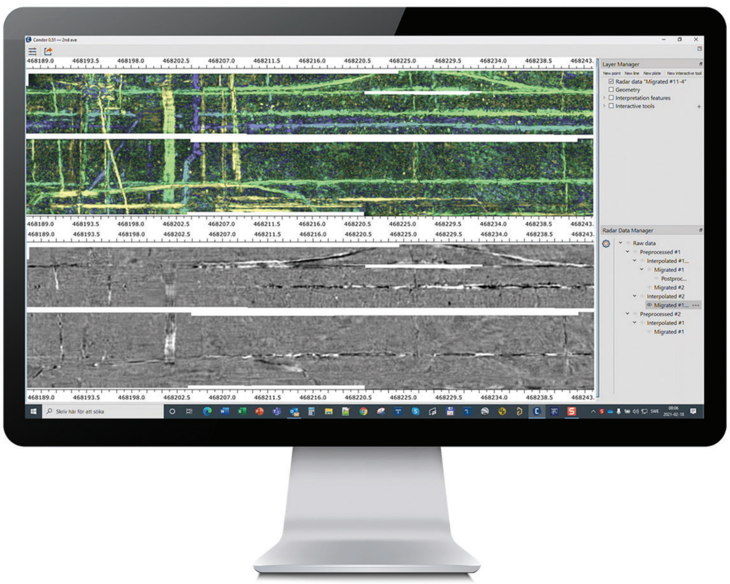
Condor

3D GPR Processing & Interpretation Software

User Manual



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3D GPR Processing & Interpretation Software

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Document information

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About This Manual

ImpulseRadar Condor is a Windows™ based software program for the processing, visualization, and interpretation of ImpulseRadar 3D Ground Penetrating Radar (GPR) data files collected with Raptor systems.

This manual is structured as follows:

Section 1 – Introduction	PC requirements, installation and setup
Section 2 – Tutorial/workflow	Brief description of workflows, features and functions
Section 3 – Reference	A more in-depth description of functionality
Section 4 – Appendices	Combining files, surface features and License agreement

For further information on the use of this software, please contact your local ImpulseRadar representative or our support team at support@impulseradar.se

We welcome your feedback concerning this manual and its content. Please send your comments or suggestions to us at info@impulseradar.se

License Agreement

Condor is a subscription-based software, which is protected by a License and governed by a License Agreement, as defined in Appendix C.

Notice

ImpulseRadar products are under continuous development, and we reserve the right to change specifications and the content of this manual at any time and without prior notice. You may verify product specifications or current versions of this manual at any time by contacting our headquarters using the details listed herein.

1 Introduction

1.1. Overview

ImpulseRadar Condor is a proprietary Windows™ based software program for the import, processing, visualization, and interpretation of ImpulseRadar 3D GPR data files. Condor can import and work with data files collected with ImpulseRadar Raptor systems. The software works with multi-profile data sets, or 'swaths'.

The software includes features to process data efficiently, mark points of interest within radar profiles, visualize markers on a map, and export markers for geo-referencing in Google Earth and supported CAD/GIS platforms.

1.2. PC Requirements

OS	Windows™ 10
Processor	1 GHz or faster, 64-bit (x64)
Memory	16 GB RAM (64-bit)
Storage	500 GB available hard disk space (64-bit)
Graphics	DirectX 9 graphics device with WDDM 1.0 or higher driver

1.3. Installation & Setup

The Condor installation package is available for downloaded via the ImpulseRadar website at https://impulseradargpr.com/condor

Note: Condor is a subscription-based software protected by a license. The license is managed either through a USB dongle (HardLock) or a software-based solution (SoftLock). If you do not already have a USB dongle, or if your current license is about to expire or has already expired, please contact us at **activation@impulseradar.se**.

1.3.1 Installation process

- Download the Condor installation package and select the appropriate version (HardLock or SoftLock) based on your license type.
- Unzip the installation package and extract all files to a suitable location on your PC
- Locate and open the Condor installation file to start the setup wizard
- When prompted by the setup wizard, click 'Next' to continue

- Select the installation folder, and click 'Next' to continue
- Confirm installation, and click 'Next' to continue
- If prompted, allow the installation file to make changes to your Windows system
- When installation is complete, confirm to close the setup wizard.

Condor is now installed but cannot yet be used until the License is activated.

1.3.2 License preparation and activation process

A detailed license activation and management guide is included in the downloaded software zip folder in PDF format. Below are the quick start steps for the first-time installation:

- If using the HardLock version, plug the USB dongle into the PC where Condor is installed.
- Locate and open the **RUS_KXQRX** (or **RUS_OWQEI**, if using the SoftLock version) software utility.
- In the pop-up window, ensure the checkbox **'Installation of new protection key'** is checked, then press **'Collect Information'**.
- The software utility will propose a file name with the extension **.c2v**. It is important not to change this file name and save it as proposed.
- Send the file via email to **activation@impulseradar.se**.
- You will receive an activation file via return email with the extension **.v2c**, which should be saved to your PC's hard drive.
- For the HardLock version, ensure the USB dongle is plugged in, and then run the RUS_**KXQRX** software utility again. For the SoftLock version, simply run the RUS_**OWQEI** utility again.
- In the pop-up window, select the **'Apply License File'** tab, locate and select the **.v2c** file, and press **'Apply Update'**.
- Read and accept the license agreement, then click **'Next'** to continue.
- Click **'Install'** to proceed with the installation.
- Click **'Finish'** to exit the setup.

The License file is now activated and installed, and Condor can be used.

Note - the first digits of the *.v2C file name is the dongle id, and we will refer to this in any correspondence concerning the subscription license, so keep a record of it for safekeeping.

2 Tutorial/Workflow

2.1. What is a Project?

All GPR data processing and interpretations are performed within the framework of a **Project**. A project is a folder which contains different types of data, such as geometry files, raw radar data, post-processed radar data, cut lines, ribbon boxes, and interpretations. Each project is kept in a separate folder. It is possible to have raw input files in any folder and let the project reside somewhere else, we recommend keeping the raw data one level up of the project folder structure.

When you launch Condor, you can create a new project or open an existing project via the **Project Manager** window, as shown below in Figure 1.

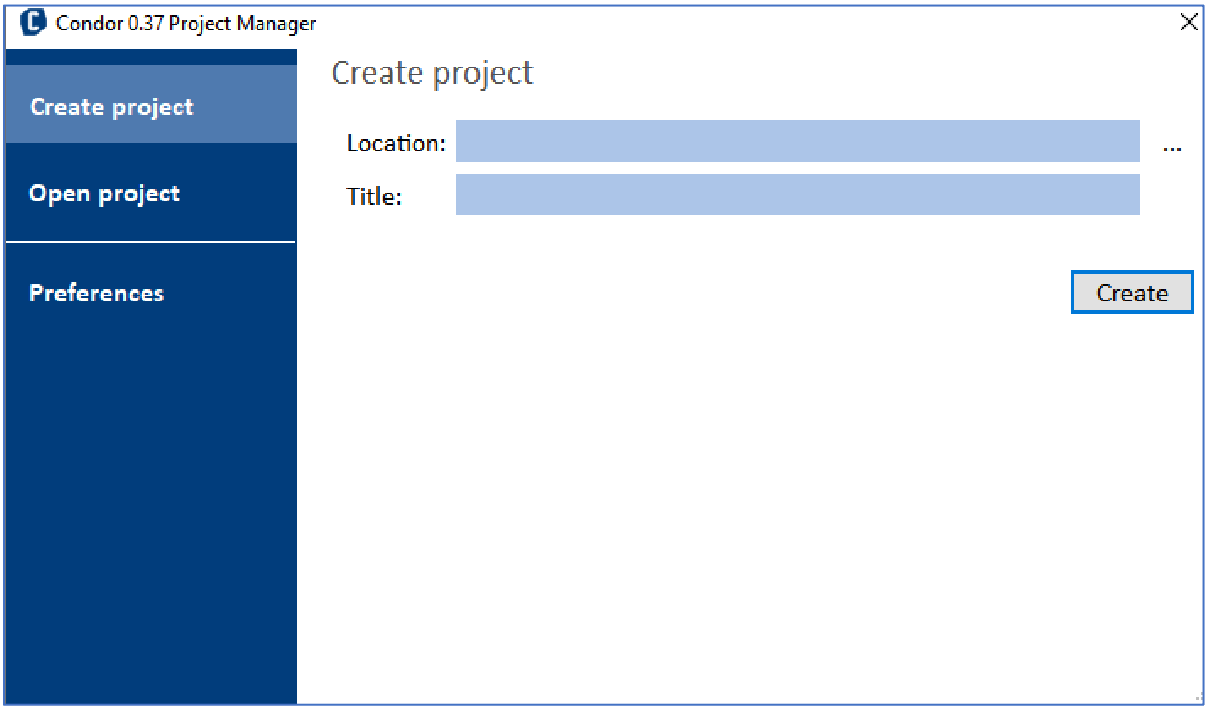


Figure 1 The Project Manager window

Each project has its own default settings; you should predefine these before you start working with the project under the Preferences tab within the Project Manager window, as shown in Figure 2 on next page.

> **Note**: Some of these parameters can be changed while working with the project, but you should predefine the rest beforehand

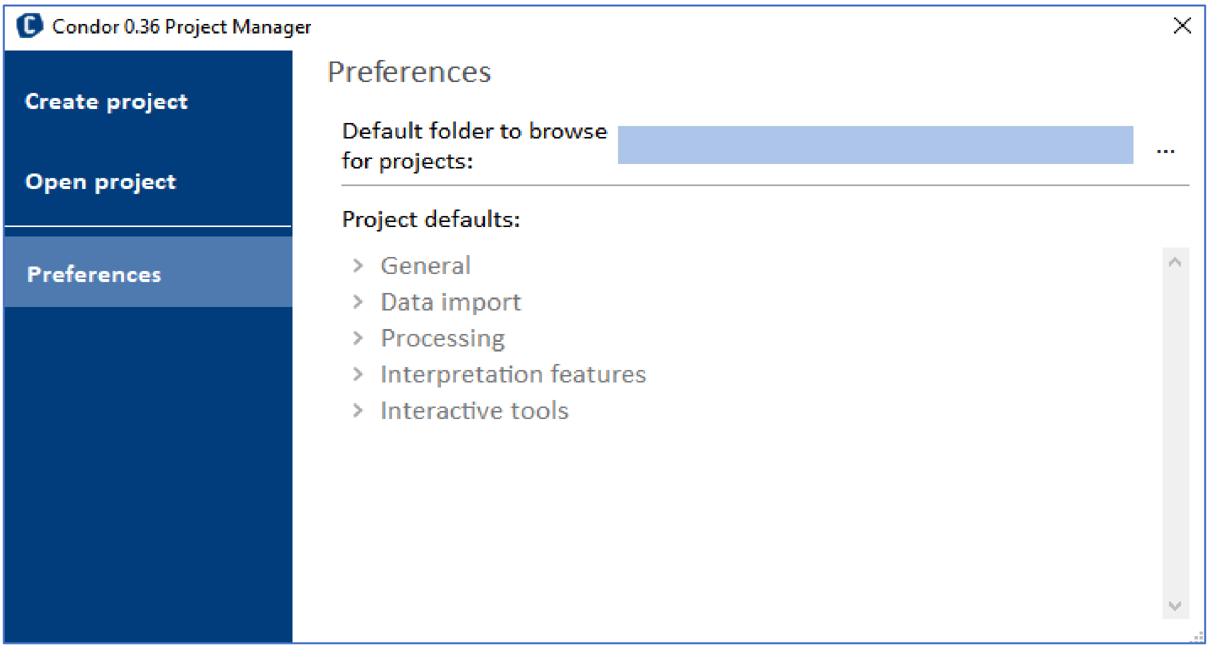


Figure 2 The Preference tab in the Project Manager window

2.2. Workflow

This chapter provides a brief overview of the main stages involved in working with the Condor software. For more detailed information about all parameters, please refer to the Reference section.

2.2.1 Creating a new project

To create a new project, you should determine a folder on your computer's hard disk, where you will store all the project's data (GPR data, processing settings, interpretation objects). You can define this location via the **Project Manager** window, as shown below in Figure 3.

In the **Location** field, specify the parent folder for the new project, either manually or by clicking the **ellipsis** button (...) and selecting a folder via the standard Windows dialog. In the **Title** field, specify the project name and click the **Create** button.

Important Note: Condor can only import ImpulseRadar swath files (.ipr). Before importing into Condor, the raw data files generated by Raptor during acquisition must first be combined to create the proper file format. This process can be performed using the ViewR software.

ViewR is a free software developed by ImpulseRadar, available for download on our website. It is designed for fast inspection, quality control, and manipulation of data collected by any ImpulseRadar system. Additionally, ViewR allows you to combine files to ensure compatibility with Condor for further processing and interpretation of the data.

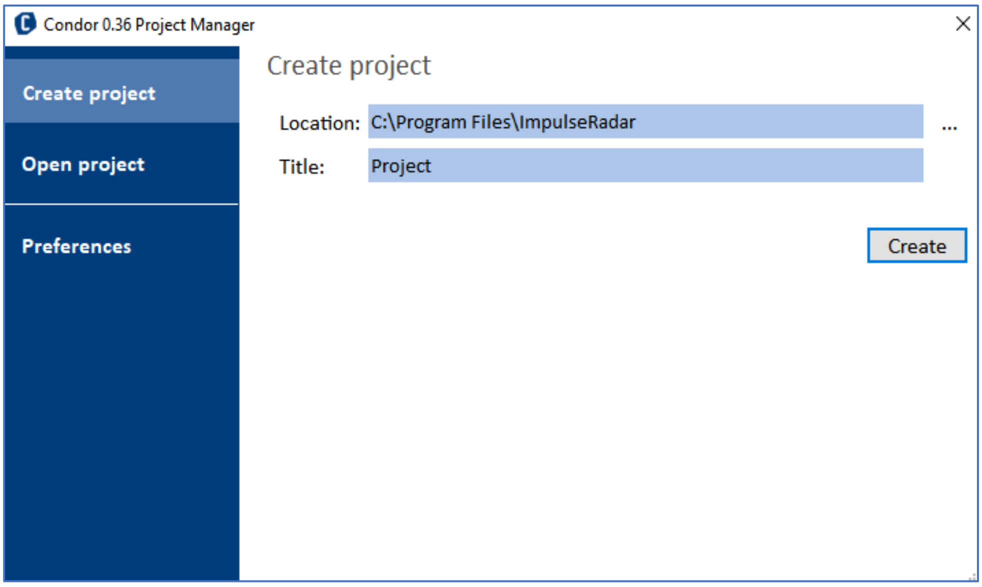


Figure 3 Define the project folder for data storage and the project name

A dialog window will now appear for selecting the appropriate data files (*.ipr), as shown below in Figure 4. Highlight the desired file/s and click the **Open** button.

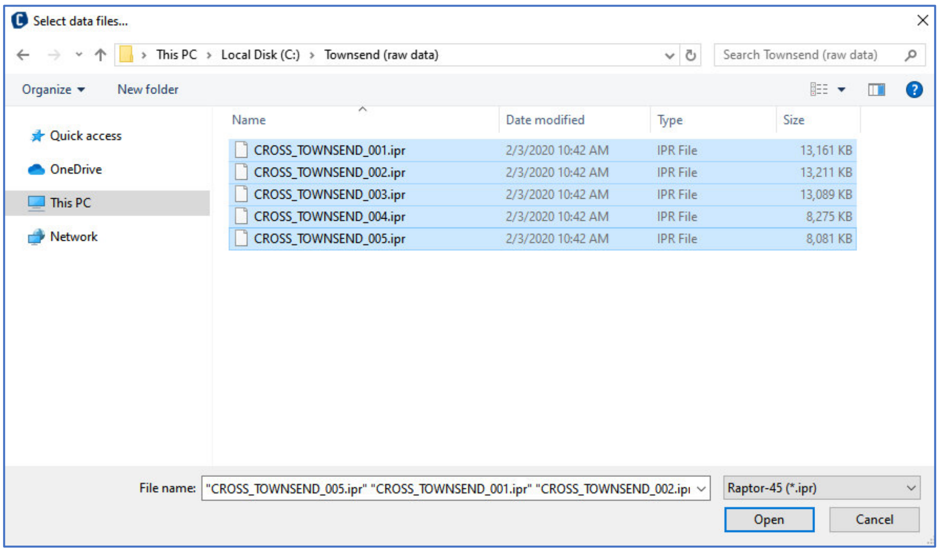


Figure 4 Select ImpulseRadar swath files (.ipr)*

2.2.2 Data import

During the data import, you preview and edit positioning data, before merging it with the GPR data. Projects may be positioned using GPS, Total stations (TS), or 'manual' positioning systems, the previous two are the dominating methods. Data import is done in two steps, both of which are designed to give the operator ability to de-select or correct bad positioning data.

2.2.3 Positioning data editing and GPR data import

The GPS/TS data collected alongside the GPR data has varying spatial sampling frequencies, so there are many more GPR data points than GPS/TS. Furthermore, both GPS/TS and GPR data may be irregular (for several reasons). Consequently, you should aim to correct GPS/TS positioning data, to make it regular along the line of each GPR swath and interpolate GPR traces on the regular positioning grid.

At the **Positioning Preview** step, as shown below in Figure 5, you can review all positioning points to detect troublesome areas with low data density, delete incorrect positioning points, and define parameters for positioning data interpolation.

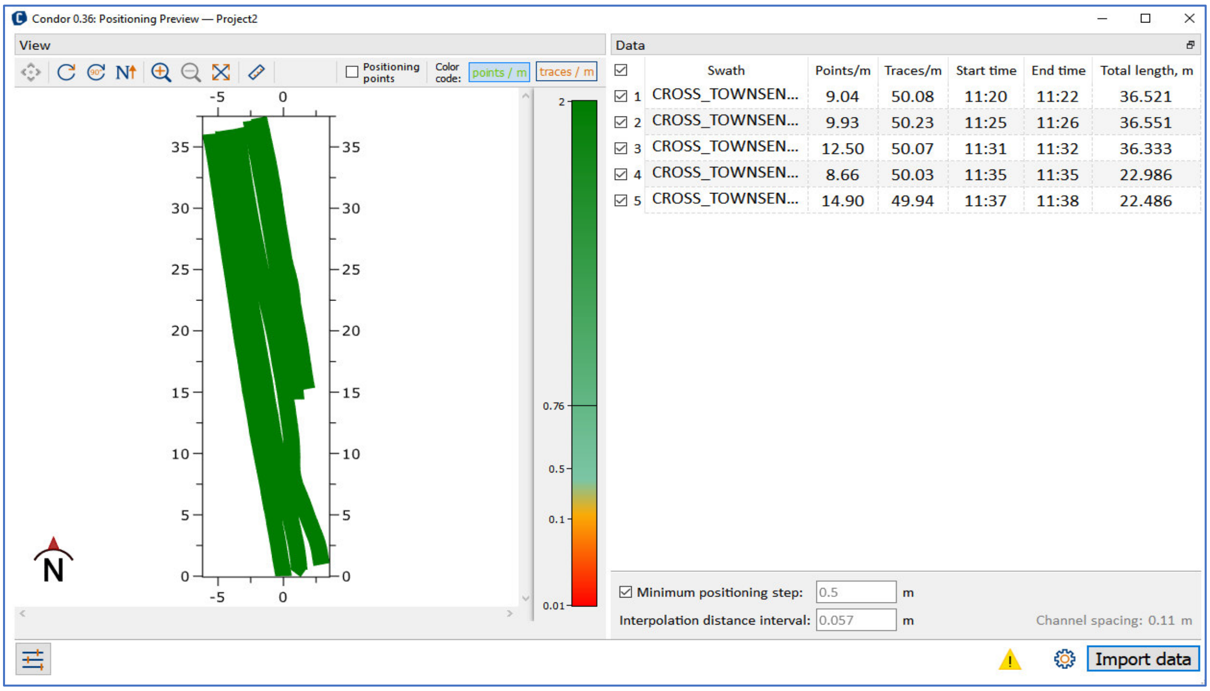


Figure 5 The Positioning Preview window

The **Positioning Preview** window is shown above in Figure 5, and consists of four parts:

1) **Data:** contains information about the swat's pre-import, so you can choose which ones will be visible by deselecting those you wish to exclude from the import (if any).
2) **View:** shows the data coverage for the survey area pre-import, along with various tools to alter the viewing parameters.
3) **Interpolation parameters:** to specify the minimal step for the original GPS/TS points and the data interpolation interval. Extra points will be removed and thus not affect the interpolation.
4) **Bottom panel:** contains warning information on possible positioning data errors, and allows you to set project parameters, and customize pre-processing routines.

After correcting any positioning data errors and defining the parameters for interpolation, press the **Import data** button, upon which the **Time Zero Adjustment** window will appear.

2.2.4 Time Zero Adjustment

Due to the methodological features of data acquisition, the position of the first arrivals can change in a specific interval. By adjusting the value of the Threshold parameter, and correcting for antenna separation*, Condor has an in-built algorithm that detects first-arrival automatically.

Enter appropriate values in each field for Threshold and Adjustment velocity, cm/ns, and ensure the Correct for antenna separation checkbox is selected, as shown below in Figure 6.

Use the navigation arrows at the top of the window to analyse the accuracy of the algorithm across different traces. Once you are satisfied with the quality of the first arrival picking, click the OK button, to import the data.

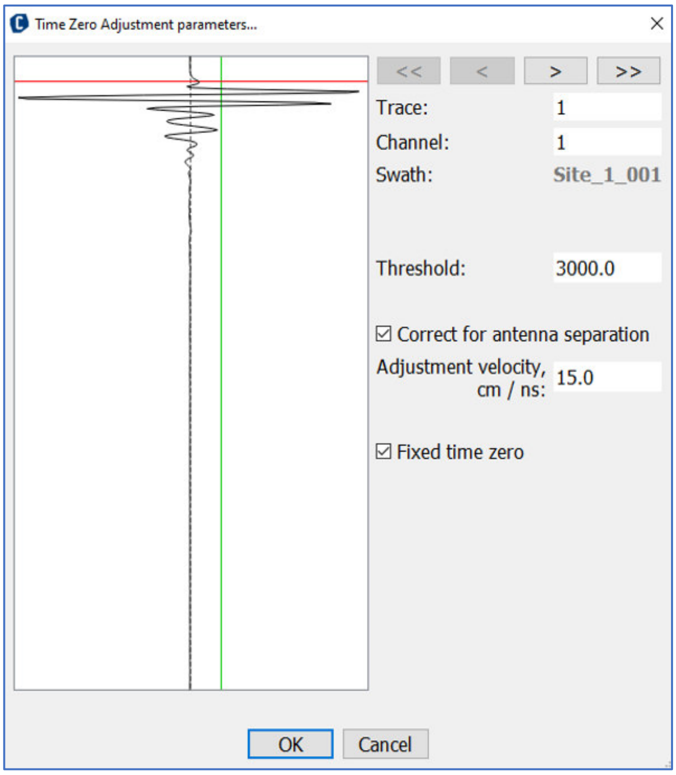


Figure 6 Time-Zero adjustment window

2.2.5 Positioning edits

At this stage, Condor binds all GPR traces to GPS positions, allowing you to view slices of the raw GPR data, as shown in Figure 7 below. If you suspect any issues with the positioning points, the Positioning Edit window provides tools to adjust the data.

You can move individual points by clicking and dragging with the left mouse button or delete points by using the right mouse button. To move entire lines, hold down Ctrl + Shift and click with the left mouse button to select and adjust the line.

Once you are satisfied with the adjustments, click OK to proceed to the next step.

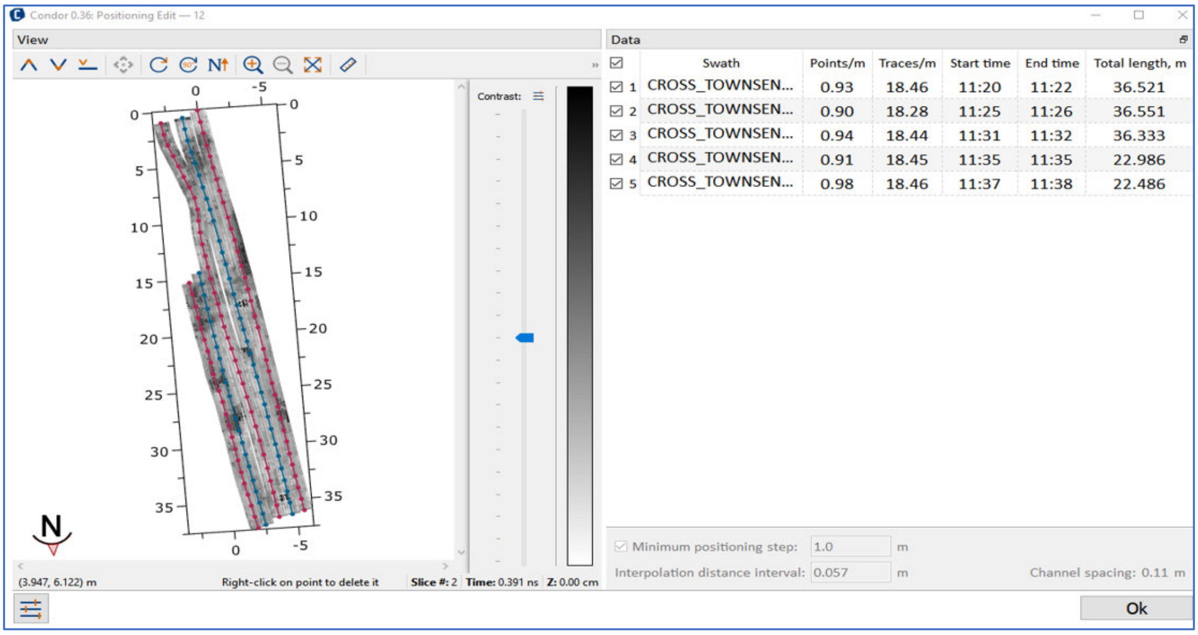


Figure 7 Positioning edit window

2.2.6 Processing and Interpretation

Figure 8 below shows the main work area where you can process and interpret the GPR data, which consists of four main windows as listed below.

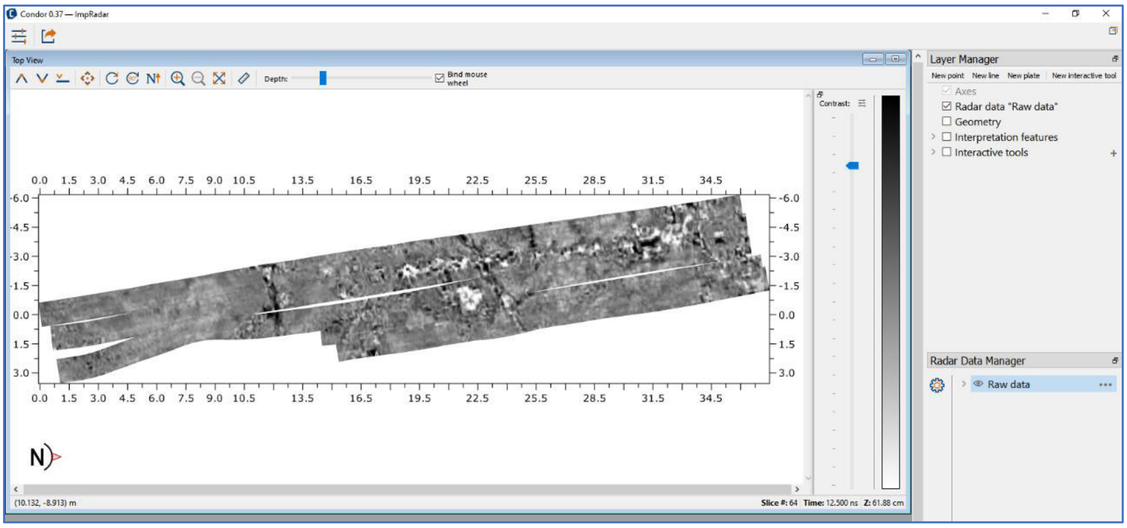


Figure 8 Main work area for processing and interpretation

1) **Top View**: shows a time slice of the data as a map in X-Y coordinates. You can change the depth of the current slice and change the representation parameters using the toolbar. By enabling **OspreyView**, a user may get better overview of available targets, not only at the depth of the current slice, see Figure 9, below.
2) **Radar Data Manager:** shows the workflow for data processing.

