. Again, highlight the data file names using the method described above.

The next step to processing data files is to create a list of processing operations. This is a list of one or more processing steps to apply to the data. The Processing window below the spreadsheet is where the processing steps can be listed out (see Figure 3-5). Processing steps can be added to the list using the Insert Process menu option (see Section 3.4.2: Processing Data Summary on page 13).

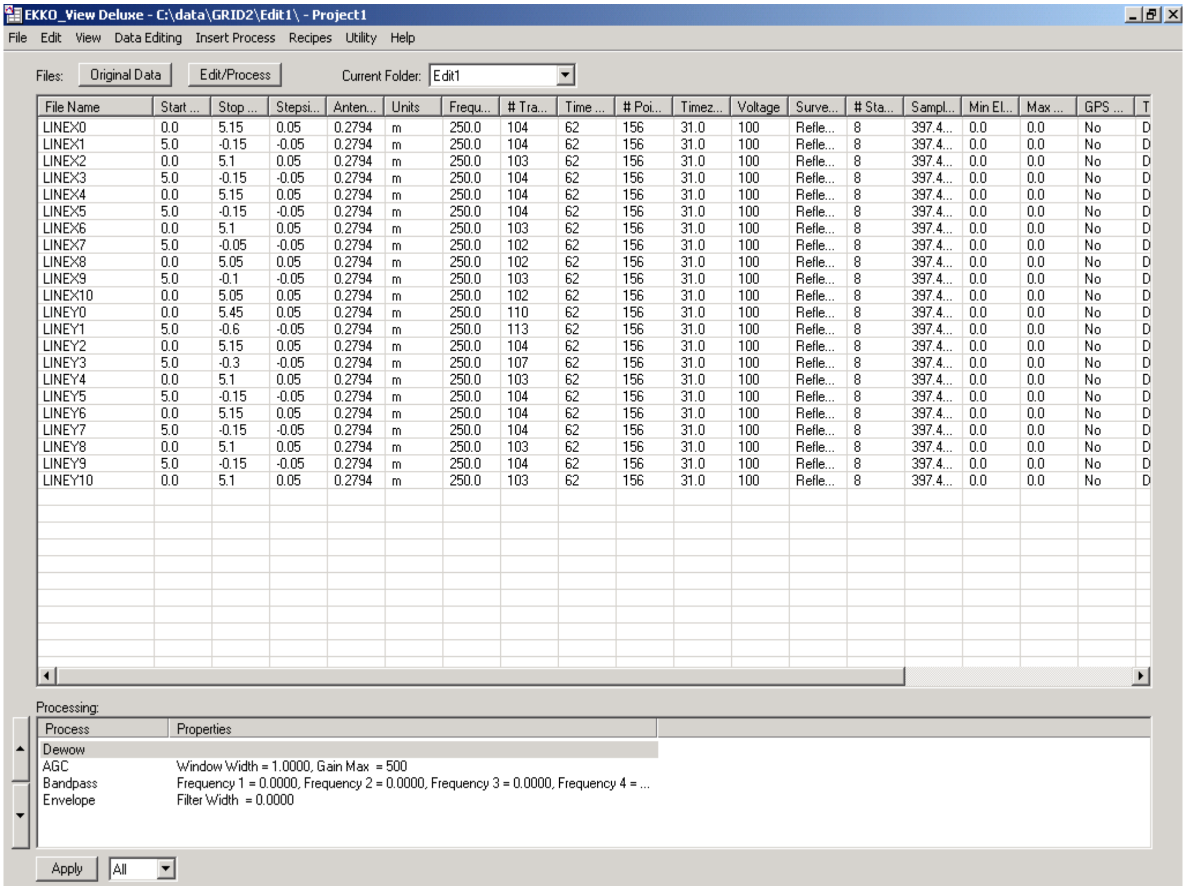


Figure 3-5: EKKO_View Deluxe window showing the Processing window at the bottom. A series of processing operations can be listed using the Insert Process menu item. When the processing list is complete, selecting Apply will apply the processing to all the data files currently highlighted in the spreadsheet.

To process the data files, select the Apply button at the bottom of the screen beside the Process window. These files are then processed with the processing operations currently listed.

A series of processing operations can be saved as a “Recipe” for future use (see Section 3.4.3: Recipe Processing on page 14).

3.4.1 Editing the List of Processing Operations

Editing the list of processing operations in the Processing window is very easy.

To delete an operation, highlight it and then press the Delete key or right click and then select Delete.

An operation can be highlighted and moved up or down the list by clicking the up and down arrows on the left side of the Processing window. This makes changing the order of the processing operations very easy.

Processing parameters can be changed by highlighting the operation, right clicking and then selecting Properties and editing the parameter settings.

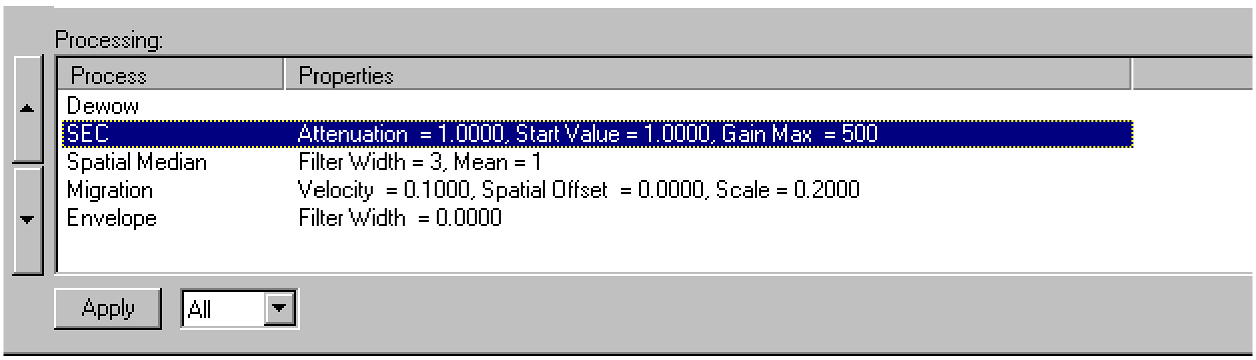


Figure 3-6: A close up view of the Processing window at the bottom of the EKKO_View Deluxe window. Processing operations in the list can be removed by highlighting them and pressing Delete. The order of processing operations can be changed by highlighting the operation and using the Up and Down arrows to move the operation within the list. The current parameters for any operation can be edited by highlighting the operation, right clicking, selecting Properties and editing the current settings.

3.4.2 Processing Data Summary

Data Processing includes about 30 different operations. These operations are available under the Insert Process menu under the headings listed below.

All the headings and processing operations are listed below with a brief description. Detailed descriptions of each operation are given in Section 8: Insert Process on page 57. Processes prefixed with a * indicate that these processes are only available in the advanced version, EKKO_View Deluxe, and not the basic version of the software, EKKO_View Enhanced.

GAINS:

AGC	apply Automatic Gain Control.
SEC	apply Spreading and Exponential Compensation.
CONSTANT	apply a constant gain.
AUTOGAIN	apply an automatic gain. No parameters required.
USERGAIN	apply a user-defined gain function.

TIME FILTERS:

DEWOW	removes low frequency “wow” from each trace.
DC_SHIFT	removes a DC level from each trace.
*BANDPASS	filter out frequencies outside a certain frequency band.
*LOWPASS	filter out frequencies above a certain frequency.
*HIGHPASS	filter out frequencies below a certain frequency.
VERTICAL	running average filter to remove high frequency noise.
*MEDIAN	alpha mean trim filter to remove sporadic high frequency noise spikes.

*DECON	apply a deconvolution operator to shorten radar wavelet to simplify data.

SPATIAL FILTERS:

HORZONTL	trace to trace averaging filter to remove dipping reflectors and enhance flat-lying reflectors.
*BINOMIAL	binomial spatial filter to remove dipping reflectors and enhance flat-lying reflectors.
*LOWPASS	spatial low pass filter to remove dipping reflectors and enhance flat-lying reflectors.
*HIGHPASS	spatial high pass filter to remove flat-lying reflectors and enhance dipping reflectors.
*MEDIAN	alpha mean trim filter to remove sporadic noisy, ringy or generally “bad” traces.
TRACE DIFFERENCE	subtract adjacent traces to remove flat-lying reflectors.
*BACKGROUND SUBTRACTION	a total or running average background subtraction filter to remove local flat-lying reflectors.

2D FILTERS:

*MIGRATION	collapses hyperbolic reflectors back to points and focuses scattered signals.
*DIP_FILT	binomial spatial weighting differencing filter to enhance reflectors of a certain dip angle.

ATTRIBUTES:

*ENVELOPE	calculates an instantaneous amplitude of each trace.
*INSTPHAS	calculates an instantaneous phase of each trace.
*INSTFREQ	calculates an instantaneous frequency of each trace.

OPERATIONS:

*RECTIFY	absolute value data to remove negative component of trace.
*N_POWER	raise each point to nth power to emphasize strong signals over weak signals.
*THRESHOLD	zeroes amplitude below a certain percentage threshold. .
*AMP_SPEC	calculate amplitude (frequency) spectrum of each trace in the data file.
*ADDSECT	add 2 sections together, point by point.
*SUBSECT	subtract a section from another, point by point.
*AVETRACE	calculate the average trace from a data section.

3.4.3 Recipe Processing

When EKKO_View Deluxe starts, the Processing window on the bottom of the screen will be blank. The user can fill in specific processing routines one at a time from the lists of processes under **Insert Process** (see Section 3.4: Edit/Process Mode - Processing Data on page 11).

It is possible to save a list of processing operations as a “Recipe” that can be loaded later and used again on another project. This is useful for preserving popular processing streams. To save the processing operations currently listed in the Processing window to a Recipe, select **Recipes – Save** from the main menu. The user is prompted to enter a name and folder for the Recipe.

Once Recipes have been saved, they can loaded at any time by selecting **Recipes – Load** from the main menu and selecting the name of the recipe. The list of processing operations in this recipe will then be listed in the Processing window. To process data files with the processing stream, select **Apply**.

Any recipe can be edited and saved as another recipe.

4 File Menu

4.1 New Project

This option allows the user to input a name for a new EKKO_View Enhanced (or EKKO_View Deluxe) project (.prj) file. The desired folder can be selected and the project name typed in. The default project name can also be used.

All GPR data files in a project must be in the same folder. Use Windows Explorer to copy or move all the data files to the same folder.

Note that each survey line of Sensors & Software GPR data consists of two files, an ASCII header file with a .HD extension and a binary data file with a .DT1 extension. Both files must be present to have complete data.

4.2 Open Project

This option allows the user to input the name of an existing EKKO_View Enhanced (or EKKO_View Deluxe) project (.prj) file. The desired folder can be selected and the name chosen from the list.

4.3 Close Project

This option allows the user to close the current project.

4.4 Save Project

This option allows the user to save the current EKKO_View Enhanced (or EKKO_View Deluxe) project (.prj) file.

4.5 Save As

This option allows the user to save the current EKKO_View Enhanced (or EKKO_View Deluxe) project (.prj) file to a different name. The desired folder can be selected and the new project name typed in.

4.6 Print Spreadsheet

This option allows the user to print the spreadsheet to a printer.

When the spreadsheet is printed it usually spans several pages. The number of columns printed can be reduced by editing the Columns displayed (see Section 5.1: Columns on page 19).

4.7 Recent Projects

This option lists the most recent EKKO_View Enhanced (or EKKO_View Deluxe) projects, allowing the user to quickly load previous files to continue work.

5 Edit Menu

5.1 Columns

Data files are listed to the spreadsheet (See Figure 3-3 on page 6). The spreadsheet lists up to 22 columns of parameters associated with the file. Selecting **Edit – Columns** allows the user to edit which columns appear on the display. This action will bring up a list of column titles that can be checked or unchecked depending on which columns are to appear on the list (see Figure 5-1).

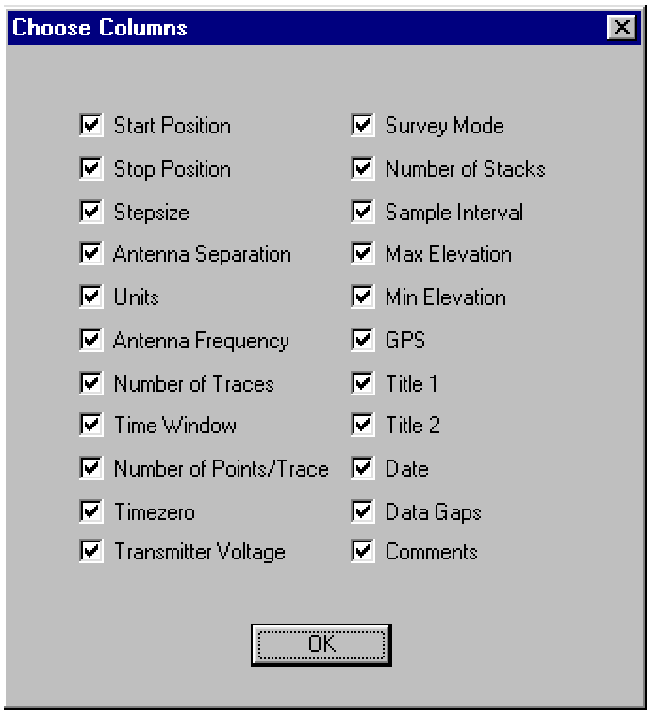


Figure 5-1: Editing the Columns list allows the user to change which columns of parameters are displayed on the spreadsheet.

5.2 Reset Selected Files

During editing and/or processing of a data file, the user may make an error or simply want to try some other processing stream. Highlighting the data file name and then selecting the **Reset** option allows the user to replace the current version of the data file with a new copy from the main data folder. The user can then continue editing and/or processing with a new copy of the data file.

5.3 Copy File

This option is only available from Edit/Process mode. This routine allows the user to make a copy of one or more data files into the same folder. Highlight one or more data file names and then select Copy File. The user is prompted to provide a name(s) for the copied data file(s).

This routine is handy when you want to apply different editing and/or processing to the same data file but keep all the copies in the same folder.

5.4 Rename

This option is only available from Original Data mode. This routine allows the user to rename a data file.

5.5 Delete

A data file or files can be removed from the current list by highlighting them and then selecting **Delete**.

Note that the data files are not permanently deleted, they are only removed from the current list. The complete list of data files present in the main folder can be seen again by pressing the **Select** button.

5.6 Reset All Files

This option is similar to Reset Selected Files described under Reset Selected Files above except that ALL the data files currently in the list are replaced with original copies from the main data folder. The user can then continue editing and/or processing with new copies of the data files.

5.7 Delete Folder

The Delete Folder option is used to delete the current sub-folder of data. It is available when data are being edited and/or processed.

5.8 Select All

Select All offers a quick way to highlight all the data file names in the current list. This is often used to highlight all the files before running some edit operation.

5.9 Invert Selection

This operation will highlight all the data file names that are currently not highlighted. This means that if no data file names are highlighted, selecting Invert Selection will highlight all the data file names. If two data file names are highlighted, selecting Invert Selection will highlight all the other files except the original two.

6 View

6.1 Section

The user can generate a section plot of any data file or files in the current list at any time. This can be done from Original Data mode or Edit/Process mode. To plot a section, double-click on the data file name in the first column or highlight the data file name or names and then select **View – Section**. Other ways of plotting a section are to highlight the file name(s) and right-click to bring up the **View** menu and select **Section** or to highlight the file name(s) and press **Ctrl+V**.

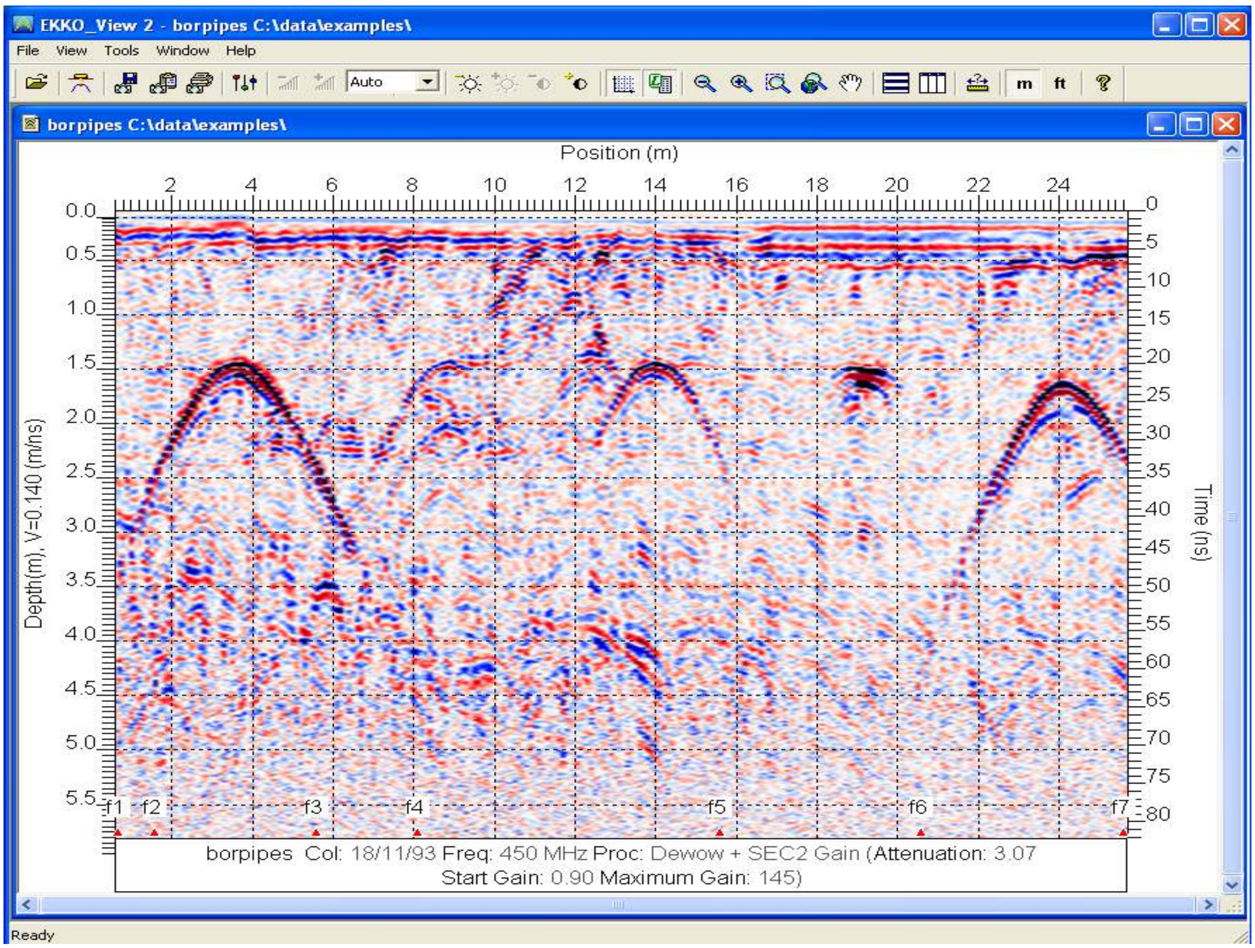


Figure 6-1: Display of a data section plotted using the EKKO_View program. EKKO_View has numerous features to edit and plot the section.

Data sections are plotted using the EKKO_View program. Details about how to use the EKKO_View program are located under the Help menu when the EKKO_View program is running.

6.1.1 How Depth is Determined

Ground penetrating radar systems record the time for a radio wave to travel to a target and back. The depth to that target is calculated based on the velocity at which the wave travels to the target and back. It is calculated as:

D = V x T/2

where D is Depth (metres)

V is Velocity (metres/nanosecond)
T is Two-way travel time (nanoseconds)

Therefore, in order to calculate the depth to a target, it is critical that the velocity of the material be known.

EKKO_View Enhanced and EKKO_View Deluxe require that an average velocity be input for calculations related to depth or elevation. Specifically, a velocity is required when viewing depth sections (see Section 6.1: Section on page 21) or when applying a topographic shift (see Section 7.1.7: Shift Topography on page 37).

Radar wave velocity can be measured using the CMP Analysis to calculate velocity from CMP surveys (see Section 6.8: CMP Analysis on page 27).

If depth or elevation data is desired but radar velocity cannot be measured, it must be estimated. The table below gives typical radar velocities for many common materials. If the material is unknown, a good average velocity to use for geological materials is 0.1 m/ns.

Table 1: Typical Velocities and Attenuations of Common Materials

Material	Velocity (m/ns)	Attenuation (dB/m)
Air	0.30	0
Ice	0.16-0.17	0.01
Dry Soil	0.15	
Dry Sand	0.15	0.01
Granite	0.13	0.01-1.0
Dry Salt	0.13	0.01-1.0
Dry Rock	0.12	
Limestone	0.12	0.4-1.0
Wet Rock	0.10	
Concrete	0.08-0.12	
Pavement	0.10	
Shales	0.09	1-100
Silts	0.07	1-100
Wet Soil	0.06	
Wet Sand	0.06	0.03-0.3
Clays	0.06	1-300
Fresh Water	0.033	0.1
Sea Water	0.033	1000

6.2 Traces

The user can display individual traces of any data file in the current list. This can be done from Original Data mode or Edit/Process mode. To plot traces, highlight the data file name and then select **View – Traces**.

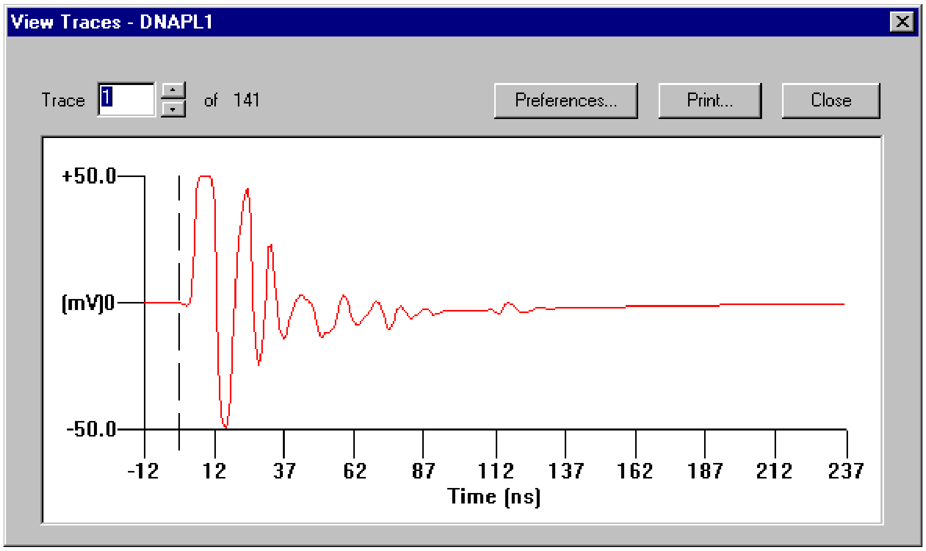


Figure: 6-2 Display of an individual data trace.

The trace display shows each trace with the time scale (in nanoseconds) in the horizontal direction and signal amplitude scale (in millivolts) in the vertical direction. The trace number and the position of the trace in the file is displayed above. Selecting the **Preferences** button allows the time axis label interval and amplitude scale can be modified. The vertical dashed line indicates the current picked position of timezero.

The user can use the up and down arrows to move to any particular trace up to the maximum number of traces in the data file.

Selecting the **Print** button will print the current trace.

Viewing Traces is useful for looking at subtle features in the data file. It can also be used to see the effect that different types of editing and processing have on the individual traces.

Viewing traces can be used to see if the timezero point needs to be edited. Normally the timezero point should occur at the first large deflection in the signal. If not, time scales and depth scales on section plots will be inaccurate. The timezero point can be edited (see Section 7.6: Timezero on page 53).

6.3 Processing History

Every time an editing or processing operation is applied to a data file a record of that operation is listed to the data header (.HD) file. Selecting **Processing History** displays the list of editing and processing operations that have been done to the data file since it was collected.

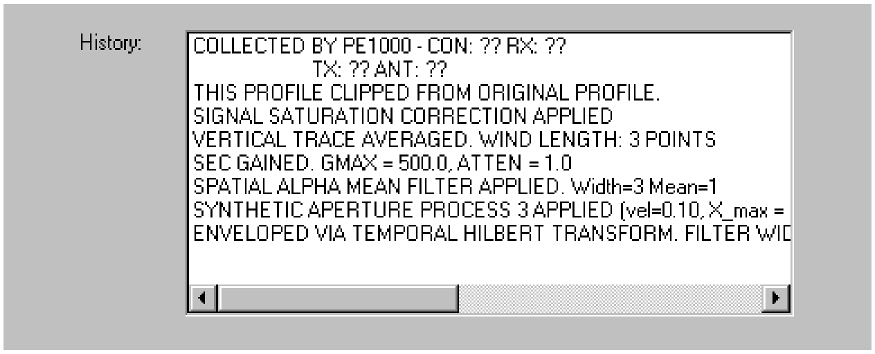


Figure: 6-3 Processing History of a data file.

6.4 Trace Header

Every time a data trace is collected, as well as saving the trace amplitude information, other parameters associated with that trace are saved to the “trace header” in the data file. The trace header consists of 25 floating point numbers. Parameters such as the trace number, trace position, elevation data (if added later, see Section 7.1.5: Add Topography using Topo File on page 35), Transmitter X, Y and Z positions, Receiver X, Y and Z positions, GPS X, Y and Z positions (if added later, see Section 7.1.8: Add GPS Data on page 37) and the time of day in seconds past midnight when the trace data were collected, are saved to the trace header.

Selecting **Trace Header** allows the user to see the values of these parameters from every trace header in the data file. The user has the option of selecting which parameters to display using a list of checkboxes.

Selecting the View TXT button, saves the data as a text file with the same name as the data file but with a .DAT extension. The Trace Header parameters in the .DAT file are listed using Microsoft Notepad or Wordpad. These programs allow the trace header parameter list to be viewed, printed or saved.

Selecting the View CSV button, saves the data as a CSV (comma separated values) file with the same name as the data file but with a _HDR suffix and a .CSV extension, i.e LINE4_HDR.CSV. The CSV file format allows the trace header information to be exported to programs like Microsoft Excel.

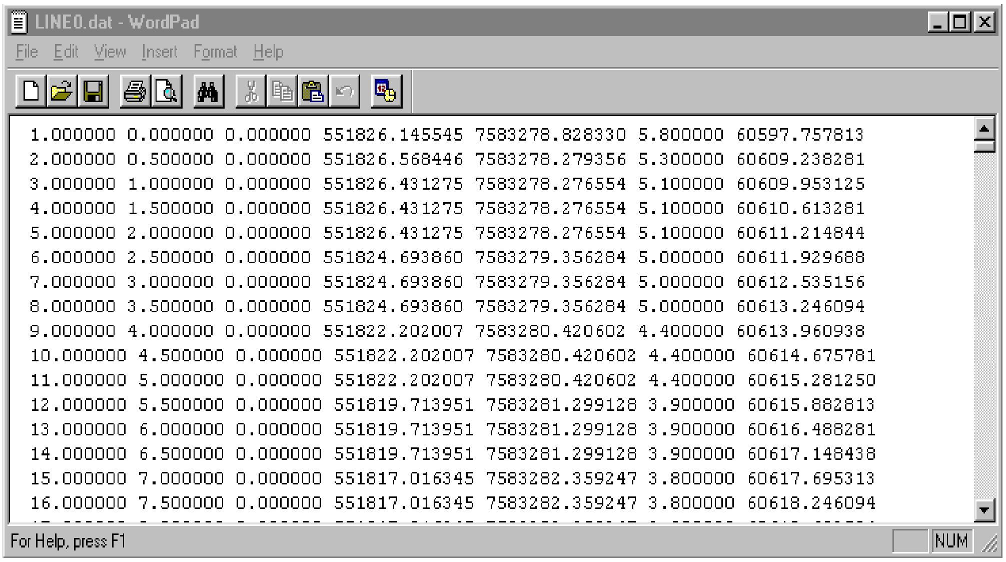


Figure 6-4: Trace Header is used to display the trace header parameters including trace number, position, GPS position and time of day when the trace was collected.

6.5 Trace Comments

During data acquisition, it is possible to attach a short text comment to an individual trace. For some Sensors & Software GPR systems, comments can be added by pausing the system during data acquisition and typing in a trace comment. For other systems a marker can be added to the trace comment field during data acquisition by pressing a trigger button or a special key on the computer or data logger.

Selecting **Trace Comments** displays all the comments in the data file to the screen along with the trace number in the file and the position.

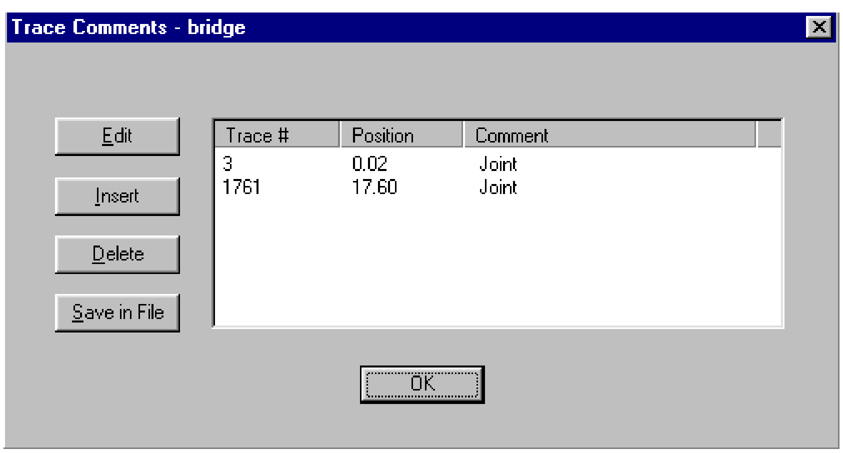


Figure 6-5: The Trace Comment window displays all the comments added to the data file during data acquisition. Comments can be added, edited, deleted and saved to a file.

Note that when Trace Comments is selected from **Original Data** mode, trace comments can be displayed but not edited. In **Edit/Process** mode trace comments can be viewed, added, edited, deleted and saved to a file.

When editing trace comments, existing comments can be modified by selecting **Edit** and deleted by selecting **Delete**. As well, new comments can be added to the list by selecting **Insert**. The comments can be saved to a text (.TXT) or a comma separated values (.CSV) file by selecting **Save to File**.

6.6 Average Time-Amplitude Plot

This process is only available in the EKKO_View Deluxe version of the program, not the EKKO_View Enhanced version.

The Average Time – Amplitude plot is used to look at the average signal amplitudes (in micro-volts) for an entire data file. Selecting the **Preferences** button allows the time axis label interval scale to be modified. Selecting the **Save** button will save the Time and Amplitude values to a .DAT text file or a .CSV (comma separated values) file. The file will have the same name as the data file but with _ATA added as a suffix.

This is a useful display for seeing how rapidly the signal amplitude decays to the background level. This gives the user an idea of the maximum penetration for the data file.

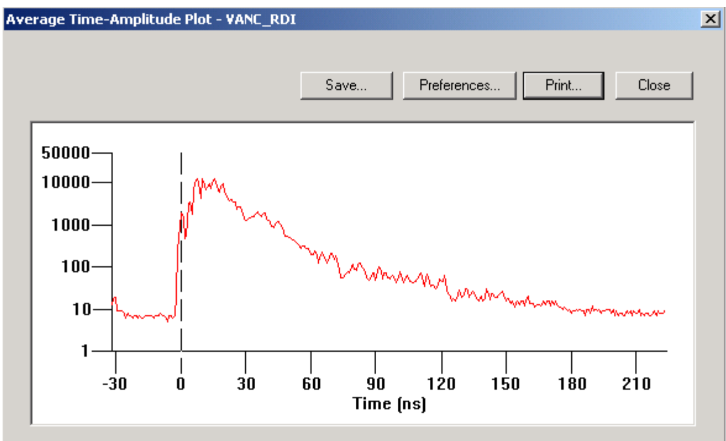


Figure 6-6: An Average Time – Amplitude plot shows the average signal amplitude for a data file. The left side of the plot shows the signal level before the timezero point. This is the background noise level. At zero time, a strong amplitude signal occurs when the GPR system fires its transmitter. At later times to the right, the GPR signal slowly decays back to the background noise level. How rapidly the signal level drops is dependent on the material being scanned. The time at which the signal level drops back to the background noise level is the maximum penetration time. This can be converted to the average maximum depth of penetration if a radar velocity for the material is known (see Section 6.1.1: How Depth is Determined on page 22).

6.7 Average Amplitude Spectrum Plot

This process is only available in the EKKO_View Deluxe version of the program, not the EKKO_View Enhanced version.

The Average Amplitude Spectrum plot is used to look at the average signal frequencies for an entire data file. Selecting the **Preferences** button allows the frequency axis label interval scale to be modified. Selecting the **Save** button will save the Frequency and Amplitude values to a .DAT text file or a .CSV (comma separated values) file. The file will have the same name as the data file but with _AAS added as a suffix.

This is a useful display for checking the dominant frequency in the data and also for determining whether there are any frequencies that could be considered noise and need to be filtered out.

Note that the centre frequency of Sensors & Software antennas are measured in air. For example, 100 MHz antennas produce a centre frequency of about 100 MHz when data are collected in air. The centre frequency of data from antennas placed on the ground will be lower in frequency than the stated frequency of the antenna. For example, the centre frequency of data collected with 100 MHz antennas is often 60 to 70 MHz.

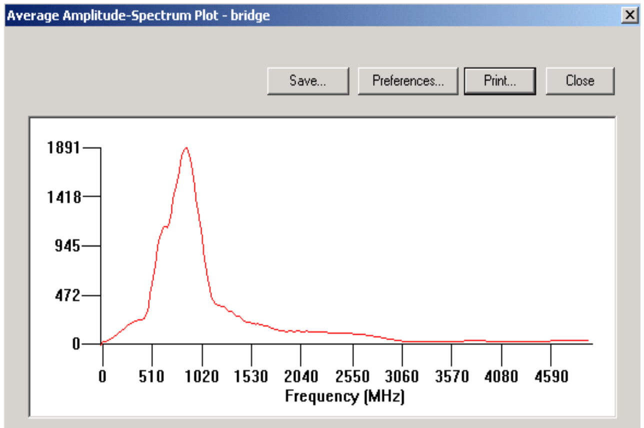


Figure 6-7: An Average Amplitude Spectrum plot shows the average signal frequencies for a data file. This is a useful display for checking the dominant frequency in the data and also for determining whether there are any frequencies that could be considered noise and need to be filtered out.

6.8 CMP Analysis

This process is only available in the EKKO_View Deluxe version of the program, not the EKKO_View Enhanced version.

An accurate radar velocity is critical for accurately determining the depth of a target. A CMP (Common Mid-Point) survey provides a way of measuring radar velocity in the ground or in a structure. The CMP Analysis routine processes a CMP file by stacking the data traces at many different velocities. When traces are stacked at an incorrect velocity, they will tend to destructively interfere and produce low amplitudes. When traces are stacked at the correct velocity, they will constructively add together and produce high amplitudes. A plot of the stacked data allows the user to match the highest amplitudes with a velocity value (See Figure 6-8 on page 27). This value can then be used when producing depth sections.

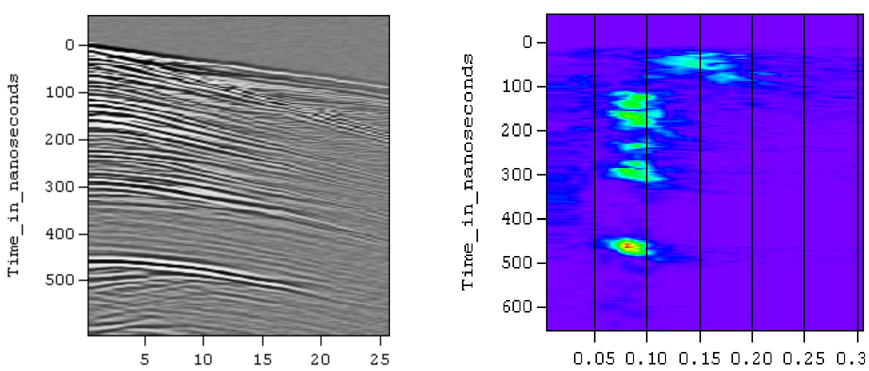


Figure 6-8: CMP Analysis. Figure (a) shows a display of CMP data. Note the curved shape of the strong reflectors as result of the antennas being gradually separated during data acquisition. Figure (b) is a display after the CMP data in Figure (a) have been processed using the CMP Analysis routine. The high amplitude “blobs” correspond to a velocity that is the “best fit” average velocity for that reflector. For example, this plot indicates that average velocity to the reflector at 450 ns in Figure (a) is 0.08 m/ns. This velocity value can then be used when producing depth sections.

7 Data Editing

7.1 File

7.1.1 Merge

Sometimes, during data acquisition, a long, continuous GPR survey line is broken up into two or more pieces and saved as separate files. The Merge program is used to combine the data from two or more data files into a single, separate file. The files are merged together to form one continuous file.

Some of the features of Merge are:

1. The program simply copies the traces as they occur in each file and writes them to the merged file. The files are merged in the order they appear on the list.
2. The start position and stepsize of the first file are assumed for all the files to be merged. The position values and stepsize of all files after the first file are ignored. Therefore, files should have the same stepsize and not overlap or have gaps.
3. The time window length and the sampling interval must be the same for all files. If files differ in time window length, try using the CHOPDATA-TIME program (see Section 7.3.5: Chop Data - Time on page 50) to chop all the data to the same window length. If files differ in time sampling interval, try using the Resample (see Section 7.5.1: Resample on page 53) program to resample all the files to the same temporal sampling rate.
4. The program also will not run if some of the files are DEWOWed and others are not.
5. Merge will run but send warnings if the two surveys differ in frequency, survey mode, antenna separation, pulser voltage, position units and number of trace stacks.
6. Traces are not shifted for differences in timezero values between files. It is best to use Datum Timezero after the merging.

7.1.2 Stack

Stack is used to vertically merge (or stack up) the data from two or more files into a single, separate file. Stacking files can be useful for quickly comparing data lines. For example, it can be useful for quickly comparing two or more parallel data lines. It can also be used to quickly compare the same data file before and after processing.

Some of the features of Stack are:

1. The files to be merged must have the same sampling interval and stepsize.

2.) The files are merged top to bottom in the order they appear on the list.

3.) The files do not have to have the same start or end positions. Stack looks for the smallest start position and largest end position in all the files to be merged and uses those for the final merged file. If a file does not have data at a certain position, zeroed data are added to the final merged file.

4.) The timewindow lengths between the files do not have to be the same.

5.) STACKSEC will run but send warnings if the two surveys differ in frequency, survey mode, antenna separation, pulser voltage, position units and number of stacks.

6.) After sections are merged in this way, timezero points for all files but the first file are ignored. Also, depth scales on vertically merged sections become meaningless for all files but the first.

7.1.3 RubberBand

When a Sensors & Software radar system is run in Continuous or Free-running mode, it is possible to add "fiducial" (fid) markers to the data by pressing a button. The fid markers can be added as the system passes some sort of landmark or an object of known position (e.g. a survey stake). They are saved to the trace comment field of the trace and appear as an "F" followed by an incrementing value, i.e. F1, F2, F3, etc.

RUBBERBAND is used to stretch or squeeze (rubber band) a data file to a constant stepsize based on the positions of the fid markers added during data acquisition. Using the positions of the fid markers, traces are interpolated and/or skipped to produce a data file with the input constant stepsize. This process eliminates the effects of speed variations during data acquisition.

The easiest way to use the Rubberband program is if the fiducial markers in the data are at a constant separation, e.g. every 10 metres. If data are collected like this, the constant value can be simply be input in the Fiducial Separation field (see below). If the positions of the fiducial markers are at a variable separation, e.g. at positions 0, 10, 22, 27, and 40, the fiducial number and corresponding position must be input in an ASCII file (see below).

Rubberband requires the user to input a stepsize value for the final rubberbanded section. This value should be on the same order of magnitude as the approximate stepsize when the radar data were collected. For example, if a file has 100 traces over a line of 100 metres, the approximate stepsize is 1 metre. It does not make a lot of sense to set the final stepsize to 0.1 metres because the number of interpolated data traces will far exceed the number of real data traces. As well, a final stepsize of 0.1 metres in this case, suggests a spatial sampling resolution that was not actually achieved during data acquisition.

Note that the program only looks for F1, F2, F3 etc. in the comment field of the trace. Other comments that may be in the data file are not used nor will they interfere with this process.

The positions of the Fid markers can be input in an ASCII file or, if there is a constant separation between Fid markers, this constant value can be input in the Fiducial Separation field. The default method is a constant Fid Separation. To switch to the ASCII file method, click the Toggle checkbox.

The details of these 2 methods are outlined below.

1. Constant Fid Separation Method

The parameters needed for this method are:

Stepsize The final stepsize between traces after processing with Rubberband
See note above about selecting an appropriate value for Stepsize.

Fid Separation The separation distance between fid markers in the data file.
Assumes that the separation between fid markers in the data file is constant.

If fid separation is NOT constant, the ASCII Fid Position File method must be used.

Start Position The start position of the data file. The trace positions increment by the Stepsize starting at the Start Position value.

The default value is zero.

2. ASCII Fid Position File Method

With this method, the user creates an ASCII file with the same name as the input file but with a .RUB extension. This file lists fid number and position at that fid. For example:

F1 0
F2 15
F3 20
F4 30
F5 60

This ASCII file can be created by any word processor or by selecting RubberBand File under the Utility menu item (see Section 10.3: Rubberband File on page 101).

The parameters needed for this method are:

Stepsize The final stepsize between traces after processing with RubberBand. See note above about selecting an appropriate value for Stepsize.

7.1.4 Convert

These routines are used to convert Sensors & Software GPR data files to other formats. For a detailed description of the Sensors & Software DT1 file format see Appendix Appendix B: Data File Formats.

7.1.4.1 SEG-Y

This routine converts a file from Sensors & Software DT1 data file format to SEG-Y format. This conversion allows the user to export radar data to seismic processing packages that require the data in SEG-Y format. The new file has the same name as the Sensors & Software file but with a .SGY extension. For a detailed description of the Sensors & Software variables loaded into SEG-Y file format see Appendix B, section B.2 SEG-Y File Format on page B-2.

Note that it may be important to apply the DEWOW correction to the radar data before converting to SEG-Y (see Section 8.2.1: Dewow on page 68). Otherwise, it important to remember that the radar data will have a low frequency component that will normally need to be removed in the seismic software package.

7.1.4.2 EAVESDROPPER

This routine converts a file from Sensors & Software DT1 data file format to EAVESDROPPER format. This conversion allows the user to export radar data to seismic processing packages that require the data in EAVESDROPPER format. The new file has the same name as the Sensors & Software file but with a .EAV extension. For a detailed description of the Sensors & Software variables loaded into Eavesdropper file format see Appendix B, section B.6 Eavesdropper Data File Format on page B-10.

7.1.4.3 ASCII 1

The data from a Sensors & Software GPR survey line consists of two files: an ASCII header (.HD) file and a binary data (.DT1) file. This routine converts the Sensors & Software data files to a single ASCII file with the same name as the original file(s) but with a .AS1 extension. The new ASCII file lists the header file information followed by the trace amplitude data arranged in rows. The trace data includes trace header information (such as trace number in the file and trace position) and a listing of the amplitude value of each data point. For a detailed description of the ASCII 1 file format see Appendix B, section B.4 ASCII 2 Data File Format on page B-7.

The user will need to write software to read this new ASCII file.

7.1.4.4 ASCII 2

The data from a Sensors & Software GPR survey line consists of two files: an ASCII header (.HD) file and a binary data (.DT1) file. This routine converts the Sensors & Software data files to a single ASCII file with the same name as the original file(s) but with a .AS2 extension. The new ASCII file lists the data in table format, that is, point amplitudes from each trace in separate columns with position values at the top of each column and time values at the beginning of each row. For a detailed description of the ASCII 2 file format see Appendix B, section B.4 ASCII 2 Data File Format on page B-7.

This format can be read by most 2D visualization programs and spreadsheet software.

7.1.4.5 CSV

The data from a Sensors & Software GPR survey line consists of two files: an ASCII header (.HD) file and a binary data (.DT1) file. This routine converts the Sensors & Software data files to a single file with the same name as the original file(s) but with a .CSV extension. The new file lists the data in table format, that is, point amplitudes from each trace in separate columns with position values at the top of each column and time values at the beginning of each row. For a detailed description of the CSV file format see Appendix B, section B.5 CSV Data File Format on page B-9.

The comma separated value (CSV) format can be read by spreadsheet software like Microsoft Excel.

7.1.4.6 Export Time Slice

The Export Time Slice option is used to export the average trace amplitudes for one or more time or depth intervals from all the traces in the file to a comma separated value (.CSV) file. The user can select to output time or depth slices.

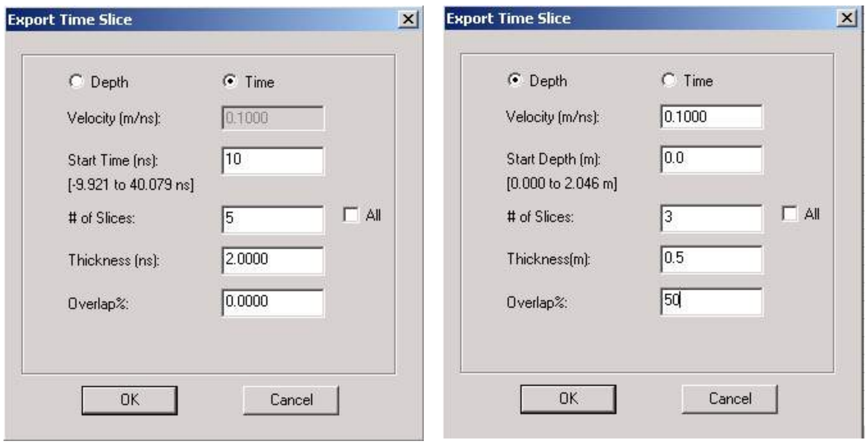


Figure: 7-1 Export Time Slice dialog box. The user can specify a Time Slice (left) or a Depth Slice (right).

Time Slices: For time slices, the user must indicate the **Start Time** (in ns) for the first slice, slice **Thickness** (in ns), **Overlap percentage** between slices and the total **Number of Slices**. If the **All** Slices checkbox is checked then every time slice from the Start Time to the end of the file is listed in the CSV file (see Figure 7-2). The last slice will be thinner than the others if the slice thickness does not fit evenly at the maximum time. For time slices, the **Velocity** value is not accessible.

For example, the user may want 5 time slices to start at 10 ns with each slice 2 ns thick and no overlap (0%). This would generate a CSV file with the average amplitude for each trace listed for the following time intervals: 10 to 12 ns, 12 to 14 ns, 14 to 16 ns, 16 to 18 ns and 18 to 20 ns (see Figure 7-2).

Depth Slices: Depth slices are calculated based on the **Velocity** (see Section 6.1.1: How Depth is Determined on page 22). The user must indicate the **Start Depth** (in meters or feet) for the first slice, slice **Thickness** (in meters or feet), **Overlap percentage** between slices and the total **Number of Slices**. If the **All** Slices checkbox is checked then every time slice from the Start Depth to the end of the file is listed in the CSV file. The last slice will be thinner than the others if the slice thickness does not fit evenly at the maximum depth.

For example, the user may want 3 time slices to start at 0 meters with each slice 0.5 m thick and an overlap of 50%. This would generate a CSV file with the average amplitude for each trace listed for the following depth intervals: 0.0 to 0.5m, 0.25 to 0.75m and 0.5 to 1.0m (see Figure 7-3).

The average amplitude data is saved with the EKKO_View Deluxe project name followed by _QMAP, for example, Project1_QMAP.CSV. The new file lists the line name, trace number, position and the average amplitude for every trace and every slice.

The comma separated value (CSV) format can be read by spreadsheet software like Microsoft Excel.

QuickMap Time Slice						
Velocity=0.100000						
Line Name	Trace	Trace Posi	Comment	10.000 to 12.000 ns	12.000 to 14.000 ns	14.000 to 16.000 ns
LINEX0.hd	1	0	*	33.667	-100.667	81.333
LINEX0.hd	2	0.05	*	25.5	-95.5	53.167
LINEX0.hd	3	0.1	*	-10.833	-142.167	17.333
LINEX0.hd	4	0.15	*	-19.167	-177	-0.667
LINEX0.hd	5	0.2	*	52.667	-174.667	46.167
LINEX0.hd	6	0.25	*	106.667	-187.333	70.5
LINEX0.hd	7	0.3	*	150.667	-213.833	70
LINEX0.hd	8	0.35	*	187.5	-203.167	101.5
LINEX0.hd	9	0.4	*	180.167	-231.5	112.5
LINEX0.hd	10	0.45	*	234.333	-249.5	122.5
LINEX0.hd	11	0.5	*	249.667	-289.167	102.167
LINEX0.hd	12	0.55	*	260.167	-270	133.833
LINEX0.hd	13	0.6	*	215.5	-259.667	147.5
LINEX0.hd	14	0.65	*	214.5	-240.667	148.833
LINEX0.hd	15	0.7	*	169.167	-229	142.5
LINEX0.hd	16	0.75	*	143.167	-231.5	129.833
LINEX0.hd	17	0.8	*	165.667	-239.167	158.833
LINEX0.hd	18	0.85	*	247.5	-238.667	200.333
LINEX0.hd	19	0.9	*	286.333	-244	218.667
LINEX0.hd	20	0.95	*	251.667	-279.833	171.667
LINEX0.hd	21	1	*	215.833	-285.167	141.5
LINEX0.hd	22	1.05	*	206.167	-248.833	121.5
LINEX0.hd	23	1.1	*	241.833	-218.833	110.5
LINEX0.hd	24	1.15	*	285.5	-175.667	134
LINEX0.hd	25	1.2	*	291.167	-144.833	127
LINEX0.hd	26	1.25	*	274.667	-133.833	134.167
LINEX0.hd	27	1.3	*	278.333	-160.167	131.833

Figure: 7-2 CSV file of time slices from a GPR data file.

If GPS data have been added to the GPR data file (see Section 7.1.8: Add GPS Data on page 37), these data will be listed in the CSV file (see Figure 7-3).

The slice information from multiple data files can be written to one CSV file. Simply highlight all the data files in the EKKO_View Deluxe project to include and then select Export Time Slice.

QuickMap	Depth Slice								
Velocity=0.100000									
Line Name	Trace	Trace Posi	Longitude	Latitude	Elevation(m)	Comment	0.000 to 0.500 m	0.250 to 0.750 m	0.500 to 1.000 m
LINEX0.hd	1	0	-115.141343	36.10919227	615.88	*	-746	-283.84	42.538
LINEX0.hd	2	0.05	-115.141349	36.10919432	615.72	*	-781.3	-245.92	42.577
LINEX0.hd	3	0.1	-115.141349	36.10919394	615.7483333	*	-781.3	-225.56	9.885
LINEX0.hd	4	0.15	-115.14135	36.10919357	615.7766667	*	-772.55	-192.64	-0.769
LINEX0.hd	5	0.2	-115.14135	36.10919319	615.805	*	-766.55	-167.96	29.346
LINEX0.hd	6	0.25	-115.14135	36.10919282	615.8333333	*	-740.85	-150.64	40.308
LINEX0.hd	7	0.3	-115.141351	36.10919244	615.8616667	*	-757.6	-169.4	42.115
LINEX0.hd	8	0.35	-115.141351	36.10919207	615.89	*	-790.15	-184.28	67.308
LINEX0.hd	9	0.4	-115.141351	36.10919177	615.9036364	*	-822.95	-193.92	54.962
LINEX0.hd	10	0.45	-115.141351	36.10919148	615.9172727	*	-799.35	-230.6	44.769
LINEX0.hd	11	0.5	-115.141351	36.10919118	615.9309091	*	-821.3	-260	22.423
LINEX0.hd	12	0.55	-115.141351	36.10919089	615.9445455	*	-854.1	-226.88	47.5
LINEX0.hd	13	0.6	-115.141351	36.1091906	615.9581818	*	-861.4	-246.44	64
LINEX0.hd	14	0.65	-115.141352	36.1091903	615.9718182	*	-835.05	-239.16	66.462
LINEX0.hd	15	0.7	-115.141352	36.10919001	615.9854546	*	-868.5	-224.6	66.192
LINEX0.hd	16	0.75	-115.141352	36.10918972	615.9990909	*	-818.1	-173.68	74.577
LINEX0.hd	17	0.8	-115.141352	36.10918942	616.0127273	*	-885.95	-194.6	100.885
LINEX0.hd	18	0.85	-115.141352	36.10918913	616.0263636	*	-890.3	-177.16	130.154
LINEX0.hd	19	0.9	-115.141352	36.10918883	616.04	*	-909.5	-199.88	138.923
LINEX0.hd	20	0.95	-115.141352	36.10918847	616.0492857	*	-888.95	-254	104.885
LINEX0.hd	21	1	-115.141352	36.1091881	616.0585714	*	-892.95	-300.96	98.115
LINEX0.hd	22	1.05	-115.141352	36.10918773	616.0678571	*	-922.75	-307.76	100.231

Figure: 7-3 CSV file of depth slices from a GPR data file with GPS positions.

A common way of using the Export Time Slice routine is to add GPS to all the GPR file collected over an area or a grid and then export the time slice data. The exported file represents the average amplitudes of all the traces in the area at the time or depth range(s) and can be plotted as a Time Slice image using Sensors & Software's QuickMap software (see Figure 7-4) or other third-party software like Surfer.

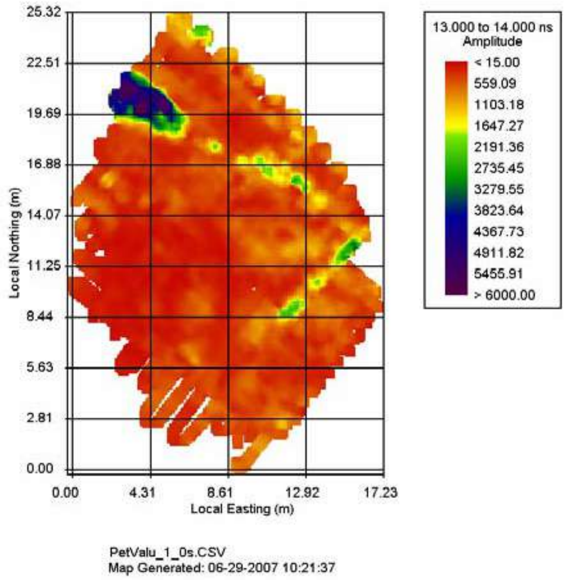


Figure: 7-4 Time slice image displayed in QuickMap.

7.1.5 Add Topography using Topo File

Add Topography using Topo file is used to add topographic (elevation) data to a Sensors & Software radar data file. It reads a text file containing topographic data and adds these data to the elevation field in each of the trace headers of the data file (see Section 6.4: Trace Header on page 24). Once this information is available, radar sections can be shifted (see Section 7.1.7: Shift Topography on page 37) and then plotted with the topographic correction applied (See Figure 7-5 on page 37). This type of display can be invaluable for understanding the proper spatial positioning of radar reflections.

The requirements for the topographic text file are:

1. Each line of text contains a pair of numbers: position and elevation.
2. The two numbers can be separated by a blank.
3. The range of topographic information need not correspond exactly to the range of positions in the data profile. Trace positions lying outside the range of available topographic data will be assigned the elevation of the nearest endpoint.
4. Linear interpolation is used to obtain the elevation at each trace position. Consequently, it is not necessary to have an elevation for every trace in the file. Topographic data can be added to a data profile with as little as 2 position and elevation pairs (in the case of a constant slope). The more data points entered, the more detail there will be in the topographic correction.

The topographic file must have a .TOP extension.

An example of the format of the file follows:

0.0	935.8
10.1	933.9
22.7	930.3
30.5	932.7
34.6	936.5

This text file can be created by any word processor or by selecting Topography File under the Utility menu item (see Section 10.1: Topography File on page 101).

Note that this process only adds the topographic data to the trace headers. It does NOT apply the topography data permanently to the traces by shifting them up or down. This process can be done after Add Topography by using Shift Topography (see Section 7.1.7: Shift Topography on page 37).