3) **Layer Manager:** shows various interactive tools and interpretation/surface features, which you can enable by selecting the corresponding check box.
4) **Main Toolbar:** allows you to define specific project settings and to set the format for the export of data

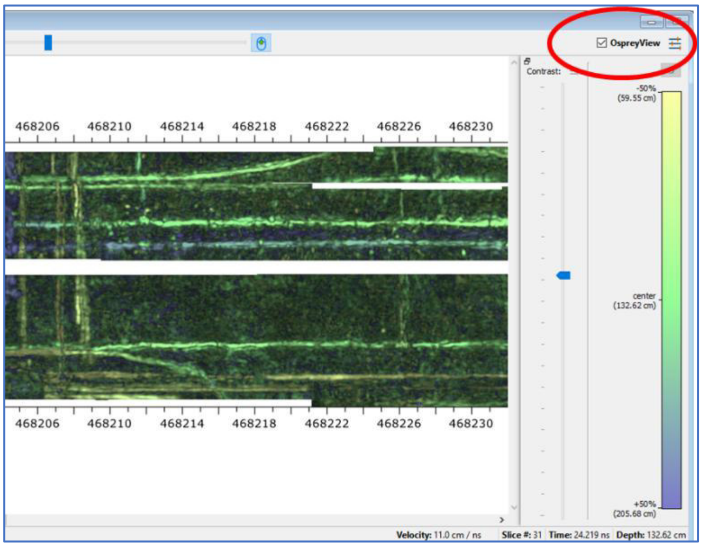


Figure 9 *By checking the OspreyView in top right corner, Condor enters thick-slice mode. This mode gives a better overview, as well as depth perception.*

2.2.7 Cross-section display

Before processing the data, you can display some cross-sections to be able to estimate the quality of the processing and adjust processing parameters.

To create a cutline, right-click on the Interactive tools option of the Layer Manager (or click on the + button) and choose **Cut-Line**. By clicking on the **Top View**, you can create pivot points for the cutline. With the mouse, use double-click, or **Ctrl + Click** to finish the line. A cross-section window with the data along the selected cutline will appear, as shown below in Figure 10. You can add as many cut-lines as you wish.

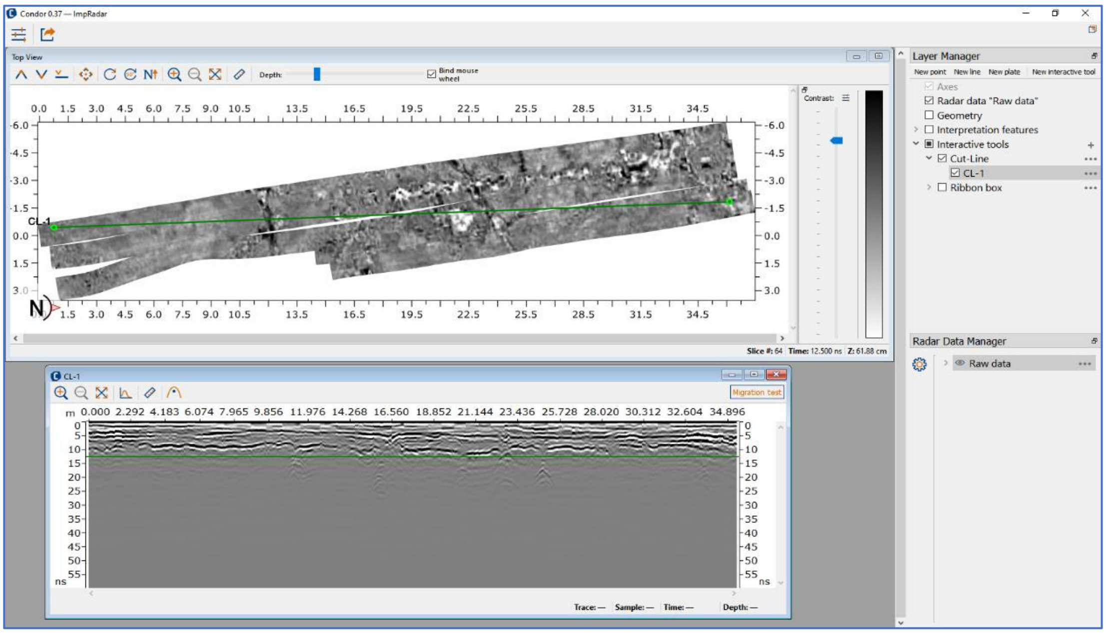


Figure 10 *Use Interactive Tools to add a Cutline and mark a polyline in the Top View*

2.2.8 Ribbon box display

In addition to the cutline, you can also use the **Ribbon box** tool to examine GPR data in a volume along the selected line. The Ribbon box will display two slices – one along the central line and another one across it.

Creating a ribbon box is very similar to creating a cutline. However, upon completing the last pivot point, you will be asked to smooth the resulting ribbon box central line, as shown in Figure 11. According to these settings, the software will draw the borders for the volume of interest, and two cross-sections will appear, as shown below in Figure 12.

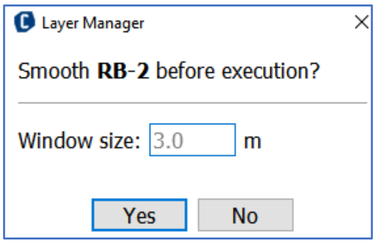


Figure 11 Dialog window for Ribbon box smoothing

Using the sliders in each cross-section view, you can move through the different cut-sections both along and across the Ribbon box volume.

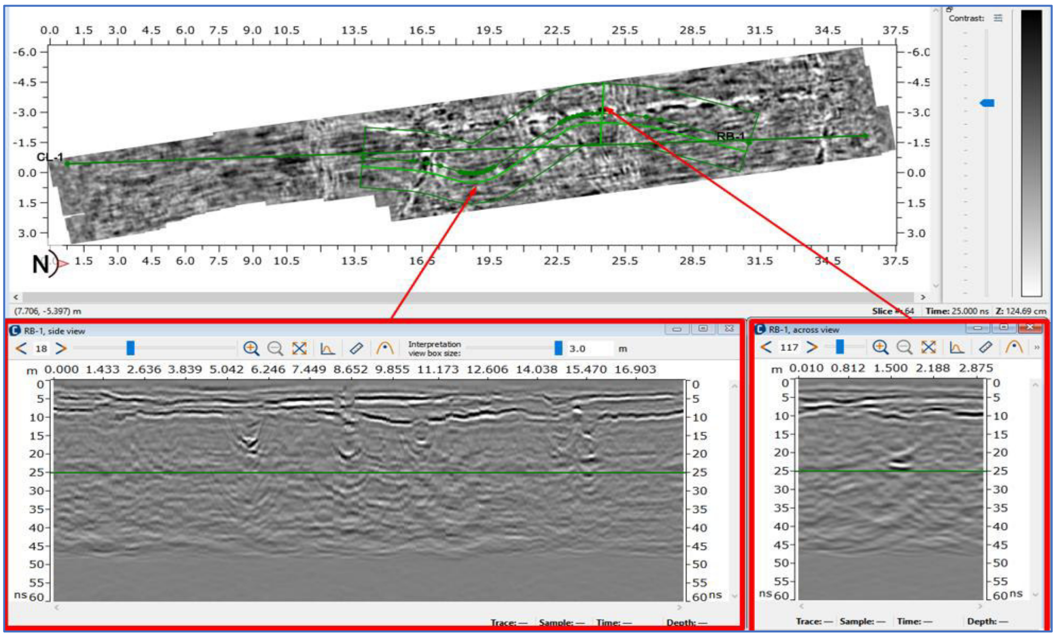
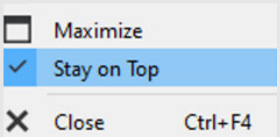


Figure 12 Ribbon box cross-section view

Note: You can input a georeferenced image (GeoTIFF) as a background layer for your radar data, such as a satellite map or a layout map. However, the input GeoTIFF must be in the same UTM zone as your Condor project. When importing data into ViewR, the Coordinate Reference System (CRS) of the project will be displayed in the top-left corner of the window, allowing you to verify that the GeoTIFF aligns with the correct CRS.

Hint: when you have several cut lines on the main screen it may be easier to evaluate them if you make them stay on top, by right-clicking on the cut-line window's uppermost section.



2.2.9 Processing

To edit the processing workflow, click the button on the Radar data manager panel. The window with available procedures will appear, as shown in Figure 13.

Condor can apply four processing stages to the raw data in a predefined order. Each step contains one or more available routines, as shown. You can select and add a routine to the processing workflow (selected routines) using the right arrow. Similarly, you can choose to remove a routine from the processing workflow using the left arrow.

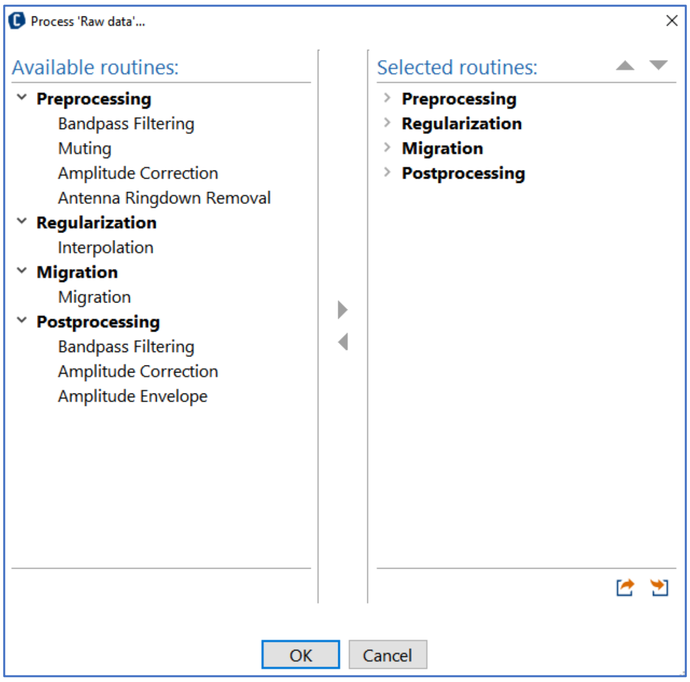


Figure 13 Available processing routines and selected routines

First stage – Pre-processing

This stage aims to remove noise and improve the quality of the data by deleting traces with very distorted amplitudes, to filter out specific frequencies with more noise than signal, to apply amplitude correction, and or delete antenna ringdown.

- **Bandpass Filtering:** applies frequency filtering to every input trace. By adjusting the bandpass filtering parameters, you can create a trapeze frequency band, which will pass all the frequencies within the specified band, while rejecting any others.
- **Muting**: replaces traces with abnormally high or low amplitudes with neighbouring traces of the same channel.
- **Amplitude Correction**: corrects for amplitude decay with the travel time using either spherical divergence correction or AGC (automatic gain control).
- **Antenna Ringdown Removal**: antenna ringing produces nearly horizontal artefact events in the data, which may interfere with or mask actual reflections, and return unreliable outputs. This routine enables the suppression of such ringing in the data.

Second stage – Regularization

Condor automatically divides the area of acquisition into several chunks with regular grids inside of them. The algorithm interpolates the traces of the original dataset to the regular grids of the chunks. You need to define the maximum gap that can be filled by the program during the interpolation.

Third stage – Migration

It can be challenging to select a proper velocity for migration; to simplify this, Condor incorporates a **Migration test** function via the cut-line tool and a cross-section window, as shown below in Figure 14. By adjusting the velocity slider, you can observe the effect on hyperbolas within and choose a velocity that will offer the best migration result for the entire dataset. If the dataset shows wide varying velocities, you may choose to create data instances migrated to different velocities. You may create as many migrated data instances as you like.

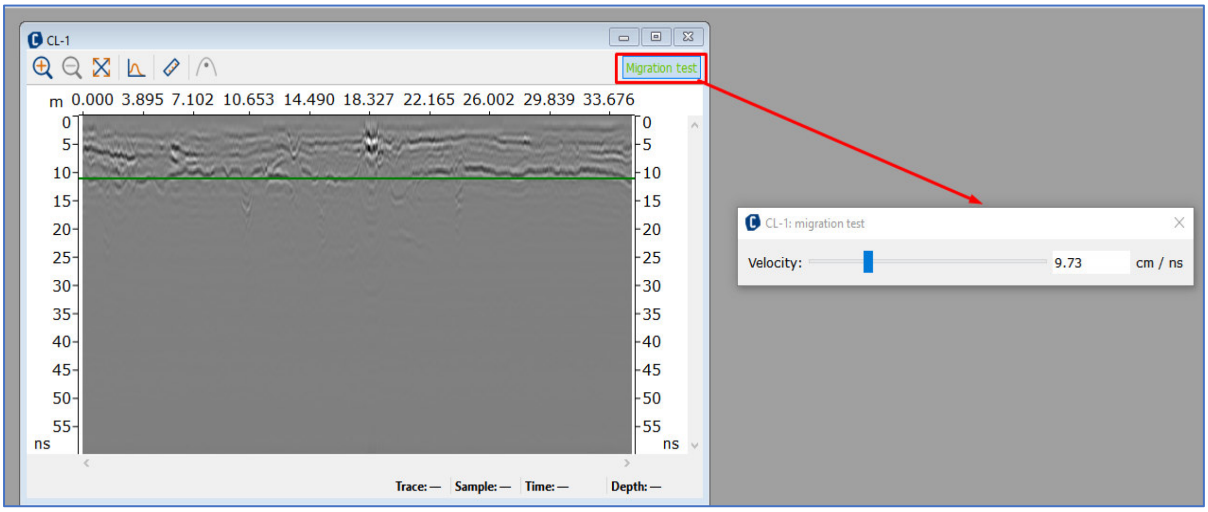


Figure 14 Migration test function via a cutline

Fourth stage – Post-processing

This stage allows you to make final improvements to the data using a Bandpass Filter and Amplitude Correction. Additionally, you may wish to calculate the Amplitude Envelope – an attribute showing reflection strength at each point of the radar data volume, as shown below in Figure 15.

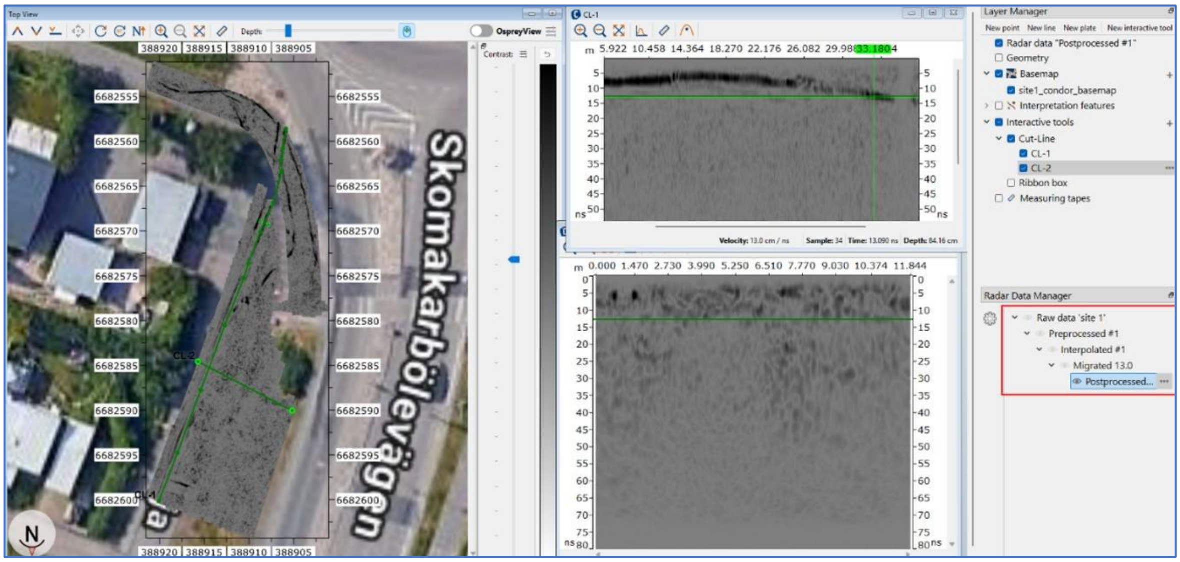


Figure 15 A cut line with an Amplitude Envelope process applied

After you set up the processing flow, click the OK button, and Condor will apply that flow to the data. The result of each processing step is saved as a separate dataset and displayed in the Radar Data Manager panel, as shown above in Figure 15 (red highlight box).

You can switch between the different processing stages by double-clicking the desired step in the **Radar Data Manager**. The step that is currently displayed is marked with the icon, as shown below in. Instead of creating full processing flow at once, you can do it step by step. For this, right-click on a dataset in the Radar Data Manager panel and select next processing step to be applied to the data.

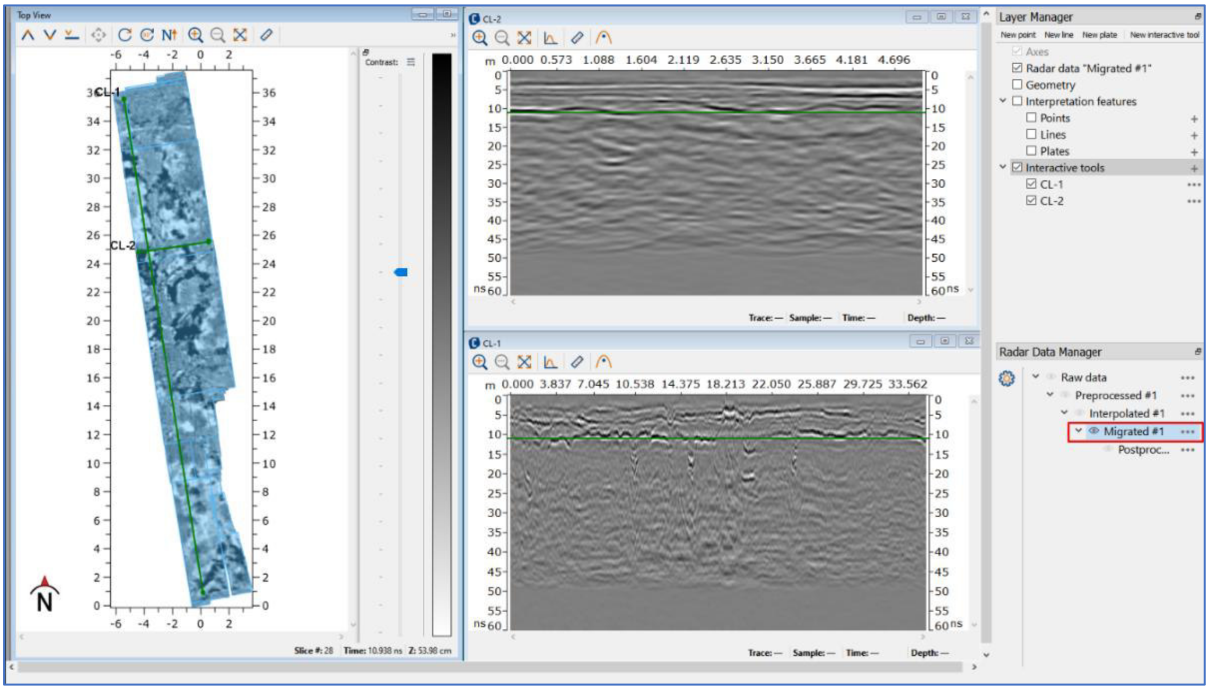


Figure 16 Switch between views to observe the results of each processing step

2.2.10 Interpretation

Once you have achieved satisfactory processing quality, you can proceed to interpretation. Note that GPR-wave velocity is an important parameter to set correct, prior to this stage, see the Reference section. The **Layer Manager** window (Figure 17) includes three types of interpretation features as listed below and shown in.

- **Points**: manholes, valves, lamppost, etc.
- **Lines:** communication lines, drains, cables, etc.
- **Plates**: some bulky objects.

To add an interpretation object, press + to the right of the desired object type; then choose the subtype of the object and place the object on the Top View, as shown below in Figure 18.

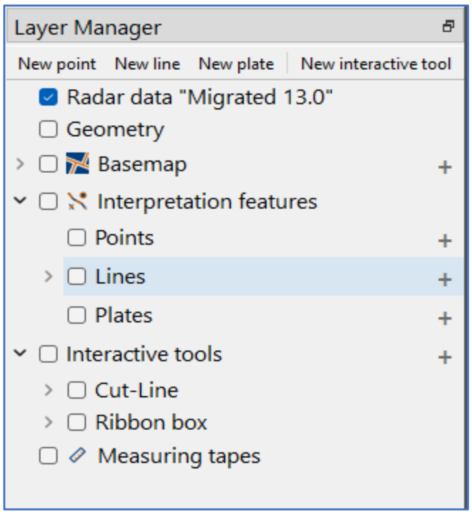


Figure 17 Interpretation/surface features

If, during data collection, surface features were marked/collected, they will appear in the layer manager. Surface features are of two types, lines and points and serve two purposes; 1) they may ease the re-localization of a dataset positioned with a total station, if 2 (at least) points with known coordinates are marked as surface markers and 2) they may give the interpreter a better understanding of the site layout and infrastructure present above ground. The appearance of surface features may be altered by the operator, see appendices.

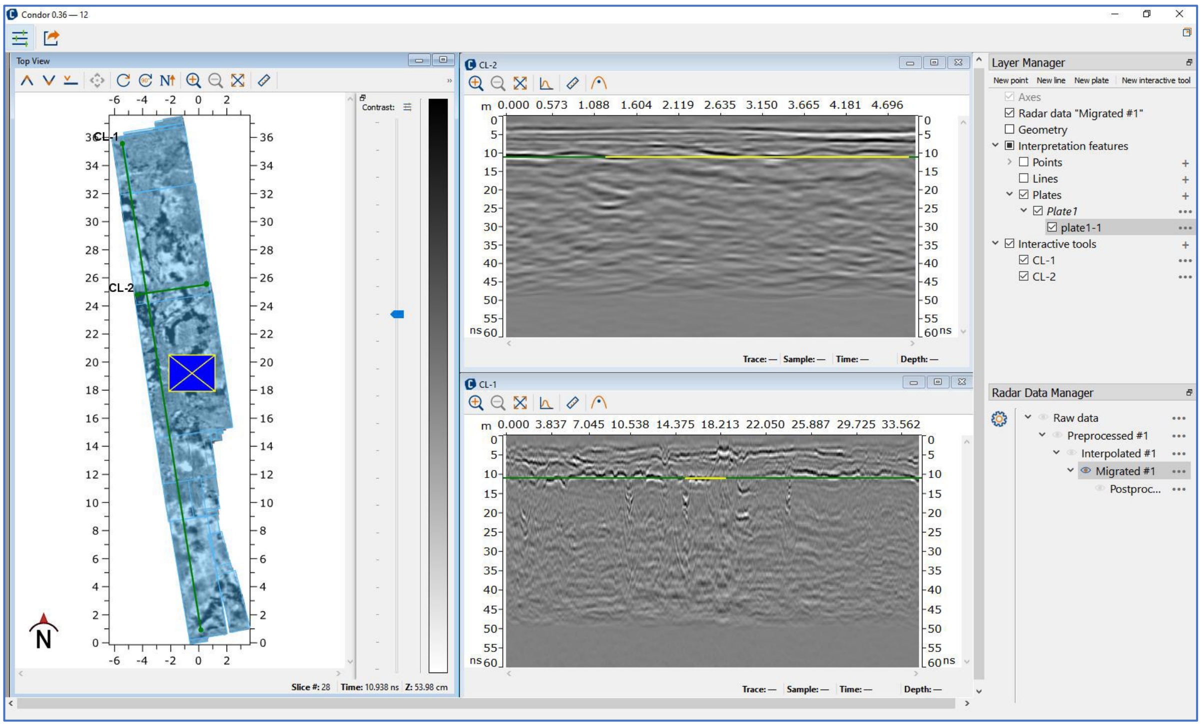


Figure 18 Example of adding a plate as an interpretation object

Note: The Top View and cross-section views are synchronized, so if an object is marked in the Top View, the projections will also be visible in the cross-section views and vice-versa.

2.2.11 Result export

After interpretation, you might want to export the results to other systems. The following four options are available (Figure 19):

- **AVI:** video format for representation results of GPR data processing and interpretation.
- **DXF:** commonly used format in software packages such as AutoCAD, ArcGIS etc. This format allows you to export interpreted objects only. During this export, the vertex-coordinates and velocities used for depth calculations are saved in text files for QA/QC purposes.

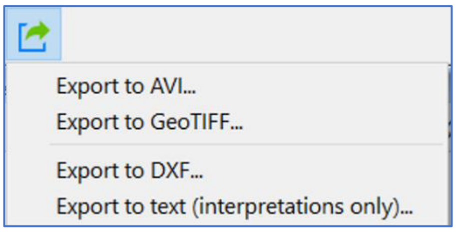


Figure 19 Exports options

- **GeoTIFF**: image file format for storing georeferenced bitmap graphics images.
- **Text**: all interpreted features are exported to text files for QA/QC purposes, surface features are not exported in this process since these already reside in text files.

Note that during DXF and text export the options for depth or height from the preferences/settings are used. Both options count positive upwards, depth starts at ground surface and height where the positioning system has its zero height. The pole-height from the raw data files will be used in this calculation when heights are exported.

3 Reference

3.1. Preferences

Preferences are global parameters that are predefined for all projects via the **Project Manager**, as shown below in Figure 20.

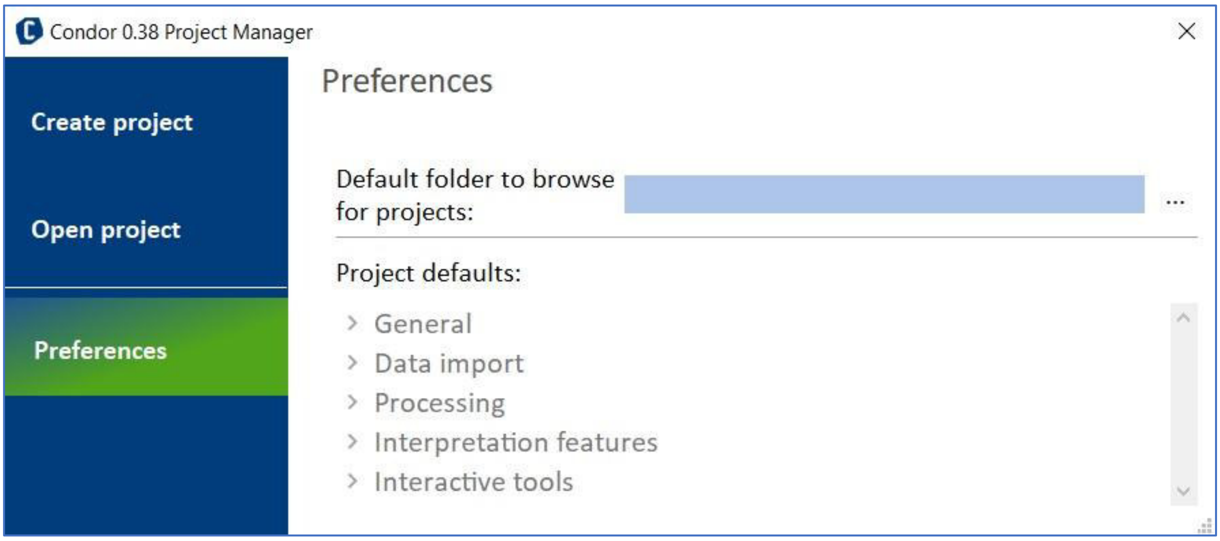


Figure 20 *Preferences window*

Default folder to browse for projects – specify the folder where all new projects will be stored by default and where you will start searching for old project to open.