7.1.6 Add Topography using GPS Z

This process is only available in the EKKO_View Deluxe version of the program, not the EKKO_View Enhanced version.

Add Topography using GPS Z is used to add topographic data to a Sensors & Software radar data file. It assumes that GPS X, Y and Z data have been added to the radar data file (see Section 7.1.8: Add GPS Data on page 37). It uses the GPS Z value to add the elevation value to the trace header of the GPR data file (see Section 6.4: Trace Header on page 24).

Once the elevation values are added to the GPR data file, radar sections can be shifted (see Shift Topography) and then plotted with the topographic correction applied (See Figure 7-5 on page 37). This type of display can be invaluable for understanding the proper spatial positioning of radar reflections.

When GPS data are collected, the GPS receiver is usually kept above the ground surface so that the GPS Z value collected does not exactly correspond to the ground elevation. The user needs to input the height of the GPS receiver so that it can be subtracted from the GPS Z value before the elevation value is saved to the trace header of the GPR data file.

Add Topo Using GPS Z Variables

The parameter needed for this application is:

GPS Receiver Height above the Ground The height of the GPS receiver above the ground The units are assumed to be the same units as the GPS data.

The default value is 0.

Note that this process only adds the topographic data to the trace headers. It does NOT apply the topography data permanently to the traces by shifting them up or down. This process can be done after Add Topography by using Shift Topography (see Section 7.1.7: Shift Topography on page 37).

7.1.7 Shift Topography

If there are significant elevation changes in the GPR survey area, it may be useful to compensate for the topography before sections are plotted.

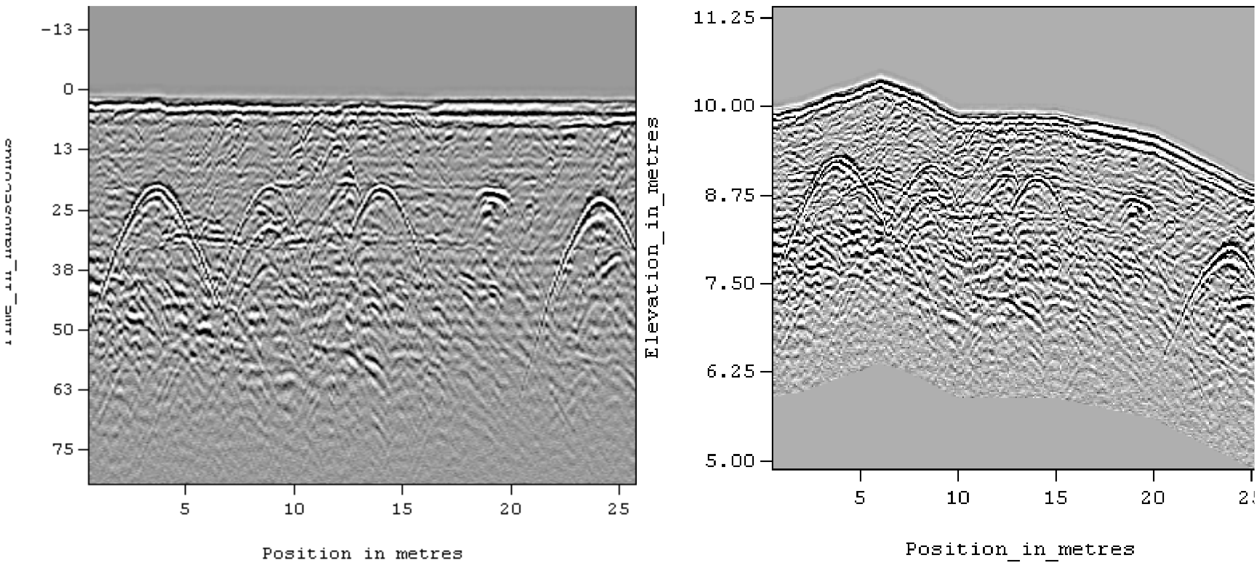


Figure 7-5: GPR data section before (top) and after (bottom) it has been corrected for elevation variations.

Shift Topography is used to permanently shift traces up and down, based on the topographic data. The topographic data must have been previously added to the data using the Add Topography program (see Section 7.1.5: Add Topography using Topo File on page 35).

Shift Topography Variables

The parameter needed for this application is:

VELOCITY is the velocity to use for the trace shift in metres/nanosecond
Should be set to the average velocity of the radar data (typically 0.06 - 0.15 m/ns).
Value must be in the range 0.01 to 0.30 m/ns.

The default value is 0.1 m/ns.

7.1.8 Add GPS Data

This process is only available in the EKKO_View Deluxe version of the program, not the EKKO_View Enhanced version.

Add GPS Data is used to add GPS X, Y, and Z positional data to a Sensors & Software radar data file. The GPS XY positional data is usually longitude and latitude but the routines described below can be used to convert the latitude and longitude values to UTM co-ordinates. The GPS positional data are saved to the trace headers of the GPR data file (see Section 6.4: Trace Header on page 24).

There are 3 different ways of adding GPS data to the GPR data file. Each method is explained in detail below.

7.1.8.1 GPS on DVL Method

If a GPS unit is connected to the DVL during the data acquisition of the GPR data, a file containing GPS positional data is saved at the same time the GPR data is saved. An example of a GPS file is shown below.

```
Trace #1
$GPGGA,134713.00,4338.221086,N,07938.421365,W,2,06,2.1,152.51,M,-35.09,M,5.0,0118*79
$GPVTG,34.0,T,,,001.4,N,002.5,K,D*70
$GPGSA,A,3,30,26,10,13,24,06,,,,,,,4.2,2.1,3.6*36
Trace #2
$GPGGA,134713.00,4338.221086,N,07938.421365,W,2,06,2.1,152.51,M,-35.09,M,5.0,0118*79
$GPVTG,34.0,T,,,001.4,N,002.5,K,D*70
$GPGSA,A,3,30,26,10,13,24,06,,,,,,,4.2,2.1,3.6*36
Trace #3
$GPGGA,134713.00,4338.221086,N,07938.421365,W,2,06,2.1,152.51,M,-35.09,M,5.0,0118*79
$GPVTG,34.0,T,,,001.4,N,002.5,K,D*70
$GPGSA,A,3,30,26,10,13,24,06,,,,,,,4.2,2.1,3.6*36
Trace #4
$GPGGA,134713.00,4338.221086,N,07938.421365,W,2,06,2.1,152.51,M,-35.09,M,5.0,0118*79
$GPVTG,34.0,T,,,001.4,N,002.5,K,D*70
$GPGSA,A,3,30,26,10,13,24,06,,,,,,,4.2,2.1,3.6*36
```

How often the GPS data are collected is determined in the DVL settings (every GPR trace, every 5th GPR trace, etc, see the GPR System User's Guide for more details).

When the GPR data are downloaded from the DVL to a PC, the GPS files are also downloaded to the same folder on the PC. The GPS file will have the same name as the GPR data file but with a .GPS extension. For example, the GPR data file LINE45.DT1 will have an associated GPS file called LINE45.GPS.

This routine uses the GPS file to add a GPS position to every GPR trace in the data file. If necessary, GPS positions are interpolated into gaps or repeated positions in the GPS data so that every GPR data trace has a unique GPS position saved in the trace header.

This routine can be used to add GPS information to one GPR data file or multiple GPR data files.

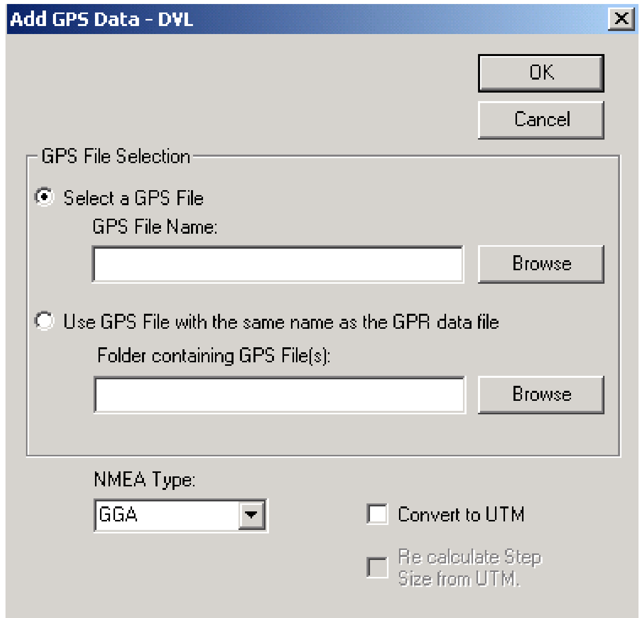


Figure 7-6: The Add GPS - GPS on DVL Method dialog box. There are options to add GPS to a single file or multiple files. The user can also specify the GPS string type to read from the GPS file. The GPS latitude-longitude information can be converted to UTM co-ordinates before it is saved in the trace headers of the GPR data file. If the UTM option is selected, the user can use the average distance between traces, calculated using the UTM positions, to update the Step Size and trace position values.

Adding GPS to One GPR Data File

To add GPS information to one GPR data file, highlight the GPR data file, then select Data Editing - File - Add GPS Data - GPS on DVL Method. From the dialog box, make sure that the **Select GPS File** button is selected (see Figure 7-6). Then use the Browse button on the right to find the GPS file. Note that the default file type is *.GPS. The file type can be changed to *.* if the GPS file has a different extension.

The GPR data file that is having the GPS information added to it is actually a copy of the original file in a sub-folder. It is not possible to add GPS data to the original GPR file.

After the GPS file is selected, click Open. The name of the GPS file will now appear in the dialog box. Select OK to start the process of adding the GPS data to the GPR data file.

Note that the user can also change the GPS data type from the default of GGA and change the GPS data to UTM format before it is written to the GPR data file. See details on these options under Variables below.

Adding GPS to Multiple GPR Data Files

To add GPS information to multiple GPR data files, highlight the GPR data files, then select Data Editing - File - Add GPS Data - GPS on DVL Method. From the dialog box, make sure that the **Use GPS File with same name as GPR Data File** is button is selected (see Figure 7-6). Then use the Browse button on the right to find the folder that contains the GPS files. If GPS data are being added to more than one GPR data file, this program assumes that the GPS data files have the same name as the GPR data file but with a .GPS extension. This is standard when GPS data are collected onto the DVL.

The GPR data files having the GPS information added to them are actually copies of the original files in a sub-folder. It is not possible to add GPS data to the original file.

After the GPS file folder is selected, click on OK. The name of the GPS file folder will now appear in the dialog box. Select OK to start the process of adding the GPS data to the GPR data files.

Note that the user can also change the GPS data type from the default of GGA and change the GPS data to UTM format before it is written to the GPR data file. See details on these options below.

GPS on DVL Method Variables

The parameters needed for this application is:

GPS File Name Use this option when adding GPS to one GPR data file at a time.
This parameter is the name of the file containing the GPS data.
The default is files with a .GPS extension but this can be changed.

GPS Folder Name Use this option when adding GPS to multiple GPR data files.
This option assumes the GPS data files have the same name as the GPR data file but with a .GPS extension.
This parameter is the name of the folder containing the GPS data files.

Type The GPS data file contains certain strings of data that contain the GPS information. See the GPS User's Guide for more information.
This program uses the GGA string as the default string.
Other string options are GLL and RMC.

UTM The GPS XY positional information is expressed in latitude and longitude. Checking this option will convert the GPS latitude and longitude values to UTM coordinates using the WGS-84 ellipsoid.

If UTM is checked, another option is enabled that allows the user to update the trace positions and step size in the GPR file using the average distance between traces, as calculated from the UTM positions. Using this option, the total line length will be approximately correct.

Once the GPS information has been added to the trace headers of the GPR data file, it can be viewed, printed and exported using options under Trace Headers (see Section 6.4: Trace Header on page 24). Longitude and UTM Easting are recorded to the trace headers under GPS X while Latitude and UTM Northing are recorded to the trace headers under GPS Y.

7.1.8.2 User GPS File Method

This method of adding GPS data to the GPR data file requires the user to create text file with a .GTP extension that lists the GPS X, Y and optionally, Z positions for two or more specific trace numbers in the GPR data file.

This routine uses the GTP file to add a GPS position to every GPR trace in the data file. GPS positions are interpolated into gaps in the GPS data so that every GPR data trace has a unique GPS position saved in the trace header.

GTP files can be created using the User GPS File option under Utilities (see Section 10.4: User GPS File on page 102).

An example is shown below. **Columns must be separated by spaces, not TABs.** The GPZ Z position, which is elevation, is an optional item in the GTP file. The GTP file must list GPS positions in Latitude and Longitude; positions in UTM coordinates will NOT work.

```
# Lines beginning with # are treated as comments
# GPS Positions must be formatted in degrees-minutes-decimal minutes DDMM.MM)
# Latitude is GPS Y and is written in the form DDMM.MM. Latitude degrees MUST be 2 digits,
# for example, 3 degrees 28.89 minutes would be 0328.89.
# Longitude is GPS X and is written in the form DDDMM.MM.  Longitude degrees MUST be 3 digits,
# for example, 97 degrees 44.11 minutes would be 09744.11.
# Trace    GPS X        GPS Y        GPS Z (optional)
1       11045.7832    4327.6754    1030
500     11045.7835    4327.6757    1024
1000    11045.7837    4327.6761    1010
1250    11045.7838    4327.6763    1034
```

This routine can be used to add GPS information to one GPR data file or multiple GPR data files.

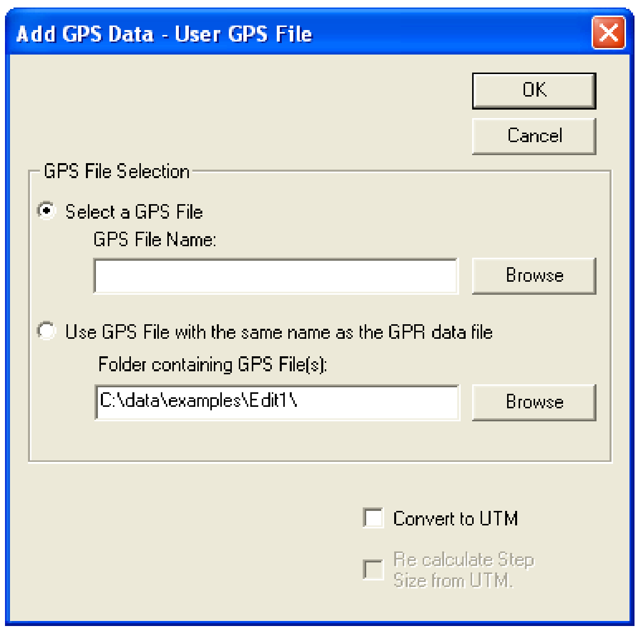


Figure 7-7: The Add GPS - User GPS File Method dialog box. There are options to add GPS to a single file or multiple files. The GPS latitude-longitude information can be converted to UTM co-ordinates before it is saved in the trace headers of the GPR data file. If the UTM option is selected, the user can use the average distance between traces, calculated using the UTM positions, to update the Step Size and trace position values.

Adding User GPS to One GPR Data File

To add GPS information to one GPR data file, highlight the GPR data file, then select Data Editing - File - Add GPS Data - User GPS File Method. From the dialog box, make sure that the **Select GPS File** button is selected (see Figure 7-7). Then use the Browse button on the right to find the GPS file. Note that the default file type is *.GTP.

If the GTP file is in the same folder as the original GPR data file, note that you will have to browse up a folder level to the original data folder to find the GTP data file. The GPR data file having GPS information added to it is actually a copy of the original file in a sub-folder. It is not possible to add GPS data to the original file.

After the GTP file is selected, click on Open. The name of the GPS file will now appear in the dialog box. Select OK to start the process of adding the GPS data to the GPR data file.

Note that if the GPS data in the GTP file are in Latitude and Longitude, the user can also change it to UTM format before it is written to the GPR data file. See details on these options below.

Adding User GPS to Multiple GPR Data Files

To add GPS information to multiple GPR data files, highlight the GPR data files, then select Data Editing - File - Add GPS Data - User GPS File Method. From the dialog box, make sure that the **Use GPS File with same name as GPR Data File** is button is selected (see Figure 7-7). Then use the Browse button on the right to find the folder that contains the GTP files. If GPS data are being added to more than one GPR data file, this program assumes that the GTP data files have the same name as the GPR data file but with a .GPS extension.

If the GTP file is in the same folder as the original GPR data file, note that you will have to browse up a folder level to the original data folder to find the GTP file. The GPR data files having GPS information added to them are actually copies of the original files in a sub-folder. It is not possible to add GPS data to the original file.

After the GPS file folder is selected, click on OK. The name of the GTP file folder will now appear in the dialog box. Select OK to start the process of adding the GPS data to the GPR data files.

Note that if the GPS data in the GTP file are in Latitude and Longitude, the user can also change it to UTM format before it is written to the GPR data file. See details on these options below.

User GPS File Method Variables

The parameters needed for this application is:

GPS File Name Use this option when adding GPS to one GPR data file at a time. This parameter is the name of the file containing the GPS data. The files must have a .GTP extension.

GPS Folder Name Use this option when adding GPS to multiple GPR data files. This option assumes the GPS data files have the same name as the GPR data file but with a .GTP extension. This parameter is the name of the folder containing the GTP data files.

UTM The GPS XY positional information is expressed in latitude and longitude. Checking this option will convert the GPS latitude and longitude values to UTM coordinates using the WGS-84 ellipsoid.

If UTM is checked, another option is enabled that allows the user to update the trace positions and step size in the GPR file using the average distance between traces, as calculated from the UTM positions. Using this option, the total line length will be approximately correct.

7.1.8.3 Time Stamp Method

Whenever a GPR data trace is collected, the time is recorded in the trace header (see Section 6.4: Trace Header on page 24). As well, when GPS positional data are collected, the time is also recorded. These times are called Time Stamps. If a GPS unit collects data as it moves along with the GPR system also collecting data, the GPS position for every GPR trace can be calculated using the time stamps.

This routine is used for the situation when GPR and GPS data were collected at the same time on two different computers or the GPR data were collected on a computer and the GPS data were collected on a data logger. In these cases, the GPS positional data can be added to the GPR data using the time stamps from each file.

For this method to work properly without errors, the time range that the GPS data were collected must fully encompass the time range of the GPR survey.

Before using this routine to add GPS positional information to the GPR data file, the raw GPS file must be reformatted. This can be done using the Reformat GPS File which is one of the **GPS Tools** under **Utilities** (see Section 10.5.1: Reformat GPS File on page 102). The reformatted GPS file must list GPS positions in Latitude and Longitude; positions in UTM coordinates will NOT work.

This utility takes the reformatted data along with times and writes the GPS XYZ positional data into the trace headers of the GPR data file.

For the time stamp method to work, the time differential between the two computers must be calculated or measured. There is a utility program called GPS_PLOT.EXE available from Sensors & Software that can be used to calculate the time differential between the computer clock used for GPR data acquisition and the computer clock or data logger clock used for GPS data acquisition. This utility program can also be used to synchronize the two clocks so that the time differential is zero.

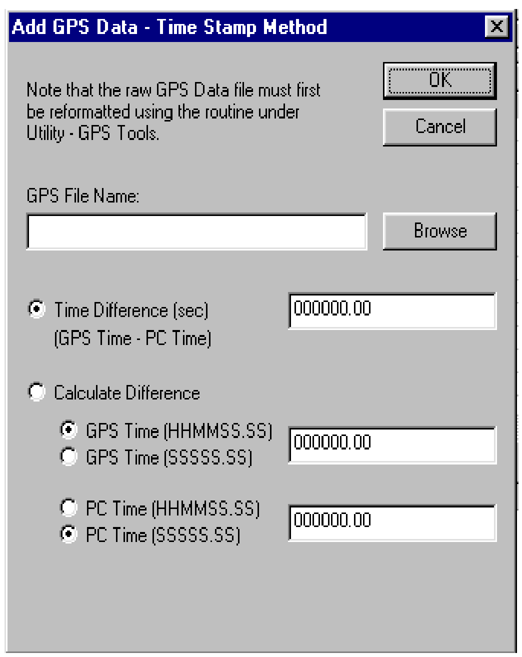


Figure 7-8: The Add GPS - Time Stamp Method dialog box. The name of the reformatted GPS file must be input. The time difference between the GPR data logger (PC) time and GPS time must be input to properly extract the GPS position for every GPR trace. The time difference can be input directly by the user or, if the PC Time and GPS Time are input, the program can calculate the time difference. When this routine is run, the GPS positional information (in Latitude-longitude or UTM) are saved in the trace headers of the GPR data file.

Time Stamp Method Variables

The parameters needed for this application is:

GPS File Name This parameter is the name of the file containing the GPS data. It MUST be reformatted from the raw GPS data file. The reformatting routine can be used to convert the Latitude-Longitude data to UTM co-ordinates if desired.

Time Difference The time difference between the clock used to record the GPS information and the clock used to the collect the GPR data. The time difference can be a negative value. If the clocks are synchronized using the GPS_PLOT program, this value will be zero.

GPS Time Time from the GPS unit corresponding to the same moment of time as the PC below. Time can be expressed in HHMMSS.SS (Hours-Minutes-Seconds-Decimal Seconds) or SSSSS.SS (Seconds-Decimal Seconds).

PC Time Time from the GPR data logger (PC) corresponding to the same moment of time as the GPS unit above. Time can be expressed in HHMMSS.SS (Hours-Minutes-Seconds-Decimal Seconds) or SSSSS.SS (Seconds-Decimal Seconds).

Examples

Say we had a GPR data file called LINE.DT1 and a reformatted GPS file. As well, it was determined that when the GPS time was 6:45:03 PM, the PC time was 6:45:13 PM.

In this case the user could calculate that the time differential is -10 seconds (GPS Time - PC Time) and put the value in as the Time Difference variable.

The other option is to click the Calculate Difference button and input the GPS Time in HHMMSS as 184503 and the PC Time in HHMMSS as 184513.

Times can also be expressed in seconds.

Getting GPS and PC Time Differences

Finding GPS_TIME and PC_TIME at the same instant can be difficult to do. It is best to get these times before any GPR data has been collected.

The best method is to use the GPS_PLOT program available from Sensors & Software. When a GPS unit is connected to the PC that will be used for GPR data collection, this program calculates the time difference between the GPS Time and PC Time and displays it to the screen. This can be recorded for latter input into the Time Stamp routine described above. The GPS _PLOYT program can also be used to synchronize the PC clock with the GPS clock. If this is done before GPR data acquisition, then the time difference will be zero.

If the GPS_PLOT program is not available, another way to get the time difference is to have the GPR computer running and the GPS computer running at the same time. On the GPR computer, at a DOS prompt, type the DOS command TIME but don't press Enter yet. Now set up the GPS computer to display a GPS time or get ready to start collecting a GPS data file. At the same instant, press Enter on the GPR computer and Enter on the GPS computer. The time displayed on the GPR computer and the time displayed on the GPS computer (or the time in the first line of the GPS file) are the times that are required for the Time Stamp routine. Either input the actual times in Hours-Minutes-Seconds (HHMMSS), Seconds (SSSSS.SS) or the difference between them.

7.2 Header File

7.2.1 Antenna Separation

This is the distance between the transmitting and receiving antennas. For reflection data this distance should normally be kept fixed for every trace collected. Appropriate values of antenna separation for each antenna frequency are given on the table in the data acquisition program.

This option is available for editing the antenna separation saved in the data file. It is important that the correct antenna separation be entered since this value is used in the computation of the depth axis.

This parameter has no meaning for any mode of operation where the antenna separation changes (as in a CMP/WARR profile).

7.2.2 Units

Two distance units are available: metres or feet. The units information is stored in the header file and is used in plotting distance and depth scales on section plots. All distance parameters i.e. Start Position, Stop Position, Stepsize, Antenna Separation and Topography, will be interpreted as to the setting of this item.

Don't make the mistake of thinking that all distance units are converted from metres to feet or vice versa by changing this setting. Editing the units only changes how the distance parameters are interpreted.

For example, if the Stepsize is set to 1 metre and then the units are changed to feet then the Stepsize will be 1 foot (which is incorrect if the data was actually collected at a 1 metre separation). To actually convert all distance units from metres to feet, all the distance parameters have to be multiplied by 3.28.Conversely, to convert all distance units from feet to metres, all the distance parameters have to be multiplied by 0.3048.

One important factor to note is that all velocities and attenuations in other submenus remain in units of metres independent of this setting.

7.2.3 Frequency

This field is for editing the frequency of the antennas saved in the data set. The easiest way is to choose one of the 10 frequencies shown: 12.5, 25, 50, 100, 110, 200, 225, 450, 900 or 1200 MHz. Alternatively, the user can manually enter the frequency. This method of entering the frequency is useful if the user is using a set of non-standard antennas. It is important that the correct frequency be entered since this value is used in many of the computations which use the pulse length as one of their parameters (like the DEWOW correction).

7.2.4 Pulser Voltage

Currently, four different transmitter pulser voltages are available: 100, 200, 400 and 1000 volts. The procedure is identical to that for editing the antenna frequency. This setting has no functional impact in data processing. It is only used for historical record keeping.

7.2.5 Survey Mode

The user has a choice of one of three types of Survey Modes: Reflection, CMP/WARR or Transillumination. This variable not only gets logged into the header, it also tells the program when to find timezero.

7.2.5.1 Reflection Surveys

Reflection surveys are those where the GPR radio energy is transmitted into the subsurface or structure being investigated, reflects from a boundary within the material and is received at the receiver antenna. The transmitter antenna and the receiver antenna are usually relatively close together and on the same side of the structure.

Reflection surveys are appealing because the subsurface or internal image of the material can be viewed immediately as data are plotted to the computer screen.

A reflection survey is the most common survey type using GPR. It produces common-offset, single-fold reflection data. This type of survey is conducted by moving the system with a fixed antenna separation along a survey line to map reflections versus position.

7.2.5.2 CMP Surveys

A Common Mid Point (CMP) survey is a special type of reflection survey used to determine radar velocity versus depth estimates of the material being surveyed. Surveys are conducted by starting with antennas at a known separation about a centre point and then increasing the antenna separation in steps about that central point. CMP's are often used in conjunction with profiling surveys to estimate the depths to reflection events.

7.2.5.3 Transillumination Surveys (ZOP’s, MOG’s and VRP’s)

Transillumination surveys are those where the GPR radio energy is transmitted through a structure to study the transmission properties of the material. The transmitter antenna and the receiver antenna are placed on opposite sides of the structure being investigated. Properties that can be measured are: velocity, attenuation and dispersion.

Transillumination surveys are less common than reflection surveys because the data requires a fair amount of processing before images can be seen.

The types transillumination surveys described here are designed for surveys in and around boreholes and therefore are all 2 dimensional (single plane). In theory, 3D GPR transillumination surveys could be conducted but the amount of data acquisition time, not to mention the software and computer resources necessary to process such a data set, make this impractical for the typical GPR user.

The 3 types of borehole transillumination surveys are zero-offset Profile (ZOP), multiple-offset gather (MOG) and Vertical Radar Profile (VRP). There is also a timezero calibration survey (CAL) that must be run before each transillumination survey.

ZOP (Zero Offset Profile): This is a quick, reconnaissance-type survey for borehole radar work. The borehole radar antennas are both moved at equal steps down their respective boreholes and radar data collected.

Variations in the travel-time and/or amplitude data can indicate anomalous zones or targets between the boreholes.

MOG (Multiple Offset Gather): This is a detailed borehole radar survey that attempts to image the location and size of anomalous features between the boreholes. For best results, it is necessary to have as many raypaths at as many different angles as possible between the boreholes. This is done by collecting numerous MOG's; each one conducted by fixing the Transmitter antenna at a certain depth in the borehole and collecting data as the Receiver antenna is moved from the top to the bottom of the borehole at regular steps. The Transmitter antenna is then moved to another depth and the process is repeated.

When all the MOG's (and VRP's, if available) are merged together and processed, tomographic images showing variations in velocity, attenuation and dispersion can be produced.

VRP (Vertical Radar Profile): If only one borehole is available, or, to increase the number of angles used to produce the tomographic image between 2 boreholes, VRP's can be conducted. This involves fixing the Transmitter antenna at a certain position on the surface and collecting data as the Receiver antenna is moved down the borehole at known steps. The Transmitter antenna can then be moved to another position on the surface and the process repeated.

When all the VRP's (and MOG's, if available) are merged together and processed, tomographic images showing variations in velocity, attenuation and dispersion can be produced.

7.2.6 Title1, Title2

These fields are used to enter information concerning the particular profile line. The user may enter any relevant pieces of information, such as site, line location, operator names, etc.

7.3 Positions

7.3.1 Reposition Traces

When radar surveys are run, the start position and stepsize are input into the computer. These two parameters are used to calculate the position of each trace and the end position of the profile. Often, for a variety of reasons, it is necessary or desirable to change the trace positions after the survey was run.

For example, a survey run at a stepsize of 0.5 metres between two survey stakes 100 metres apart, should produce 201 traces. However, if the step between traces was estimated during the survey, the 100 metre stake will likely be encountered before or after the 201st trace is collected. This means that over the course of the survey the actual stepsize was not exactly 0.50 metres, but more like 0.54 or 0.45 metres. Other examples where Reposition Traces may be useful are:

- the wrong start position was input so all the traces are in the wrong position.
- the wrong stepsize was input so all the traces are in the wrong position.

Reposition would be used in these situations to adjust the trace positions to their actual position on the radar line.

Reposition can be used in two different ways (the Toggle checkbox determines which):

1. adjust trace positions based on input Start Position and Stepsize.
2.. adjust trace positions based on input Start and Stop Positions.

Reposition Variables

The parameters needed for this application are:

Stepsize	The distance between traces (in metres or feet) in the data file of traces.
Start Position	The Start Position (in metres or feet) of the data file of traces.
End Position	The End Position (in metres or feet) of the data file of traces.

Example 1

A data file was collected from Start Position of 0.0 and an End Position of 100.0 with a Stepsize of 0.5. An error was made in that the Start Position should be 10.0. To correct this, set the Start Position to 10.0 and the Stepsize to 0.5 (as it was before). This will adjust all the trace positions with respect to the new Start Position. The End Position will change to 110.0.

Example 2

A data file was collected from Start Position of 0.0 and an End Position of 100.0 with a Stepsize of 0.5. An error was made in that the End Position should be 120.0. To correct this, set the Start Position to 0.0 (as it was before) and the End Position to 120.0. A new Stepsize will be calculated to allow the traces to fit within the set Start (0.0) and end positions (120.0). For example, if the data file contains 201 traces, the new calculated Stepsize is 120.0/(201-1) = 0.6 units.

7.3.2 Reverse

Reverse is used to reverse the direction of a data file.

Reverse is useful when lines are collected in opposite directions (this often happens when collecting parallel lines of data) and it is necessary to reverse some lines so they all will plot in the same direction.

Several things happen when a file is reversed:

1. the trace data is physically reversed in the file,
2. the start position of the line becomes the end position,
3. the end position becomes the start position, and
4. the sign of the stepsize is made opposite.

To reverse a line but still have the same Start and End Positions and a positive stepsize it is necessary to run Reverse and then Reposition (see Section 7.3.1: Reposition Traces on page 47)

Reverse Variables

There are no input parameters required for this application.

7.3.3 Polarity

Some Sensors & Software GPR systems have independent transmitters and receivers that can be put in any orientation relative to one another i.e. the pulseEKKO 100 system. In the course of collecting data along a profile line, it is important to keep the relative transmitter and receiver orientation the same especially after any interruption in data collection to change batteries, etc.

One way to control polarity is to always have the Sensors & Software or pulseEKKO name on the electronic units pointed in the direction of antenna movement.

If the transmitter or receiver is rotated 180 degrees and changes the relative orientation, the signal polarity will reverse. If this happens in the middle of a survey line, negative signals called troughs will change to positive signals called peaks and vice-versa. Should this occur, the Polarity routine is used to reverse the polarity of all or part of a survey line.

This option is also useful when one wants to merge two profile lines but they have different signal polarities. Simply reverse the polarity of one of the profile lines and then use the Merge program (see Section 7.1.1: Merge on page 29).

Polarity Variables

The parameters needed for this application are:

Start, End Position Position range of traces to have the polarity flipped.
To flip the polarity of one trace at one position make that position both the Start and End Position.

Position ranges must be input in the left-to-right order that they occur in the profile. Thus, if stepsize is positive, position ranges should go from a smaller position to a larger position. Similarly, if stepsize is negative, position ranges should go from a larger position to a smaller position.

7.3.4 New Stepsize

New Stepsize is used to resample a data set at a different stepsize i.e. change the distance between traces. The new stepsize can greater than or less than the original stepsize. If the new stepsize is less than the old stepsize, new traces are interpolated between the original traces. If the new stepsize is greater than the old stepsize, traces are skipped and/or interpolated as necessary.

Note that this function is different than putting a new stepsize in the Reposition routine (see Section 7.3.1: Reposition Traces on page 47). Reposition never changes the number of traces in a file; it only adjusts the position of each trace. New Stepsize, on the other hand, will increase or decrease the number of traces in the file depending on whether the new stepsize is greater than or less than the old stepsize.

Comments associated with traces are never lost; they are moved to the closest trace that will exist after processing.

New Stepsize Variables

The parameter needed for this application is:

New Stepsize The new distance between traces in the profile of traces. If a trace does not exist at a multiple of the new stepsize, one is interpolated using the two adjacent traces.

7.3.5 Chop Data - Time

Sometimes a profile of data contains too much data in time. For example, if the chosen time window was too long, the area of interest might occur at early times and the later times on the profile may contain poor, noisy or otherwise useless data. If these useless data are retained they only slow down processing and take up disk space.

Chop Data - Time is used to delete data outside the input start and end time range.

Chop Data - Time Variables

The parameters needed for this application are:

Start, End Times Start and end times (in nanoseconds) to retain in the cropped profile. Note that if you crop the start time of a profile after timezero, the times in the profile will no longer be the same as the original profile. For example, if your original profile had a start time of -20 ns and an end time of 480 ns and you cropped the start time to 50 ns, the cropped section will have a start time of 0 ns and an end time of 430 ns.

7.3.6 Chop Data - Pos

Sometimes a profile of data contains too much data spatially (in the position range). For example, the ends of a profile may contain poor or uninteresting traces. If these useless data are retained they only slow down processing and take up disk space.

Chop Data - Pos is used to delete data outside the input start and end position range.

Chop Data - Pos Variables

The parameters needed for this application are:

Start, End Positions Start and end positions of traces to retain in the cropped profile. Positions must be input in the left-to-right order that they occur in the profile.
i.e. if stepsize is positive, End Position must be greater than Start Position.
If stepsize is negative, End Position must be less than Start Position

7.3.7 Mute Data

Occasionally, a profile of data contains areas of poor data that draws the eye away from the more important data. Mute Data is used to mute (zero) a rectangle of data within a profile. The rectangle of data to be muted is defined by input start and end times and start and end positions.

Mute Data Variables

The parameters needed for this application are:

Start, End Positions Start and end positions of traces to mute in the data file. Positions must be input in the left-to-right order that they occur in the profile.
i.e. if stepsize is positive, End Position must be greater than Start Position

if stepsize is negative, End Position must be less than Start Position

Start, End Times Start and end times to mute in the data file.
End Time must be greater than Start Time.

Position Gradient Distance, in the position units the data were collected in, over which to reduce the signal from full values to being completely muted (zero). A longer position gradient gradually reduces the signal to zero, avoiding a very abrupt change in the signal level. The default value is zero, meaning there is no gradient and the signal level will abruptly change from full signal to zero.

Time Gradient Time, in nanoseconds, over which to reduce the signal from full values to being completely muted (zero). A longer time gradient gradually reduces the signal to zero, avoiding a very abrupt change in the signal level. The default value is zero, meaning there is no gradient and the signal level will abruptly change from full signal to zero.

7.3.8 Insert Traces

Insert Traces is used to insert blank traces in a data file of traces. After the insertion of the blank traces, the traces are renumbered and repositioned so the total length of the line is correct.

The purpose of Insert Traces is to allow blank traces to be inserted at locations which, for one reason or another, had to be skipped in the field. In this way the trace positions along a line can be spatially consistent.

Note that no matter where and how many blank traces inserted, the start position is preserved. Inserting traces only causes the end position to change.

Insert Traces Variables

The parameters needed for this application are:

Start Position The position at which to add blank traces in the profile.

Number of Traces The number of blank traces to add at the corresponding position.
If the number of traces is positive, traces are inserted after the position.
If the number of traces is negative, traces are inserted before the position.

7.3.9 Delete Traces

Occasionally, extra traces are recorded in a profile that later need to be purged. Delete Traces allows the user to delete a trace at a specific position or several traces in a range of positions. After the deletion of the traces, the traces are renumbered and repositioned so the total length of the line is correct.

Delete Traces Variables

The parameters needed for this application are:

Start, End Position Position range of traces to delete in the profile.
To delete one trace at one position make that position both the Start and End Position.
Position ranges must be input in the left-to-right order that they occur in the profile. Thus, if stepsize is positive, position ranges should go from a smaller position to a larger position. Similarly, if stepsize is negative, position ranges should go from a larger position to a smaller position.

7.3.10 Fill Data Gaps

Data acquisition can be controlled by an odometer triggering the radar system to collect data at specified position increments. In this operating mode, it is possible to move too fast and trigger too quickly for the system to keep up. When this occurs, position accuracy is retained but some traces may be skipped and "gaps" will appear in the data when it is plotted. Fill Gaps is used to interpolate traces into any "gaps" or skipped traces in the data set.

Note that if data is processed with these gaps present some of the editing and processing routines may fail. It is strongly recommended that Fill Gaps be run on the data file before any editing or processing is done.

Fill Gaps Variables

There are no input parameters required for this application.

7.4 Time Window

7.4.1 New Time Window

New Time Window is used to extend or shorten a data set to a new time window. If the time window is decreased, the data set is truncated at the new time window. If the time window is increased, zeros are added to the end of each trace to extend it to the new time window length.

New Time Window Variables

The parameters needed for this application are:

New Time Window The length of the new time window in nanoseconds (ns).

7.5 Points/Trace

7.5.1 Resample

Resample is used to resample a data set at a different time sample interval. The new sampling interval can greater than or less than the original sampling interval. If the new sampling interval is less than the old sampling interval, new points are interpolated between the original points. If the new sampling interval is greater than the old sampling interval, points are skipped and/or interpolated as necessary.

Resample will abort the resampling process if the new sampling interval will seriously alias the data. This occurs if:

$$SamplingInterval > \frac{1000}{3 \cdot AntennaFrequency(inMhz)}$$

Resample Variables

The parameters needed for this application are:

New Sampling Interval The new sampling interval (in picoseconds, 1000 ps = 1 ns) at which to resample the input data.

7.5.2 Decimate

DECIMATE is used to reduce a data set in the time direction to a percentage of its original size. The objective is to reduce data by reducing X points into 1 point. The number of traces in the file is not affected but the number of points in each trace, npts, is reduced to npts/decimation factor.

The purpose of this application is to allow large data sets of rectified or amplitude spectra processed data to be reduced in size so further processes that do not require high data resolution can be applied to the data without taking large amounts of computer time.

Decimate Variables

The parameters needed for this application are:

Decimate Factor The number of points to compress into one point.

7.6 Timezero

7.6.1 Re-pick Timezero

Re-pick Timezero is used to re-pick the timezero point number in the header (.HD) file.

When data are collected, the first trace collected is searched to find timezero. This is the first large deflection (either a positive peak or a negative trough) in the trace and indicates the arrival of the direct air wave to the receiver. Sometimes the timezero search fails and timezero is set to the wrong point. The Re-pick Timezero routine uses a threshold value (either default or user-defined) to re-pick timezero. The threshold value is a percentage of the peak amplitude value in the trace. The first point in the trace to exceed the threshold value is the timezero point.

Re-pick Timezero allows the user to define timezero with an input threshold or use a default threshold. The threshold is input as a percentage (-100% to +100%) of the maximum trace value. Typical required to get a good timezero pick are 5% to 10%, but if the data are particularly noisy, a higher threshold may be required.

When determining a threshold value to input, it is a good idea to look at the traces (see Section 6.2: Traces on page 23) and see whether the first major deflection is positive or negative. If the first deflection is positive use a positive threshold i.e. 10%. If the first deflection is negative use a negative threshold, i.e. -7%. Re-pick Timezero searches the input traces and the first point to exceed the threshold value (absolutely) is timezero.

As mentioned above, Re-pick Timezero may not always give a good pick for timezero. To check the pick, plot the traces (see Section 6.2: Traces on page 23) and see where the timezero line (a dashed vertical line) is placed on the traces (See Figure 6-2 on page 23). If not, try another threshold value and see if the pick can be improved.

Re-pick Timezero Variables

The parameters needed for this application are:

THRESHOLD Percentage amplitude value to define timezero.
Default is 5%.
If value is positive, timezero is the first point greater than the value; if value is negative, timezero is first point less than the value.

7.6.2 Datum Timezero

Usually the timezero point on each trace lines up horizontally. However, if data are collected before the radar system has warmed up properly or if the fibre optic cables (on some Sensors & Software GPR systems) are damaged, the timezero point may drift up and down from trace to trace. When this problem is visible in the data, the Datum Timezero can be used to shift all the traces back to a horizontal datum. A threshold value, based on a percentage of the peak amplitude value, is used to find the timezero point. Then, all the traces are shifted to this timezero datum.

Datum Timezero is used to pick the timezero on the first trace and then find the number of points the other traces must be shifted up or down so that timezero is a horizontal datum for the entire data set. This correction is usually called the "timezero drift" correction.

It is important to be aware that this shift causes data to be lost at the start or end of the trace depending on which way the trace is shifted. For example, a trace shifted down 10 points will have 10 zeroes added to the beginning of it and, in order to preserve the length of the trace, the last 10 points are deleted. Similarly, a trace shifted up 5 points will have its first 5 points deleted and 5 zeroes added to the end. In normal use this is not a large problem because these data are not usually in the target region of the survey.

If Datum Timezero is not lining up the first breaks properly, try experimenting with the threshold value. Remember that Datum Timezero works by looking for the first point above the input threshold. So the threshold needs to be large enough so that the transmit pulse (which should be a higher amplitude than anything before it) is the point that gets picked.

It is especially important to use Datum Timezero if the timezero point drifts from trace to trace AND further data processing on the data file is required. Many processes like any of the Spatial Filters or the 2D filters use calculations on amplitude values in adjacent traces. If there is much drift in the data, these processes may not work as well.

Datum Timezero Variables

The parameters needed for this application are:

THRESHOLD Percentage amplitude value to define timezero.
Default is 5%.
If value is positive, timezero is the first point greater than the value; if value is negative, timezero is first point less than the value.

7.6.3 Edit Timezero

Rather than using Re-pick Timezero or Datum Timezero to determine the timezero point number, it is sometimes desirable to calculate or estimate the timezero point yourself and directly edit it into the header (.HD) file. This can be done using the Edit routine under Timezero.

To calculate the timezero point number use the Trace plot (see Section 6.2: Traces on page 23) to estimate the number of nanoseconds from the beginning of the trace to the timezero point. Then divide the number of nanoseconds by the Sampling Interval of the trace and multiply the quantity by 1000. For example, if the number of nanoseconds to the timezero point is 5 and the Sampling interval is 100 (picoseconds) then:

Timezero Point = (5/100) * 1000 = 50

Edit Timezero Variables

The parameters needed for this application are:

Timezero Point The point number of the timezero point in the trace.

7.7 Trace Comments

When collecting data it is possible to add comments and/or fiducial markers at any trace (for details on doing this, see the data collection guide for the particular system being used).

In Original Data mode (see Section 3.2: Original Data Mode on page 7) choosing Trace Comments allows comments to viewed.

In Edit/Process mode (see Section 3.3: Edit/Process Mode - Editing Data on page 7) choosing Trace Comments allows comments to viewed and edited. The user has the option of editing the existing comment, deleting the existing comment or inserting a new comment at any trace number or position value.

To edit an existing comment, highlight the comment line and click on the Edit button. A window opens up that allows the comment to be changed.

To delete a comment, highlight the comment line in the list and click on the Delete button.

To insert a new comment, click on Insert. A window opens that allows the user to insert a comment at any trace number or position value. If a trace number is filled in, the corresponding position appears. Or, if the position value is entered, the corresponding trace number appears.

```
Trace # 10 Position  9.00 : car
Trace # 15 Position 14.00 : line4
Trace # 37 Position 36.00 :
Trace # 54 Position 53.00 : stream
Trace # 78 Position 77.00 : sign
```

8 Insert Process

It is important to line up the data traces of a profile on a horizontal datum before using certain programs in EKKO_View Deluxe. Specifically, all the spatial filters (Horizontal, Binomial, Highpass, Lowpass, Median, Trace Difference, Background Subtraction) and the Operations routines Add Section and Subtract Section apply trace to trace processes. These programs expect the first breaks to line up horizontally otherwise they may produce unexpected results. If necessary, use Datum Timezero (see Section 7.6.2: Datum Timezero on page 54) to perform this datuming.

8.1 Gains

Since the radar signal strength normally decreases with increasing time, it is usually necessary to apply some sort of gain function to boost the weaker signals at later times.

The raw, ungained data shows little signal except for the strong near-surface reflectors (see Figure 8-1). No gain may be useful in areas where the radar signal is very strong or in areas where the targets are very shallow.

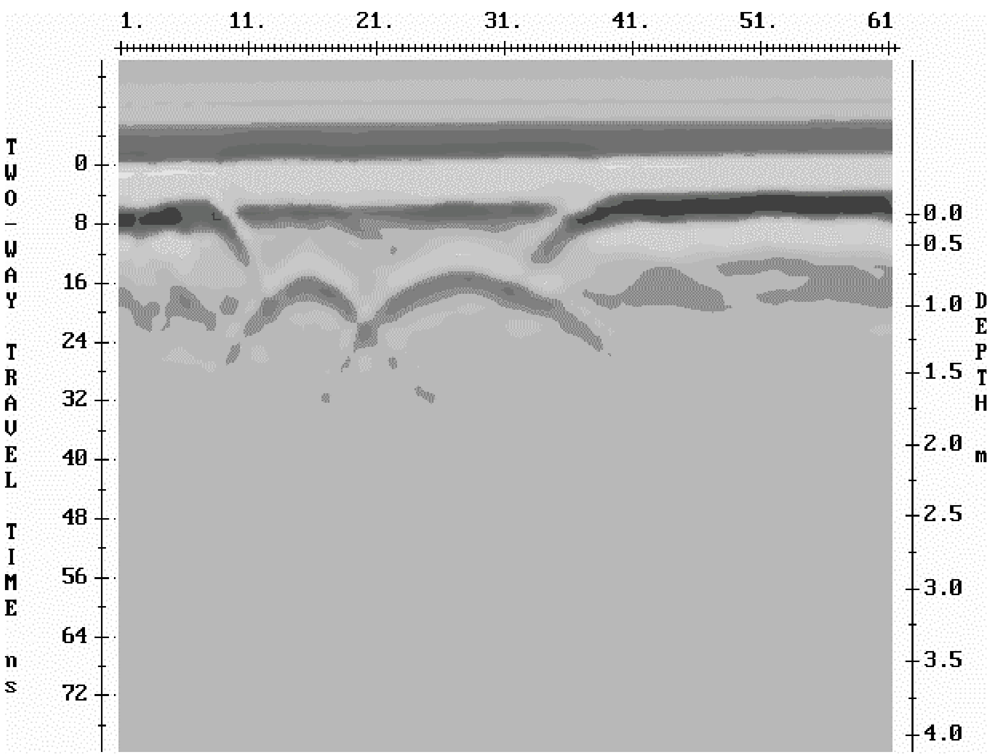


Figure 8-1: Display of a data section over buried tanks. No gain was applied before plotting.

There are 5 gain functions available: AGC, SEC, Constant, Autogain and Usergain. These are each described below.

Special Notes:

- None of the gain functions are permitted to boost a data point value to greater than 32767 or less than -32767. Values where this occurs are trapped and forced to 32767 or -32767.

- Some of the gain functions (AGC and SEC) use points before timezero to determine a maximum gain value. It is possible to edit the data set using Chop Data (see Section 7.3.5: Chop Data - Time on page 50) and eliminate these points. If you do this, do not expect to be able to use these points to determine the maximum gain and get good results.

8.1.1 AGC Gain

The AGC (Automatic Gain Control) gain attempts to equalize all signals by applying a gain which is inversely proportional to the signal strength (See Figure 8-2 on page 59). This type of gain is most useful for defining continuity of reflecting events. The user should realize that AGC does not preserve relative amplitude information. Hence once the data have been AGC'ed, one can no longer make reliable deductions concerning the strength of any particular reflector relative to other reflectors.

Since the AGC gain is inversely proportional to the signal strength, very small signals can produce very large gains. Therefore some type of gain limiting scheme must be applied. The AGC gain has two gain limiting schemes.

The first method is a manual one. In the manual method, the user enters the maximum gain which can be applied to the data. This maximum gain is then fixed for the whole data set.

The second type of gain limiting scheme is a dynamic one and will change from trace to trace. Here the data points between the start of the data window and the first break (timezero) are used to compute an ambient noise level. The maximum gain for that particular trace is then the amount needed to increase this ambient noise to 'x' percent of the maximum window. This 'x' percent is entered as the Gain Max Auto variable. Therefore as the external RF (radio frequency) background noise increases the maximum gain level decreases.

Note that if a data point value multiplied by the gain value exceeds 32767 absolutely the new data point value becomes 32767 or -32767.

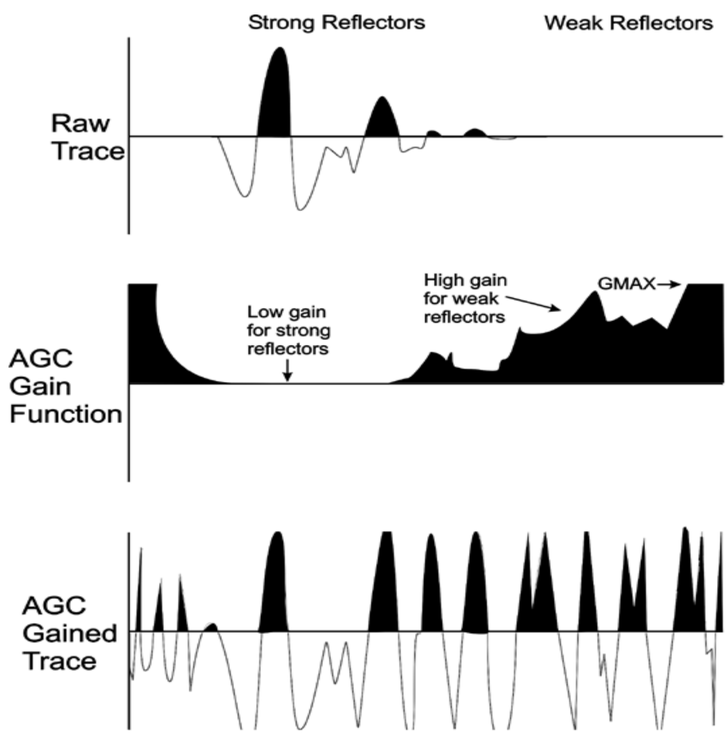


Figure 8-2: Shows how the AGC function (middle) is inversely related to reflector strength of the raw trace (top). The AGC gained trace (bottom) is a result of multiplying each point in the raw trace with the equivalent point in the AGC function.

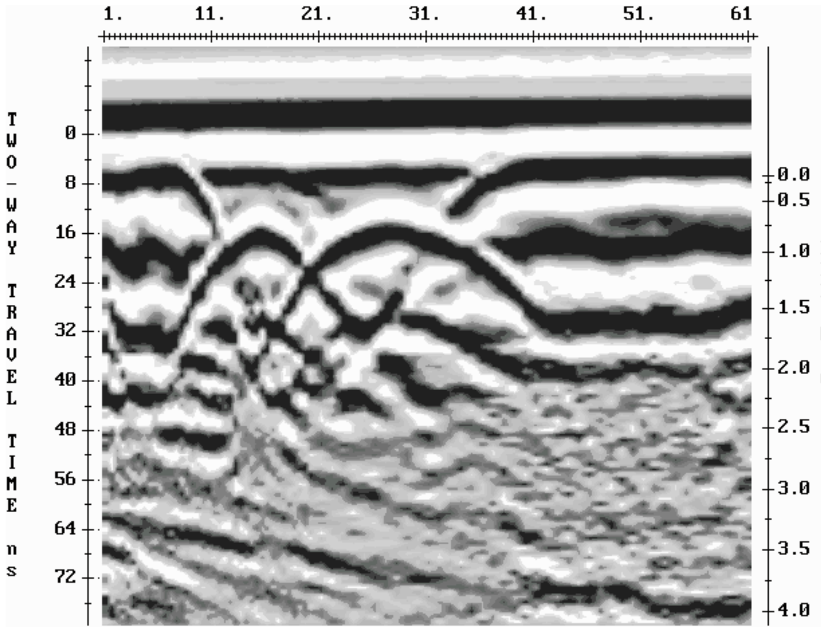


Figure 8-3: Display of a data section over buried tanks. An AGC gain was applied before plotting.

The parameters used in either AGC gain type are described below:

AGC Variables

Note that depending on which gain limiting scheme you choose (Gain Max Manual or Gain Max Auto described above) there are different input formats. You can toggle between these formats using the Toggle checkbox.

Gain Max Manual This is a number between 1 and 32767 which determines the maximum gain that can be applied to any data point. This maximum gain is fixed for the whole data set.
A typical value would be 50 - 2000 depending on the noise and average signal levels.

Window Width In computing the gain to be applied at each point, the program actually finds the average signal level over a window of width given by Window Width and centered about the point. The Window Width is specified in units of pulsewidth based on the nominal antenna frequency. In the case of data collected at 100 MHz with a sampling interval of 800 ps, and a window width of 1.0, 25 points would be used to compute the average signal strength.
The default of 1.0 for Window Width is perfectly adequate in most cases.

Gain Max Auto This is a number between 0 and 1 which determines the maximum gain that can be applied to any data point. The maximum gain is computed by first finding the average signal level in the gain region before the transmit pulse (before the first break or timezero). This average signal level is also called the ambient noise level. The maximum gain is then the value needed to increase the noise level such that it reaches that fraction of the

data limit value of 32767 given by Gain Max Auto. So, if Gain Max Auto = 0.1, the maximum gain is that value needed to make the noise level in the gain region (as computed above) come up to 10% of 32767.
A typical value is 0.01 - 0.10

Gain Region Start and end points (N1 and N2) of the gain region used to calculate the ambient noise level and the maximum gain value.
If N1 and N2 are both zero, the program will calculate appropriate points to define the gain region. These points will be from the first point to the first break point.

8.1.2 SEC Gain

The SEC (Spreading & Exponential Compensation) gain is a composite of a linear time gain and an exponential time gain. This gain has the objective of compensating for the spherical spreading losses and the exponential ohmic dissipation of energy in the data being collected. Since radar data is attenuated exponentially and the SEC is an exponential gain, it tends to be the gain closest to physical reality. Therefore, unlike the AGC gain, reflections can be compared for relative signal strength.

This gain is essentially an exponential function. This exponential function could, in fact, go to infinity. Therefore, as with the AGC gain some gain limiting factor must be applied. There are two types of gain limiting factors used with the SEC gain. These schemes are identical to those used in the AGC gain (see AGC above).

The SEC gain function takes on the form:

$$g(t) = C + \left(1 + \frac{\tau}{\tau_\omega}\right)e^{\beta\tau} \qquad \tau \ge 0$$

$$g(t) = 1 \qquad \tau < 0$$

where:

C = Constant start value

$\tau = (t - (\tau - t_0))$

τ_ω = pulsewidth

t_0 = timezero

$\beta = \alpha \cdot v / 8.69$

α = radar wave attenuation in dB/m

v = radar wave velocity of 0.1 m/ns

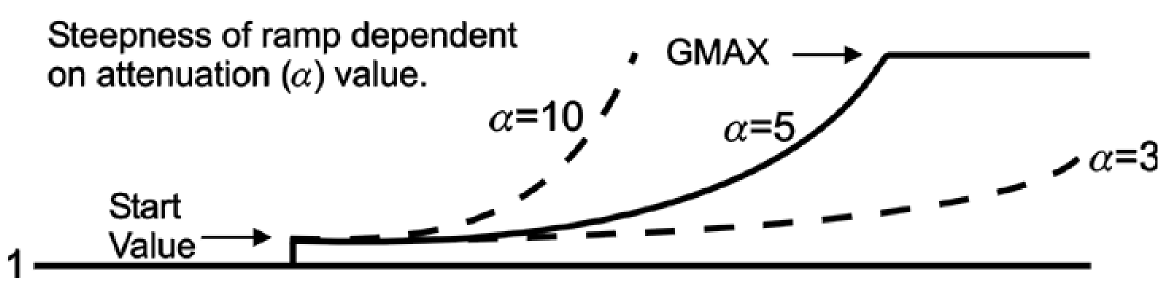


Figure 8-4: The SEC function has three parameters that must be specified. The Start Value is the initial value of the function at timezero. GMAX is a limiting value on the function. The Attenuation value determines the steepness of the ramp. When data are collected in areas with high attenuation, a higher Attenuation value may be necessary to reveal weaker signals.