3.2. Project defaults

3.2.1 General

Measurement system: select between Metric or Imperial, where distances will display in meters or feet, and velocities will display in cm/ns or ft/µs respectively.

Project velocity: is used for calculating depths from the travel time values. It is essential to understand that the software assumes constant velocity for the subsurface at each time of interpretation. This velocity can be varied but it will be simplest if you set a velocity which can be used throughout the whole project. Note that in most projects the velocity does not vary enough to justify the extra work of trying to estimate the precise values, if groundwater table is present this is obviously not the case.

3.2.2 Data import

Minimum positioning step: defines a minimum distance between neighbouring GPS/TS positioning points by removing positioning points which are closer than the specified interval. This is essential, if it has not already been done while combining files for Condor. The reason is that raw data is just that, raw. So that, if the data collection is done very slowly or if the system is brought to stand still, we may have many positions tagged to the same, or nearly the same GPR-data point.

Interpolation distance interval: after positioning data is thinned, Condor will interpolate the GPR-data along each swath's central line with the specified interval. You can set this parameter in meters/feet, or as a percentage of channel spacing.

Trace Filters: define which filters will appear as default in the Selected routines.

Time Zero Adjustment: define the default values for the Time Zero Adjustment parameters.

3.2.3 Processing

Define the default modules and associated parameters for the Selected routines in each processing stage as follows:

- Preprocessing
- Regularization
- Migration
- Postprocessing

3.2.4 OspreyView default color palette

Set default color palette for OspreyView.

3.2.5 *Interpretation features*

Define the default styles for the interpretation features and their subtypes as follows:

- **Points**: set the font, character, size and color.
- **Lines**: set the color and line style.
- **Plates:** set the color.

Note – you can reset any changes made back to the software's original default values by pressing the ⮌ icon.

3.2.6 Interactive tools

Cut-Line – define the bin size using either the 'Data import' settings or as a percentage of the channel spacing.

Ribbon box

- **Bin size**: define the bin size using either the 'Data import' settings or as a percentage of the channel spacing.
- **Width**: a value in meters/feet.
- **Default view bin size for interpretation features:**
  - side view
  - across view

3.2.7 Export

When exporting to DXF and text-files Condor use either depth positive downwards from the surface or height as read from the positioning system for the z-coordinate, see **Figure 21**.

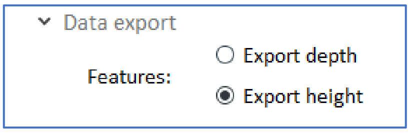


Figure 21 *Export options, depth, or height*

3.3. Positioning Preview

After creating a new project and importing swaths, the **Positioning Preview** window appears. The purpose of this step is to eliminate positioning errors in the data, either by deleting individual position data or eliminating the whole swat. Note that importing poorly positioned data generates more work and uncertainty in the following interpretation process.

3.3.1 Data

This part of the **Positioning Preview** window contains information about the imported swaths, as shown below in Figure 22. Below you will find an explanation of data and how to interpret it.

Data

		Swath	Points/m	Traces/m	Start time	End time	Total length, m
☑	1	bridge 2_001	1.23	24.60	06:35	06:36	58.421
☑	2	bridge 2_002	1.34	24.42	06:36	06:37	152.020
☑	3	bridge 2_003	1.39	24.87	06:39	06:40	155.663
☑	4	bridge 2_004	1.27	24.45	06:41	06:41	144.526
☑	5	bridge 2_005	1.16	24.90	06:42	06:43	148.863
☑	6	bridge 2_006	1.22	24.44	06:44	06:44	145.540
☑	7	bridge 2_007	1.14	24.91	06:45	06:46	147.016
☑	8	bridge 2_008	1.41	24.65	06:49	06:51	108.216

Figure 22 *The Data window contains information about imported swaths*

- **Points/m**: the average number of GPS/TS points per 1 m. If you find large variations in this column you may consider removing swats with few points. E.g. a value of 0.1 means that the swath has 10m between every positioning point.
- **Traces/m**: the average number of GPR traces per 1 m (for one source-receiver pair). If this parameter varies a lot, it may mean that the odometer was not attached correctly or that the odometer wheel was not in contact with ground all the time or slipping.
- **Start time**: the swath start time, informative, helping operator to recall in what order swaths were collected.
- **End time** – the swath end time. Informative as previous.

- **Total length (m)**: the total length of the swath. Typically, a real-life data set will contain swaths clearly erroneous. E.g., operators forget to start data acquisition, start the GPS, loosing contact with Total stations etc. The total length often indicates such swaths.

To the left side of each Swath is a checkbox, which allows you to select which swaths will be displayed on the map in the **View** window. If a swath is unchecked, the software will not load it into the project, as shown below in Figure 23.

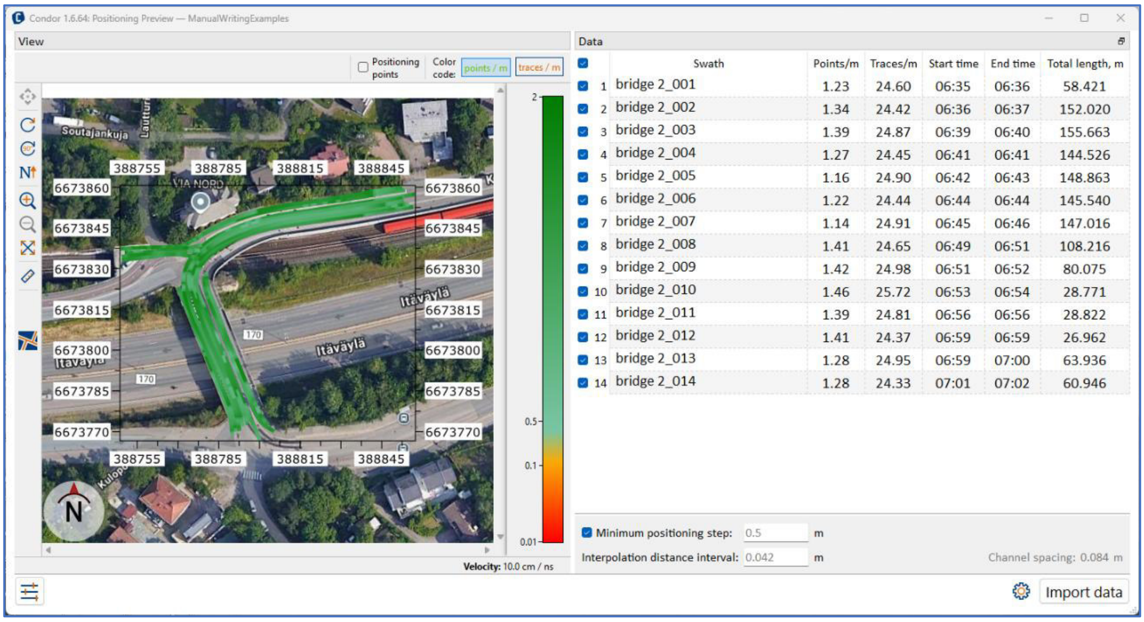


Figure 23 Select swaths to display and load into the project

3.3.2 View

This part of the **Positioning Preview** window contains a display of the swaths and positioning map, and a toolbar to change the display parameters. As shown below in Figure 24, the map is color-coded and shows either the number of positioning points or the traces per meter, as shown in the **Data** window. The goal with the color coding is to give you a quick overview of the positioning quality and to ease the identification of problematic areas.

Each line is also made up of points with connecting lines of different color, dependent on the direction during data collection.

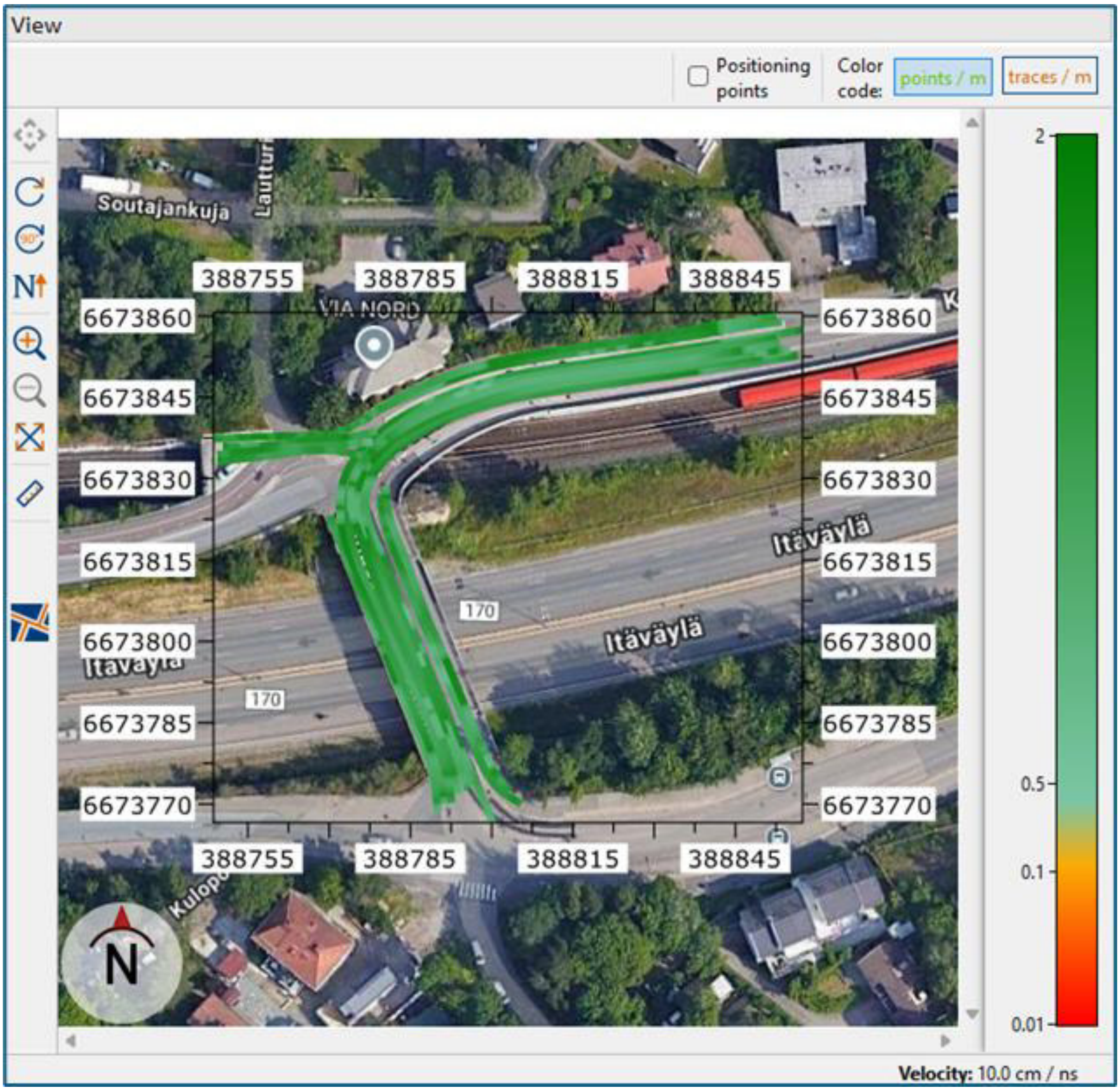
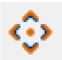


Figure 24 *Positioning Preview window*

Positioning Preview Toolbar

	Planning mode. Holding the left mouse button down, move the mouse to pan the map.
	Rotation mode. Holding the left mouse button down, move the mouse to rotate the map.
	Rotate the map 90 degrees.
	Orient the map to the North.

	Start zoom. Hold the left mouse button down and move the mouse to select an area the map to zoom in. Release the mouse button when ready. Condor will quit zoom mode right after zooming operation is complete, so you will have to click this button again to be able to zoom further.
	Zoom out
	Fit the map to window size
	Ruler, a measuring tool that allows you to calculate the length of a created path on the map, as shown below in Figure 25. Click the left mouse button on the map to add a point to the path. You also can move a point by left mouse click and delete it by double click

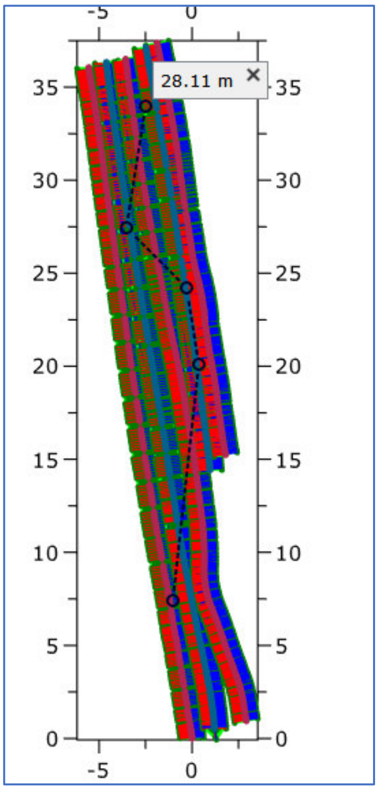


***Figure 25** Example of the Ruler tool applied to data in the Top View*

Positioning points

The GPS path and geometry of each swath is displayed by default. Deselect the checkbox to turn this view off. When positioning points are displayed, you may delete one or more positioning points using the mouse, as follows:

- Right-click on an individual point to delete it.
- Left-click on an individual point to select it. Then press the <Delete> key to delete it.

- Hold the <Shift> key and drag a rectangle to select several points as a rubber-band selection. Then press the <Delete> key to delete all selected points.

Note – the position of the array system is calculated automatically and perpendicular to the trajectory of the swath central line if the prism/GPS was positioned in the center of the array during the survey. This also means that curved lines will stretch/compress GPR data on the outer/inner perimeter of the curve.

Color code

The color representation on the map, as shown below in Figure 26, is determined by:

- **points/m:** the color scheme corresponds to the number of GPS points in 1 m.
- **traces/m**: the color scheme corresponds to the number of GPR traces on 1 m.

The color schemes may be adjusted arbitrarily by double-clicking the color bar and change the palette settings, see Figure 27 below.

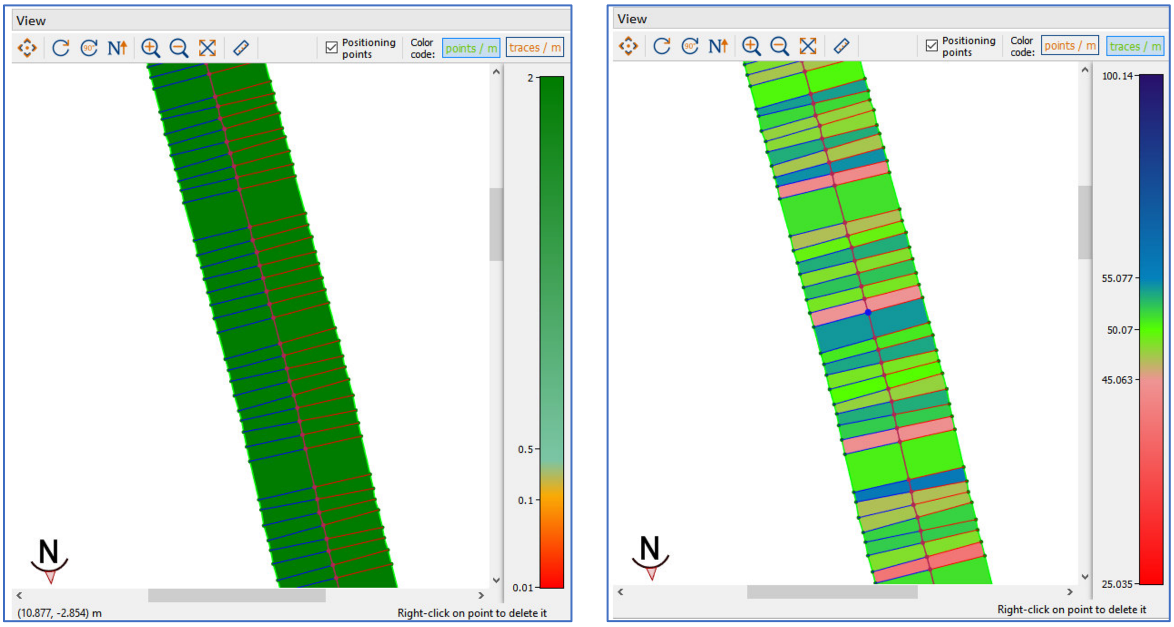


***Figure 26** Positioning Map in points/m (L), and traces/m (R)*

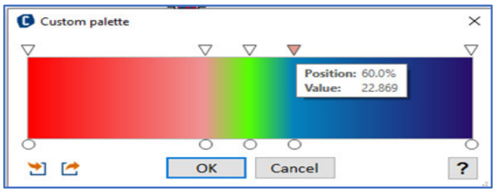


***Figure 27** Adjusting color coded via the palette*

3.3.3 Positioning parameters

Minimum positioning step: set the minimum distance between neighbouring GPS/TS positioning points by removing positioning points which are closer than the specified interval.

Interpolation distance interval (m): after GPS/TS data is thinned, Condor will interpolate the GPR-data along each swath's central line with the specified interval. By default, this parameter is set to half of the channel spacing. The channel spacing in the array is shown in the rightmost lower corner, for reference. See Figure 28.

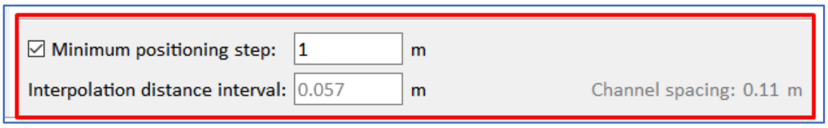


Figure 28 Positioning parameters

After clicking the **Import** button, Condor will bind the data to the interpolated positioning grid, preprocess the selected swaths, and import them to the project.

3.3.4 Editing of Preprocessing Flow

You can edit the flow that will be used to preprocess the data on import. To do so, click on the button located in the bottom panel to the left of the **Import data** button. The import processing window will appear, as shown below in Figure 29.

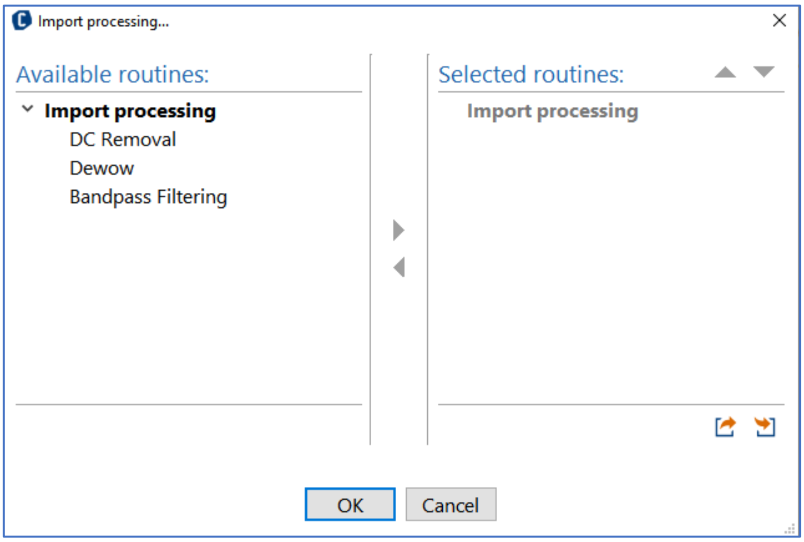


Figure 29 Selection of import processing routines

The following procedures are currently available:

- DC Removal
- Dewow
- Bandpass Filtering.

Add/Remove routines using the left/right arrows.

DC Removal

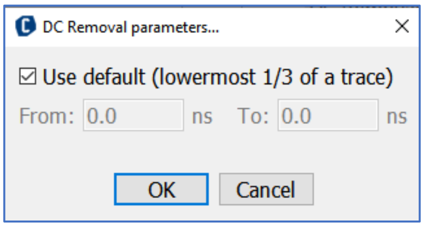


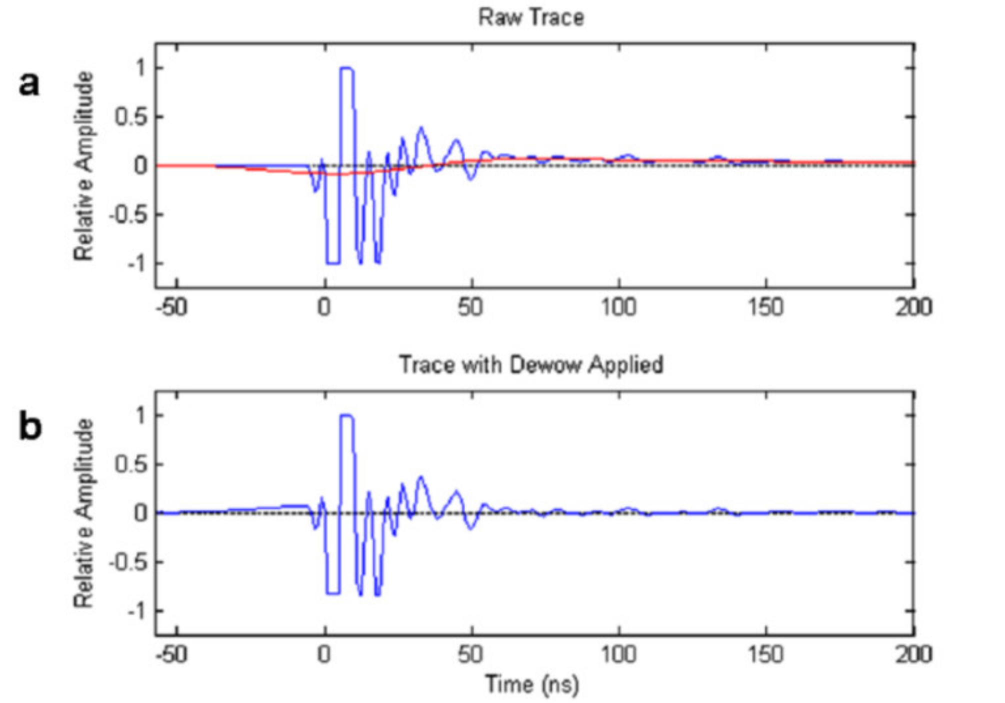
Figure 30 DC Removal parameters

This routine removes any DC component from each trace, via the window shown below in Figure 30Figure 30.

From and **To** define the time range where the software will evaluate the DC level. Select the checkbox to use the default (the lowermost third of a trace).

Dewow

The GPR-data often shows noise comprised of very low frequencies. As shown below in Figure 31, the Dewow routine removes these low-frequency components from the data. The algorithm is based on Gaussian filtration (weighted summation).



4. GPR trace before (a) and after (b) application of dewow filter. The red line in (a) is the wow component which is then subtracted from the raw trace. 1.2.2 Topography Considerations

***Figure 31** Illustration of Dewow algorithm.*

For each point of a trace, a weighted average value is calculated within a time window. The weights follow the Gauss distribution curve, see Figure 32, with the maximum at the central point of the time window. These weighted average values are taken as a low-frequency component, which is then subtracted from the trace.

Here there are two parameters:

- **Time window width, samples** – defines the total length of the averaging window**.**
- **Filter width, samples** – defines the width of the Gauss main dome relative to the total window length. Use wider filters for a wider main dome and thicker tails of the weighting curve, and, thus, more averaging.

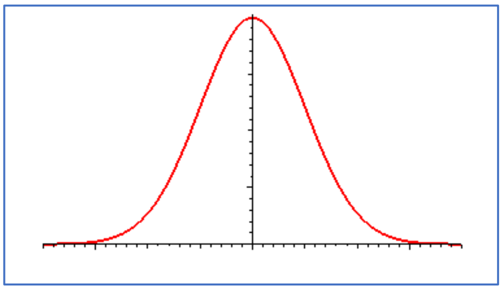


Figure 32 Form of the Gaussian filter

You can choose one of the three predefined parameter options or set them manually, as shown below in Figure 33.

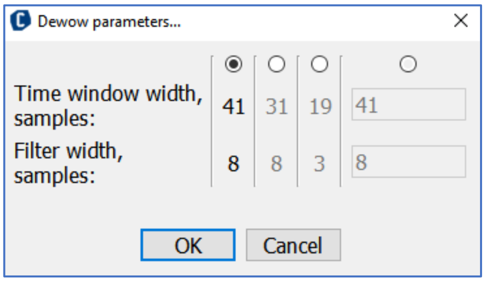


Figure 33 Dewow parameters

Bandpass Filtering

This routine applies frequency filtering to every input trace. Condor uses an algorithm of a simple trapezoid bandpass filter, which operates in the frequency domain. You need to specify four values of frequency in Hz in the filter parameters selection field, as shown below in Figure 34.

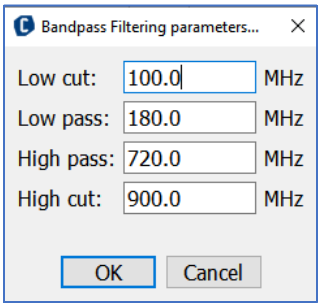


Figure 34 Bandpass filtering parameters

3.3.5 Project settings

It is possible to change some settings of the current project, without affecting the global settings. To do so, press the button in the bottom left of the window, and a pop-up window will appear, as shown below in Figure 35. This allows you to change the **Measurement system** and the **Project velocity**, which is used for the time to depth calculations in the current project, up to the first migrated data instance.

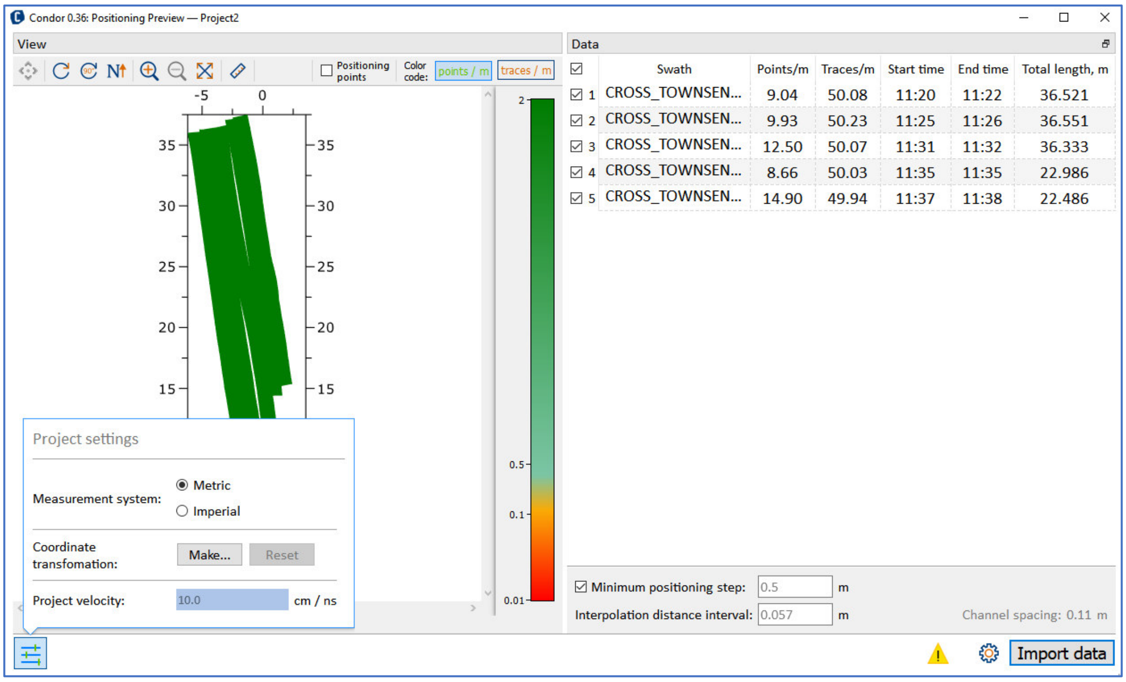


Figure 35 *Project settings window*

Additionally, you can change the coordinates of the project to match your preferred local coordinate system, using the **Coordinate transformation** function.