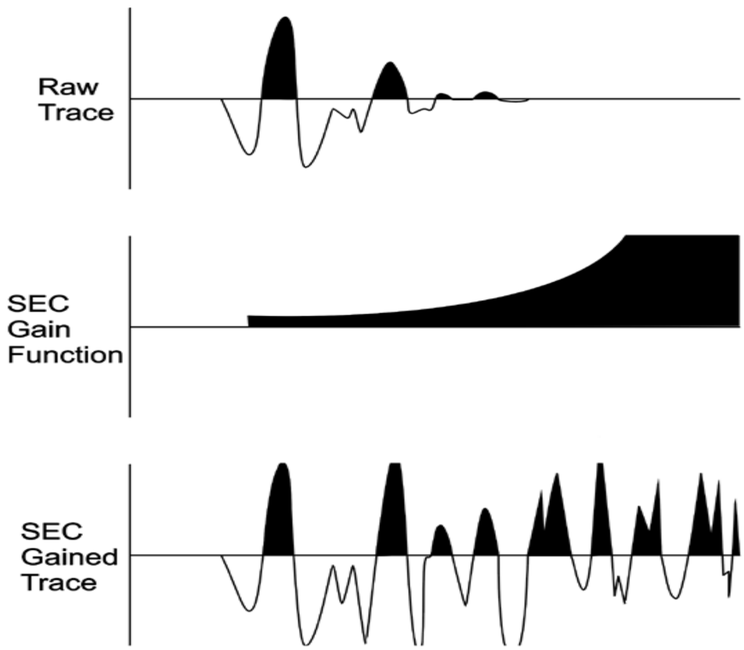


Figure 8-5: Shows the exponential nature of the SEC function (middle). The SEC gained trace (bottom) is a result of multiplying each point in the raw trace (top) with the equivalent point in the SEC function.

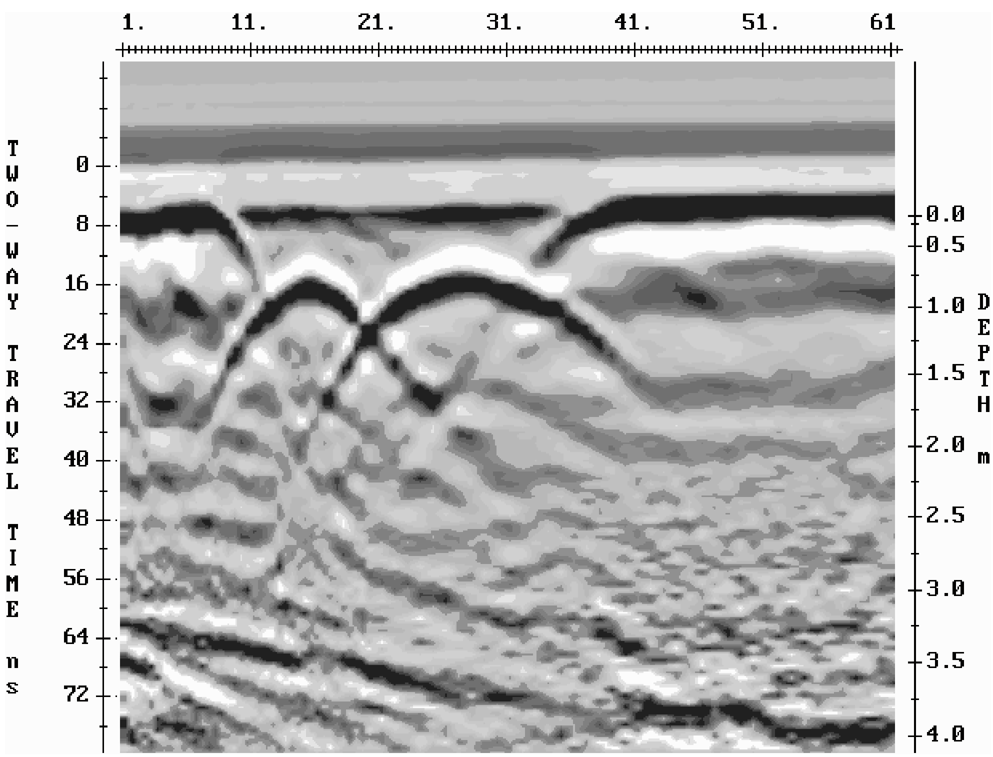


Figure 8-6: Display of a data section over buried tanks. An SEC gain was applied before plotting.

SEC Variables

Note that depending on which gain limiting scheme you choose (Gain Max Manual or Gain Max Auto described above) there are different input formats. You can toggle between these formats using the Toggle checkbox.

The parameters needed for this gain function are:

Gain Max Manual This is a number between 1 and 32767 which determines the maximum gain that can be applied to any data point. This maximum gain is fixed for the whole data set. Therefore, the exponential gain function will ramp up to this Gain Max Manual number then level off.
Typical value: 50 to 2000

Start Value This is a constant value (or DC) added to the exponential function. The SEC gain ramps up from this value; normally it will be 1 but for those data sets where more gain is required at early times, this value can be increased accordingly.
Typical value: 0 to 10

Attenuation This quantity represents the radar wave attenuation given in decibels/ metre.
For a chart of the radar wave attenuation and velocity (needed below) for a number of common materials, see Table 1 on page 22.
Typical value: 0.5 to 5.

Gain Max Auto This parameter is identical to that of the AGC function. A number between 0 and 1 should be entered. The maximum gain is computed by first finding the average signal level in the gain region before the transmit pulse (before the first break or timezero). This average signal level is also called the ambient noise level. The maximum gain is then the value needed to increase the noise level such that it reaches that fraction of the data limit value of 32767 given by Gain Max Auto. So, if Gain Max Auto = 0.1, the maximum gain is that value needed to make the noise level in the gain region (as computed above) come up to 10% of 32767.
A typical value is 0.01 - 0.10

Gain Region Start and end points (N1 and N2) of the gain region used to calculate the ambient noise level and the maximum gain value.
If N1 and N2 are both zero, the program will calculate appropriate points to define the gain region. These points will be from the first point to the first break point.

8.1.3 Constant Gain

This routine will apply a constant gain factor to the input data set. Only one parameter is needed, namely the constant factor to multiply all data points by. Thus if the user enters the number 10, all data points will be multiplied by a factor of 10. This will gain strong signals and weak signals equally and result in the clipping of strong signals.

The advantages of a constant gain are:

- it is easy to understand how the amplification works and,
- there is only has one parameter to adjust.

The disadvantage of a constant gain is that it tends to over-gain the strong signals at the beginning of the trace (see Figure 8-7).

Constant Variables

The parameters needed for this gain function are:

CONSTANT_MULTIPLIER The constant gain factor that the data set will be multiplied by. Typical values for the Constant gain are in the range from 5 to 1000

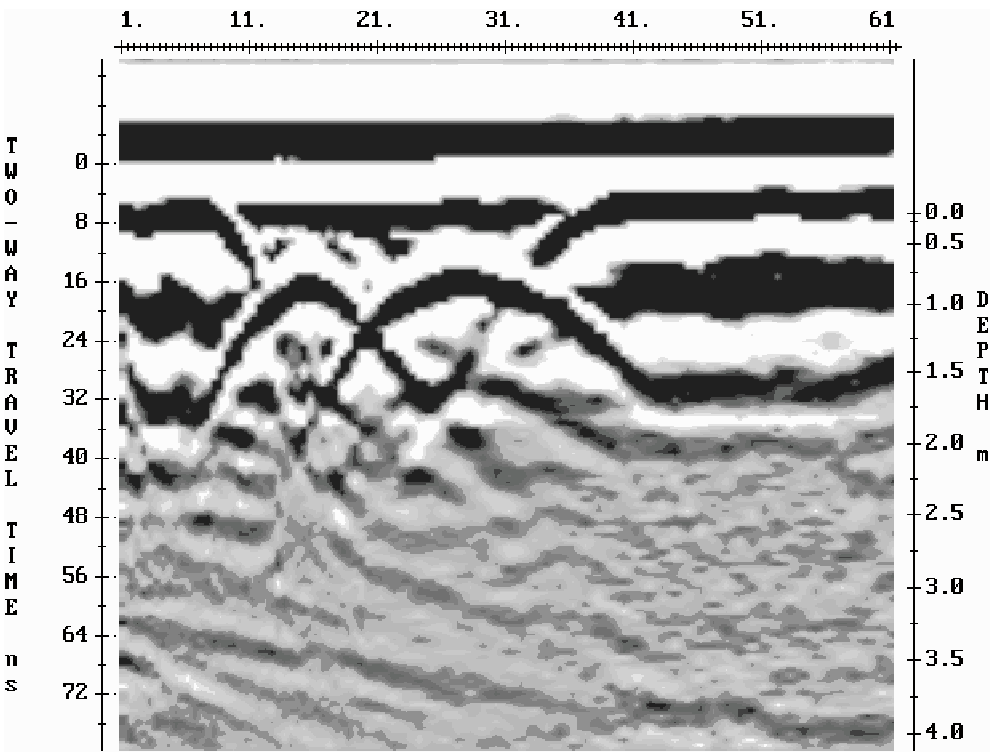


Figure 8-7: Display of a data section over buried tanks. A Constant gain was applied before plotting.

8.1.4 Autogain

Autogain will calculate and apply a gain function tailored to the input data set. No user parameters are required. This is done by calculating the decay of the average signal strength over time. The inverse is then used to gain the data set.

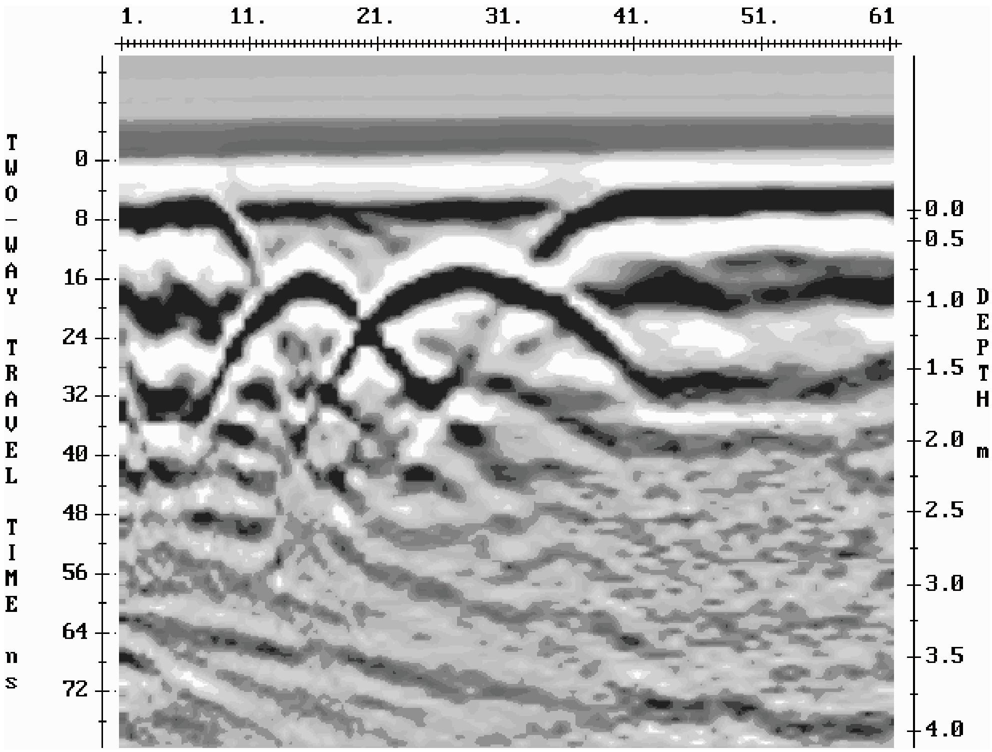


Figure 8-8: Display of a data section over buried tanks. Autogain was applied before plotting.

Autogain Variables

There are no input parameters required for this application.

8.1.5 Usergain

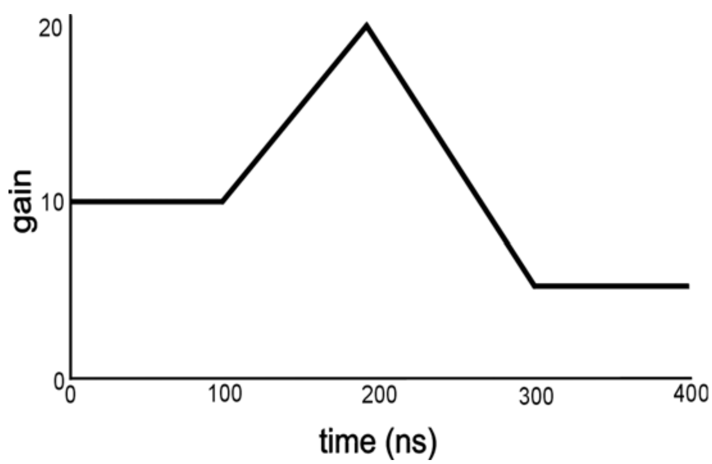
This routine allows the user to apply a custom gain function to a data set. A tabulated gain function is read in from a file. This file must be in ASCII format with each line containing the time in nanoseconds followed by the gain factor. Using these values and linearly interpolating values if necessary, a gain factor is calculated for each point of the input data set. This gain function is then applied to the data set.

This ASCII gain file must have the file extension ".GAN" and can be created by any word processor or by selecting Usergain File under the Utility menu item (see Section 10.2: Usergain File on page 101).

For example, GAINTEST.GAN might contain the following time and gain data:

```
100  10
200  20
300   5
```

If the input trace data set was 400 ns in length, this gain function would look like:



Note that the gain values before the first time value in the gain file will be set to the gain value at that first time value; in this case all the gain values before 100 ns are set to 10, which is the value at 100 ns. Similarly, gain values after the last time in the gain file are set to gain value at that time. Gain values between two points are linearly interpolated. Also note that negative time values are not allowed. Data points before the timezero (first break) point are not gained.

When generating a user gain, the gain should be created to vary smoothly with time. Abrupt changes will create artifacts in the data.

Usergain Variables

The parameters needed for this gain function are:

GAIN_FILE The drive/path/name of file containing time and gain values used to create the gain function to apply to the data file.

No extension is required because .GAN extension is assumed.

8.2 Time Filters

Time filters act on radar data in the time direction. Unlike spatial filters which use adjacent traces during the filtering procedure, time filters are applied to a single trace at a time. They alter the shape of the trace through various mathematical manipulations designed to enhance or eliminate certain features.

DEWOW should be applied before any other processing to all data sets to correct for signal saturation or "wow" in the data.

8.2.1 Dewow

It is recommended to most users that this process always be applied.

Depending on the proximity of the transmitter and receiver as well as the electrical properties of the ground, the transmit signal may induce a slowly decaying low frequency "wow" on the trace which is superimposed on the high frequency reflections.

This process is designed to remove this unwanted low frequency while preserving the high frequency signal. The removal of this wow in the data is also called the "signal saturation correction".

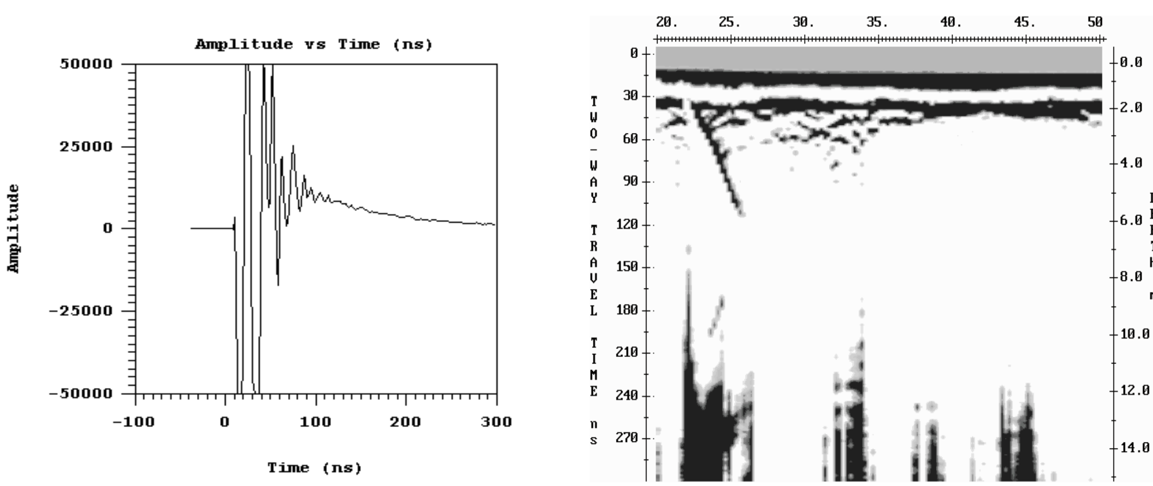


Figure 8-9: Display of a single data trace (left) and data section (right) with the low frequency WOW component present. Compare these plots to the figure below where the WOW has been removed with the DEWOW high pass filter.

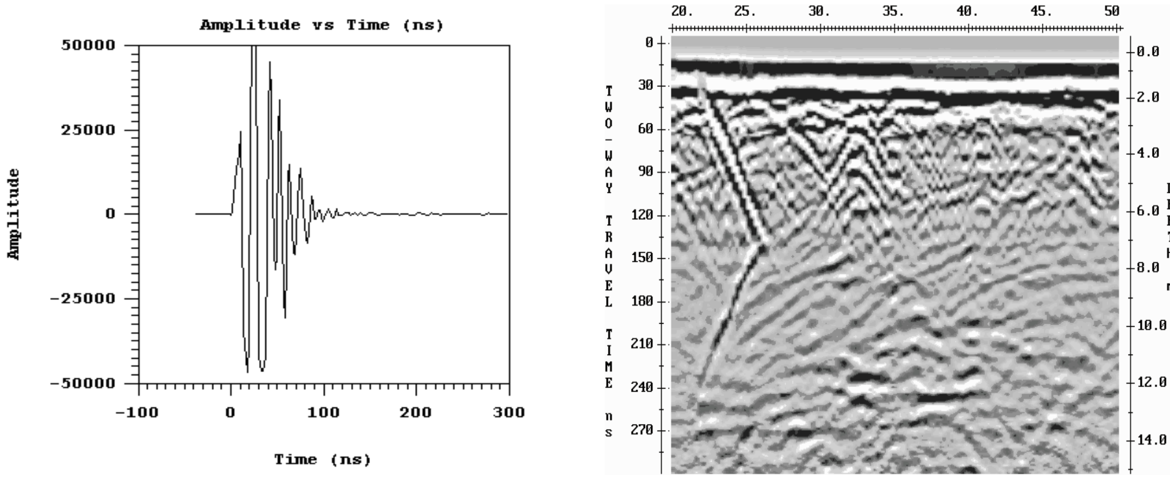


Figure 8-10: Display of a single data trace (left) and data section (right) where the Wow seen in the figure above has been removed with the Dewow high pass filter.

The wow is removed from the data by applying a running average filter on each trace. A window with a width the same as that of one pulsewidth at the nominal frequency is set on the trace. The average value of all the points in this window is calculated and subtracted from the central point. The window is then moved along the trace by one point and the process is repeated.

While any filter produces unwanted artifacts in the data to which it is applied, Dewow has been optimized after many experiments over many years to reach a satisfactory compromise filter. For a more detailed description see Appendix A: GPR Signal Artifacts.

DEWOW is also important to apply to radar data before further processing either in EKKO_View Deluxe or an outside processing package; for example, if the data are to be converted to SEG-Y format and exported to a Seismic processing package (see Section 7.1.4.1: SEG-Y on page 31).

DEWOW Variables

There are no input parameters required for this application.

8.2.2 DC Shift

While the DEWOW process (see Section 8.2.1: Dewow on page 68) automatically removes any low frequency “wow” from the data, sometimes it may be desirable to perform a DC shift on the data in addition to, or instead of DEWOW. For example, tests have shown that a DC shift correction applied to high frequency radar data (collected with the pulseEKKO 1000) rather than a DEWOW correction may be more effective in reducing correction artifacts.

DC_SHIFT is used to remove a DC level from all the traces in the input data set. The DC level to be removed can be manually input by the user or calculated by the program.

With an input DC level, the value is subtracted from all the points in all the traces in the data set.

If DC_SHIFT calculates the DC level to be removed, it calculates a new DC level for each trace in the profile. This is done by taking all or a specified range of points in each trace and calculating a DC level for that trace. This value is then subtracted from each point in the trace. This process is repeated for each trace in the data set. Typically, traces will have approximately the same DC shift in a given data set.

DC Shift Variables

The Toggle checkbox toggles program calculated DC level based on start and end points specified or user-input DC Level.

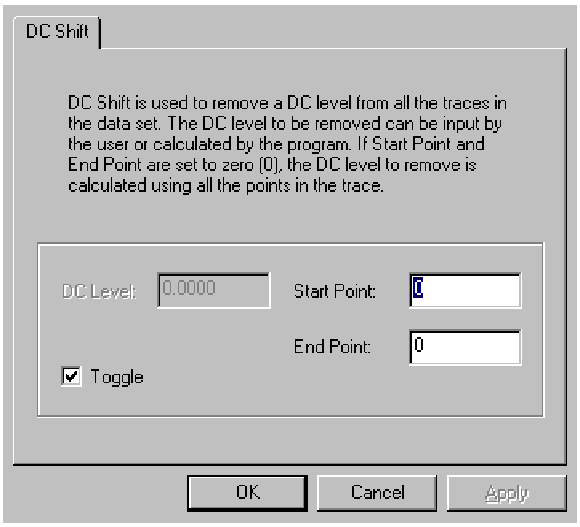
The parameters needed for this application are:

Start, End Point Start and end points used for the computation of DC level to be subtracted from trace data.
If both are zero, all points in the trace are used in the computation.

DC Level User input DC level to subtract from each point in all the data traces in the profile.

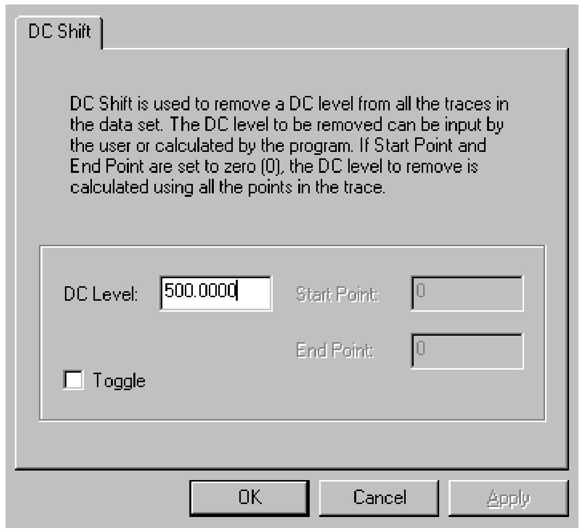
Example 1

To apply a DC shift calculated by the program based on all the points in the trace fill the parameter screen as follows:



Example 2

To apply an input DC shift of 500 use the Toggle selection to change input to user-input DC level and fill the parameter screen as follows:



8.2.3 Bandpass

Bandpass filtering is a common practice when the signal to be observed is contained in a limited portion of the spectrum recorded and where there is considerable "noise" energy in the remainder of the spectrum. By bandpass filtering, the desired signals can be enhanced at the expense of the out of band noise. Bandpass is designed around the use of Fourier transform filtering concepts.

The use of Fourier transform based filtering is quite common in the geophysical realm and many texts and papers describe the concepts very well. In the following, we only provide a brief outline of the processing so that the user will understand how we have implemented the filtering and can anticipate what side effects improper application of the filtering may induce.

In the present program, filtering is restricted to zero phase bandpass filtering. To describe the transfer function of a bandpass filter one has to define its lower and upper cut-off frequencies. In addition, the sharpness of the cut-off at either end of the pass band must quantified.

To keep things simple, the transfer function of the filter used in this program is characterized by four frequencies, f1, f2, f3, and f4. The filter has 0 amplitude at all frequencies below f1 and above f4. In the pass band between frequencies f2 and f3, the filter has unit amplitude. Between f1 and f2 and f3 and f4, the transition from zero amplitude to unit amplitude is a cosine curve that gives a smooth transition.

Each radar trace is a time series which can be viewed as being composed of a superposition of Sinusoidally signals. With a Fourier transform based filter, a radar trace is decomposed into its spectral (sinusoidal) components by the use of a Fourier transformation algorithm, the spectral amplitudes multiplied by the filter transfer function, and the resultant spectrum is inverse Fourier transformed to create the filtered radar trace.

The most efficient way of Fourier transformation is to exploit the Fast Fourier Transform (commonly referred to as the FFT) algorithm. The FFT algorithm is based on the assumption that the times series being processed is one cycle of an infinitely recurring signal. While this is not strictly true, by extending a finite time series with zeros and tacitly assuming periodicity, one can use the FFT algorithm with impunity to carry out a periodic convolution operations. BANDPASS uses this approach.

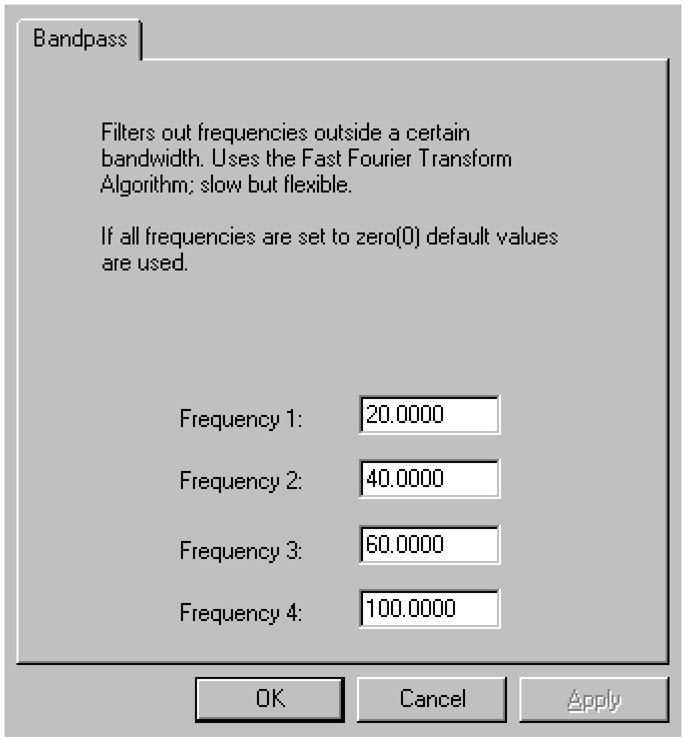
Bandpass Variables

The parameters needed for this application are:

Freq1-Freq4 Corner frequencies to define the bandpass trapezoid.
They must be ascending order. It is suggested that the slope of the high frequency side be less steep than the slope of the low frequency side to minimize filter artifacts on the data.
If all 4 frequency fields are zero (0) default frequencies of 40%, 80%, 120% and 160% of the antenna frequency are used.