Click the **Make…** button and in the **Coordinate transformation** window will appear, as shown in below Figure 36. Use the + button to add reference points, of which there must be a minimum of two. For each, you need to specify the coordinates in both the old (source) and the new (destination) coordinate systems. Alternatively, you can select a point on the **Top view** and specify new coordinates for it.

Note that when using a total station, its practical to mark positions with known coordinates as surface markers during the survey and then use these markers when converting the project to a coordinate system. In that way it is not necessary to establish the total station whiting the coordinate system, a local, arbitrary, system may be used during the survey.

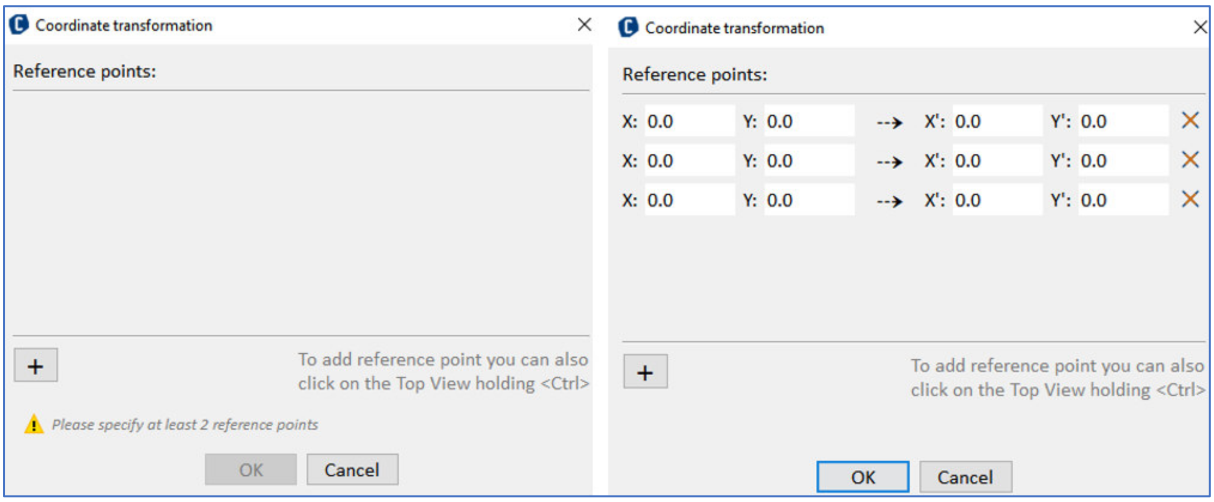


Figure 36 Specify reference points to apply a coordinate transformation

You can cancel any coordinate transformation applied, by clicking the **Reset** button, as shown below in Figure 37.

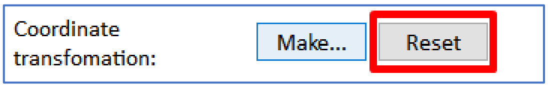


Figure 37 *Reset coordinate transformation*

3.3.6 Warnings

Anytime a problem exists with the positioning data, the ⚠ symbol will appear to indicate that some action is required, as shown below in Figure 38.

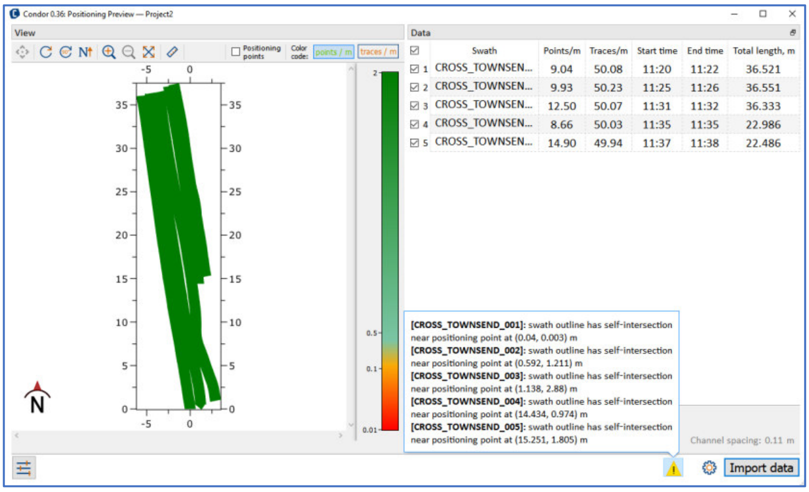


Figure 38 *The warning symbol indicates problems with positioning data that require action*

Figure 39 below, shows an example of a positioning error, where the outline of the swath has a self-intersection. You can correct such errors by deleting extra positioning points until all warnings are gone. Alternatively, you can rely on automatic decimation of points during data import.

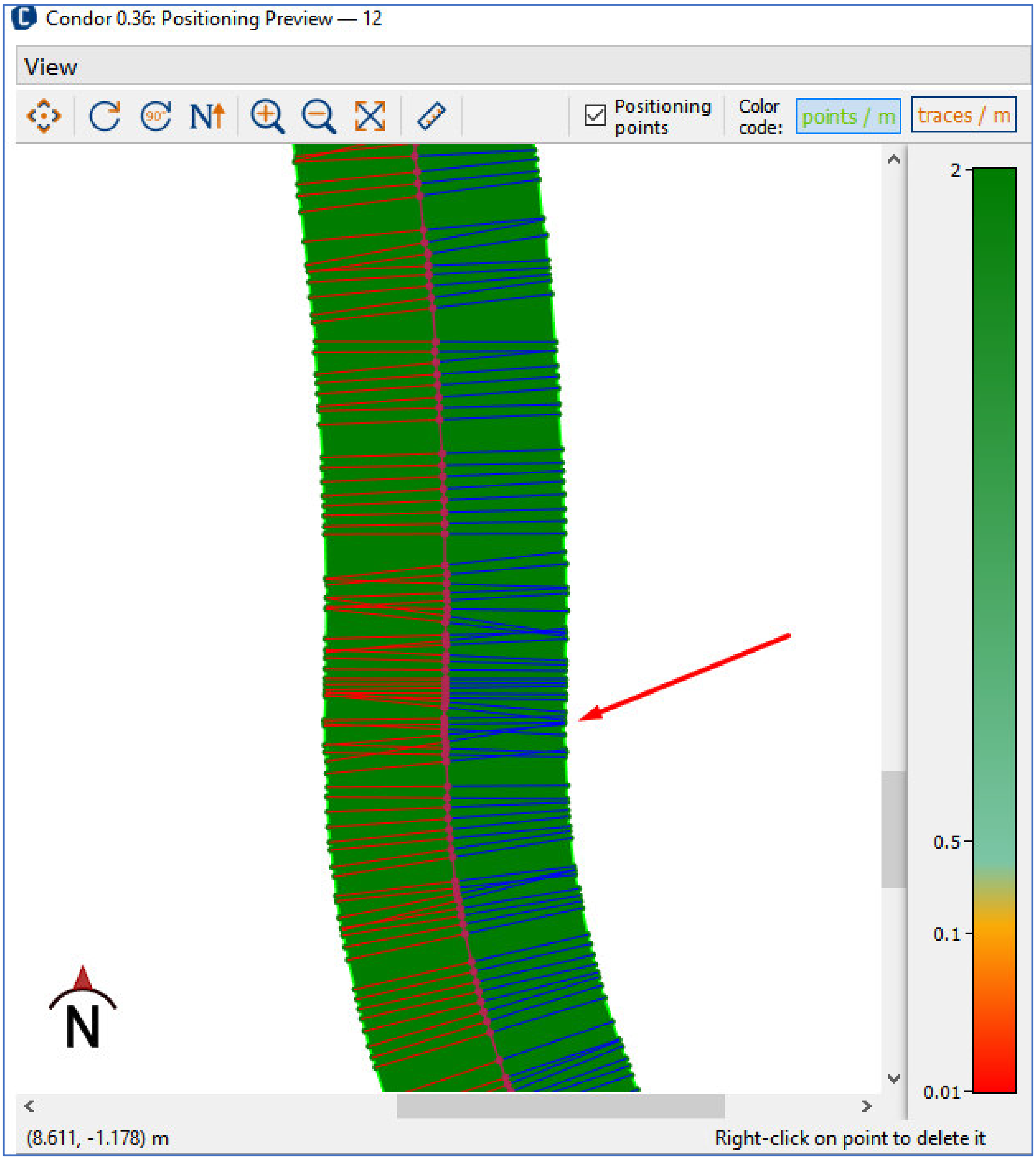


Figure 39 *An example of a Swath outline with positioning error caused by self-intersection*

3.4. Time Zero Adjustment

Figure 40, shows the Time Zero Adjustment parameters window. Here you can enter appropriate values for each field and ensure the Correct for antenna separation checkbox is selected.

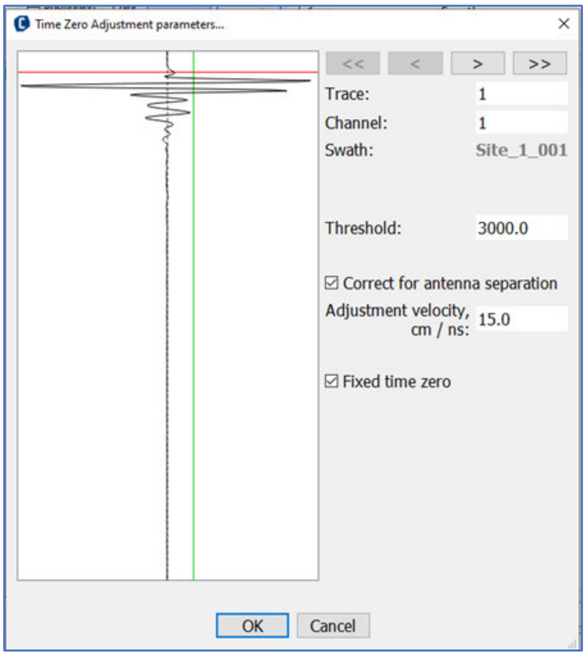


Figure 40 Time Zero Adjustment window

Trace: defines the scan number. A scan consists of traces obtained by the system in one shot. This number spans all scans of all swaths.

Channel: defines the channel number within one scan.

Swath: the name of the current swath that contains the displayed trace.

Threshold: the algorithm finds the first sample which amplitude exceeds the **Threshold** parameter**.** From that time, Condor will search the first maximum and assign this point as the first break. The Threshold parameter should not be too small because in this case, the software can perceive noise as the first break.

Correct for antenna separation: there is some distance between the source (transmitters) and the receiver antenna for each channel in the array. When this option is selected, time-zero is calculated as the first break time minus the travel time of the wave from the source to the receiver. The travel time is calculated using the **Adjustment velocity**.

The basic algorithm, including the threshold detection, may be further refined by checking the **Fixed time zero** checkbox. When checked, Condor calculates an average time zero on the first section of the project and assumes identical data with respect to this characteristic throughout the project. This gives better image smoothness in first time-slices and is the recommended setting.

Note – if the Raptor array is altered in any way, Tx/Rx units swapped or changed, this function cannot be used.

3.5. Positioning Edit window

The **Positioning Edit** window, as shown below in Figure 41, allows adjustment of the positioning data if you suspect that something is wrong with any of the positioning points before final import. You can move points (left mouse click) or delete them (right mouse click) as needed. Whole lines are moved by first marking them with cntrl+shift + left mouse click and then move with right mouse button.

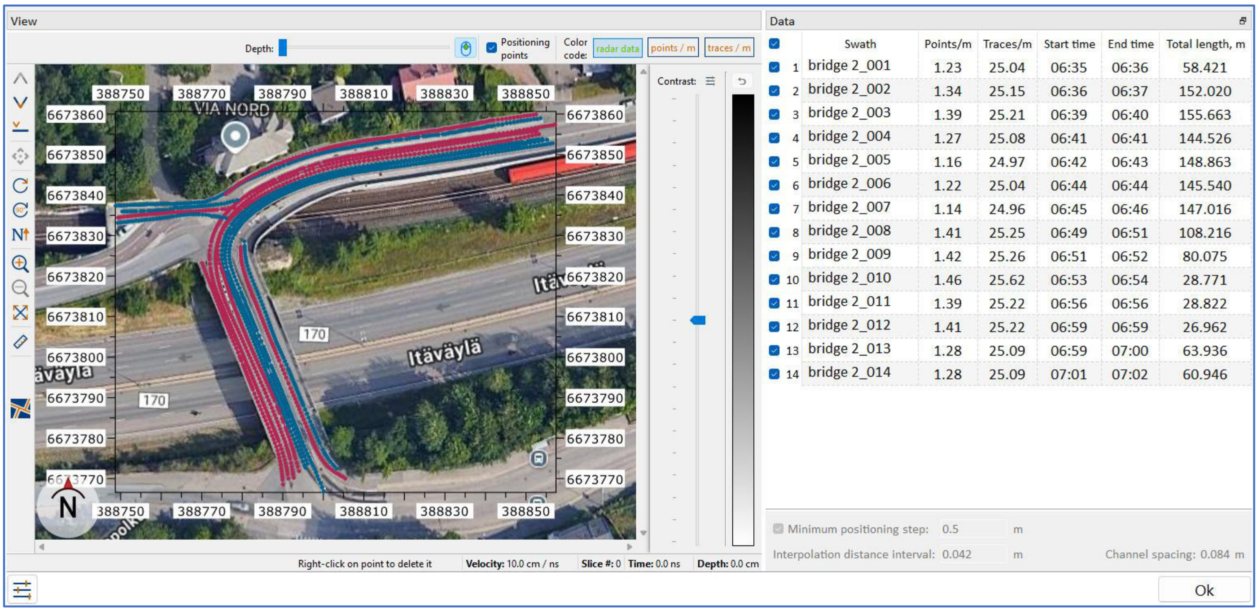


Figure 41 *Positioning editing window*

Positioning Edit Toolbar

^	Move the slice up.
v	Move the slice down.
(navigate icon)	Navigate to a particular slice. Specify index, time, or depth of a slice you want to look at, as shown below in Figure 42.

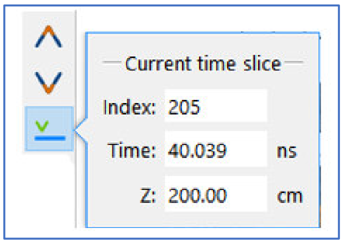


Figure 42 Time slice navigator

You can also gradually change the depth using the slider in the top panel, as shown below in Figure 43. The Bind to mouse wheel, makes the mouse wheel control the depth whenever the mouse is not pointing on a different control, which should be controlled by the wheel.

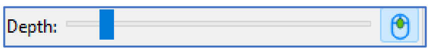


Figure 43 *Slider for changing the depth view*

The other buttons of the toolbar are the same as those in the Positioning Preview window.

Contrast and normalization

You can adjust the intensity of the contrast for the depth slice display using the slider shown in Figure 44 (red highlight box).

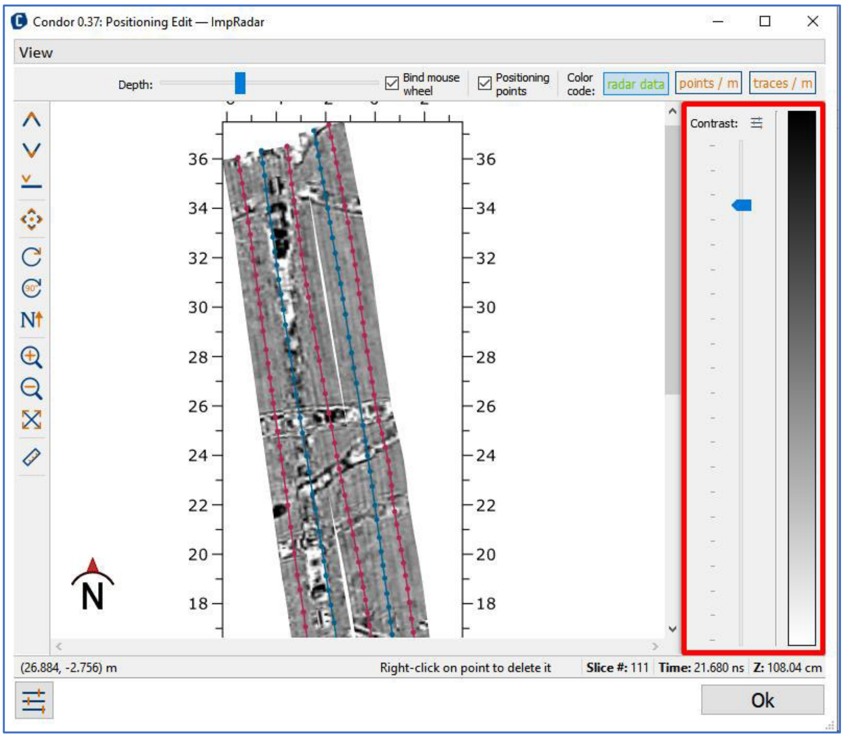


Figure 44 Contrast intensity adjustment slider

To select the type of normalization, click on the  button, and chose one of the two options available.

- **Individual slice:** each slice is displayed with individual contrast, to make the analysis of each slice easier.
- **All slices**: Condor uses a single contrast for the display of all slices. If there is a big range of amplitudes present in the data, it's possible that weak events (e.g. those at the bottom of the section) will be indistinguishable on the slices. This option requires all slices to be read, which can slow down operation.

3.6. Velocity management

When the water content of the soil varies significantly, it may be necessary to interpret objects while using a different wave velocity compared to the one set in the preferences. It may also be necessary/advisable to save the velocity used during the interpretation to QC the whole project. In the following we describe how this can be done.

The initial wave velocity is set in preferences. If this velocity is not changed by the operator, all depths to interpreted targets will be calculated based on this velocity, time zero and antenna separation.

If the project velocity is altered, consecutive interpreted objects are depth-defined according to the new velocity, see Figure 45.

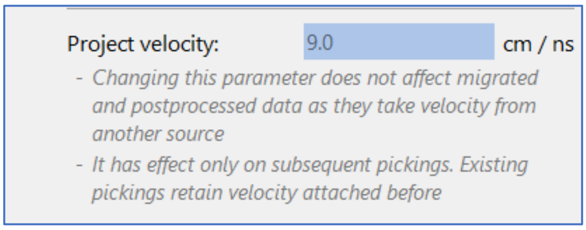


Figure 45 Changing of project velocity does not affect already made interpretations

Every time a migration-data instance is created, the velocity for this branch, and following post processing instances, is set to the velocity used during the migration. The project velocity is not valid in these instances. The velocity set for the migration branch may be overruled manually, see Figure 46.

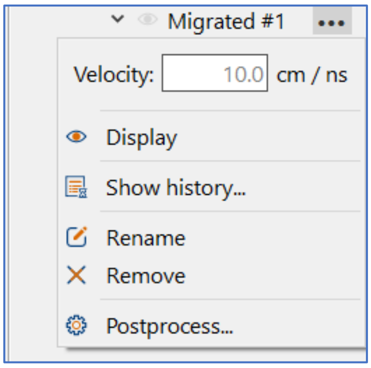


*Figure **46** Manual velocity setting of migrated instance*

This can also be expressed as: For all data-instances up to migration, the project velocity is used, and for all migrated and following instances an individual velocity is used during depth calculations when exporting to DXF.

When you pick a target (a vertex of), the velocity which is valid in the data instance you use, is saved with the two-way travel time to the vertex. But in Condor the vertex of the pick is always presented based on the time. When exported to DXF, the depth of each object is calculated based on the velocity valid at the time of picking the object. This has the consequence that all interpreted targets stay at the locations where they were marked, regardless of velocity alterations, but when you export to DXF, the velocities will be used for depth calculations.

Since you can interpret in any data instance, this means that if you alter the velocity, you must keep track of what velocity currently is valid. The currently valid velocity is displayed at the bottom of the window. Note that we have limited the functionality so that each object will have one velocity attached to it only. If you change the velocity or move to an instance with different velocity, you will not be able to create more vertexes nor editing existing ones, for that specific target.

3.7. Main processing and interpretation window

3.7.1 Radar Data Manager

The Radar Data Manager (Figure 47) allows you to manage the data sets and processing procedures to be applied to the data. You can add new procedures to stages, remove existing ones, and adjust procedures' parameters.

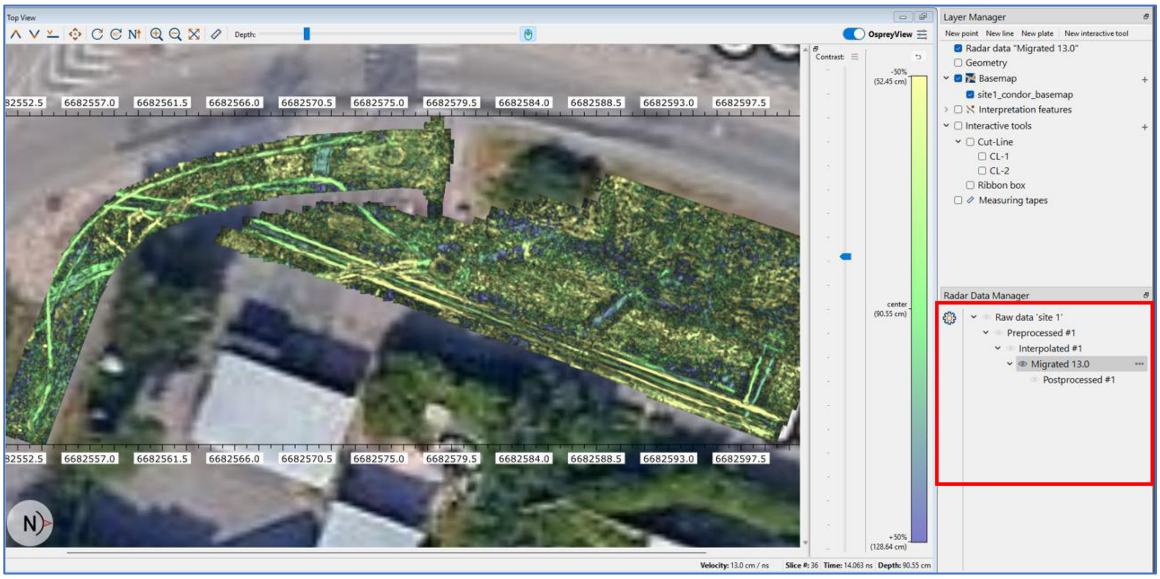


Figure 47 The location of the Radar Data Manager

There are four predefined stages in GPR data processing as shown in Figure 48:

1) Preprocessing
2) Regularization
3) Migration
4) Postprocessing

Each stage has a particular set of routines. You don't need to add all of them to your processing flow, only the ones you find useful at each processing stage.

Preprocessing

There are four available procedures on this stage:

- Bandpass filtering described in previous section.
- Muting
- Amplitude Correction
- Antenna Ringdown Removal

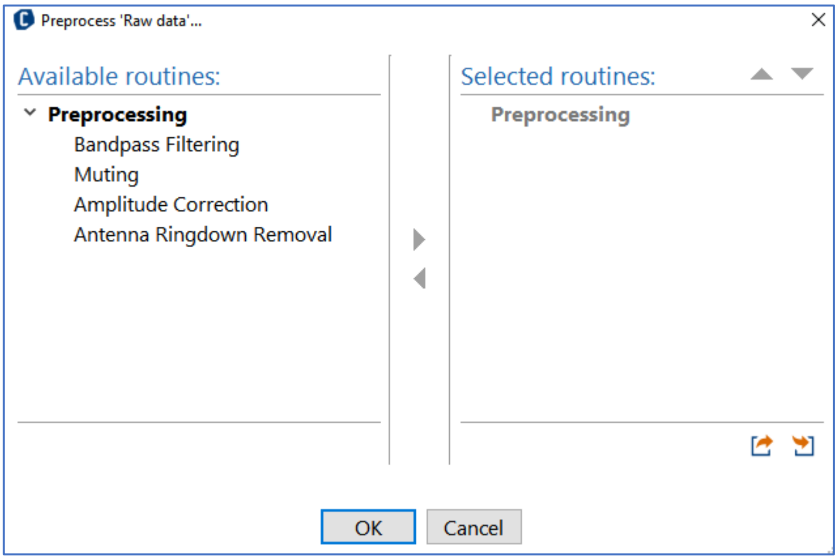


Figure 48 Preprocessing stage

Muting

For each GPR swath, the algorithm evaluates the average modulus amplitude, followed by the same for every single trace. If the average value for a trace significantly differs from the average value for the dataset, Condor will reject a scan containing this trace from dataset. In the parameters dialog, as shown in Figure 49, you need to specify the **High-amplitude muting ratio** and the **Low-amplitude muting ratio** separately.

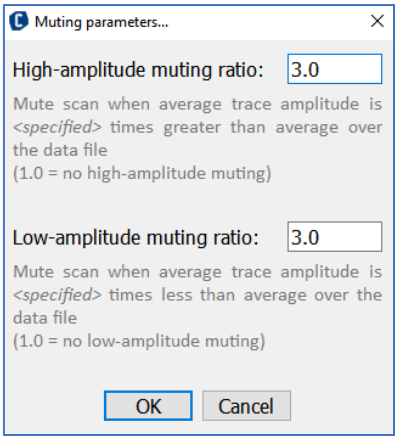


Figure 49 Muting parameters

Amplitude Correction

There are two available options to carry out amplitude correction, either spherical divergence correction or AGC.

Spherical divergence correction: in a homogeneous medium, energy density decays proportionately to $1/r^2$, where r is the radius of the wavefront. Wave amplitude is proportional to the square root of energy density; it decays as 1/r. Spherical divergence correction eliminates the influence of the divergence on GPR-signal amplitudes.

AGC: Automatic Gain Control, a procedure applied to the data to amplify weaker signals. It allows for improving the visibility of low-amplitude events. AGC is applied to the data on a trace-by-trace basis using a sliding time window. For each position of the window, a scaling factor is calculated as 1/average modulus amplitude within the windows. Then this scaling factor is applied to either the central, the first or the last sample of the window.

As shown in Figure 50, there are two parameters to adjust:

- **Operator length**: length of sliding window, specified in nanoseconds.
- **Application basis**: select sample for multiplying by scaling factor:
  - **Centered** – central sample to be multiplied
  - **Leading** – first (lowermost) sample to be multiplied
  - **Trailing** – last (uppermost) sample to be multiplied

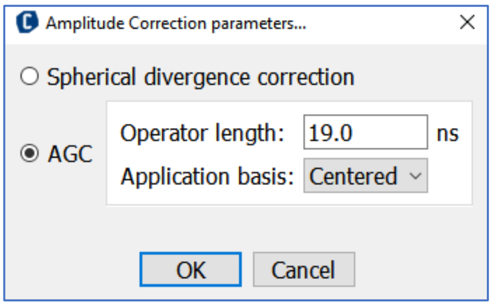


Figure 50 *Amplitude correction parameters*

Predictive Deconvolution

Predictive deconvolution is a signal processing technique used to remove unwanted multiple reflections from seismic or Ground Penetrating Radar (GPR) data. It enhances signal clarity by predicting and subtracting repetitive events while preserving primary signals.

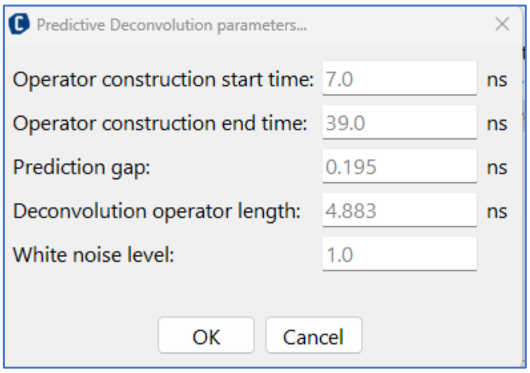


Figure 51 Predictive deconvolution parameters

Predictive deconvolution parameters:

The key parameters include (Figure 51) the operator construction start and end times, which define the time window for analysing the signal. The prediction gap determines the delay between the current signal and the predicted point, targeting specific periodic events like multiples.