Example 1

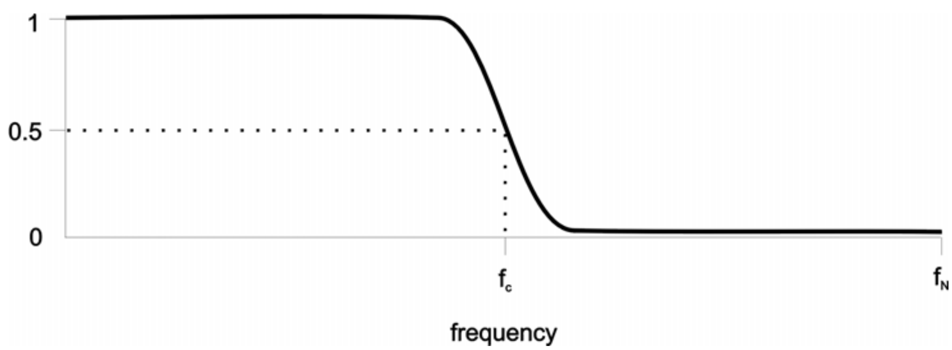
To apply a Bandpass filter with corner frequencies of 20, 40, 60, 100 MHz on 50 MHz radar data fill the parameter screen as follows:



8.2.4 Lowpass

Lowpass is a low pass recursive filter designed to be a fairly quick time domain based filter for low pass filtering of radar traces in the time domain. The filter is slightly better than the simple box car running average filter (see Section 8.2.6: Vertical on page 76) in that its high frequency side lobes are much suppressed. The frequency domain character of the low pass recursive filter is shown below. In order to implement this filter efficiently, only select cut off frequencies between 10% and 90% of the Nyquist frequency can be implemented.

Note that the Nyquist frequency of a data file can be determined by plotting the Average Amplitude Spectrum (see Section 6.7: Average Amplitude Spectrum Plot on page 26) and looking at the highest frequency on the frequency axis.



The filter is a zero phase an infinite impulse response and is applied recursively. This type of filter is used to selectively cutoff high frequency components in the data.

Lowpass Variables

The parameters needed for this application are:

Cutoff Percent Frequency below which data are preserved and above which data are removed.
As a percentage of the Nyquist frequency in 10% increments from 10%-90%.
The Nyquist frequency is calculated as:

$$F_{nyq} = \frac{1}{2 \cdot SamplingInterval}$$

For example:

If sampling interval is 0.8 ns

Fnyq = 1/(2 * 0.8 X 10-9) = 625 MHz

Therefore, possible cutoff frequencies that correspond to cutoff percentages are:

10% = 62.5 MHz
20% = 125 MHz
30% = 187.5 MHz
40% = 250 MHz
50% = 312.5 MHz
60% = 375 MHz
70% = 437.5 MHz
80% = 500 MHz
90% = 562.5 MHz

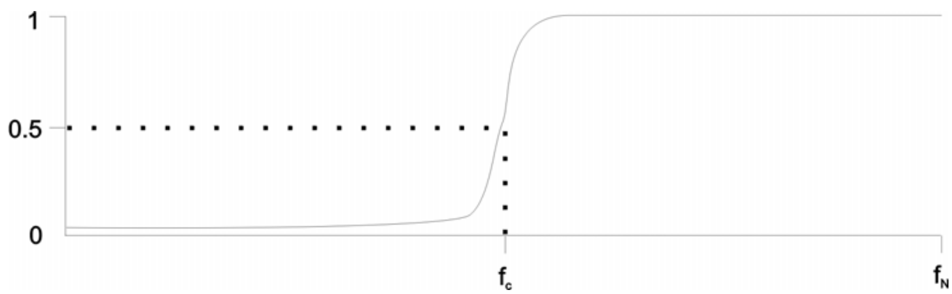
8.2.5 Highpass

The high pass recursive filter complements the low pass recursive filter by retaining low frequency content in the signal. The typical frequency domain characteristics of the filter are as shown below. In order to implement this filter efficiently, only select cutoff frequencies between 10% and 90% of the Nyquist frequency can be implemented.

Note that the Nyquist frequency of a data file can be determined by plotting the Average Amplitude Spectrum (see Section 6.7: Average Amplitude Spectrum Plot on page 26) and looking at the highest frequency on the frequency axis.

The high pass recursive filter is an infinite impulse response zero phase filter. Input of a spike results in a symmetric high pass filtered wavelet.

Applications of the high pass recursive filter include such features as replacing the DEWOW filter commonly applied to radar data. As well, the combination of the low pass recursive and the high pass recursive filter can be used to create a selected band pass filter.



Highpass Variables

The parameters needed for this application are:

Cutoff Percent Frequency above which data are preserved and below which data are removed.
The cutoff frequency is defined as a percentage of the Nyquist frequency in 10% increments from 10%-90%.
The Nyquist frequency is calculated as:

$$F_{nyq} = \frac{1}{2 \cdot SamplingInterval}$$

For example:

If sampling interval is 0.8 ns

Fnyq = 1/(2 * 0.8 X 10-9) = 625 MHz

Therefore, possible cutoff frequencies that correspond to cutoff percentages are:

10% = 62.5 MHz
20% = 125 MHz
30% = 187.5 MHz
40% = 250 MHz
50% = 312.5 MHz
60% = 375 MHz
70% = 437.5 MHz
80% = 500 MHz
90% = 562.5 MHz

8.2.6 Vertical

The Vertical Filter is used to apply a running average filter vertically (down the trace) along a profile of data. The signal is averaged by replacing the data value at a given point by the average data value over a window centered about that point. Its primary purpose is to reduce random or high frequency noise by acting as a low pass temporal filter.

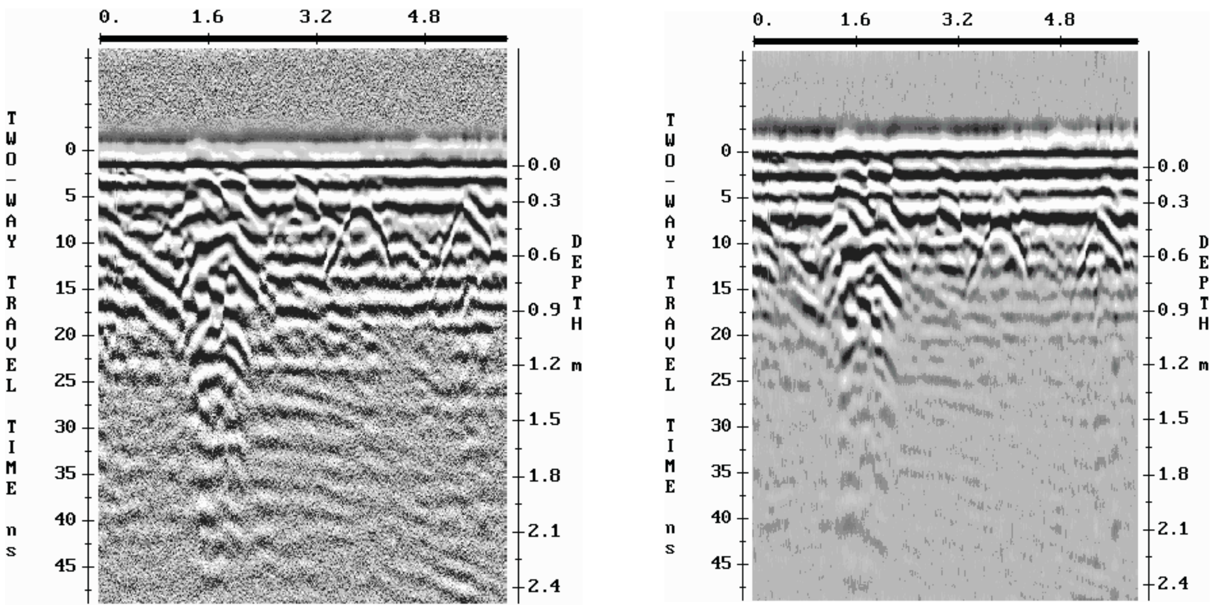


Figure 8-11: Showing a data section before (left) and after (right) noise filtering. Noise filtering is a low pass filter that smooths the data by removing the high frequency component.

To illustrate the process, if the averaging window is 5 points, then the program calculates point #10 by averaging points 8 through 12 inclusive. Point #11 is the average of points 9 through 13, and so on. If the number of points to average is even, then the extra point is taken from the 'upper' side, i.e. from the lower point number.

The more points used in the noise filter, the more high-frequency data will be removed from the data. Typical values for the number of points in the filter are 3 to 21. However, there's a simple calculation that can be performed to determine how many points to use in the averaging window. Say you would like to filter out high frequency noise that's affecting your data. First, estimate from a plot of the data profile the length (in nanoseconds) of the noise. Pick a typical noise cycle from the section and measure the peak-to-peak or trough-to-trough time length. Then divide this number by the sampling interval in nanoseconds per point. (If you are not certain what the sampling interval is, look at the value displayed under Sampling on the GPR data spreadsheet and divide by 1000) This gives you the length of the noise cycle in points (round up to the nearest whole number if necessary). To average out this noise you must use a window equal to or greater than this number.

This process is similar to the filtering performed by the recursive temporal filters Lowpass and Highpass, and the Fast Fourier Transform bandpass filter Bandpass except for one important difference. Since Vertical is an averaging filter, it uses an equal weighting to all the points in the window. Lowpasss, Highpass and Bandpass on the other hand use unequal weighting to points in their windows. This generally means that the Vertical program has less calculations to perform and runs faster than the Lowpass, Highpass and Bandpass programs.

VERTICAL Variables

The parameters needed for this application are:

Numpoints The number of points added together to produce the average point.
Must be greater than one.
Default value is 3.

8.2.7 Median

Median is used to apply an alpha-mean trim filter vertically (down the trace or temporally) to a data set. The signal is filtered by replacing the data value at a given point by the median data value over a window centered about that point. Its primary purpose is to eliminate high frequency noise spikes which sometimes occur in the data.

The Filter Width (in points) and Mean (in points) are input by the user.

To illustrate the process, if the Filter Width is 3 points and the Mean is 1 point, then the program calculates the new value of point #10 by using the comparing the values of points 9, 10 and 11. For example, if point #9 has a value of 2850, point #10 is 29067 and point #11 is -123, the filter arranges the values in ascending order (in this case -123, 2850 and 29067) and uses the middle value (in this case 2850). In this way, single point noise spikes (like 29067 above) are eliminated from the data. The number of points in the Filter Width can be any odd number greater than 1 but in practice 3 points is sufficient for most purposes.

If the Filter Width is 7 points and the Mean is 3 points, then the program calculates the new value of point #10 by using the comparing the values of points 7, 8, 9, 10, 11, 12 and 13. Again, the filter arranges the values in ascending order and this time uses the average value of the middle 3 points.

Median Variables

The parameters needed for this application are:

Filter Width Number of points in the temporal alpha-mean trim filter.
Must be an odd value greater than 1.
Default value is 3.

Mean Number of points in the middle of the Filter Width to use in the calculation of the mean.
Must be an odd value.
Default value is 1.

8.2.8 Deconvolution

The predictive deconvolution algorithm follows most of the standard seismic processing concepts (for an overview, see Yilmaz, O., 1987, Seismic Data Processing; Investigations in Geophysics No. 2: Society of Exploration Geophysicists.). Deconvolution attempts to convert a radar wavelet into a spike.

Unlike seismic signals, GPR wavelet signals are more like zero-phase than minimum phase wavelets. In addition, estimation of the GPR wavelet based on the seismic approach that the autocorrelation of the data trace yields a reliable estimate of the excitation wavelet is just not a reliable approach. Therefore, Deconvolution uses the GPR centre frequency to constrain the wavelet estimation process.

The program uses the following logic for deconvolution:

1. The GPR signal is assumed to be an idealized dipole wavelet with 1 -2 1 basis.
2. The desired output is a triangular pulse.
3. The deconvolution filter is created using the Weiner least squares approach traditional in the seismic literature. The process requires the computation of the GPR wavelet autocorrelation and the cross correlation of the GPR wavelet and the desired triangular waveform. The least squares solution generates a Toeplitz matrix which is iteratively solved to estimate the deconvolution filter.
4. The wavelet is zero phase so the deconvolution requires a finite lag to achieve proper pulse shaping. The lag must be at least as much as the half length of the GPR wavelet. Experience has shown somewhat larger lags may improve the spiking performance but at the expense of somewhat longer effort and memory needs. This is less and less of a concern as computer memory increases and CPU speeds increases.
5. The GPR data traces are then convolved with the deconvolution filter to provide the filtered deconvolved GPR data set in the .dt1 file.
6. This program applies the process described and uses the Numerical Recipes canned code for Toeplitz matrix inversion.

Deconvolution Variables

The parameters needed for this application are:

Frequency is the centre frequency of the GPR signal.
If set to zero, the default value is the centre frequency of antennas.

Filter Width is the width of the decon filter in nanoseconds.
If set to zero, the default value is 3 pulse widths at centre frequency.

Delay is the amount of time lag (in nanoseconds) between input signal and the output spike. Should be equal to 0.5*FILTER_WIDTH.
If set to zero, the default value is 1.5 pulse widths at centre frequency.
To get good results should be the Filter Width > Delay + Spike Width.

Spike Width is the width of the output triangular spike in nanoseconds.
If set to zero, the default value is 0.3 pulse widths at centre frequency.

Whiten is a factor from 0.0-1.0 to stabilize the deconvolution filter estimation.
If set to zero, the default value is 0.1.

8.3 Spatial Filters

Spatial filters act on radar data in the spatial (or position) direction. These filters use adjacent traces during the filtering procedure. They alter the shape of the trace through various mathematical manipulations designed to enhance or eliminate certain features.

It is important to line up the data traces of a profile on a horizontal datum before using certain programs in EKKO_View Deluxe. Specifically, all the spatial filters (Horizontal, Binomial, Highpass, Lowpass, Median, Trace Difference, Background Subtraction) and the Operations routines Add Section and Subtract Section apply trace to trace processes. These programs expect the first breaks to line up horizontally otherwise they may produce unexpected results. Use Datum Timezero (see Section 7.6.2: Datum Timezero on page 54) to perform this datuming.

8.3.1 Horizontal

Horizontal is used to apply a running average filter horizontally along a profile of data. It replaces each trace with an average trace produced by adding two or more adjacent traces together. Its primary purpose is to emphasize flat-lying or slowly dipping reflectors while suppressing rapidly changing ones (i.e. diffraction tails or random noise).

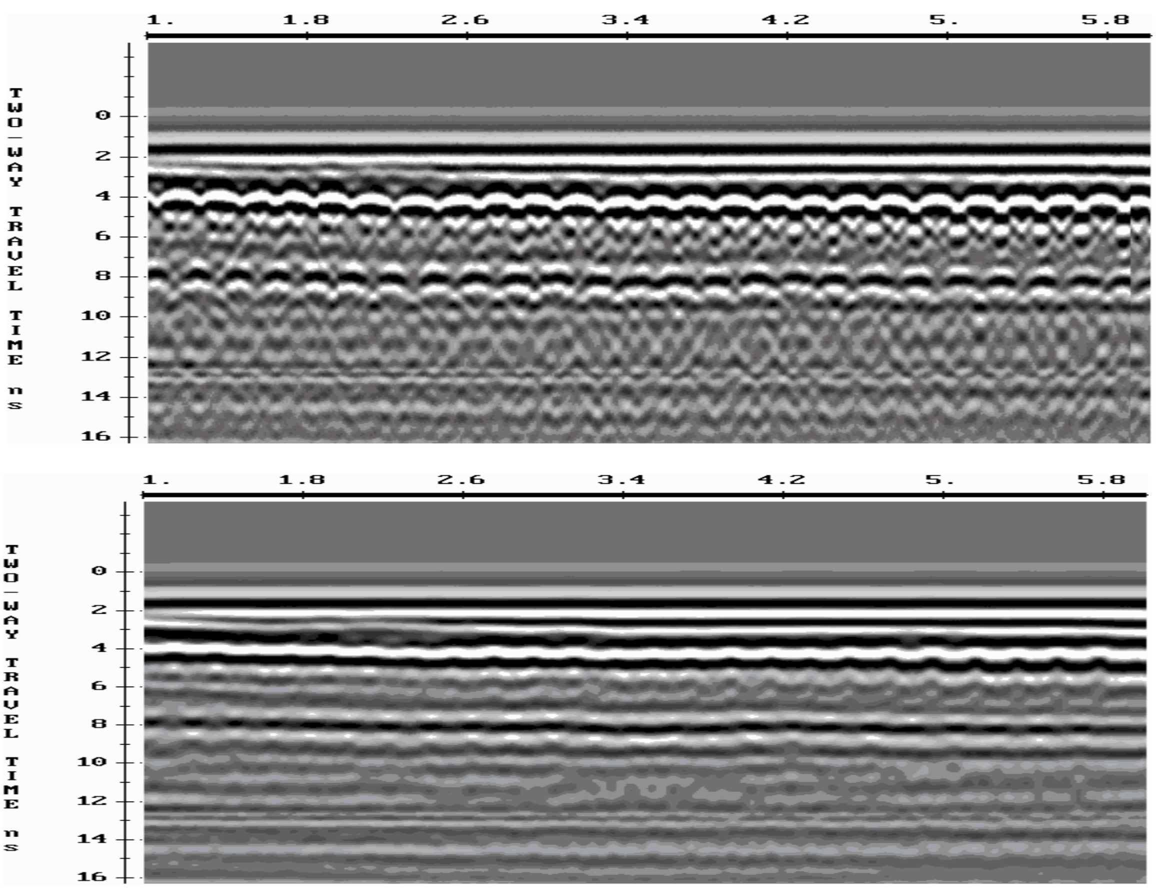


Figure 8-12: A data section before (top) and after (bottom) trace to trace averaging. This process is effective for suppressing dipping reflectors like the responses from point targets while enhancing flat-lying responses like material or soil layers.

The user must specify the number of traces to be added together. This value must be greater than one. To illustrate the processing performed consider the case of averaging 3 traces. Suppose the program is ready to process trace number 5. It reads traces 4, 5, and 6, finds the average of the three traces and uses the average trace in place of trace 5. It then does the same thing with trace 6, and so on. If the number of traces to average is even, then the extra trace is taken from the 'left' side, i.e. from the lower trace number.

This process is similar to the filtering performed by the recursive spatial filters Lowpass and Highpass except for one important difference. Since Horizontal is an averaging filter, it uses an equal weighting to all the traces in the window. Lowpass and Highpass, on the other hand, use unequal weighting to traces in their windows. This generally means that the Horizontal routine has less calculations to perform and runs faster than the Lowpass and Highpass routines.

Horizontal Variables

The parameter needed for this application is:

Numtraces The number of traces added together to produce the average trace.
Must be greater than 1 and cannot exceed the number of traces in the profile.
The default value is 3.

8.3.2 Binomial

Binomial is used to apply a binomial running average filter horizontally (trace to trace) along a profile of data. It replaces each trace with a weighted average trace produced by adding two or more adjacent traces together. Its primary purpose is to emphasize flat-lying or slowly dipping reflectors while suppressing rapidly changing ones (i.e. diffraction tails or random noise).

Binomial is similar to Horizontal (see Section 8.3.1: Horizontal on page 80), except that unlike Horizontal, the filter width (in traces) that Binomial uses is tapered on the ends. This means that traces in the centre of the running average window are weighted more in the averaging calculation than traces towards the ends.

The number of traces added together is input by the user and providing the number is an odd number greater than one, processing proceeds. To illustrate the processing performed let's consider the case of averaging 3 traces. Suppose the program is ready to process trace number 5. It reads traces 4, 5, and 6, finds the average of the three traces and uses the average trace in place of trace 5. It then does the same thing with trace 6, and so on.

Binomial Variables

The parameter needed for this application is:

Numtraces The number of traces added together to produce the average trace.
Must be odd, greater than 1 and cannot exceed the number of traces in the profile.
The default value is 3 traces.

8.3.3 Lowpass

The spatial low pass recursive filter operates in exactly the same manner as the low pass time domain recursive filter. In this case the filtering is applied to the spatial direction rather than the time direction. The cutoff frequencies are picked in exactly the same manner. The frequency response in the spatial domain is exactly the same as the transfer function sketched in the discussion under low pass recursive temporal filters (see Section 8.2.4: Lowpass on page 74).

This filter is useful for providing a smoother filter with less severe frequency domain side lobes than available from the simple running box car average filter (see Section 8.3.1: Horizontal on page 80). Long wavelength spatial signals can be enhanced and short spatial variations suppressed. The filter would be applied to enhance flat line stratigraphy or slowly varying features in the ground. Some applications of this type of filter include suppressing diffraction tails so that the main geologic stratigraphy is more visible. The filter is zero phase so that a symmetric response is generated by any feature when passed through this filter.

Lowpass Variables

The parameters needed for this application are:

Cutoff Percent Spatial frequency above which data are removed and below which data are preserved.
The cutoff frequency is defined as a percentage of the spatial Nyquist frequency in 10% increments from 10%-90%.
The Nyquist frequency is calculated as:

$$F_{nyq} = \frac{1}{2 \cdot Stepsize}$$

For example:

If stepsize is 1.0 metres

Fnyq = 1/(2*1.0) = 0.5 cyc/metre

Therefore, possible cutoff spatial frequencies that correspond to cutoff percentages are:

10% = 0.05 cycles/m
20% = 0.10 cycles/m
30% = 0.15 cycles/m
40% = 0.20 cycles/m
50% = 0.25 cycles/m
60% = 0.30 cycles/m
70% = 0.35 cycles/m
80% = 0.40 cycles/m
90% = 0.45 cycles/m

8.3.4 Highpass

The spatial high pass recursive filter is the complement of the spatial low pass recursive filter. In this case long wavelength spatial signals can be suppressed and short spatial variations enhanced. The spatial frequency response is identical to that for the temporal high pass recursive filter as sketched in the discussion under high pass recursive temporal filters (see Section 8.3.4: Highpass on page 84).

The application of this filter is to enhance localized features at the expense of strong long wavelength features such as stratigraphy or flat lying horizons. This filter is of particular use for enhancing diffraction tails and scattering features. For pipe location and buried object location this can be a useful filter to apply.

Highpass Variables

The parameter needed for this application is:

Cutoff Percent Spatial frequency above which data are preserved and below which data are removed.
The cutoff frequency is defined as a percentage of the spatial Nyquist frequency in 10% increments from 10%-90%.
The Nyquist frequency is calculated as:

$$F_{nyq} = \frac{1}{2 \cdot Stepsize}$$

For example:

If stepsize is 1.0 metres

Fnyq = 1/(2*1.0) = 0.5 cyc/metre

Therefore, possible cutoff spatial frequencies that correspond to cutoff percentages are:

10% = 0.05 cycles/m
20% = 0.10 cycles/m
30% = 0.15 cycles/m
40% = 0.20 cycles/m
50% = 0.25 cycles/m
60% = 0.30 cycles/m
70% = 0.35 cycles/m
80% = 0.40 cycles/m
90% = 0.45 cycles/m

8.3.5 Median

Median is used to apply an alpha-mean trim filter horizontally (trace to trace or spatially) along a profile of data. The signal is filtered by replacing the data value at a given point by the median data value of points from adjacent traces in a window centered about that point. Its primary purpose is to filter out single bad traces from the data. Bad traces can occur for a variety of reasons including collecting data too close to a highly conductive object i.e. a manhole cover or fence. Often the trace is 'ringy' with a single frequency dominating the trace and obscuring the desired signal. These traces make a section difficult to interpret so this filter is designed to eliminate these traces.

The Filter Width (in traces) and Mean (in traces) are input by the user.

To illustrate the process, if the Filter Width is 3 traces and the Mean is 1 trace (like a median filter), the program calculates point #5 in trace #12 by using the median value of point #5 in traces 11, 12, and 13. For example, if point #5 in trace #11 has a value of -23431, point #5 in trace #12 is 168 and point #5 in trace #13 is -1248, the filter arranges the values in ascending order (in this case -23431, -1248 and 168) and uses the middle value (in this case -1248). In this way extreme values (like -23431 above) are eliminated from the data.

If the Filter Width is 7 traces and the Mean is 3 traces, then the program calculates the new value of point #10 in trace #37 by using the comparing the values of points 10 in traces 34, 35, 36, 37, 38, 39 and 40. Again, the filter arranges the values in ascending order and this time uses the average value of the middle 3 points.

Median Variables

The parameters needed for this application are:

Filter Width Number of traces in the spatial alpha-mean trim (median) filter.
Must be an odd value greater than 1.
The default value is 3.

Mean Number of traces in the middle of the Filter Width to use in the calculation of the mean.
Must be an odd value.
The default value is 1.

8.3.6 Trace Difference

With trace differencing, each trace is replaced by the difference between itself and the previous trace (except for the first trace which is obtained by taking the difference between itself and the second trace).

This has the effect of enhancing rapidly changing features in the profile (i.e., diffraction tails, point reflectors, like pipes and barrels) and suppressing flat-lying and constant features. This filter is a simple high pass spatial filter.

Trace Difference Variables

There are no input parameters required for this application.

8.3.7 Background Subtraction

Background Subtraction is used to apply a running-average background subtraction to the data set. A window of traces is averaged and the resultant is subtracted from the trace in the centre of the window. The window moves along one trace and the process is repeated.

This process has the effect of enhancing dipping events (like diffraction tails) and suppressing horizontal events. This can be very useful for removing localized flat-lying events.

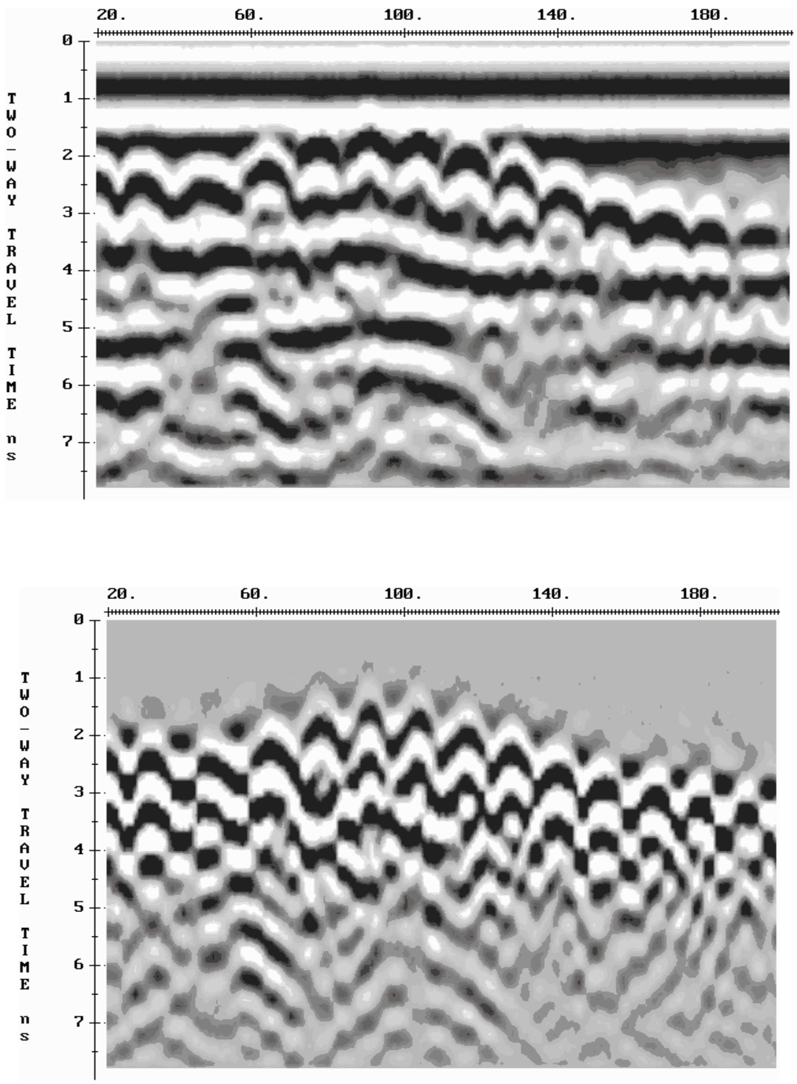


Figure 8-13: Showing a data section before (top) and after (bottom) background subtraction. This process is effective for emphasizing dipping reflectors like the responses from point targets like pipes.

The more traces used in the background subtraction process, the more flat-lying reflections will remain in the data. To remove all flat-lying events from data, set the number of traces to 3.

To illustrate the processing performed, let's consider the case of spatially differencing 5 traces. Suppose the program is ready to process trace number 9. It reads traces 7, 8, 9, 10, and 11, finds the average of the five traces, subtracts that average trace from the original trace 9 and puts the resultant in place of trace 9. It then does the same thing with trace 10, and so on.