The operator length specifies how far forward the algorithm predicts, and the white noise level adds stability, preventing noise amplification during processing. Together, these settings allow for efficient removal of unwanted signal components.

Antenna Ringdown Removal parameters

To suppress antenna ringing, an average GPR trace is calculated using all traces within the **Operator design window**. Then, the average trace is subtracted from each GPR trace, sample by sample. Figure 52.

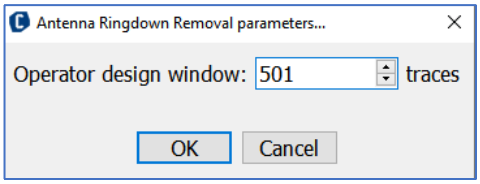


Figure 52 *Antenna Ringdown Removal parameters*

Regularization

There is only one procedure on **Regularization** stage.

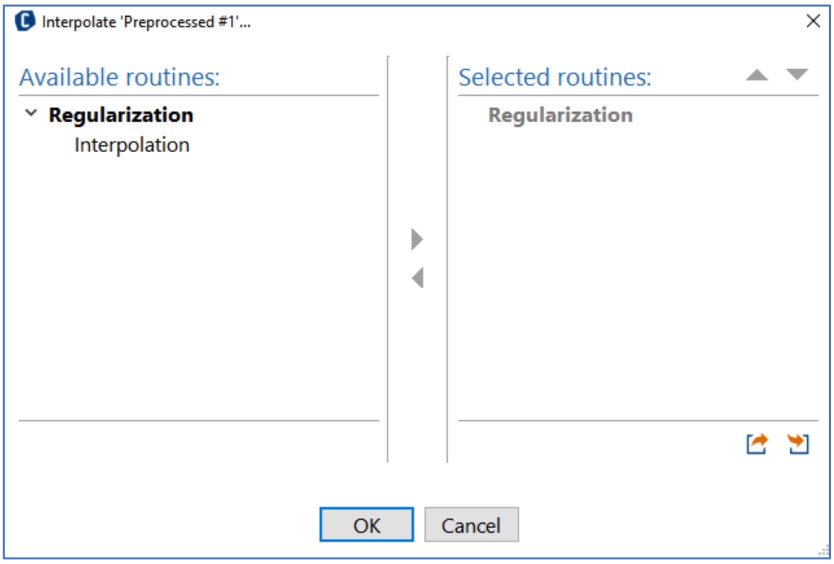


Figure 53 *Regularization stage*

Interpolation

Condor automatically divides the area of acquisition into rectangular chunks depending on the **Max allowed gap** parameter. Then it bilinearly interpolates amplitudes for each slice to a regular grid within each chunk.

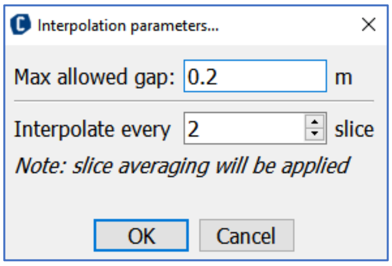


Figure 54 *Interpolation parameters*

It is possible to average several slices before interpolation as shown in Figure 54. This would reduce the number of time slices in the resulting dataset as well as significantly reduce the space required on the ssd-drive. Note that you cannot average too many slices, if you approach the number of samples covering a full envelope of the GPR-signal, the resulting average will approach zero.

Interpolation parameters:

- **Max allowed gap:** maximum gap that will be filled by the interpolation algorithm. This parameter significantly influences how the dataset is divided into chunks, so if you not satisfied with result of interpolation try to adjust this parameter.
- **Interpolate every Nth slice:** specify step between slices for interpolation. If this parameter is 1, then every slice of the initial dataset will be interpolated. If N is greater than 1, the algorithm will average every N sequential slices and then interpolate the averaged slices. The resulting dataset will contain N times less slices than the input one.

Migration

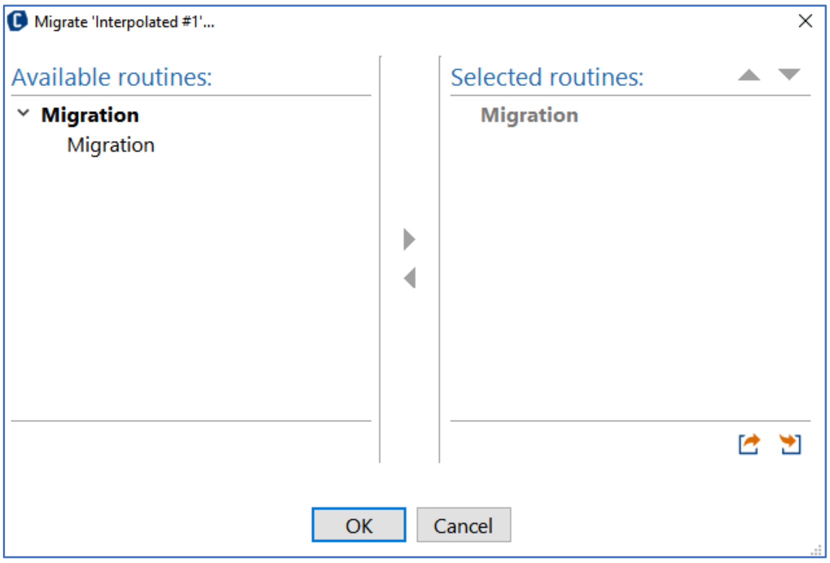


Figure 55 Migration stage

There is only one procedure on **Migration** stage. Figure 55.

Migration

Due to the wide lobe pattern of UWB-antennas and the physical process of diffraction, the wave energy dissipates almost omnidirectional into ground. Thus, a reflection from a small point-like object will look like a hyperbola. The migration algorithm allows focusing these hyperbolic reflections back to one point, which significantly improves the quality of the resulting images. Additionally, any tilted boundaries will move slightly so that their shape becomes correct after migration. Migration works best on linear or point targets showing strong hyperbolic edges as shown below in Figure 56 and Figure 57. This may significantly ease interpretation.

Note 1 – It can be challenging to determine the exact migration velocity that will give the best result from the first time. Therefore, the common approach in GPR data processing is to iterate through several different velocities, to compare the results and choose a value that produces the best image.

Note 2 – After migration has been applied that data instance will have an attached velocity equal to the velocity used in the migration process. This velocity may be manually overruled but the first vertex you set for an interpretation object will be attached to that active velocity. Current velocity is shown in each data window.

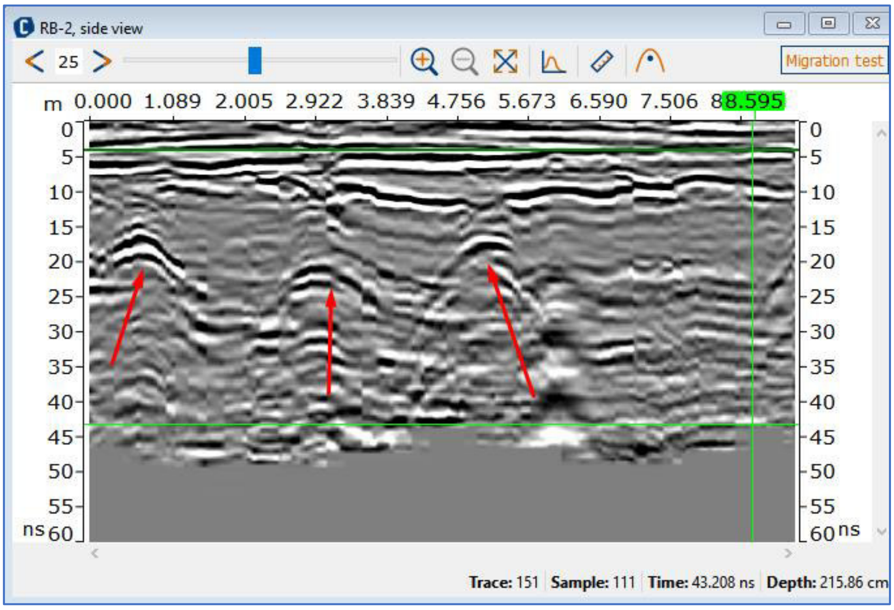


Figure 56 Hyperbola reflections from point objects

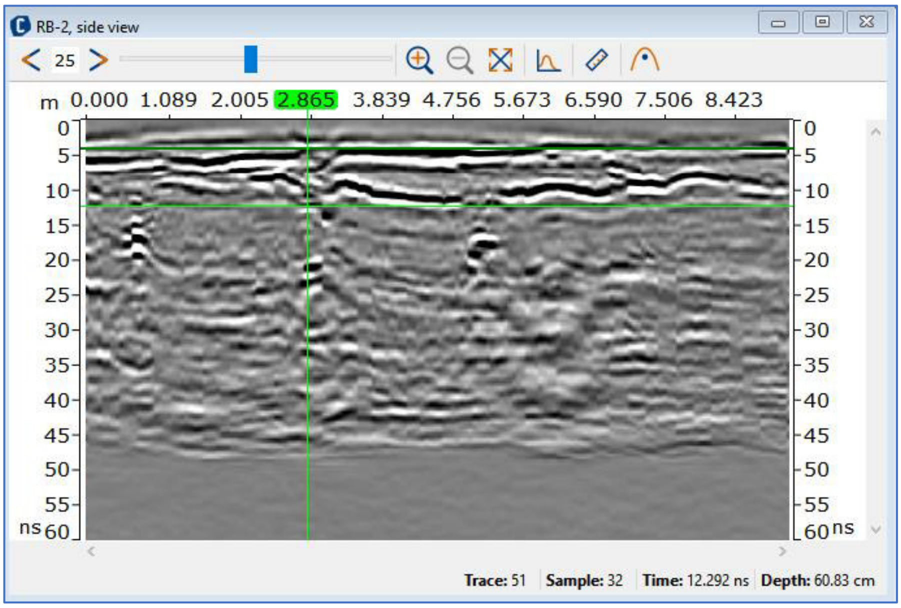


Figure 57 The effect of migration on the data shown in Figure 56

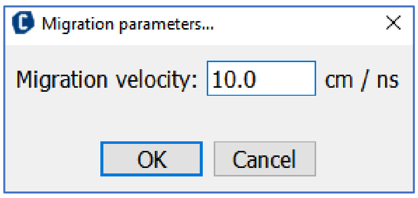


Figure 58 Migration parameters

In Condor, a constant velocity migration algorithm (known as 3D Stolt F-K migration) is implemented. There is only one parameter in this routine – **Migration velocity cm / ns**, as shown in Figure 58.

The best way to find an optimal velocity value is to run Migration Test. To do so, select an interpolated dataset, create or execute a cutline or a ribbon box and on an opened side/across view press **Migration test** button, as shown below in Figure 59.

A slider to adjust migration velocity will appear, and you can try different values and select the one that gives the best result.

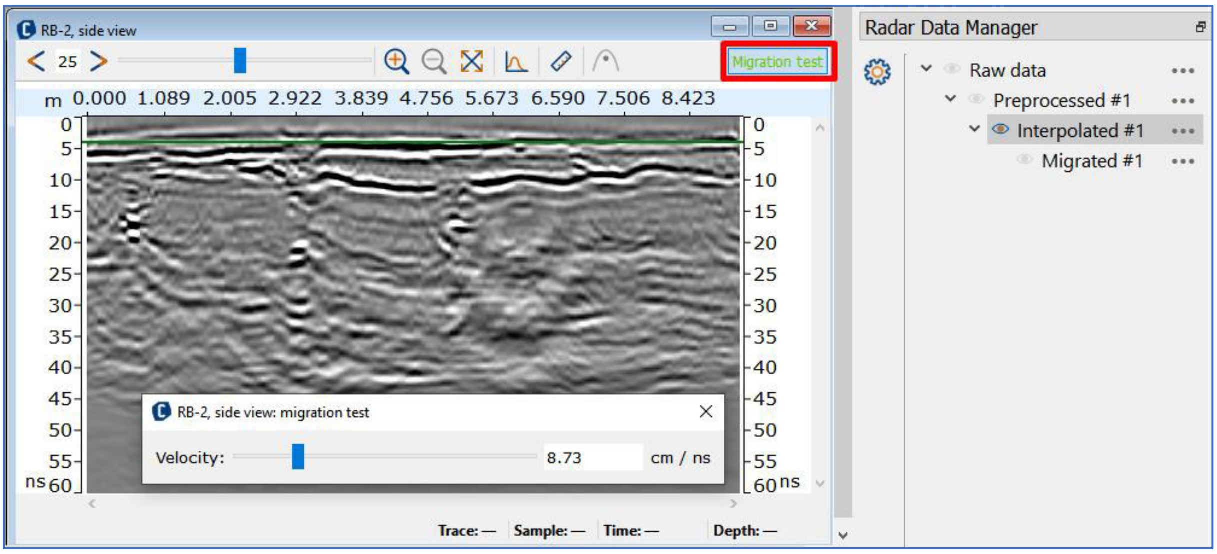


Figure 59 The Migration

After you have made your mind about migration velocity you can initiate the Migration procedure for your interpolated data, as shown below in Figure 60.

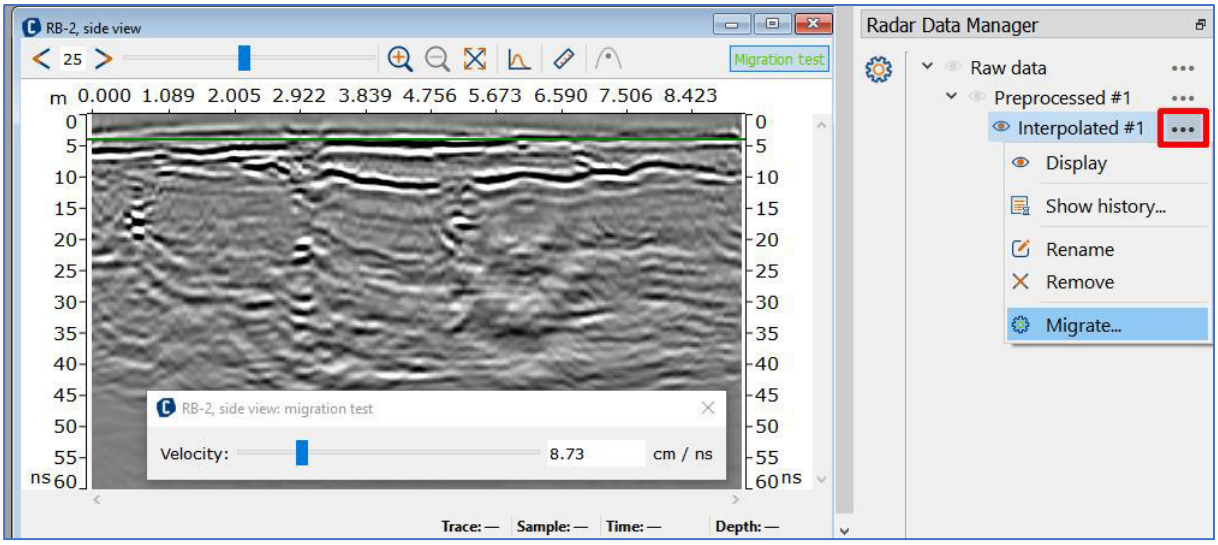


Figure 60 Initiating the Migration procedure

Postprocessing

There are three available procedures on the **Postprocessing stage**, as shown below in Figure 61.

- Bandpass Filtering
- Amplitude Correction
- Amplitude Envelope

You may refer to the preceding sections for an explanation of the Bandpass Filtering and Amplitude Correction routines.

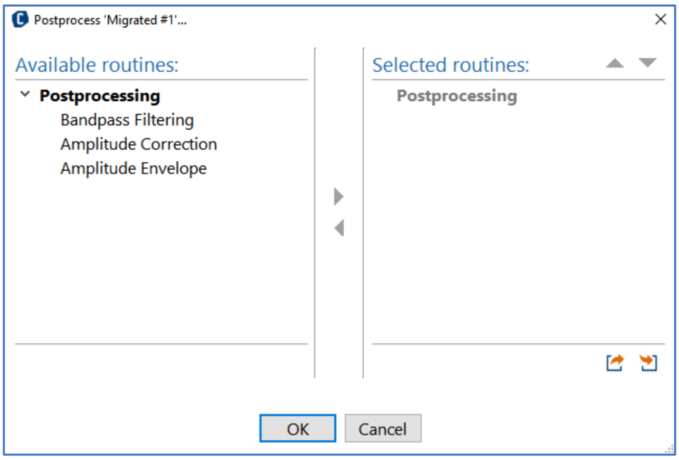


Figure 61 Postprocessing stage

Amplitude Envelope

This routine allows you to transform each GPR trace to a trace of *amplitude envelope* (sometimes it is also referred to as *reflectivity strength* or *instantaneous amplitude*). This representation can make easier detection of amplitude variations. The procedure has no parameters.

3.7.2 Import and export of the workflow

Sometimes it may be useful to reuse workflows with pre-established parameters. You may **Export** a preferred workflow for later use, then use the **Import** function to reload it. Use the buttons at the bottom right of the workflow window, as shown below in Figure 62.

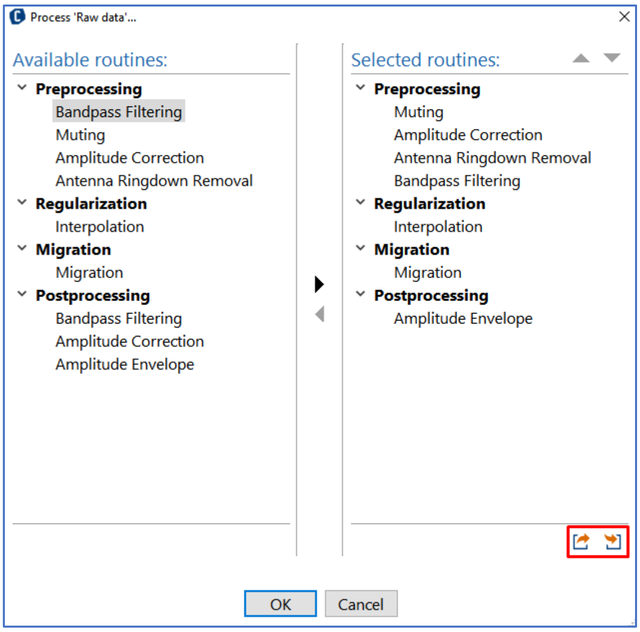


Figure 62 Export and Import buttons for saving or loading workflows

3.7.3 Different processing branches

You can create different processing branches to compare the result of applying procedures with different settings.

For example, you want to estimate two parameter sets for the **Postprocessing stage**. To do so, you can create two branches from within the migration stage. To create a new branch, select the processing stage after which you want to try a different set of parameters, click the 'ellipsis' button and create the first branch, as shown below in Figure 63.

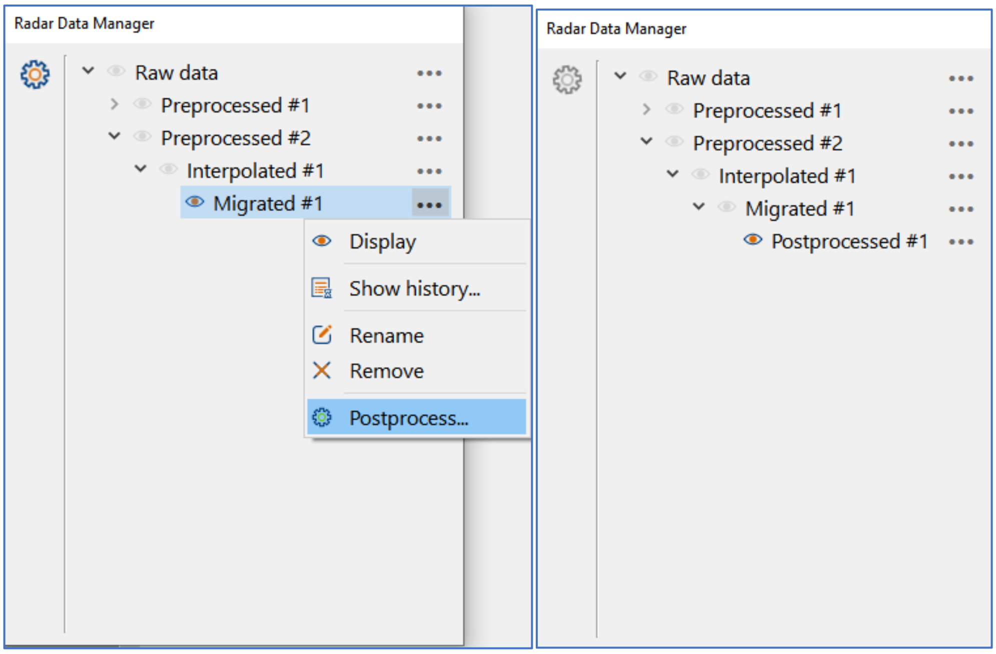


Figure 63 *Adding the first branch with Postprocessing procedures*

Now, create the second branch, as shown below in Figure 64, by repeating the same action.

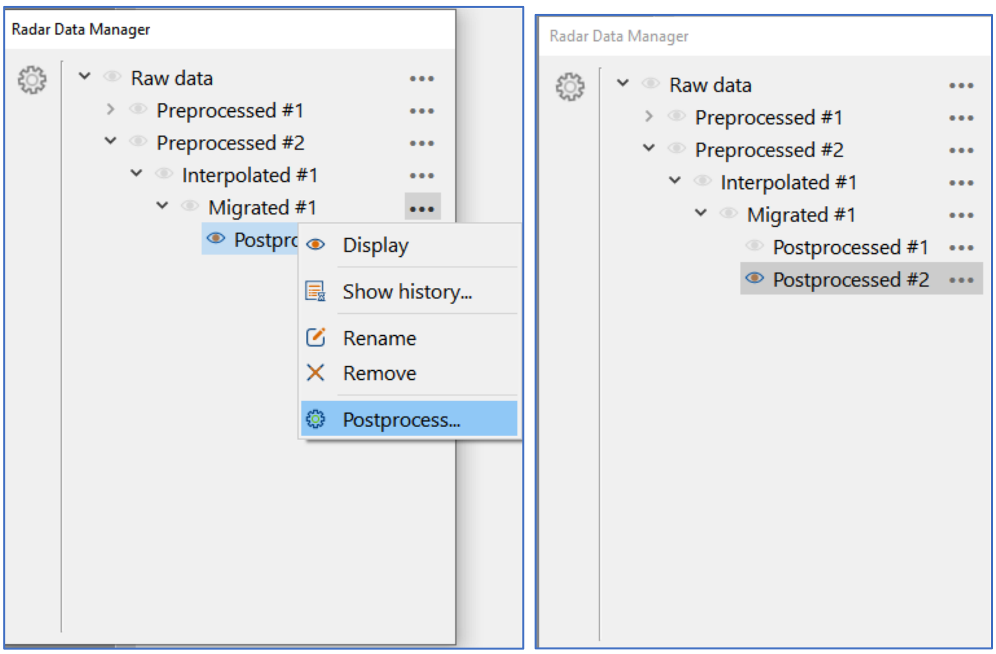


Figure 64 *Adding second branch with Postprocessing procedures*

Show history

As shown below in Figure 65 and Figure 66, you can use the **Show history** command at any processing stage to see all the processing routines and their parameters.

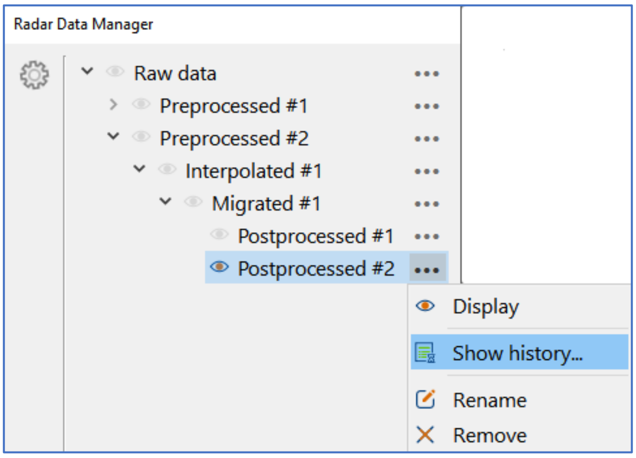


Figure 65 *Show history option*

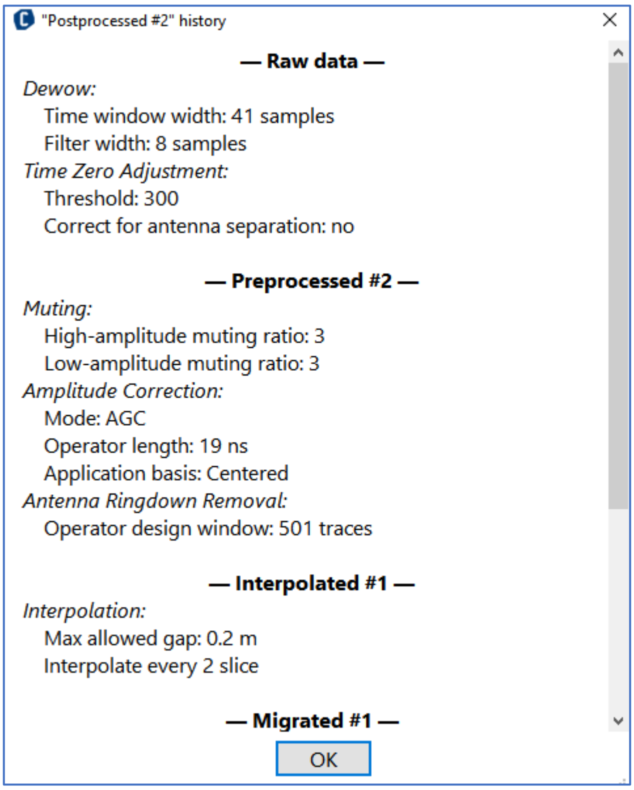


Figure 66 *History log*

3.8. Layer Manager

The **Layer manager** panel, as shown below in Figure 67, controls the visibility of different layers on the top view, through the following functions:

- Radar data
- Geometry
- Basemap

- Surface features, if defined during data acquisition.
- Interpretation features
- Interactive tools

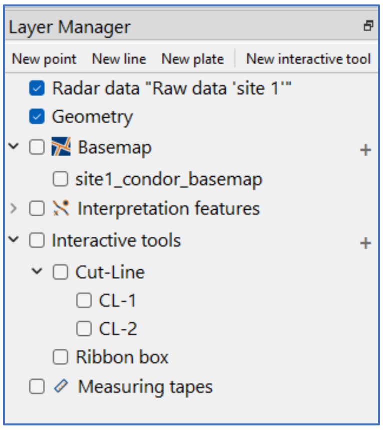


Figure 67 Layer Manager panel

Radar data "Raw data" – this layer displays the top view of the GPR cube. You can select any cube at any processing step to be displayed at this layer. Simply double-click on the dataset of interest at the **Data Manager** panel.

Geometry – this layer simply displays swath central lines and positioning points.

Basemap - you can upload a geotiff image for e.g. a satellite map or utility layout as a background image to the radar data.

Interpretation features – this is the layer where the interpretation objects are stored. You can create, rename, and delete them from the Layer Manager.

Interactive tools – this layer allows you to create and display vertical sections: cut-lines and ribbon-boxes. You can create them, edit their properties, execute those closed before, and remove them.

The following section covers a more in-depth explanation of the **interpretation features** and **interactive tools**.

3.8.1 Interpretation features

As listed below, there are three types of interpretation features, and each of them has several different subtypes.

- **Points** valves, manholes, lamppost, etc.
- **Lines** – communication lines, drains, cables, etc.
- **Plates** – some bulky objects.

To add an interpretation object, press the + button to the right of the desired object type; then choose the subtype of the feature and place it in the Top View. You can also locate them on vertical sections if any of the interactive tools are open.

Points

To create a point, select one of the point sub-types from the pop-up menu, as shown in Figure 68. Then, simply click on the top view or on one of the sections to position the new point object.

Once the point object is created, you can move it to a new location by drag-and-drop with the left mouse button.

You can create point objects of different types. Points of each type will be displayed in a separate branch of the Layer Manager tree. Figure 69 shows an example where two Lamppost points, and one Drainage well, have been created.

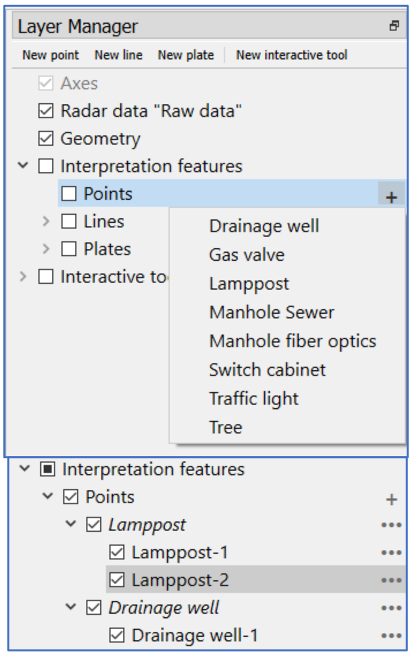


Figure 69 *multiple point types*

Right-click on a point type branch (or click its ••• button) to see its context menu. Here you can either create a new point of this type (**Add item**) of edit the symbol that is used to display this type of object (**Drawing parameters**). When you select Drawing parameters command, currently used symbol will be displayed.

Click on the currently used symbol to edit it. Figure 70 below shows the drawing parameters window that will open to enabling editing. Here you can change the symbol, its size, and color for the selected type of points.

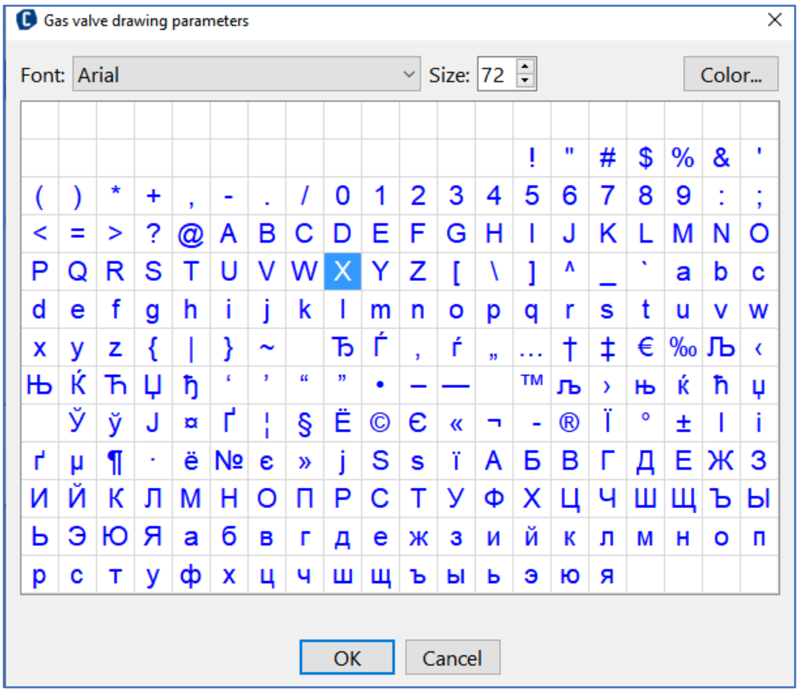


Figure 70 Adjusting drawing parameters for a point type

Right-click on a point object (or click its ••• button) to see the context menu of the individual point. You can **Rename** the point, change its type (**Transform into**) or delete the point (**Remove**), as shown in Figure 71.

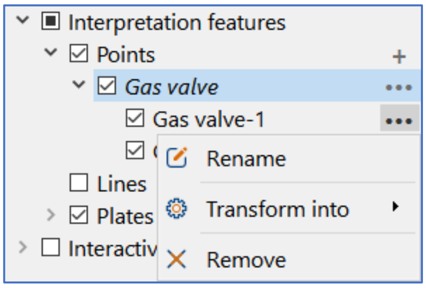


Figure 71 *Rename/Transform commands*

Lines

To create a line, select one of the line sub-types from the pop-up menu, as shown in Figure 72.

Then, start clicking on the top view or on one of the cross-sections to add pivot points to the newly created line. Double-click to add a final pivot point and stop editing the line.

You can select a line in the Layer Manager tree or on the screen at any time and continue editing. Left-click to add a pivot point to the end of the line, right mouse button drag-and-drop to move an existing pivot point to a new position.

As with Points, you can create Line objects of different types, and each type will be displayed in a separate branch of the Layer Manager tree. Line features have the same adjustment options as Point features.

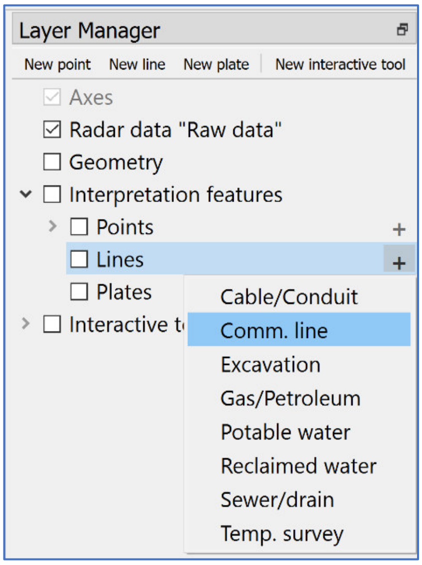


Figure 72 *Create a new line*

Plates

Creating a new plate, select one of the plate sub-types from the pop-up menu, as shown in Figure 73. Then, hold the left mouse button down and move the mouse to select a rectangular area on the top view to locate a new plate object. Additionally, hold <Ctrl> key to rotate the plate. Release the mouse button when ready.

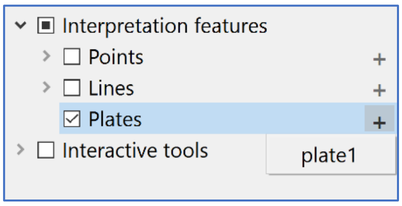


Figure 73 *Creating a Plate feature*

You can select a plate in the Layer Manager tree or directly on the screen at any time. Once selected, you can continue editing it, including changing its size and/or rotating it.

Adding new subtype to main features categories

Default Condor installation includes three main interpretation features (Points, Lines and Plates) and then further sub-types under each category. For example, interpretation feature 'Plates' has further sub-types 'Rectangle' and 'Disk'. It is possible to add user-defined sub-type interpretation features to any of the main feature categories.

To do so, locate the 'FCODES.TXT' text file in the installed Condor directory, open it and write a new sub-type under any of the main feature types as shown in Figure 74 – upper panel. In this case, sub-type feature '302 Round' was added to 'Plates' main category. After saving, close the text file. Now, open Condor and the new sub-type of feature is visible under the 'Plates' category as shown in Figure 74 – lower panel.

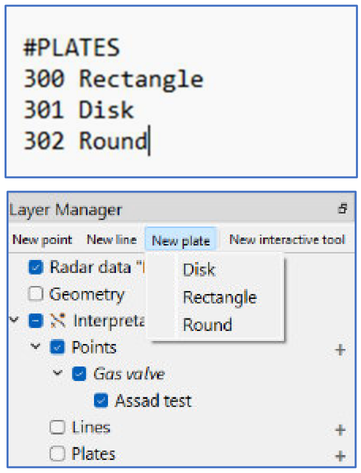


Figure 74 Adding a new subtype feature.

> **Note:** It is not possible to add a new main interpretation feature in addition to above three main feature categories.

3.8.2 Interactive tools

Two interactive tools comprising **Cutline** and **Ribbon box**, are available to analyse GPR data in vertical sections.

Cutline

To create a cutline, right-click on the Interactive tools branch of the Layer Manager tree (or click on the + button) and choose **Cut-Line…**, as shown in Figure 75. You can also right-click on the Cut-Line branch and select **Add item** command.

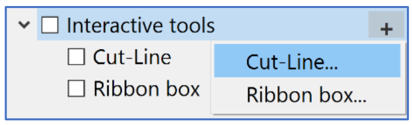


***Figure 75** Creating a Cutline*

Click on the **Top View** to create pivot points for the cutline. Use double-click or Ctrl+click to finish the line. A cross-section window with the data along the selected cutline will appear, as shown below in Figure 76.

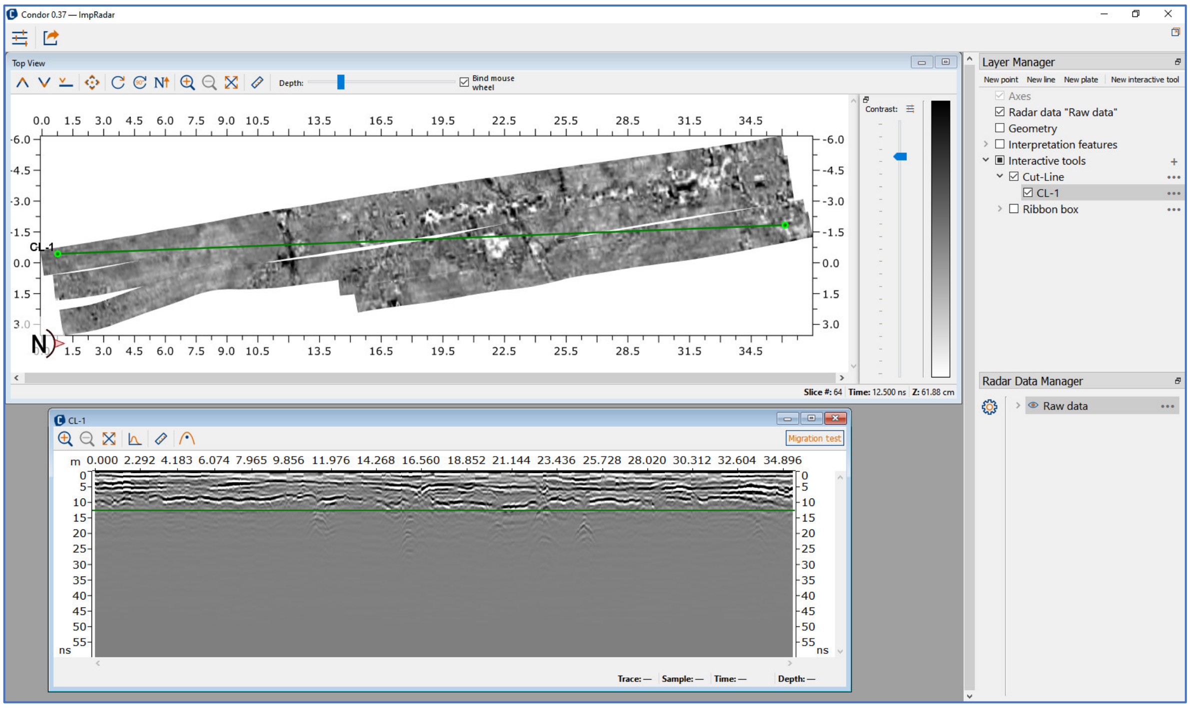


Figure 76 *After you have marked the polyline on the top view cut-line window will appear*

Right-click on an existing cutline to see its context menu, as shown in Figure 77.

Bin size: this setting controls the number of traces to be displayed in a cutline of a given length. A line is divided into several square bins with their centres located on the line. Among all traces that fall within a bin, the one that is the closest to the centre of the bin is displayed.

Note: if a bin contains no traces, Condor will display nothing there. Setting the bin size smaller than the distance between traces will result in some empty bins with no data in them.

Here, you also can **Rename** the line, change **Line color**, toggle **Title** visibility, change **Title font** and **Title color**, **execute** a closed cutline to bring its window back to display and delete it (**Remove**).

Figure 78 below shows an example of a cut-line view window.

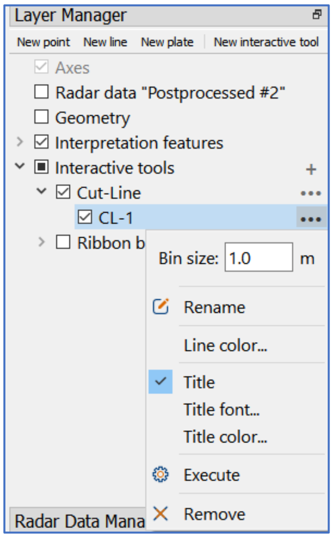


Figure 77 *Cut-line parameters*

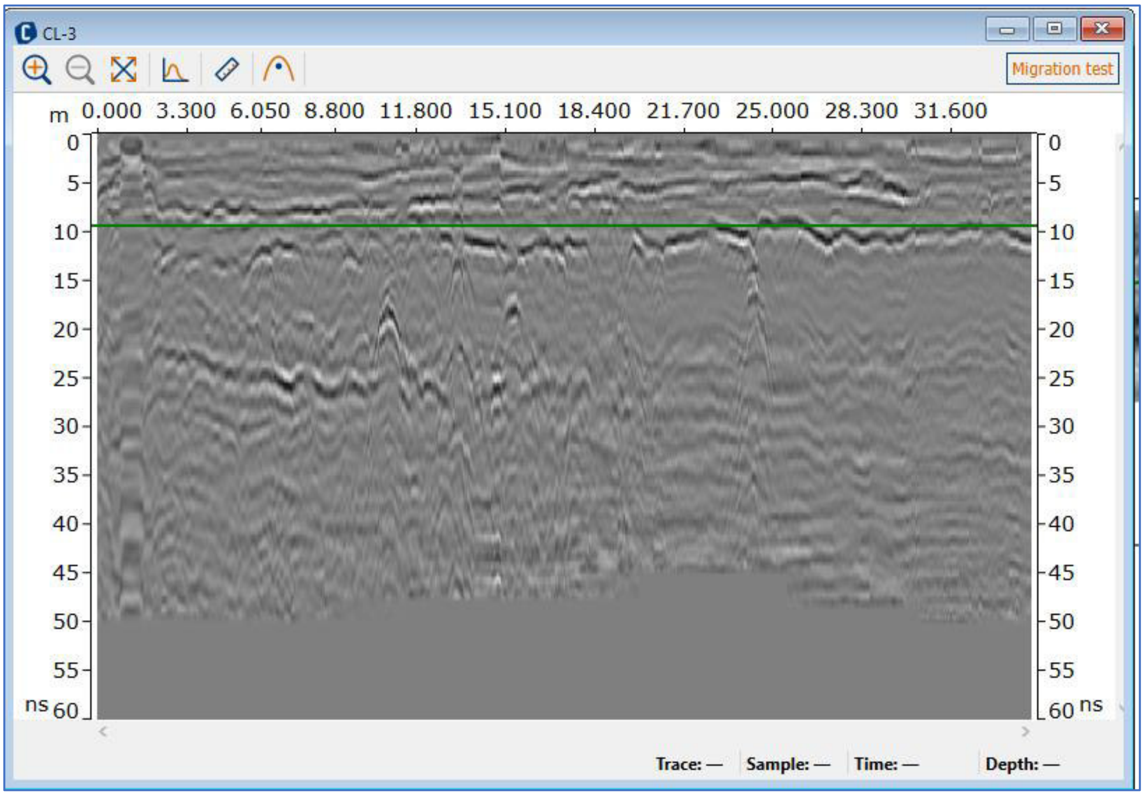
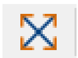
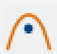


Figure 78 The cut-line view

The toolbar contains the following buttons as shown the table below:

	Start zoom. Hold the left mouse button down and move the mouse to select an area the map to zoom in. Release the mouse button when ready. Condor will quit zoom mode right after zooming operation is complete, so you will have to click this button again to be able to zoom further.
	Zoom out
	Fit to window
	View amplitude spectrum. Hold the left mouse button down and move the mouse to select an area of the radargram you are interested in. Release the mouse button when ready – an average amplitude spectrum of the selected area will be displayed.
	Ruler, a measuring tool that allows you to calculate the length of the created path on the map. Click the left mouse button on the map to add a point to the path. You also can move a point by left mouse click and delete it by double click.
	Hyperbola fit tool. This tool displays a theoretical time-curve for refraction events. Left click on an observed hyperbolic event of the

	radargram to position the axis of the theoretical hyperbola. Now you can change velocity in the media until you achieve the best fit between the theoretical time curve and the real event. The resulting velocity gives you the RMS velocity in the media above the hyperbola. Figure 79
	This tool allows you to choose the best velocity for migration. Click on this button and gradually change the velocity until you get the best image. With the correct migration velocity, a hyperbola will collapse back to a point, as shown below in Figure 80.

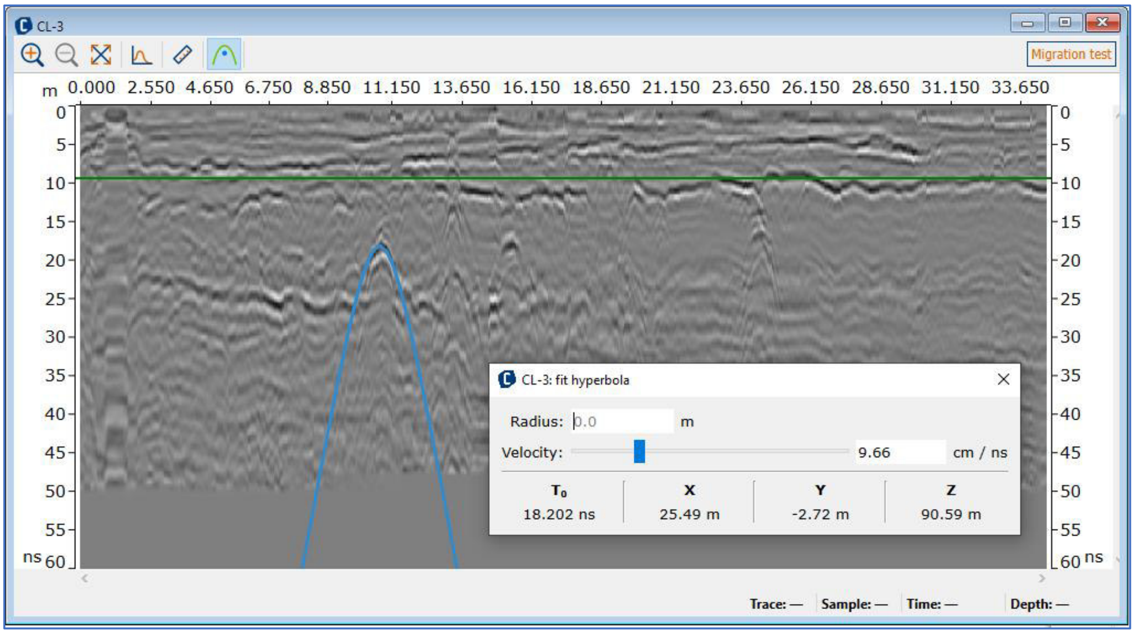


Figure 79 *Hyperbola fit tool*

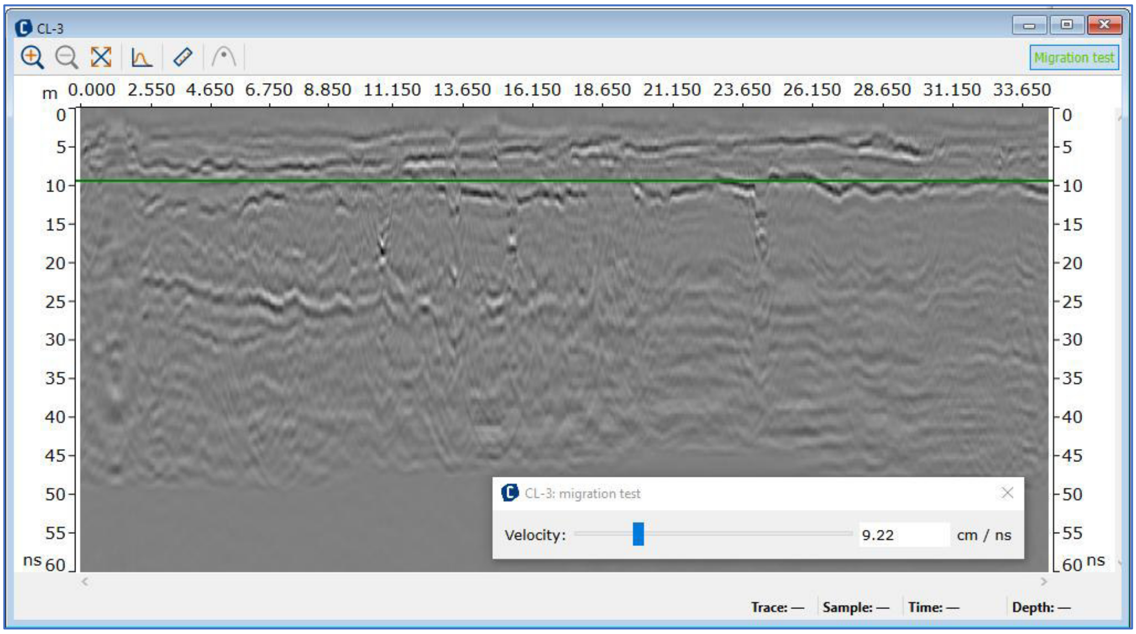


Figure 80 *Migration test tool. Correct velocity collapses hyperbolic events to points.*

Ribbon box

Ribbon box allows you to examine GPR data in a volume along the selected line. Ribbon box will display two cut-line slices – one along the central line and another one across it.

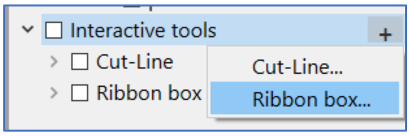


Figure 81 *Creating a Ribbon box*

To create a Ribbon-box, right-click on the Interactive tools branch of the Layer Manager tree (or click on the + button) and choose **Ribbon box...**, as shown in Figure 81. You can also right-click on the Ribbon box branch and select **Add item** command.

While defining pivot points, the user as a crosshair available to help setting the points as to cross targets at 90 degrees. Doing so helps whenever if you want to mark the target in the across-view, see Figure 82.

Upon completing the last pivot point, you will be asked to smooth the resulting ribbon box central line, as shown in Figure 83.

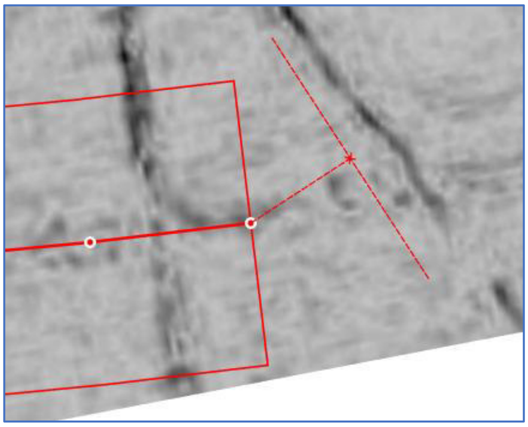


Figure 82 While defining the Ribbon box, a crosshair is available to help align the box

According to these settings, the software will draw the borders for the volume of interest, and two cross-sections will appear, as shown below in Figure 84.

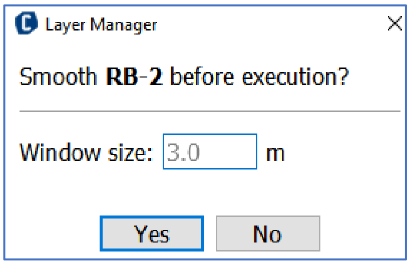


Figure 83 *Dialog window for Ribbon box smoothing.*

Using the sliders in each cross-section view, you can move through the different cut-sections both along and across the Ribbon box volume..R ght-click on an existing ribbon-box in the Layer Manager tree to display its context menu.

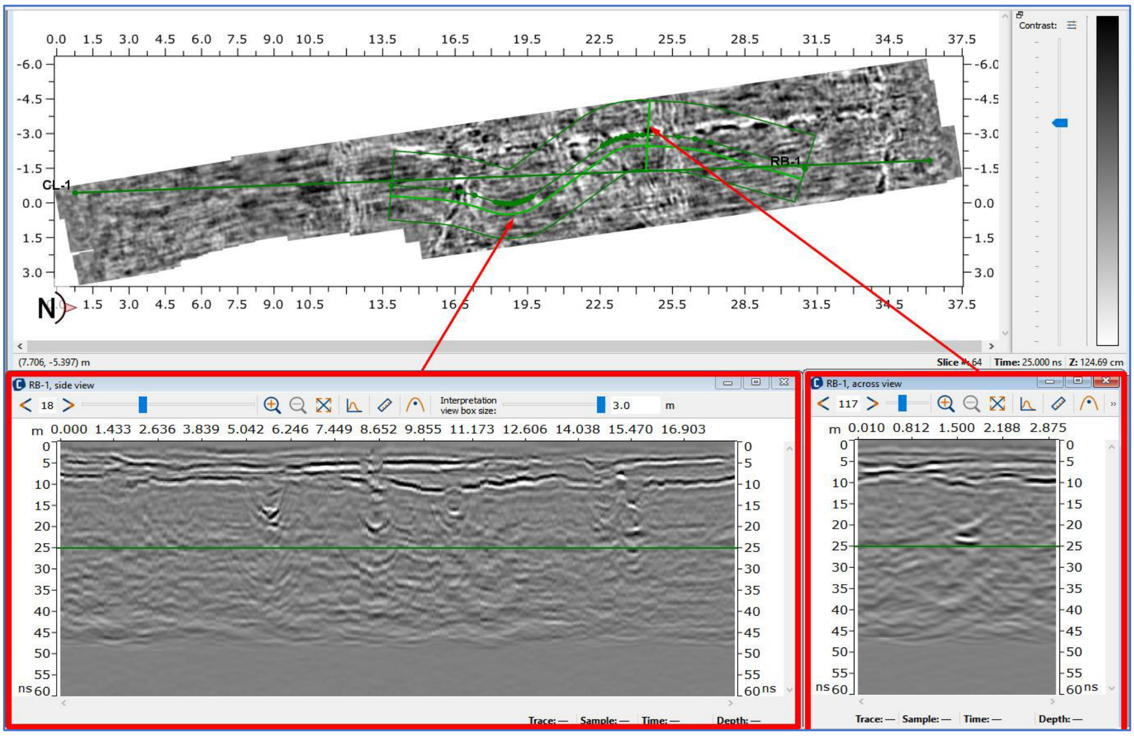


Figure 84 Ribbon box cross-section view

Ribbon box context menu is very similar to that of the cutline. The only extra parameter here is **Width** that controls the width of the ribbon box across view. Figure 85.

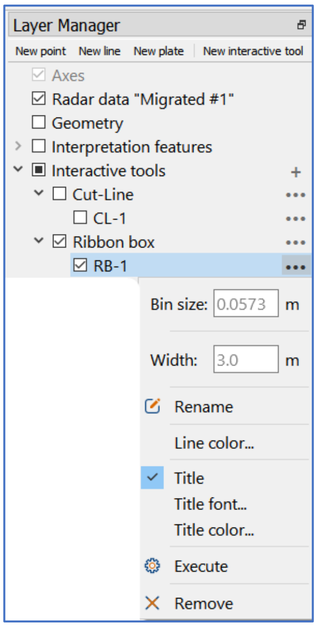


***Figure 85** Ribbon-box context menu.*

Each of the ribbon box view windows are very similar to that of the cutline. The only difference is the scroll bar that allows scrolling through the slices – along and across the central line of the ribbon box.

3.9. OspreyView

OspreyView is our name of a specific type of thick-slice processing, utilizing a color matrix combined with return amplitudes from a selected depth range.