Background Subtraction is similar to the trace differencing routine (see Section 8.3.6: Trace Difference on page 86), but because it averages over several traces rather than one, it tends to be less severe in its removal of horizontal events. The more traces in the Background Subtraction window, the more horizontal features remain in the data.

Rather than setting a number of traces for the background subtraction process, the user can select the “All Traces” checkbox. The subtracted average trace is the average trace calculated using all the traces in the file. This option is useful when the flat-lying reflectors to remove from the data are present throughout the length of the cross section data.

Background Subtraction Variables

The parameter needed for this application is:

Numtraces The number of traces in the running-average window added together in the spatial trace-differencing filter.
Must be odd and cannot exceed the number of traces in the profile.
The default value is 3 traces.

8.4 2D Filters

8.4.1 Migration

The migration process applies a synthetic aperture image reconstruction process to the data set. The process tends to focus scattered signals, i.e. collapsing hyperbolic responses to point targets.

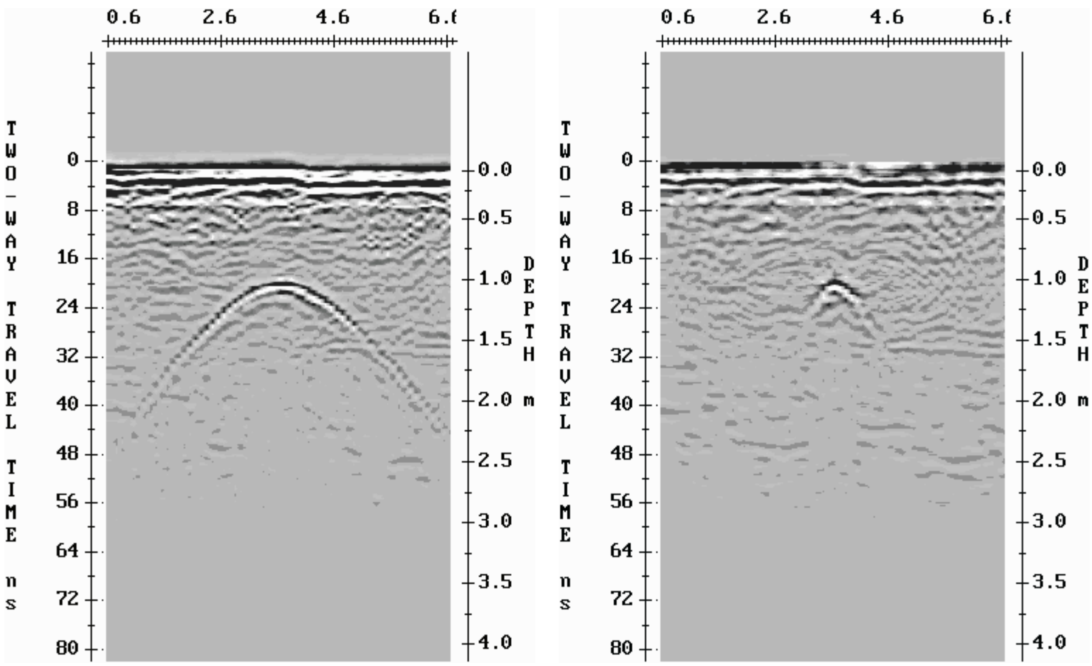


Figure 8-14: Showing a section before (left) and after (right) migration. Migration can "refocus" energy scattered along a hyperbola (the characteristic response of a point target) back to a point. This can improve the spatial accuracy of the data.

Migration Variables

Velocity Radar velocity to use in the synthetic aperture process.
Must be 0.01 to 0.30 metres/nanosecond.
Typical velocities of geological materials is 0.06 to 0.15 metres/nanosecond.
The default value is 0.1 metres/nanosecond.

Spatial Offset The window width (in metres) to use for the synthetic aperture process.
If set to zero, a program calculated value, based on the velocity and time window, is used.

Scale Scale factor between 0.01 and 1.0 to multiply data by.
The synthetic aperture process tends to gain the data (even sometimes causing it to be clipped at the ±32767 data limits) and the scale factor reduces this gain effect.
The default value is 0.2.

8.4.2 Dip Filter

Dip Filter applies a binomial spatial weighting differencing filter at a particular dip angle. It is used to enhance events at a certain dip angle.

Dip Filter Variables

Dip Slope The moveout slope in nanoseconds per metre. This is the slope angle that will be enhanced.
Must be between -30 and +30 nanoseconds per metre.

Filter Width The width of the binomial spatial weighting differencing filter in traces.
The default value is 3 trace.

Scale Scale factor between 0.01 and 1.0 to multiply data by.
Dip filtering may tend to gain the data and the scale factor reduces this gain effect.
The default value is 1 (no scaling).

8.5 Attributes

Since this is an involved topic, it is strongly suggested that those unfamiliar with it refer to outside references. (A good one is: Yilmaz, O., 1987, Seismic Data Processing; Investigations in Geophysics No. 2: Society of Exploration Geophysicists.) Only a brief description of the topic will be discussed here.

While we normally only plot and interpret the real part of a complex-valued signal, the imaginary (or quadrature) component can be used to reveal some useful information about the signal. These attributes, usually called 'instantaneous attributes', include instantaneous amplitude (or trace envelope), instantaneous phase and instantaneous frequency.

If a complex trace is given by:

$$z(t) = x(t) + iy(t)$$

where $x(t)$ is the real component of the trace

and $y(t)$ the imaginary component of the trace

Instantaneous Amplitude (or Trace Envelope) is given by:

$$e(t) = (x^2(t) + y^2(t))^{1/2}$$

Instantaneous Phase is given by:

$$\phi(t) = \mathrm{atan}\left(\frac{y(t)}{x(t)}\right)$$

and, since Instantaneous Frequency is the derivative of Instantaneous Phase, it is given by:

$$\omega(t) = \left(\frac{1}{2\pi}\right)\frac{d\phi}{dt} = \left(\frac{1}{2\pi}\right) \cdot \frac{y'(t)x(t) - y(t)x'(t)}{x^2(t) + y^2(t) + \varepsilon}$$

where $x'(t)$ and $y'(t)$ are calculated using central differences:

$$x'(t) = \frac{x_{i+1} - x_{i-1}}{2\Delta t} \quad \text{and} \quad x'(t) = \frac{y_{i+1} - y_{i-1}}{2\Delta t}$$

and ε is a constant value (defined as 1) to increase the stability of the function by preventing division by zero.

Since these attributes can only be calculated using the imaginary component of the complex trace, it is necessary that it be obtained before processing the data. This is done automatically in the Envelope, Instantaneous Phase and Instantaneous Frequency routines using the Hilbert Transform method. Basically, this method uses a time convolution approach to find the imaginary part of the trace.

8.5.1 Envelope (Instantaneous Amplitude)

The basic idea behind enveloping a trace, is to convert the trace from a wavelet with both positive and negative components to a monopulse wavelet with all positives. This is illustrated below. The process removes the oscillatory nature of the radar wavelet and shows the data in its true resolution. This process can also "simplify" the display of a radar section making it, perhaps, easier to interpret.

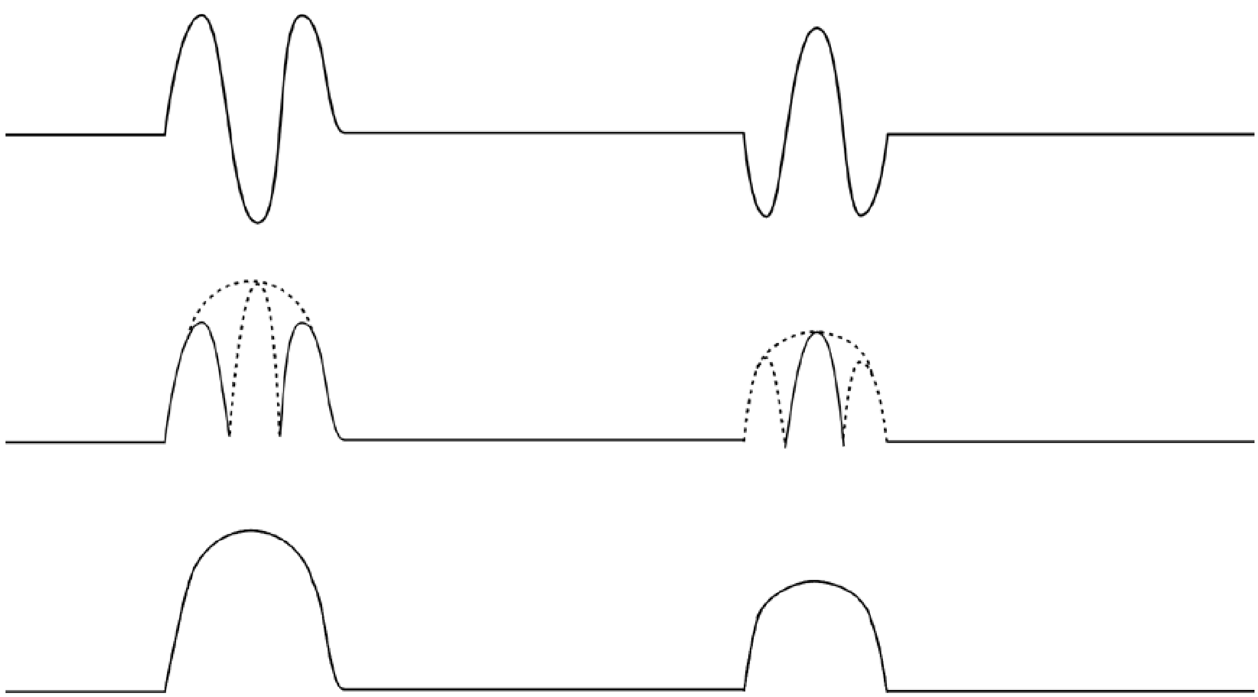


Figure 8-15: The original trace (top) consists of positive and negative components. The enveloping process makes the negative component positive (middle) and smooths the outline of the wavelet (bottom).

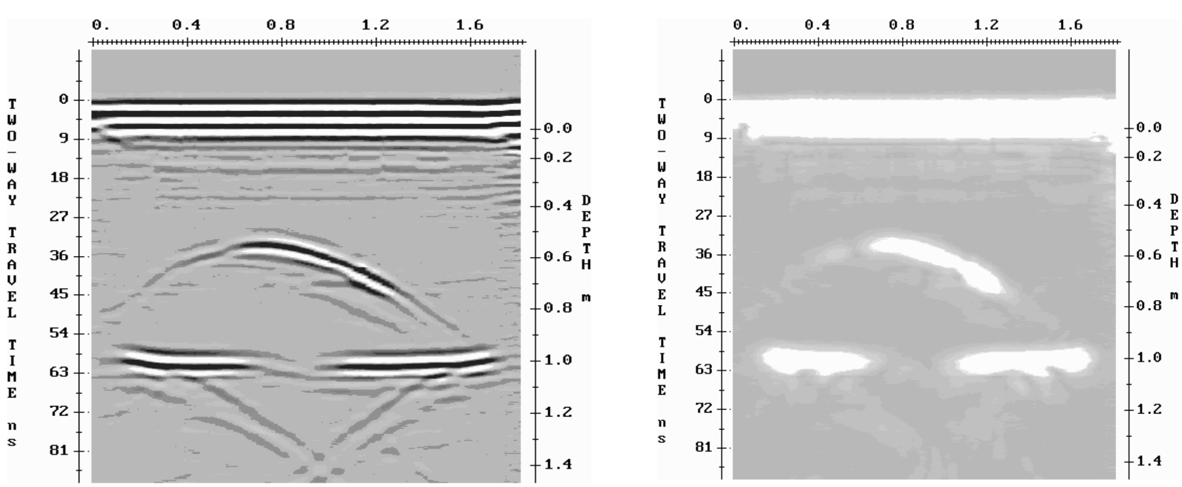


Figure 8-16: A data section before (left) and after (right) enveloping. Enveloping "simplifies" the data by removing the oscillatory nature of the radar wavelet and shows the data in its true resolution.

The mathematical definition of instantaneous amplitude is shown above. The instantaneous amplitude outlines the envelope of the trace. It is independent of phase, that is, it may have its maximum at points other than the peaks and troughs of the real trace, especially where an event is the composite of several reflections. While it is often referred to as "reflection strength", some believe that this term places a dubious interpretational assumption on the true meaning of instantaneous amplitude. They suggest that the envelope of a trace is simply an interpretational tool that describes waveform shape. Interpretation is aided by comparing the constancy of reflection character.

Envelope Variables

Filter Width is the width of the filter in nanoseconds.
If set to zero, the default value is 1.5 pulse widths.

8.5.2 Instantaneous Phase

The mathematical definition of instantaneous phase is show above. It is used to emphasize the continuity of events. Since phase is independent of the trace envelope, it can often make weak coherent events more prominent, even events that interfere with one another. Instantaneous phase is always measured between $-\pi$ and $+\pi$ and therefore data tends to have a sawtooth appearance.

Instantaneous Phase Variables

Filter Width is the width of the filter in nanoseconds.
If set to zero, the default value is 1.5 pulse widths.

8.5.3 Instantaneous Frequency

The mathematical definition of instantaneous frequency is shown above. It is used as a correlation tool. The frequency character of a event will change as the lithology changes, the thickness changes or at interfaces such as pinchouts and the water table.

Instantaneous Frequency Variables

Filter Width is the width of the filter in nanoseconds.
If set to zero, the default value is 1.5 pulse widths.

8.6 Operations

8.6.1 Rectify

Rectify goes through the input data file and outputs the rectified version of each trace (i.e. the absolute value of each point in the trace).

The Rectify utility is very useful when one wants to look at the L1-norm of a data set. By rectifying a data file and then averaging all the traces together one can obtain a very useful estimate of amplitude fall-off versus time.

Rectifying a trace converts the trace from a wavelet with both positive and negative components to a wavelet with all positives.

L1 norm (rectify equation)

$$x_{Rectify} = \frac{\sum_{i=N}^{M} |x_i|}{N - M + 1}$$

At a single time or depth value the amplitude value will be the same amplitude as the raw value but always positive. When amplitude values are averaged over a time or depth range this will give the average, absolute value.

Rectify Variables

There are no input parameters required for this application.

8.6.2 Nth Power

The Nth Power utility is used to take a data set and for every point in each trace raise the data value at that point to the nth power. Note that the sign of the amplitude value is preserved during this process.

Such a utility is useful for either compressing or expanding the dynamic range of a data set. For example, raising all the data to the second power can be used to compute RMS signal levels. Raising the data set to 1/2 power can amplify weak signals and suppress large amplitude signals so that one gets a better dynamic range compression for data analysis or data plotting.

A simple illustration of the Nth Power utility would be to compute the amplitude spectra (see Section 6.7: Average Amplitude Spectrum Plot on page 26) for every trace in a data set. The average amplitude would then be obtained by computing the average trace in the data file. The power spectrum would then be computed by applying Nth Power to the result to square the amplitudes in the file.

Nth Power Variables

Power	The value of the exponent to raise each point of the profile data to. The value must be non-zero and positive.

8.6.3 Threshold

Threshold is used to zero all amplitude data points below an input threshold. This threshold is based on a percentage of the maximum amplitude in the trace. For example, if the maximum amplitude in a trace is 28967 and the cutoff percentage is set to 40 percent, all amplitude values below 11587 will be set to zero.

This routine is useful for emphasizing high amplitude signals.

Threshold Variables

Cutoff Percent The percentage of the maximum amplitude that determines the threshold. Amplitude values below this threshold are zeroed.

8.6.4 Amplitude Spectra

Amplitude Spectra uses the Fourier Transform to calculate the amplitude spectrum of each trace in the input data file.

The amplitude spectrum is a plot of amplitude versus frequency and consequently reveals the frequency composition of the trace. This can be extremely useful information in determining which filter or processing technique would be the most effective in eliminating noise or emphasizing the desired signal.

Probably the most popular processing stream using Amplitude Spectra is used by the Average Amplitude Spectrum routine (see Section 6.7: Average Amplitude Spectrum Plot on page 26). Amplitude Spectra is run on the radar profile to calculate the amplitude spectrum of each trace. Then the average amplitude spectrum is calculated and displayed. This can be used to decide an appropriate filter to apply to the profile data.

It is also possible to plot an amplitude spectrum section like a radar data section to see how the frequency content varies over the survey line.

Amplitude Spectra Variables

Factor Factor to multiply all of the amplitude spectrum values by.
The default value is 1.0 which is perfectly adequate for most applications.

8.6.5 Subtract Section

Subtract Section will take two files of identical sizes and subtract them. The operation reads in the trace from the input file and subtracts the corresponding trace from the defined subtract file and stores the difference. Such an operation has a wide variety of applications.

The general type of use of this tool is to apply some process to a data set and save the result. The original data set and the processed data set are then differenced and the resultant output is used to be diagnostic of a particular feature in the data. One such example would be to apply a temporal median filter to the data and then subtract the median filtered data from the original data set. The result would be a display of the data which had been pruned by the median filter.

Another example of such an operation would be to carry out a long wavelength running average spatial filter. The filtered data set would then be subtracted from the original data set and the resulting data set would contain the high pass localized features in the data set. Obviously, many other types of operations can be used for both noise diagnostic and any combination of filtering. For example, the high pass recursive filter result can be obtained by applying a low pass recursive filter operation and subtracting the two data sets.

Special Notes:

- This program will only perform a straight subtraction of the two files so it is assumed that both profiles have been shifted to the same timezero using Repick Timezero (see Section 7.6.1: Re-pick Timezero on page 53) or Edit Timezero (see Section 7.6.3: Edit Timezero on page 55).
- Both files must have exactly the same number of traces and points in each trace.

Subtract Section Variables

File Name Drive/path/name of the second of the two data sets to be differenced. No extension is required because .DT1 and .HD extensions are assumed.

8.6.6 Add Section

Add Section will take two files of identical sizes and add them together. This is a very powerful tool for merging data sets together. The operation goes through two data sets and adds corresponding traces together and writes the new trace to the output data file.

A wide variety of applications can be addressed with this utility. The most common is to display multiple frequency data on the same section. For example the first 100 ns of a 200 MHz data file can be added to the next 200 ns of 100 MHz file and subsequently the result can be added to the next 200 ns of a 50 MHz data file etc. By using a combination of the Chop Data (see Section 7.3.5: Chop Data - Time on page 50) and Stack (see Section 7.1.2: Stack on page 29) one can create composite sections which can be very useful for displaying variable resolution versus depth.

Special Notes:

- This program will only perform a straight addition of the two files so it is assumed that both profiles have been shifted to the same timezero using Repick Timezero (see Section 7.6.1: Re-pick Timezero on page 53) or Edit Timezero (see Section 7.6.3: Edit Timezero on page 55).
- Both files must have exactly the same number of traces and points in each trace.

Add Section Variables

File Name Drive/path/name of the second of the two data sets to be added together. No extension is required because .DT1 and .HD extensions are assumed.

8.6.7 Average Trace

Average Trace is used to compute the average trace in a profile of trace data. After this process the file is a standard Sensors & Software DT1 file, but containing only a single trace.

The average trace can be viewed using the **View - Traces** option (see Section 6.2: Traces on page 23).

9 Recipes

When EKKO_View Enhanced and EKKO_View Deluxe starts, the Processing window on the bottom of the screen will be blank. The user can fill in specific processing routines one at a time from the lists of processes under **Insert Process** (see Section 3.4: Edit/Process Mode - Processing Data on page 11).

9.1 Save Recipe

It is possible to save a list of processing operations as a “Recipe” that can be loaded later and used again on another project. This is useful for preserving popular processing streams. To save the processing operations currently listed in the Processing window to a Recipe, select **Recipes – Save** from the main menu. The user is prompted to enter a name and folder for the Recipe.

Any recipe can be edited and saved as another recipe.

9.2 Load Recipe

Once Recipes have been saved, they can loaded at any time by selecting **Recipes – Load** from the main menu and selecting the name of the recipe. The list of processing operations in this recipe will then be listed in the Processing window. To process data files with the processing stream, select **Apply**.

10 Utility

This menu allows the user to edit/create a Usergain (.GAN) file (see Section 8.1.5: Usergain on page 67), a Topographic (.TOP) data file (see Section 7.1.5: Add Topography using Topo File on page 35), a Rubberband (.RUB) file (see Section 7.1.3: RubberBand on page 30) or a User GPS file (see Section 7.1.8: Add GPS Data on page 37).

Creating or editing any one of these files requires following the same steps. The required parameters are described at the top of the screen for each file. For example, the gain file requires time and multiplication factors on each line and the topography file requires line position and elevation data on each line.

Note that positional data is assumed to be in the same units as the GPR data were collected in i.e. metres if the data collected in metres and feet if the data were collected in feet.

10.1 Topography File

Here is an example of a Topography file. It must have a .TOP extension.

```
# Lines beginning with # are treated as comments
# POSITION    ELEVATION
0.0           25.2
10.4          20.5
23.5          15.6
50.2          17.1
```

10.2 Usergain File

Here is an example of a Usergain file. It must have a .GAN extension.

```
# Lines beginning with # are treated as comments
#TIME         GAIN
0.0           1
50            15
73.5          100
99            500
```

10.3 Rubberband File

Here is an example of a Rubberband file. It must have a .RUB extension.

```
# Lines beginning with # are treated as comments
#FID NUMBER   POSITION
F1            0.0
F2            25.9
F3            115.6
F4            217.1
```

10.4 User GPS File

This routine is used to create a user defined GPS text file with a GTP extension. This file lists the GPS X, Y and optionally, Z positions for two or more specific trace numbers in a GPR data file.

This routine is useful if the user has collected GPS positional information at two or more GPR trace positions along a GPR survey line and wants to interpolate GPS positions for every GPR trace in the GPR data file.

After creating a GTP file, GPS positions can be interpolated into every trace in the GPR data file using the User GPS File Method (see Section 7.1.8: Add GPS Data on page 37).

Here is an example of a User GPS file. **Columns must be separated by spaces, not TABs.** The GPZ Z position, which is elevation, is an optional item in the GTP file. The GTP file must list GPS positions in Latitude and Longitude; positions in UTM coordinates will NOT work.

```
# Lines beginning with # are treated as comments
# GPS Positions must be formatted in degrees-minutes-decimal minutes DDMM.MM)
# Latitude is GPS Y and is written in the form DDMM.MM. Latitude degrees MUST be 2 digits,
# for example, 3 degrees 28.89 minutes would be 0328.89.
# Longitude is GPS X and is written in the form DDDMM.MM.  Longitude degrees MUST be 3 digits,
# for example, 97 degrees 44.11 minutes would be 09744.11.
# Trace     GPS X        GPS Y      GPS Z (optional)
1           11021.32     4354.54     1030
500         11021.35     4354.57     1024
1000        11021.37     4354.61     1010
1250        11021.38     4354.63     1034
```

10.5 GPS Tools

10.5.1 Reformat GPS File

This routine reformats a standard NMEA-string GPS text file to extract positional information and write it to a simple column text GPS positional file.

Each NMEA string of a GPS data file has various information embedded in it. The information that is useful for GPR surveys is the XYZ positional information (X = longitude, Y = latitude and Z = elevation). This routine takes the original GPS data file and extracts the positional data and writes it to an output text file.

The original GPS data file must contain one or more of the GGA, GLL, or RMC NMEA sentences. The default NMEA sentence is GGA, but this can be changed to GLL or RMC by the user.

For example, say you have a file called \DATA\GPS.TXT that has the following GPS information in it:

```
$GPGGA,184512.00,4338.135101,N,07938.456704,W,1,04,6.3,183.13,M,-35.09,M,,*54
$GPVTG,34.0,T,,,001.4,N,002.5,K,D*70

$GPGSA,A,3,30,26,10,13,24,06,,,,,,,4.2,2.1,3.6*36

$GPGGA,184513.00,4338.135002,N,07938.456657,W,1,04,6.2,183.13,M,-35.09,M,,*50
$GPVTG,34.0,T,,,001.4,N,002.5,K,D*70

$GPGSA,A,3,30,26,10,13,24,06,,,,,,,4.2,2.1,3.6*36

$GPGGA,184514.00,4338.134870,N,07938.456641,W,1,04,6.2,183.13,M,-35.09,M,,*5C

$GPVTG,34.0,T,,,001.4,N,002.5,K,D*70
```

```
$GPGSA,A,3,30,26,10,13,24,06,,,,,,,4.2,2.1,3.6*36
```

The contents of reformatted file would be

LINE	TIME	X	Y	Z	PDOP
1	184512.00	-07938.456704	4338.135101	183.13	6.3
2	184513.00	-07938.456657	4338.135002	183.13	6.2
3	184514.00	-07938.456641	4338.134870	183.13	6.2

This routine is usually used as a pre-processor before using the Time Stamp Method routine under Data Editing - File - Add GPS Data (see Section 7.1.8.3: Time Stamp Method on page 42) to add GPS information to a GPR data file. It is also possible to take the reformatted file and, with a little bit of editing, convert it to a User GPS file (.GTP) that can be used with the User GPS File Method found under Data Editing - File - Add GPS and described in Section 7.1.8.2: User GPS File Method on page 40.

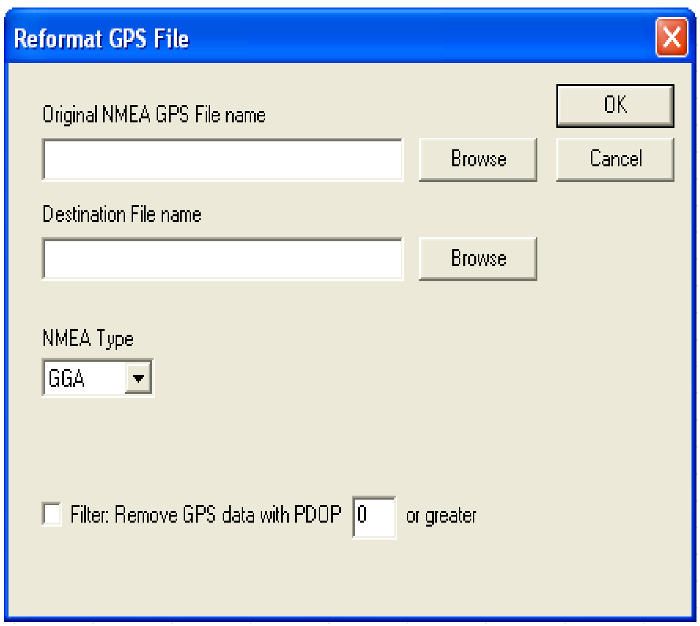


Figure 10-1: The Reformat GPS file dialog box. The user inputs the name of the original GPS file and the name of the destination file. The routine extracts information from the original GPS file and writes it to the destination file in a simple column format. The user can control which NMEA string is read from the original file and filter the data based on PDOP values, if desired.

Reformat GPS File Variables

Original GPS File The name of the original GPS file containing NMEA strings (see example above).

Destination File The name of the reformatted GPS file created by this routine (see example above).

NMEA Type The GPS data file contains certain strings of data that contain the GPS information. See the GPS User's Guide for more information.
Only the GPS information from lines with this prefix are used to create the destination file.
This program uses the GGA string as the default string.
Other string options are GLL and RMC.

PDOP The GPS data file often has a precision indicator called PDOP that provides a measure of how accurate the GPS data collected is. The higher the PDOP value, the poorer the data accuracy.
This option allows the user to remove data of poor quality.
If the user specifies a non-zero PDOP value, any GPS lines with PDOP values greater than the input value will not be written to the destination file. The default value is 0 which means that all data, no matter what the PDOP value is, will be written to the destination file.

10.5.2 View GPS File

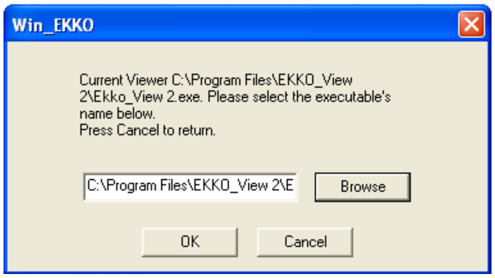
This routine is used to view a GPS file. This allows the file be edited or printed.

11 Help

11.1 Change DT1 Viewer

The Change DT1 Viewer option changes the program that displays GPR data (DT1) files.

The user is prompted to browse and select the name of the data viewer program.



The most common use of this option is for EKKO_View Deluxe and Enhanced users to update to the latest version of the EKKO_View software.