Referring to Figure 86, below: OspreyView is activated by checking a box in the top-right corner of the top-view. Once activated it displays the return amplitudes (targets) in a color dependent on the depth from which the return arrives. In effect, the operator will "see trough" the depth range selected.

The depth range and contrast in this mode, is controlled by sliders and the color may be arbitrary selected in the palette, just as with any other palette. By default, we have coloured the view for giving a depth sense, bluish at deeper depths.

When picking targets in the OspreyView, the vertexes of the picks are aligned with the depths according to the color matrix. This means that correct depth pickings may be done from the top view, without changing the depth slice, a time saving option. The ribbon-box and cut-lines are working as with the normal top-view, regardless of whether OspreyView is enabled or not.

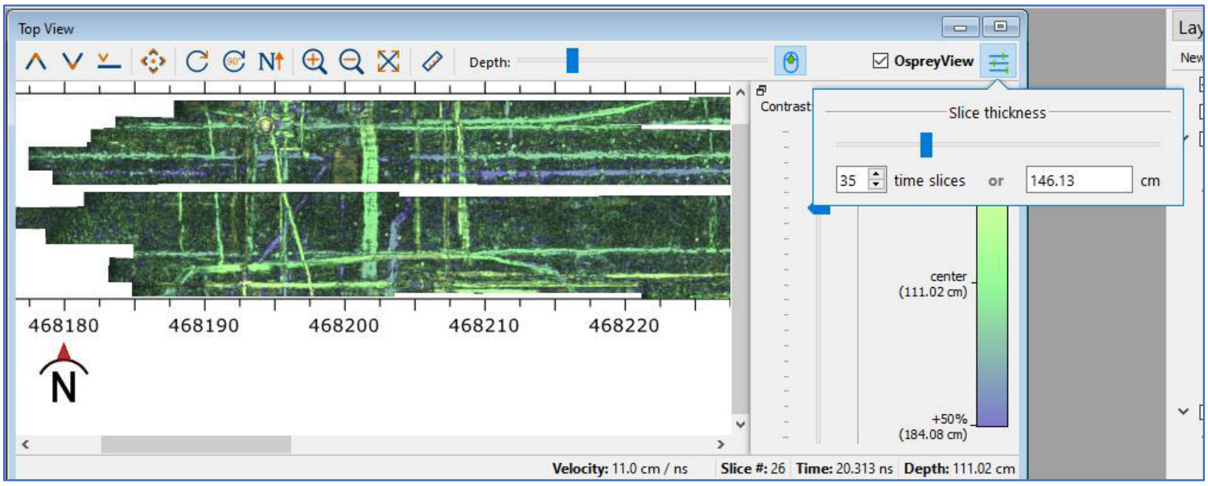


Figure 86 OspreyView is giving an overview of targets within a selected depth range. The default color matrix is chosen to paint deep target bluish, shallow targets yellowish and targets at the centre of the depth range greenish.

3.9.1 Export

To access the export functions, click on the export button on the toolbar of the Condor main window. The following types of export are currently supported:

- AVI
- DXF
- GeoTIFF
- Text

Note that dependent on the project settings, exports may contain depths below surface or absolute height as reported by the positioning system during data collection. Figure 87.

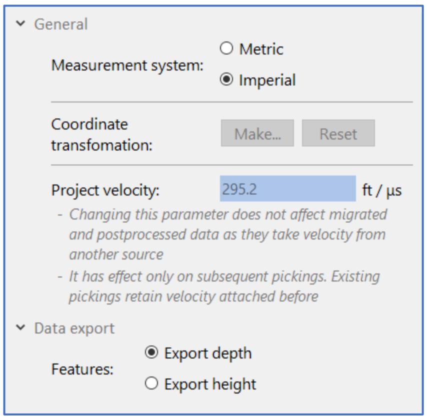


Figure 87 Exports of features to dxf may be done based on depth below surface or absolute height.

Also, the text-export is intended as QC documents, it can't be read back or manipulated by any other means than with a text editor.

AVI export

AVI allows you to record scrolling through time slices on the Top view. It provides you with convenient way to demonstrate existence of different objects presented in GPR data volume and their distribution by area and depth.

File: an AVI file to save the video to. Refer to Figure 88 and Figure 89.

You can either **Export all slices Export slice range** specifying **from** and **to** slice numbers as well as scrolling **step**.

If you want to demonstrate a particular area in video tick up, **Select area** box and select the area on the top view using **Ctrl+MB1**. Otherwise, the whole study area will be exported.

Slice info string: tick up this parameter if you want the information about the current slice to be presented in video.

Frame rate: specify frame rate of slice demonstration.

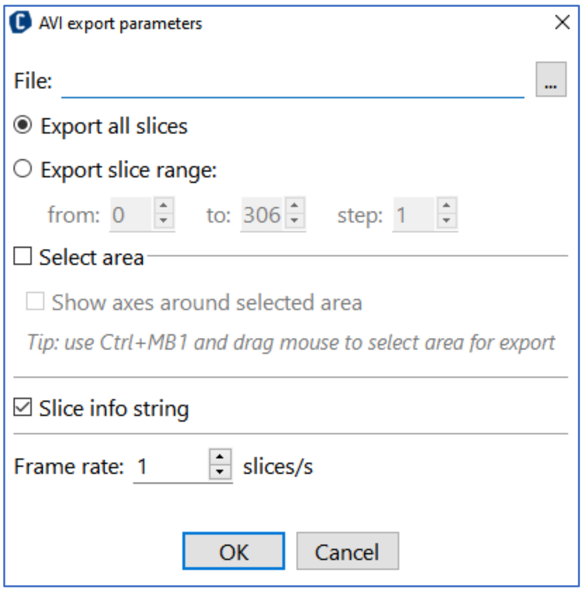


Figure 88 *AVI export parameters*

DXF export

AutoCAD DXF is a CAD data file format developed by Autodesk for enabling data interoperability between AutoCAD and other programs. Select this command and specify an output file to export interpretation features to DXF. Note that during export the velocity attached with all objects will be used to calculate the z-coordinates.

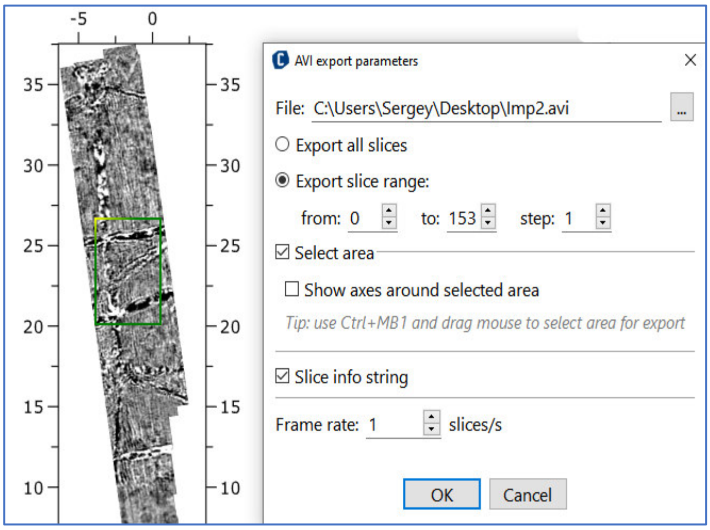


Figure 89 Area selection for AVI export

GeoTIFF export

GeoTIFF is a common geo-referenced image file format for storing raster graphics images that allows binding image to a particular coordinate system. Dialog box shown in Figure 90.

File: output GeoTiff file.

Export current slice: export only one GeoTIFF image with the current time slice.

Export slice range: export several GeoTIFF images with the time slices in the specified range. You need to specify **from** and **to** slice numbers as well as a **step** between the slices.

If you choose this option, several GeoTIFF files will be created in output folder. Each output file name will contain a suffix with the slice number it corresponds to.

If you want to export just a particular area into GeoTiff tick up, **Select area** box and select the area on the top view using **Ctrl+MB1**. Otherwise, the whole study area will be exported.

Slice info string: tick up this parameter if you want the information about current time slice to be presented on the images.

Transparent background: makes the background of images transparent.

Resolution: specify resolution of the images in DPI.

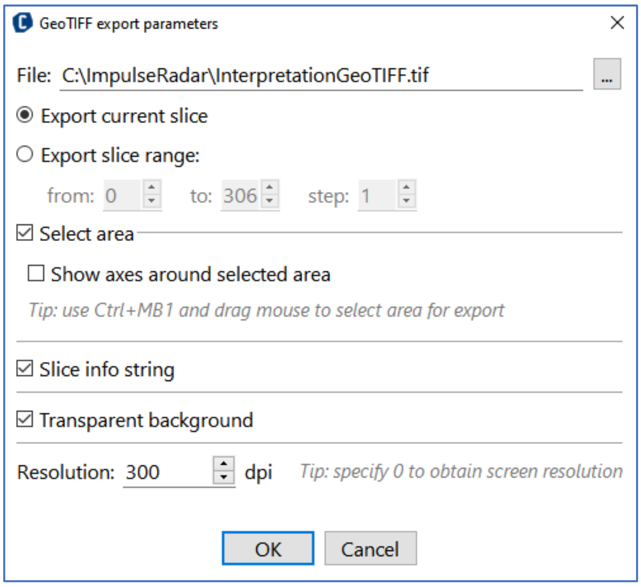


Figure 90 *GeoTIFF export parameters*

Georeference: If the project was not aquired using a GPS and combined into UTM, it has to be referenced to a location. This is done by specifiying two coordinate in the local system and their respective UTM-coordinates, see Figure 91. The most convenient way of doing this is by having surface markers, with known locations, defined during the acquision process.

Note that if the project was rotated prior to geotiff export, google-earth will not interpret the image correctly. Professional software, like QGIS will though.

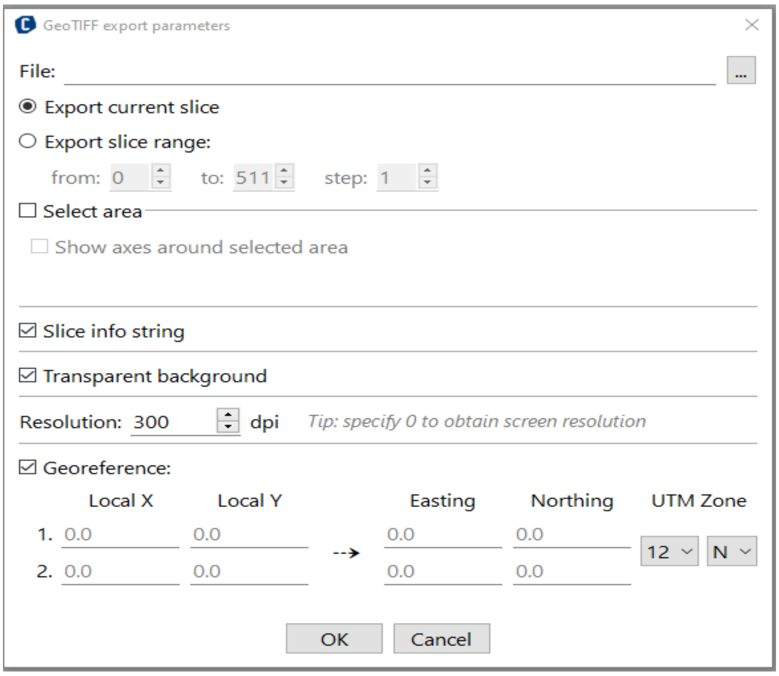


Figure 91 *Georeferencing a Geotiff export. Two local coordinates and their respective UTM coordinates must be specified.*

4 Appendix A: Surface feature definitions

Object Feature definition file (.cnf)

This file contains definitions for which object features that can be used in a project. This file is global and does not exist under a project directory. This file is stored in the file …\AppData\Roaming\Talon\ObjectFeatureDefinitions.cnf This is saved in UTF-8 format.

Each object feature is of a specific feature type, which can be line or point. Each feature is a user defined feature which can be placed on the map or defined coordinates for. Each feature has a user defined type, such as a well or traffic light.

This definition file only contains the definitions of the object features. The data for created objects for a specific object feature is saved together with the project. See ** for information about created objects file)

The object feature file is as:

Row #	**Data**	**Description**
1	VERSION:[version]	Version info for the content of this file. [version] is a number.

Version 1

This shows the content of the file for the version specified in the caption

Row #	**Data**	**Description**
2…	FTYPE[t] FGROUP[t] FCODE[t] COLOR[t] Symbol Code[t] SIZE[t] WIDTH	Each row contains one feature definition. [t] is the delimiter between fields and is a tab character. There is no space between fields. It is only done so here to create line breaks in the table. Its fields are: • FTYPE: 1=Point, 2=Line • FGROUP: Feature group as: 1=Surface feature, 2=Interpretation feature • FCODE: A user supplied feature code, which is also the name of the feature. Can contain spaces, but no tabs, CR or LF. Cannot only contain dashes (-) • COLOR: A 6-letter color code in HEX number format, with RED, GREEN and BLUE components of its color • Symbol Code: The character code for the character to use as symbol in hex format. The font to use does not matter. The code is in UTF-8 • SIZE: The size of the symbol, in millimeters.

		• WIDTH: Width of the line, in millimeters. Only applicable when FTYPE = 2(Line)

Point Object features for combined files (.pobj)

This file contains created point object features in the project and is created when doing combined files. This file is stored in the combined files directory and contains only point features. Color, size, symbol, name etc exist in the object feature definition file. The file is in UTF-8 format.

The format of this file is as:

Row #	**Data**	**Description**
1	VERSION:[version]	Version info for the content of this file. [version] is a number.

Version 2

This shows the content of the file for the version specified in the caption

Row #	**Data**	**Description**
2	COORDINATE TYPE:[type]	Type is which coordinate system that all coordinates in this file are stored in. Possible options are GPS or CARTESIAN
3	---	Marks the beginning of an object feature
4	FCODE[t]NAME	FCODE, as defined in the object feature definitions. See Appendix A: Surface feature definitions Object Feature definition file (.cnf) for information about feature codes. NAME = the name of the object. This can be null
5	X[t]Y[t]Z	The coordinates for the point (either gps or cartesian coordinates). In the case of GPS coordinates, the x,y and z are longitude, latitude and altitude
…	Line 3 to 5 are repeated for each object in the project	

Line Object features for combined files (.lobj)

This file contains created line object features in the project and is created when doing combined files. This file is stored in the combined files directory and contains only line features. Color, size, symbol, name etc exist in the object feature definition file. The file is in UTF-8 format.

The format of this file is as:

Row #	Data	Description
1	VERSION:[version]	Version info for the content of this file. [version] is a number.

Version 2

This shows the content of the file for the version specified in the caption

Row #	Data	Description
2	COORDINATE TYPE:[type]	Type is which coordinate system that all coordinates in this file are stored in. Possible options are GPS or CARTESIAN
3	---	Marks the beginning of an object feature
4	FCODE[t]NAME	FCODE, as defined in the object feature definitions. See Appendix A: Surface feature definitions Object Feature definition file (.cnf) for information about feature codes. NAME = the name of the object. This can be null
5…	X[t]Y[t]Z	The coordinates for each point in the line (GPS or cartesian). This line is repeated for each position along the line object. In the case of GPS coordinates, the x,y and z are longitude, latitude and altitude
…	The above pattern is repeated for each line object in the file	

5 Appendix B: Data Collection with Modern 3D GPR-Arrays

People new to GPR-Arrays may think that array-data means more of the same thing. While this is partly true, there are other details, which, if considered, may ease the following stages of loading, processing, and interpretation of such data. This note aims to give a few hints on the data collection process and the subsequent management of collected data.

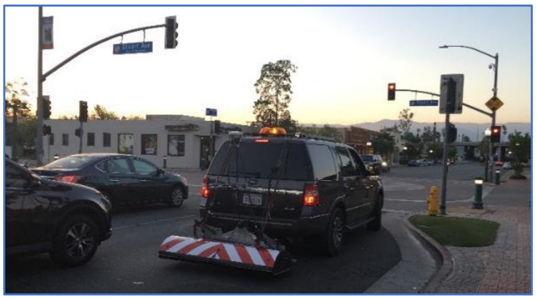


Figure 92 Typical environment in which GPR-Array data is gathered

5.1. Data Volume & Density

A small 3D project can hold some 5 GB of raw data in total. Not a big file by modern standards and easy enough to transfer using a memory stick. However, from a data security and processing perspective, it's not wise to put all that data into a single file. Why? Cheap memory sticks are prone to file corruption during transfer, and this can be especially problematic if the data is in a single file and affected in any way not immediately noticeable by the operator.

Consequently, we recommend dividing even small projects into several parallel swaths (if possible). Also, the data volume is linear to the point distance, where half the point distance means double the data volume. It is usually of no benefit to collect data with a higher density than half the array channel spacing. Therefore, an array with 8 cm channel spacing equates to a point distance of 4 cm.

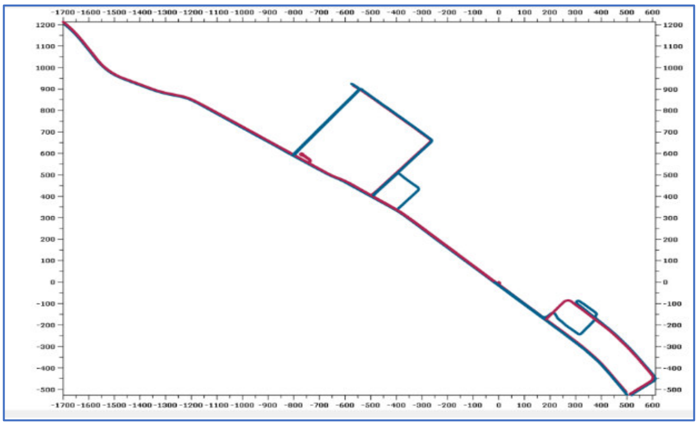


Figure 93 A small project, with respect to raw radar data, but note; the square holding the data is about 4km^2

5.2. Navigation (in the data):

Figure 93 above shows a rather small project, as far as the raw radar data is concerned (approx. 4.5 GB), but the interpretation of a project like this means navigating from a km-scale down to a few meters, which puts quite a high demand on the processing software in use.

5.2.1 Positioning

Positioning is, by far, one of the biggest talking points concerning the collection of array data. The use of high precision RTK-GPS is the most convenient and efficient positioning method and, for those reasons, takes preference over the use of total stations. However, this convenience becomes ineffective in areas where the signal is interrupted, e.g., by tree cover, tall buildings, or other overhead obstacles. Ultimately, it is the survey environment itself that determines the positioning method to use. For the descriptions that follow, it's important to note that only RTK-fix is sufficient, and that any loss of RTK-fix will cause extra work in the data management.

Sometimes, it's possible to salvage a project with poor positioning; however, if the project is large with a high percentage of positioning errors, it may be more economical to re-survey with better positioning than to expend valuable time trying to fix it. Another important consideration that may later ease processing is the choice of positioning density during data collection, since too high a density may cause extra work. If you don't have adequate control over the positioning process, it makes little sense to deploy to the field for data collection.

5.2.2 Sharp turns during data collection

When collecting data in the field, it's perfectly feasible to move the array in a manner that produces a sharp turn, or radius, along the collected swath. However, it's a good idea to think about what this kind of manoeuvre will do to the subsequent data management. As illustrated in Figure 94, such a radius results in data that is significantly stretched along the outer perimeter, while being compressed along the inner perimeter. How this may affect the final image depends on how the data was collected. For example, if the point distance is set to 4 cm during data collection and 8 cm during interpolation, then it may work, but interpolating to the same bin-size as the point distance will definitively impact the data. Therefore, it's important to consider such factors when planning a survey; if such turns are unavoidable, structure the survey so that data collected at these points is not the most important to the overall survey.

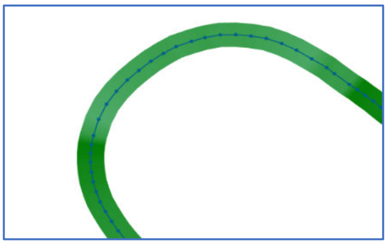


Figure 94, Sharp turns should at best be avoided during data collection

5.2.3 Holes in data

What happens with areas not covered by radar data? Well, modern software offers some ability to interpolate data into such empty spaces, but sometimes applying regularization may be a better choice. Regardless of the theoretical function employed, if the empty spaces are too big, no software can fix it, and those areas will be useless for interpretation. Another less obvious issue is that the interpolation/ binning function takes up memory space on the processing computer, but to what extent is dependent on the chosen processing software. A project like that shown in Figure 95 may be difficult to process due to

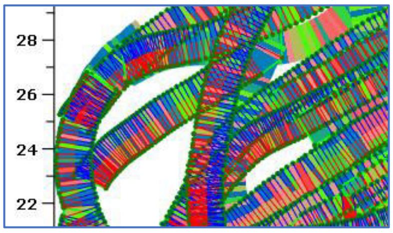


Figure 95, Project with areas not covered by radar data the very large, unfilled, and closed areas. Of course, if opting to process by manually defining the areas to interpolate ('chunking'), it may always be possible, but that's rather old fashion.

Figure 96 shows a project with 4.5 GB of raw radar data, the same as the project shown above in Figure 93. However, the layout of this project is much better concerning data management, because it's easy to navigate. It has no sharp turns, nor holes in data.

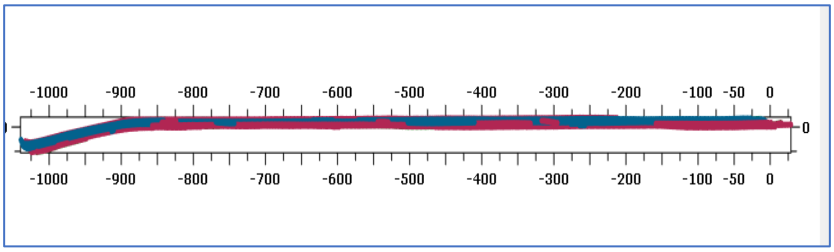


Figure 96, This project is of the same size, with regards to raw radar data as the project in figure 2, 4.5GB. However, this one will be easy to navigate in as well as having no artefacts from polarizations or turns.

Takeaway

Even with the best planning, a real-world project could contain data that is less than optimal. Therefore, when dealing with the data volumes from a modern GPR-array system, it's always advisable to get rid of problematic data as early as possible. The next note in this series will deal with the topic of data QA/ QC and will discuss useful tools for the selection and management of data imports.

5.3. Geometry Clean Up and QA/QC of Raptor Data

The introductory note in this series offered advice on the collection of GPR array data. The key takeaway of which was that a real-world project could contain data that is less than optimal. Therefore, this note focuses on the topic of data QA/ QC and will discuss useful tools for the selection and management of data imports into processing software. The primary objective being the import of quality data and efficient workflows.

Figure 97 shows a project containing 2800 individual GPR-profiles, which combine to form 175 input files for easier management, although still a substantial number to handle.

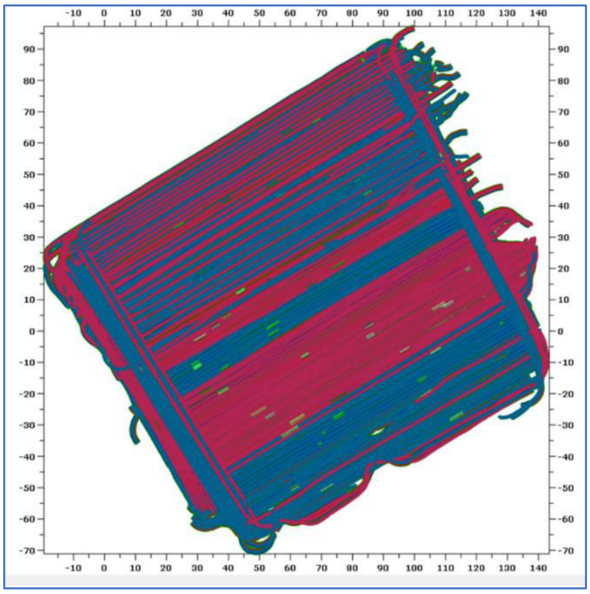


Figure 97 A project, with 175 input files, containing 2800 individual radar profiles

Further, the original data contains over 70000 positioning points, a large percentage of which are problematic — consequently, data sets such as these require practical tools to sort out problems early on before processing.

Figure 98 shows a closeup of one part of this project, where the zoom function reveals clear positioning errors (self-intersecting swaths) as well as data swaths that don't make sense.

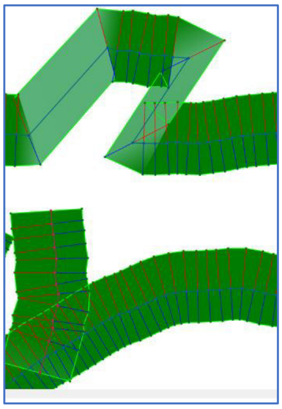


Figure 98 Zoomed picture revealing erroneous data

5.3.1 Swath statistics

Figure 99 shows the swath statistics tool, which is a useful first step to identify essential data readings outside the project norms. In the example shown, the average position density is approx. 3-4/m, but some read as low as 0.06/m. It is safe to assume that these swaths will cause a problem if they import, so uncheck to ignore.

Another noticeable variation is in swath length, where some files indicate only a few meters versus an average of 125 m; again, a simple uncheck of the problem files will omit them from import.

■		Swath	Points/m	Traces/m	Start time	End time	Total length, m
☑	58	ALDERSHOT_...	3.78	20.78	11:21	11:21	105.002
☑	59	ALDERSHOT_...	0.06	0.16	11:39	11:40	88.172
☐	60	ALDERSHOT_...	0.06	0.08	11:48	11:48	84.096
☐	61	ALDERSHOT_...	0.06	0.08	11:50	11:50	95.826
☑	62	ALDERSHOT_...	4.43	20.72	08:31	08:32	131.700
☑	63	ALDERSHOT_...	3.20	21.33	08:32	08:33	121.351

Figure 99 Statistics showing positioning and data density and total length of profiles

5.3.2 Colour coding statistics

Colour coding is a simple way to highlight swaths with problematic positioning density. Easy to identify visually, a simple cursor mouse-over reveals specific information concerning the swath file name and position, as per the example in Figure 100. The density of radar data may be treated in a similar way to highlight problems with the odometer values and wheel slip.

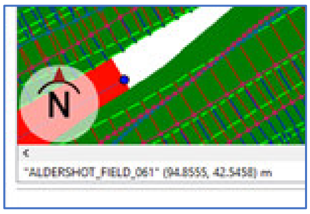


Figure 100 Identifying outliers by colour coding

5.3.3 Removal of positioning data

Continuing with the same project example, a lot of data on the perimeter will not process well in 3D, so removing such points will speed up the data processing and reduce the amount of PC storage space required. Figure 101 shows an example of a simple tool to mark and remove such positioning points.

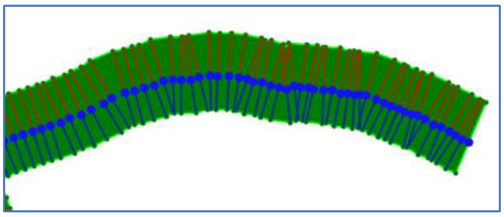


Figure 101 Means of effectively mark and delete positioning points, may significantly reduce workload in later stages

5.3.4 Reducing the positioning density

As indicated earlier, swaths with a very high density of positioning will be problematic upon import, which is due to the self-intersection of swaths, an effect typically caused by the GPS antenna swaying side-to-side. Reducing the positioning density by half from 3-4/m to 1-2/m will decrease this problem. Although it does mean removing some data from the project, it will simplify and speed up the processing time.

5.3.5 Final clean-up and radar data import

Even after observing the preceding steps, there may still be some cause for errors in the data. Modern processing software should be able to warn the user of this and guide them on where to search for such errors, as per the example shown in Figure 102.

Figure 103 illustrate how this project will look after following the methodology described above, both as a whole project and a section closeup using zoom.