11.2 Help Topics

The Help Topics option opens this PDF document for viewing.

The Adobe Acrobat Reader program must be installed on the PC to open this document. If not, the user is prompted to download it from the Adobe website.

11.3 About

Gives details about the version of the program being used.

Appendix A: GPR Signal Artifacts

A.1 Inductive WOW Removal Artifacts

All GPR data has a low frequency component to it. The magnitude of the low frequency component and how it manifests itself in the data depends on the ground conditions around the antennas and the distance between the antennas. In general, the low frequency component of the radar signal does not propagate but diffuses into the ground. In other words the lower end of the spectrum sees an inductive (eddy current) type response as opposed to a propagating (displacement current) type response.

The result is that the large transmit pulse emitted by the radar can be followed by a slowly decaying transient (see Figure A-1). Various terms have been applied to this decaying transient. In some instances it is referred to as wow; sometimes it is referred to as system saturation recovery. These terms are historical in nature because the response was often caused by system response characteristics rather than being a ground induced response.

With this wow usually being present, it is common practice that GPR data is high pass (DEWOW) filtered. With Sensors & Software GPR systems the high pass filter is optimized to pass the transmitted signal spectral peak for the specific antenna centre frequency with fidelity and suppress the low frequency wow in the data. In the initial software releases, this high pass filtering was integral to all of the plotting and display programs. As a result the user was, in many situations, unaware of this wow or low frequency component in the data. The raw recorded data, however, always retained this information.

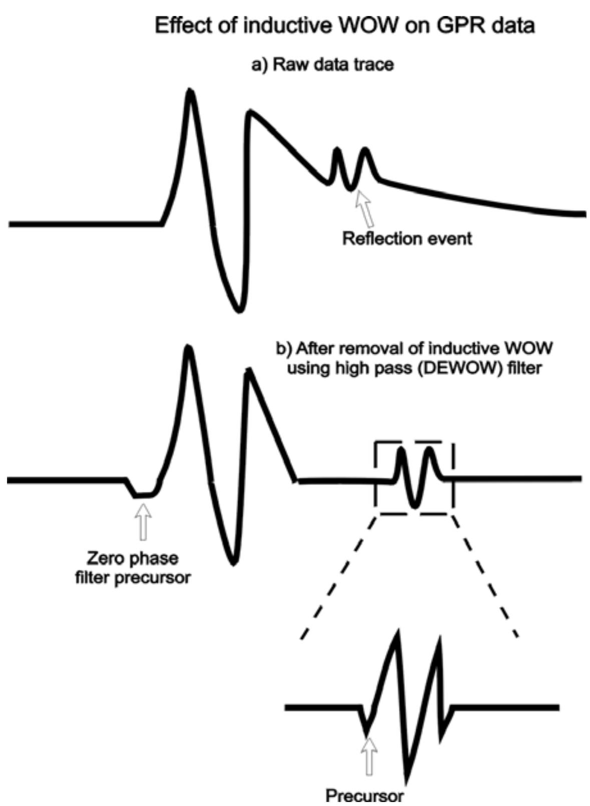


Figure A-1

The result of high pass filtering can induce two types of artifacts into the plotted data sections. The first is a pre-cursor to the onset of a pulse (Figure A-1b). When the original data are high pass filtered the wavelet is stretched in time with additional oscillations occurring before and after the original pulse. This is what gives rise to a pre-cursor in the data before time-zero when looking at the plotted sections.

For dealing with the inductive wow response, high pass filtering is necessary. If an alternative high pass filter is available or the user wishes to try a different type of high pass filtering, the raw data contains all of the information and experimentation can be carried out using the raw data. The user is directed to making use of the EKKO_View Deluxe software package. DC shift removal is another correction that may be used to reduce the wow (see Section 8.2.2: DC Shift on page 70).

A.2 Inductive WOW Clipping Artifacts

The second artifact is caused by electronic clipping. The basic concept is depicted in Figure A-2a, b and c. The original signal which is acquired by the antenna and presented to the receiver electronics looks like that sketched in Figure A-2a. The radar electronics clip any signals above the 50 millivolt level. Figure A-2b shows the type of result that will be measured if clipping occurs in the signal pre-conditioning circuitry. When these data are finally high pass filtered, a blank zone in the

area where the original signal had a large wow above the clipping level of the electronics can appear. This results in a blank section on the record with no reflections visible.

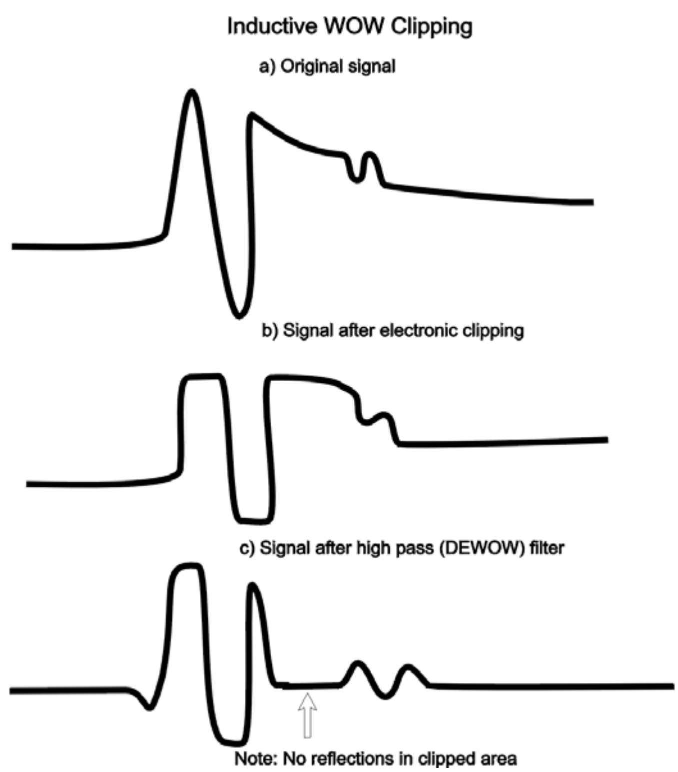


Figure A-2

In the second case where signal saturation clipping occurs, there is no software correction for this. The user must be aware that this can occur in some geologic settings and the antenna spacing should be increased to reduce the wow signal amplitude below the clipping level of the receiver electronics. As a general rule, we recommend using an antenna separation at least equal to the length of the antenna being employed. For example, 100 MHz antennas should have an antenna spacing of at least 1 metre, a 50 MHz antenna system should use an antenna spacing of 2 metres. Obviously this rule depends on the level of wow or inductive response present at the particular site. One some Sensors & Software GPR systems like the pulseEKKO, the level of wow present can be observed in Scope Mode by pressing the Filter button and turning off the Dewow filter to see the raw trace. For other systems, the wow can be observed when the data are plotted on the PC by turning off the Dewow filter in the EKKO_View software. Again, note that the processing affects only the displayed data, not the recorded data.

Appendix B: Data File Formats

(pulseEKKO, SEG-Y, ASCII 1, ASCII 2 and EAVESDROPPER)

B.1 pulseEKKO Data File Format

HEADER (.HD) FILE:

The header file, identified by the file extension .HD, is an ASCII file. An example is shown below.

```
8000
Fracture Mapping In Rock
21/09/89
NUMBER OF TRACES  = 136
NUMBER OF PTS/TRC  = 409
TIMEZERO AT POINT   = 96
TOTAL TIME WINDOW = 327
STARTING POSITION   = 9.500000
FINAL POSITION         = 77.000000
STEP SIZE USED         = 0.500000
POSITION UNITS         = metres
NOMINAL FREQUENCY = 100.000000
ANTENNA SEPARATION = 1.000000
PULSER VOLTAGE (V) = 400
NUMBER OF STACKS   = 128
SURVEY MODE            = Reflection
SIGNAL SATURATION CORRECTION APPLIED
SELECTED TRACE 20 TO 155 FROM LARGER SET
SELECTED 409 PTS. FROM ORIGINAL 640 PTS.
```

It can be read and/or printed using any Word Processor.

DATA (.DT1) FILE:

The data file contains as many records as there are traces. Each record in turn consists of a header section and a data section. The header section consists of an array of 25 real*4 numbers and a string of 28 characters which is used for annotation. The 25 element real array contains the following information:

Item #	Description
1	Trace number
2	Position
3	Number of points per trace
4	Topographic data, if available
5	(not used)
6	# bytes/point (always 2 for Rev 3 firmware)
7	Trace Number
8	# of stacks
9-10	reserved for GPS X Position
11-12	reserved for GPS Y Position
13-14	reserved for GPS Z Position
15	reserved for receiver x position
16	reserved for receiver y position
17	reserved for receiver z position
18	reserved for transmitter x position

19	reserved for transmitter y position
20	reserved for transmitter z position
21	timezero adjustment where: point(x)= point(x+adjustment)
22	Zero flag: 0 = data okay, 1=zero data
23	(not used)
24	Time of day data collected in seconds past midnight.
25	Comment flag: 1 = comment attached.
26 - 32	Comment

The data section consists of an array of two-byte integers, one value for every data point.

B.2 SEG-Y File Format

The following describes in detail which variables are loaded in the pulseEKKO to SEG-Y conversion program.

Reel Identification Header - ASCII Portion

The reel identification header is first loaded with the pulseEKKO header file (*.HD). This file is copied directly into the ASCII portion.

Reel Identification Header - Binary Portion

The following lists the variables used in the binary portion.

Bytes	Description
3201-3204	Set to zero.
3205-3208	Set to zero.
3209-3212	Set to zero.
3213-3214	Set to one for REFLECTION data. Set to # of offsets for CDP data.
3215-3216	Set to zero.
3217-3218	Sample interval down trace in psec.
3219-3220	Sample interval down trace in psec.
3221-3222	Number of points in trace.
3223-3224	Number of points in trace.
3225-3226	Set to three (fixed point 2 bytes).
3227-3228	CDP fold. Set to zero for REFLECTION data. Set to # offsets for CDP data.
3229-3230	Trace Sorting Code. Set to three for single fold data. Set to one for multifold data.
3231-3250	Not used.
3251-3252	Set to two (no binary gain recovery).
3253-3254	Set to one (no amplitude recovery method).
3255-3256	Set to 1 or 2 depending on units used.
3257-3258	Not used.
3259-3260	Not used.
3261-3600	Not used or NON STANDARD (see the following).

Non-Standard

Bytes	Description
3261-3262	number of traces (I*2)
3401-3410	pulseEKKO job number (CHAR*10)
3411-3480	pulseEKKO title 1 (CHAR*70)
3481-3550	pulseEKKO title 2 (CHAR*70)
3551-3570	pulseEKKO date (CHAR*20)
3571-3572	pulseEKKO number of stacks (I*2)
3573-3574	pulseEKKO pulser voltage (I*2)
3575-3594	pulseEKKO survey mode (CHAR*20)
3595-3598	pulseEKKO frequency (R*4)
3599-3600	pulseEKKO dewow (I*2) (0-NOT DONE 1-DONE)

The following lists the variables used in the binary portion.

Bytes	Description
1-4	Trace number from 1 to number of traces.
5-8	Trace number from 1 to number of traces.
9-12	Tape record number 1 to number of traces.
13-16	Set to one.
17-20	Not used.
21-24	CDP ensemble number.
25-28	Trace # within CDP. (one for REFLECTION data)
29-30	Set to one.
31-32	Set to one.
33-34	Set to one.
35-36	Set to one.
37-40	Antenna sep. times 1000. (Not official SEG-Y format)
41-44	Receiver Elevation data times 1000.
45-48	Transmitter Elevation data times 1000.
49-68	Set to zero.
69-70	Set to -1000.
71-72	Set to -1000.
73-76	Transmitter x-coord times 1000.
77-80	Transmitter y-coord (set to zero).
81-84	Receiver x-coord times 1000.
85-88	Receiver y-coord (set to zero).
89-104	Not used.
105-106	Timezero in ns.
107-114	Not used.
115-116	Number of points in trace.
117-118	Sample interval in psec.
119-120	Set to one.
121-240	Not used.

B.3 ASCII 1 Data File Format

Below is a sample of the file produced with the ASCII output.

```
8000
Fracture Mapping In Rock
21/09/89
NUMBER OF TRACES  = 136
NUMBER OF PTS/TRC  = 409
TIMEZERO AT POINT   = 96
TOTAL TIME WINDOW = 327
STARTING POSITION   = 9.500000
FINAL POSITION         = 77.000000
STEP SIZE USED         = 0.500000
POSITION UNITS         = metres
NOMINAL FREQUENCY = 100.000000
ANTENNA SEPARATION = 1.000000
PULSER VOLTAGE (V) = 400
NUMBER OF STACKS   = 128
SURVEY MODE            = Reflection
SIGNAL SATURATION CORRECTION APPLIED
SELECTED TRACE 20 TO 155 FROM LARGER SET
SELECTED 409 PTS. FROM ORIGINAL 640 PTS.
TRACE NUMBER        : 1
POSITION                : 9.500000
ELEVATION              : 0.000000
TIME ZERO ADJUST : 0.000000
TRACE ZERO FLAG  : 0.000000
TIME OF DAY(sec)    : 36348.000
COMMENT FLAG       : 0.000000
COMMENT               :
```

-66	4	24	99	-32	-30	62	-101	-62	100
-30	42	-69	22	102	-23	-19	-5	-41	3
-27	56	-21	0	26	11	-14	-2	-13	-58
20	-6	59	36	-17	6	44	14	-60	-73
-34	12	55	-15	17	-3	15	44	-112	8
36	18	-44	10	-11	2	73	16	-43	-41
28		3	-12	128	10	-241	23	103	68-67
-43	-99	15	45	48	72	69	-84	25	-15
16	-45	-55	1	67	-26	8	90	-78	-64
40	202	285	684	1004	926	621	238	858	1267
3621	10140	10182	5438	-9380	-15595	-19337	-21618	-18650	-8084
7325	14854	20858	18952	15491	13490	11575	1840	-13590	-26370
-28929	-26257	-13129	20547	29881	29448	23113	16189	-16035	-26669
-29305	-25835	-13708	-2981	14216	17033	17608	16270	14702	10114
4185	-5567	-12475	-15085	-13111	-7231	-784	5879	7494	5800
4187	1158	-1151	-1926	-2417	-1310	-115	1075	1585	945
-2394	-2887	-3071	-2593	-1088	443	909	345	-497	-1348
-1927	-349	4169	10223	14309	13773	10117	1342	-6569	-14578
-21594	-23668	-21315	-15084	1432	12366	20968	20225	17374	14033
4451	-4926	-10218	-8760	-6795	-4174	-2170	-673	-47	1154
1400	1573	1251	915	195	-119	-127	104	522	589
340	92	-485	-847	-1219	-1139	-910	-252	282	861
1047	1002	827	311	-155	-452	-502	-470	-360	-159
-66	27	-95	-120	-152	-213	-80	-46	152	355
523	379	350	415	222	193	58	-294	-555	-742
-713	-419	72	338	697	729	84	-29	-249	-171
-225	-157	-83	40	118	-30	62	-51	-41	-94
-158	54	55	-1	-58	-19	41	50	211	126
172	30	-110	-150	-171	-57	107	195	-11	23
-97	-72	-84	-97	-48	-29	-36	-31	153	260

90	51	9	-83	28	11	57	22	59	-76
-158	-200	-82	-113	0	49	98	65	97	-20
174	27	-26	-125	-201	-8	49	-13	32	30
50	119	57	116	-37	-125	-200	-97	-11	92
73	5	58	18	-105	53	34	107	25	50
-19	-69	-87	-60	-63	-55	53	88	-53	-16
-32	-5	90	53	60	96	10	-31	16	-180
-81	-86	-79	27	6	87	50	109	78	-24
0	-52	-61	-68	-90	88	1	51	103	-42
14	-21	17	-6	1	90	-21	6	-9	39
-78	-6	0	-2	-51	-33	-42	-42	24	

TRACE NUMBER : 2
POSITION : 10.000000
ELEVATION : 0.000000
TIME ZERO ADJUST : 0.000000
TRACE ZERO FLAG : 0.000000
TIME OF DAY(sec) : 36350.000
COMMENT FLAG : 1.0000
COMMENT : stop sign

10	19	4	-15	-3	-3	44	-10	6	-53
16	6	-76	62	-12	-6	-8	22	-70	38
-31	50	53	3	-7	-14	28	-54	-59	34
-9	47	0	-27	-67	120	-40	24	-26	12
143	-36	-25	-135	-4	0	7	4	45	-1
21	-42	64	-27	-19	4	-2	23	-105	18
58	26	9	9	52	-17	-39	-134	68	52
-4	-8	-20	57	1	10	10	-31	-49	-9
18	5	4	-19	-56	76	-7	79	-3	83
130	353	663	864	911	28	405	99	1446	5056
9239	10784	6515	-7356	-15600	-18940	-20870	-21024	-12653	3522
17099	22825	19830	16879	14928	10145	3253	-16520	-24074	-29268
-28492	-9805	18567	29988	30085	25120	18853	-12093	-21608	-26144
-26442	-2040	-10062	-1430	15735	19395	19595	16591	12970	4458
-5363	-11313	-13277	-9236	-2630	4409	6101	4706	1671	-341
-1700	-2406	-2340	-2269	-1932	-1547	-776	-88	1524	2103
1983	1665	1349	708	-123	-1482	-1942	-2054	-2561	-2551
-3162	-1585	-88	4090	10820	13935	14248	11140	4722	4899
-16395	-19563	-22015	-21100	-15146	-3701	7151	20994	22162	21643
18935	1852	-3449	-9362	-10074	-9438	-7995	-5876	-4657	-1078
-384	2442	4815	5212	5084	3616	1216	-696	-1681	-1735
-1448	-671	-125	239	131	-283	-585	-707	-713	-180
63	868	1167	780	618	107	-101	-408	-514	-538
-353	-105	36	116	-41	-264	-455	-521	-374	192
398	719	895	755	701	365	47	-460	-557	-700
-638	-452	-217	-34	25	339	320	293	184	173
-14	-73	-88	-106	-54	4	209	122	205	14
-36	-282	-290	-284	-280	-169	-55	31	98	142
157	233	188	214	203	11	-51	-160	19	17
-23	-95	-137	-288	-242	-196	-16	94	240	246
175	119	20	26	-51	-22	-16	38	67	69
6	-249	-164	-104	-104	-63	-18	68	53	109
107	49	-9	41	-27	-32	18	-1	57	3
8	38	-37	24	-8	-39	-61	-45	-44	-93
-97	64	8	87	144	65	90	-24	4	93
12	-10	-81	-81	-149	-112	-99	-33	97	53
100	24	72	32	-23	1	35	-18	4	25
13	-33	-43	-18	-50	0	-49	-86	-34	15
21	-9	68	50	59	74	58	7	-9	31
-51	-84	-46	-49	35	30	-25	-10	21	2
-16	4	-19	44	-47	21	-4	-2	35	

TRACE NUMBER : 3
POSITION : 10.500000
ELEVATION : 0.000000

TIME ZERO ADJUST : 0.000000
TRACE ZERO FLAG : 0.000000
TIME OF DAY(sec) : 36352.000
COMMENT FLAG : 0.000000
COMMENT :

-50	-65	-24	-13	21	25	2	56	70	-28

B.4 ASCII 2 Data File Format

The ASCII 2 format lists the radar data in a spreadsheet format that can be exported into many common programs like EXCEL, Transform and Surfer.

The ASCII 2 file lists the data in table format, that is, point amplitudes from each trace in separate columns with position values at the top of each column and time values at the beginning of each row.

Each column (after the first) represents the amplitude values for one trace of data. The positions of each trace are listed in the first row. Therefore the position of any trace is found by looking at the number at the top of the column.

The first column lists the times for each point in the trace in nanoseconds. Negative time values mean that the data point is before timezero which is when the transmitter fires.

The first value of column 1 is always set to -999, a dummy value not representing a position or a time. This value is included so all the columns in the table line up correctly. This value is usually ignored when the file is exported to other software.

-999	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00
-14.31	0	238	89	-114	-257	-191	139	79	-86
-13.51	0	679	610	654	701	864	568	747	779
-12.72	0	1495	1536	1313	1481	1604	1657	1392	1404
-11.92	0	1787	2128	1659	2048	2196	1758	2154	1880
-11.13	0	2541	2692	2653	2617	2401	2495	2695	2795
-10.33	0	3660	3533	3658	3752	3797	4032	3801	4052
-9.54	0	4886	4951	4477	5067	4501	4804	4612	4744
-8.74	0	2857	2266	3280	2843	2814	2431	2198	2387
-7.95	0	2377	2455	2796	2358	2621	2567	2769	2764
-7.15	0	4093	4399	4323	4311	4511	4621	4548	4496
-6.36	0	4294	3862	4322	4045	4133	4409	3854	4075
.									
.									
.									
12.72	0	8102	6963	9384	9590	7216	6976	8296	9194
13.51	0	5377	5918	8110	7759	5399	4149	3268	4377
14.31	0	3313	4896	5696	5341	4429	2431	742	984
15.10	0	1438	3254	3736	3720	3880	2273	-467	-970
.									
.									
.									
23.85	0	-549	730	914	34	-341	-784	-125	813
24.64	0	-233	1345	1318	664	1029	508	972	2095
25.44	0	462	1577	1726	1066	1586	1728	2109	2664
26.23	0	373	856	1517	1349	1273	1790	2651	2609
27.03	0	36	-332	1133	1563	1269	1418	1786	1998
.									
.									
.									
35.77	0	626	-662	-49	748	1216	1169	1015	894
36.56	0	697	-150	-203	683	1180	1312	1242	1087
37.36	0	652	91	349	477	1051	1242	1250	1012
38.15	0	578	100	235	-186	498	730	919	759
38.95	0	116	269	187	-310	213	268	505	259
39.74	0	-61	521	371	61	49	6	-54	26
40.54	0	-633	401	414	218	-819	-538	-431	-275
41.33	0	-545	22	324	17	-583	-597	-652	-268
42.13	0	-466	-760	-602	-497	-286	-693	-945	-844

42.92	0	-386	-754	-858	-386	-194	-390	-578	-754
43.72	0	-347	-360	-704	-304	287	79	-308	-377
44.51	0	337	-184	-424	22	164	125	320	125
45.31	0	185	309	-26	-20	115	186	244	482
46.10	0	682	338	419	501	141	240	561	549
46.90	0	440	290	408	201	-13	154	479	394
47.69	0	137	-131	251	-80	-194	-92	-18	81
48.49	0	-522	-237	43	-231	-80	-66	-84	-28
49.28	0	27	-195	412	-129	24	-20	-44	27
50.08	0	-273	-21	123	327	7	279	124	56
50.87	0	-180	194	-29	199	119	236	243	-1

B.5 CSV Data File Format

The CSV format lists the radar data in a spreadsheet format that can be exported into many common programs like EXCEL, Transform and Surfer.

The CSV file lists the data in table format, that is, point amplitudes from each trace in separate columns with position values at the top of each column and time values at the beginning of each row.

The trace number is listed in the first row and the position of that trace is listed in the second row.

Each column (after the first two) represents the amplitude values for one trace of data.

The first column lists the point numbers and the second column lists the times for each point in the trace in nanoseconds. Negative time values mean that the data point is before timezero which is when the transmitter fires.

	TRACE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Position (m)	0	0.02	0.04	0.06	0.08	0.1	0.12	0.14	0.16	0.18	0.2	0.22	0.24	0.26	0.28
Point	Time (ns)															
1	-7.38	-270	-283	-268	-271	-253	-266	-269	-258	-246	-263	-284	-282	-243	-300	-273
2	-7.28	-265	-248	-274	-322	-271	-277	-280	-262	-273	-280	-275	-295	-260	-268	-277
3	-7.181	-271	-296	-312	-324	-286	-283	-282	-272	-275	-292	-293	-274	-239	-271	-290
4	-7.081	-303	-275	-289	-310	-276	-256	-284	-293	-309	-296	-270	-276	-283	-297	-283
5	-6.981	-282	-281	-300	-337	-291	-275	-265	-304	-301	-303	-289	-286	-285	-298	-320
6	-6.881	-274	-296	-303	-314	-273	-295	-296	-291	-311	-301	-305	-282	-275	-286	-302
7	-6.782	-302	-281	-282	-319	-286	-306	-307	-302	-314	-295	-290	-282	-257	-303	-314
8	-6.682	-279	-269	-285	-316	-275	-286	-305	-312	-292	-293	-289	-311	-275	-272	-300
9	-6.582	-279	-285	-280	-301	-296	-279	-293	-309	-300	-315	-289	-296	-279	-308	-308
10	-6.482	-271	-265	-275	-305	-291	-302	-305	-311	-294	-308	-300	-292	-300	-286	-301
11	-6.383	-281	-268	-299	-303	-291	-299	-269	-276	-303	-292	-306	-289	-276	-286	-292
12	-6.283	-281	-271	-291	-300	-266	-309	-274	-297	-279	-313	-303	-298	-302	-284	-302
13	-6.183	-261	-261	-273	-296	-283	-291	-284	-284	-296	-304	-290	-260	-276	-310	-308
14	-6.084	-304	-271	-265	-270	-275	-316	-281	-296	-293	-291	-279	-276	-275	-301	-286
15	-5.984	-276	-274	-281	-274	-288	-291	-285	-295	-277	-284	-301	-288	-291	-284	-288
16	-5.884	-276	-241	-267	-291	-273	-290	-271	-288	-290	-289	-279	-272	-280	-294	-281
17	-5.784	-289	-272	-256	-301	-276	-259	-274	-295	-288	-298	-275	-262	-281	-272	-272
18	-5.685	-284	-275	-265	-290	-279	-290	-278	-258	-286	-284	-291	-258	-254	-283	-277
19	-5.585	-289	-276	-259	-282	-283	-277	-273	-285	-298	-289	-284	-273	-282	-262	-258
20	-5.485	-268	-301	-276	-303	-292	-287	-267	-291	-307	-295	-289	-263	-261	-288	-271
21	-5.385	-255	-259	-277	-285	-292	-285	-284	-282	-307	-319	-290	-261	-268	-287	-287
22	-5.286	-272	-273	-283	-294	-277	-273	-280	-284	-301	-286	-292	-285	-289	-286	-276
23	-5.186	-293	-288	-271	-313	-263	-271	-274	-291	-282	-302	-298	-278	-287	-269	-279
24	-5.086	-294	-277	-268	-300	-277	-280	-278	-278	-296	-294	-277	-282	-292	-284	-292
25	-4.987	-312	-271	-298	-288	-289	-290	-291	-270	-281	-285	-266	-284	-306	-296	-316
26	-4.887	-298	-297	-290	-315	-283	-259	-271	-268	-294	-287	-275	-303	-310	-301	-285
27	-4.787	-305	-266	-294	-323	-295	-291	-285	-284	-312	-288	-295	-279	-285	-298	-270
28	-4.687	-298	-291	-282	-327	-291	-279	-283	-256	-296	-272	-274	-273	-289	-281	-304

B.6 Eavesdropper Data File Format

The following describes in detail which variables are loaded in the pulseEKKO to Eavesdropper conversion program.

The data file contains as many records as there are traces. Each record in turn consists of a header section and a data section. The header section consists of an array of 120 integer (2 bytes) numbers. All items other than those below are set to zero:

Item #	Description
1	Data type. (set to 0 = raw field)
2	Total Recording Channels. (set to 1)
3	Trace header word of record number. (set to 19 = common offset)
4	Trace number within each record (set to 1)
5	Trace direction. (set to 1 = ascending)
6	Original field record number. (set to trace #)
8	Recording channel number. (set to 1)
10	Repeated shot number. (set to # of stacks)
12	CMP Number. (set to trace #)
14	Trace number within each record. (set to trace #)
15	Trace ID code (set to 1 = seismic data)
16	Number of vertically summed traces. (set to # of stacks)
17	Number of horizontally summed traces. (set to 1)
19	(Transmitter to Receiver offset)*multiplication factor in word 35.
21	Receiver elevation.
23	Transmitter elevation.
35	Multiplication factor for horizontal distance. (set to 1000)
58	Number of samples in trace. (set to # points in trace)
59	Sample interval in picoseconds. (set to sampling rate)
88	Last trace flag. (set to 1 for last trace)
92	Source sequence number. (set to trace #)

The data section follows and consists of an array of two-byte integers, one value for every data point.