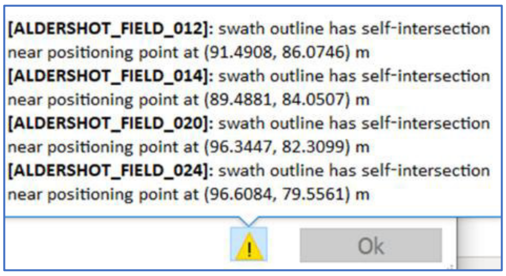


Figure 102 Additional statistics showing self-intersections in data

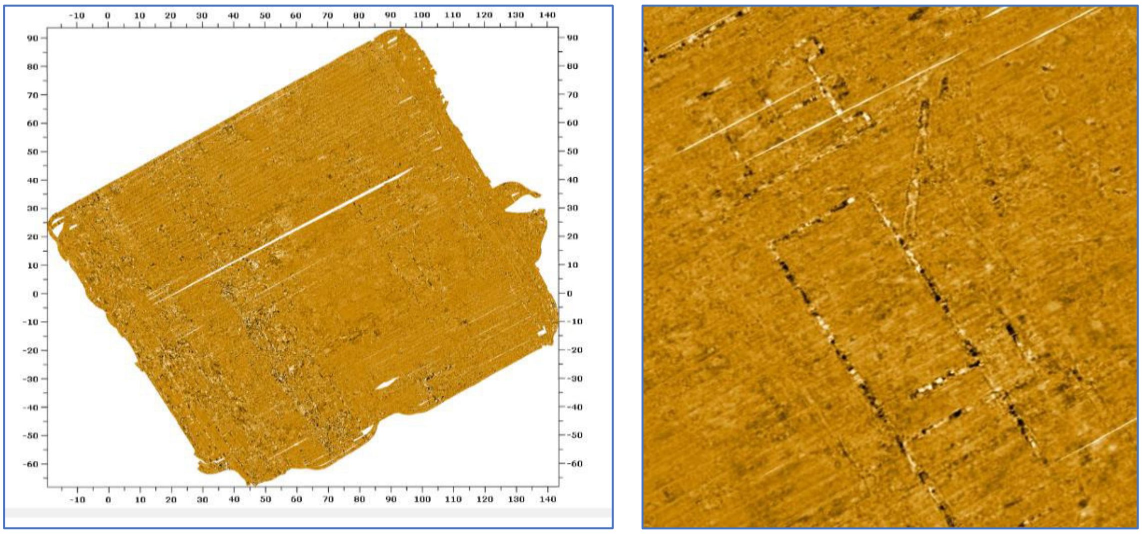


Figure 103 Whole project radar data (left), and a zoom-in version on to the right

Takeaway

An important takeaway from this exercise is that the geometry requires cleaning as much as possible before the import of radar data. Processing radar data takes up a lot of computer memory and can slow operations down. In this instance, none of the geometry was moved as that would be very difficult since we have no references, before radar data import. The next note will show how we may use visible object in the radar data to correct for some positioning errors, besides some other hints.

5.4. Interpolation and Positioning Correction of Raptor Data

In the previous note, we covered some steps for cleaning up geometry before loading radar data; the main idea was to save time by not going through the process of loading a large amount of compromised data. This note will deal with the possibilities to edit geometry after loading radar data and explain why, in general, positioning needs to be very good in 3D-projects.

5.4.1 Loading of radar data

When we load radar data, we must specify the interpolation distance the software will use internally (Figure 104). As mentioned before, it's usually of little use to make this distance shorter than half the channel spacing.

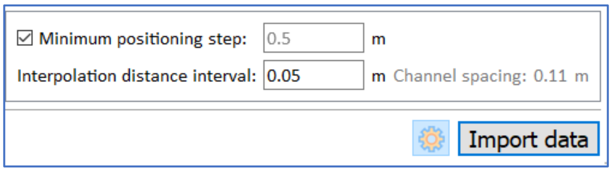


Figure 104 Data import parameters, reduction of positioning points and interpolation distance

Another factor is the memory needed for managing the data, and this distance directly dictates that. In Figure 105, we show a small project, with raw data of 55 MB. During data collection, the point distance was 2 cm, with a channel spacing of 11 cm. The images show data interpolated to 2 cm, 4 cm, and 10 cm bins. As can be seen, to locate the utilities, any one of those settings would be just fine. However, the disk space needed to accommodate all steps in the post-processing up to the stage shown is quite different – 0.25 GB for 10 cm binning and 3.8 GB for 2 cm binning. So, in this case, by interpolating to 2 cm, we ended up with 70 times the original data size. However, any visible benefit is negligible, so interpolation with 10 cm binning seems a suitable choice, given that it only requires 5 times the disk space for the raw data.

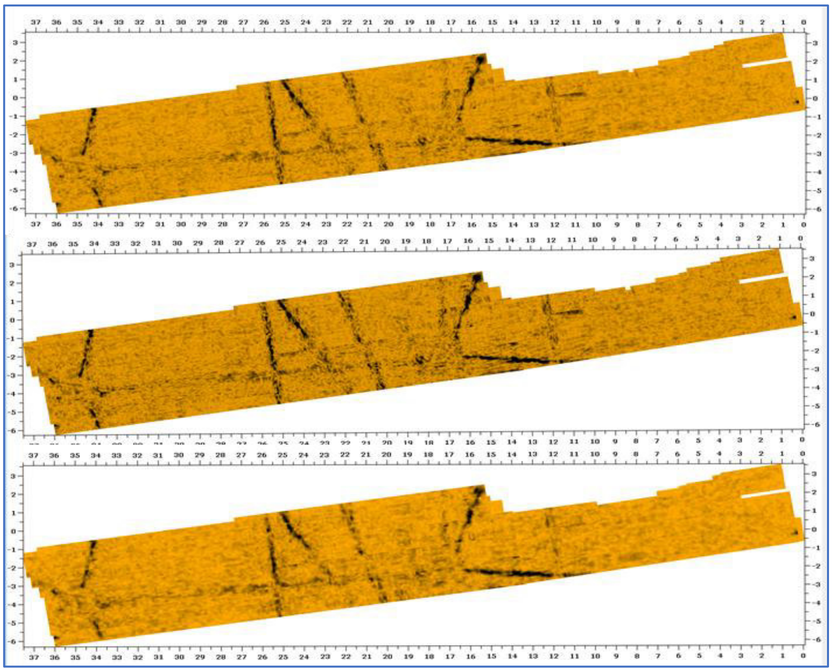


Figure 105 a small project, raw data takes up 55MB, interpolated to 2cm, 4cm and 10cm bins

Do we need some fancy filtering for importing the data? No, dc-adjustment, de-wow, or bandpass, combined with threshold and compensation for the Rx-Tx distance, is all that's needed – assuming, of course, the raw data is of good quality.

5.4.2 Correcting bad positions

Figure 106 below shows a section from a survey conducted with a vehicle-mounted array. Not even the most erratic driver could create the track A-B-C as shown. This type of positioning error is typical when you allow for variations in RTK-coordinates between fix and float. When the fix is lost, the output from the GPS jumps unpredictably.

We don't know whether the positioning before B and after C is good, but we can conclude from the anomaly at A that we're not entirely lost. At A, we have a continuous anomaly crossing over two swaths, so at least the relative position between these two swaths is good at that point.

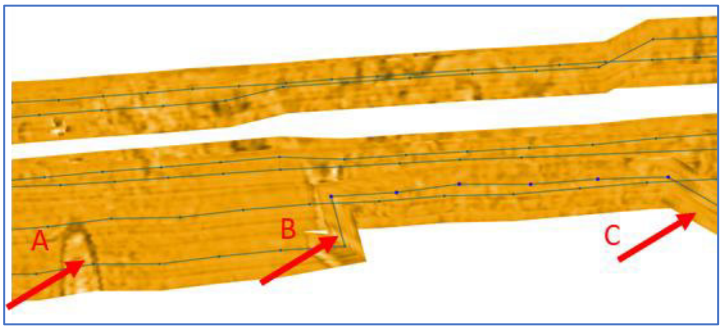


Figure 106 A section with clear positioning errors, marked by red arrows at B and C

In Figure 107, the result of the correcting actions is shown, with some higher gain on the data. We now have a continuous anomaly at B and can be sure that we did something in the right direction. What we did here was mainly to delete positioning points between B and C, leaving the odometer wheel as the only positioning device between these points.

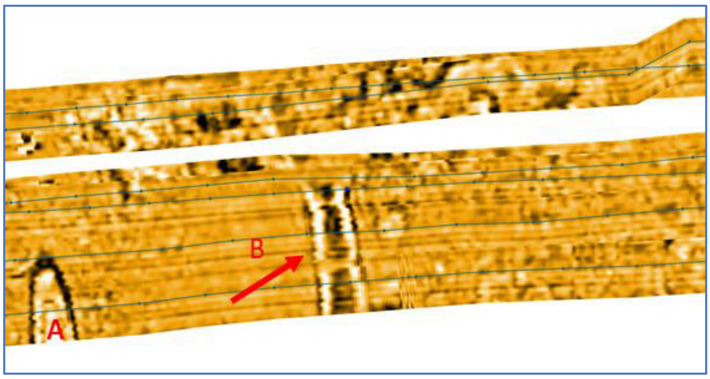


Figure 107 Same section as in previous figure but with corrected positions and higher gain. Note the now continuous anomaly at B

So, can we now conclude that it's possible to fix bad positioning? No, we should not think in that direction. It's possible to correct minor errors, but if the positioning is bad throughout a project, it will be too time-consuming to fix. Recall the project shown in a previous note, with more than 70,000 positioning points; it would be impossible to correct a large chunk of those.

In practice, we're limited to deleting some visibly wrong positioning points and moving others, provided we have anomalies to aid in doing so. Having said all this, we should also mention that commercially it's often ok to live with some minor errors, and the ability to correct some of the geometry may not always be worth the effort.

Takeaway

Often interpolation distances are chosen too short in the belief that this will enhance the data, while in fact, the channel spacing is the most limiting parameter. We're not saying that one should always interpolate to the channel spacing, only that one should not overestimate the ability to use the seemingly higher density along the swath to enhance the final images. We haven't seen any significant benefit in interpolating to less than half the channel spacing. We've also noticed that a modern, interactive software makes it possible to correct for some positioning errors, although we also warn for over-optimistic views on this ability. In large datasets, it's impossible, and when it is possible, it relies heavily on having anomalies visible.

In our next note, we'll cover some of the processing we do before the interpretation and export stages.

5.5. Processing of Raptor 3D GPR Data

In the previous notes, we've covered a few steps concerning the cleaning up of geometry and the loading of raw GPR array data. In this note, we'll deal with some necessary processing steps before data interpretation.

5.5.1 Raw data

Figure 108 below shows the raw data from one section of a project. The lower image shows the data with an overlay of the geometry. This data set is by no means ideal. Firstly, there are quite some gaps in the data. Secondly, and more striking, is the inconsistent coverage, with different orientations, collection patterns, and overlapping data. Some filtering has been applied in the form of a dc-removal filter, and a threshold level for time-zero alignment. We'll see now how it looks after a few simple steps.

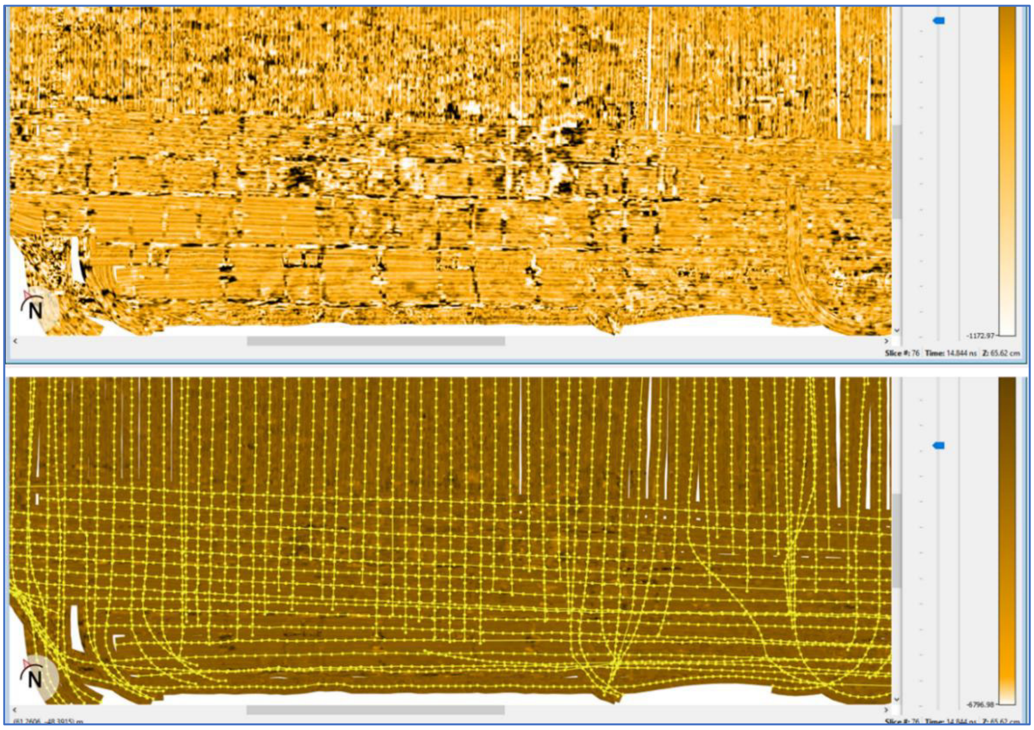


Figure 108 Raw data (top) with geometry overlay (bottom). Note the crisscrossing of lines and non-symmetrical coverage

5.5.2 Step 1. Pre-processing

Figure 109 shows the available pre-processing routines of which the following three are the most used.

- Antenna ring-down (500 traces in background removal)
- Bandpass (170 – 600 MHz)
- Amplitude correction (spherical divergence correction with no parameters)

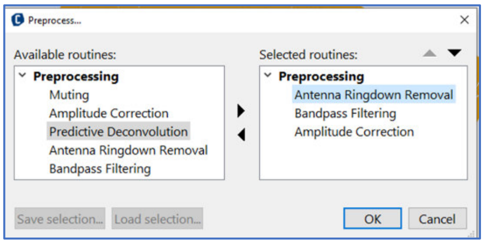


Figure 109 Pre-processing routines

The defaults for each routine are well defined, so there's usually no need to change settings, just select and run.

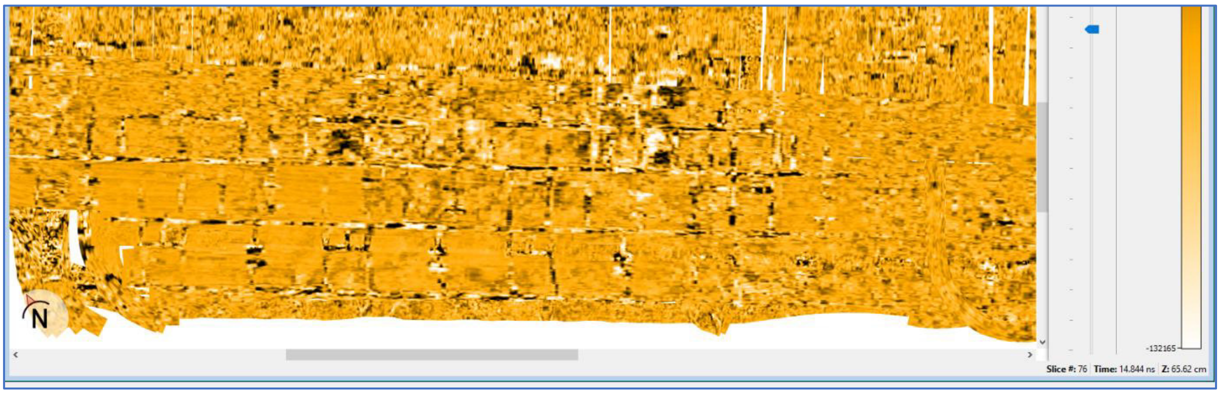


Figure 110 Top view after pre-processing with background removal, bandpass and amplitude correction

The effect of these basic pre-processing routines is shown above in Figure 110. In this case, one may think it's possible to start the interpretation here. However, we're only viewing a single depth slice now, and deeper ones may be much more blurred. Thus, we recommend continuing to the post-processing.

In the original data from Figure 103, linear (humanmade) features were visible, but the pre-processed data in Figure 110 represents a significant improvement. Striping in the data is gone, and most features are more apparent.

5.5.3 Step 2. Regularization/ interpolation

To this point, only 1D and 2D routines have been used. To apply a 3D-migration routine, we need to interpolate the data into regular bins (the size of which (4 cm) was selected when loading the data). At this stage, gaps are also filled by interpolating data from adjacent points.

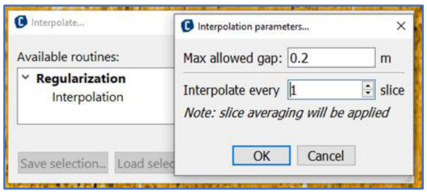


Figure 111 Menu for selecting interpolation parameters

Figure 111 shows the options for the interpolation routine, including the maximum gap the software will attempt to fill. The rationale behind this parameter is that there's no use in trying to fill in significant gaps with any interpolation algorithm, as it won't work if the gap is too large. Then we also have the option of slice averaging, which may save some significant disk-space. Figure 112 shows the result after interpolation. Note that this stage is usually the most time-consuming routine applied to 3D-data.

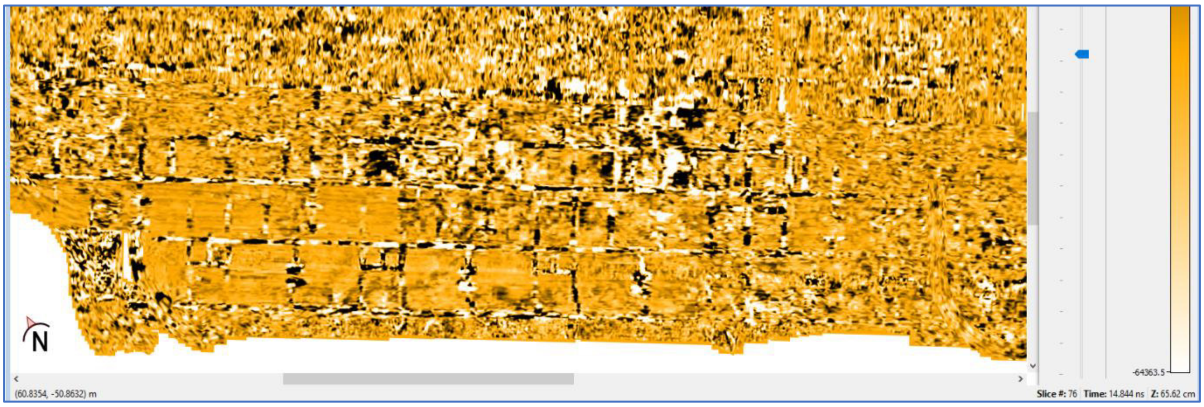


Figure 112 The result after the Regularization/interpolation stage

5.5.4 Migration and post-processing of GPR Data

Migration is the process during which hyperbolic anomalies are collapsed into points with the help of a known velocity and a selected algorithm. There are a few mathematical algorithms to choose from, each with their pros and cons. However, the key to dealing with 3D-GPR data is to apply a true 3D-migration after interpolation. The alternative is to use 2D-migration and then interpolate the migrated profiles into a 3D-volume, but this approach does not give the same excellent results.

When applying migration, we need to know to which velocity. Instead of guessing, we can use an interactive tool to select the optimal value, and that process will be discussed later in a separate technical note. For now, we jump directly to the post-processing stage.

Figure 113 shows the available post-processing routines, the majority of which will be discussed later in a separate technical note. For now, we concentrate on the commonly used Amplitude Envelope.

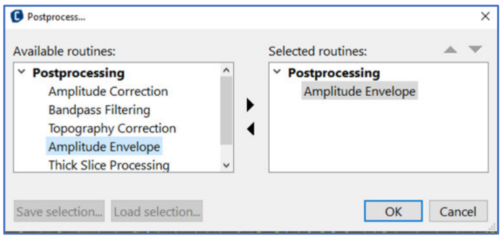


Figure 113 post-processing routines

Amplitude Envelope is the process of applying a Hilbert transform to the data. In simple terms, this effectively moves negative data values over to the positive side and draws lines between peaks. It may reduce resolution slightly, but this is generally acceptable due to the more straightforward interpretation that follows.

Of course, in modern software, a user can always jump between the different processing stages to make use of higher resolution available in other data instances, although this is rarely needed.

Figure 114 displays the impact of migration and the post-processing routines on the working data example. Following a few simple processing steps, we now have data that is much easier to interpret. Again, this is only one depth-slice, so scrolling through the entire depth range, will reveal all targets.

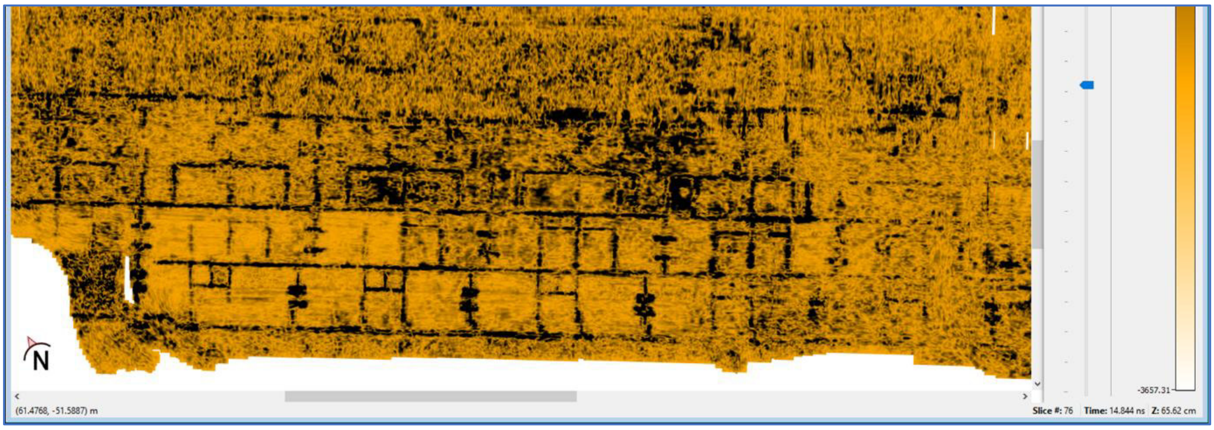


Figure 114 Migrated, and post-processed data (at the same depth as in previous figures)

Takeaway

Modern and interactive processing software makes Raptor 3D GPR data easy to manage. You don't need to be a scientist; just follow a few simple guidelines, and the resulting data is significantly more straightforward to interpret than ordinary 2D GPR data, and the ambiguities are gone!

5.6. Efficient 3D-migration of Raptor Data

In the previous note we covered the processing steps up to post-processing, jumping the migration procedure. In this note we'll look specifically at migration and how modern and intuitive software makes this a straightforward process.

5.6.1 3D-migration

Migration is the process by which hyperbolic anomalies are collapsed into points using a known velocity and a mathematical algorithm. Nowadays, it's not used extensively in 2D-profiling, since operators learn quickly to recognise the hyperbolic shapes commonly formed by utility lines and other targets.

In our view, the value of migration is most pronounced in top views (C-scans) of data, where linear targets and edges spread out laterally in un-migrated data. The process also has the potential to clean up the asymptotes from the sides of ditches or other buried targets, which are not necessarily linear. It's worth noting that in the past it was quite common to migrate 2D profiles and then apply interpolation to the migrated sections, but this is not what we mean with true 3D processing.

To make a stringent migration, one must know the wave velocity throughout the whole surveyed site. In 2D-data, it's possible to apply a layered velocity model before migration, while in a large 3D-data set, this becomes very difficult, if not impossible. Add to this that migration is a quite time-consuming process and that we know of no software able to handle variable velocities over large areas effectively. So, we should have some tools and strategies to make this process smooth and effective.

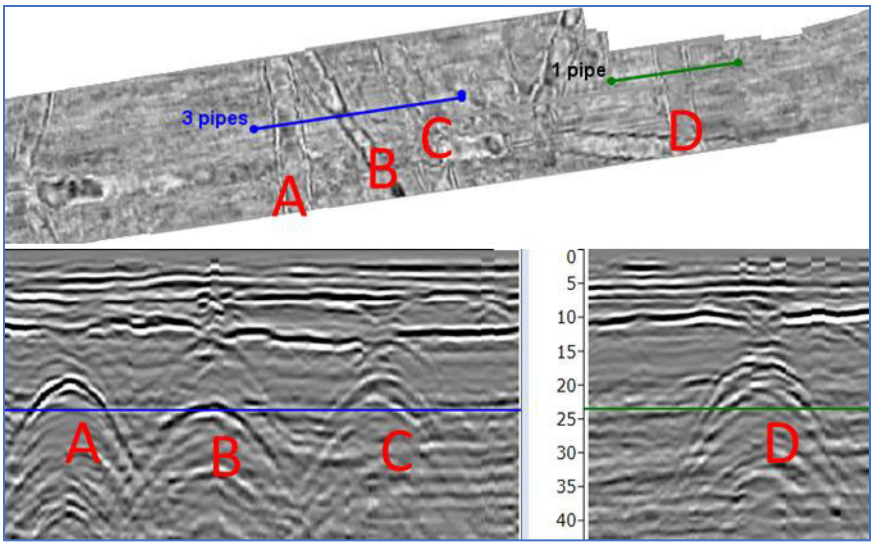


Figure 115 Top: C-scan with marked 2D cuts across four linear targets. Bottom 2D-views of the cuts marked in C-scan. Horizontal lines in the 2D views shows the depth/time of the C-scan

It's common to apply hyperbola fitting on 2D sections to estimate local velocity. While this may work well in many cases, we propose a more robust method, via test migration of selected 2D sections.

Modern and interactive software will allow the user to select and visualise any 2D cut from the top view. As illustrated in Figure 115, we see two lines crossing four linear targets and the corresponding radargrams showing the hyperbolas. While the first three targets may easily be estimated with hyperbolas, although a keen eye will note the variations in the diameters, the fourth does not look that clean at all. It may be the roof of a culvert rather than pipe.

Method

Since 2D migration is fast enough to make interactive tools possible, we provide a slider for varying the velocities in the radargrams shown in Figure 116. Then we fine-tune the velocity to find the setting that compresses the anomalies the most. We don't think about this as finding the true velocity in a stringent way, but rather to compress the hyperbolas the most. Figure 2 shows a result when focusing on targets A and D, where the resulting velocities are 75 m/μs and 84 m/μs, respectively. So, which one to use? A variation of almost 10 m/μs is quite significant, and a velocity of 75 m/μs is considered low, in a case like this. Now, it's easy to find out by using the slider to adjust the velocity up to 84 m/ μs, which gives the result shown in Figure 117. Now target A shows the typical 'smiles' characteristic of too high a velocity, while the other targets compress better.

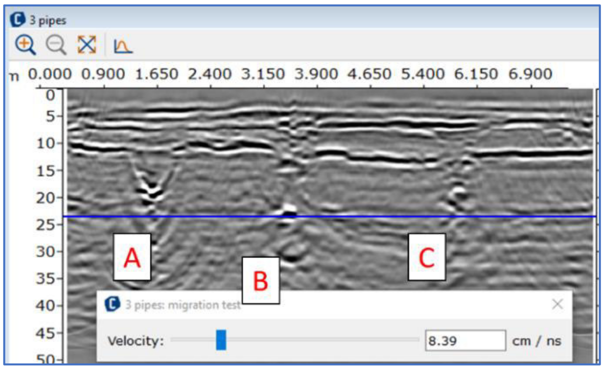


Figure 116 First radargram migrated with velocity set to 84 m/μs shows better compression of target A and B, but starts to look over-migrated

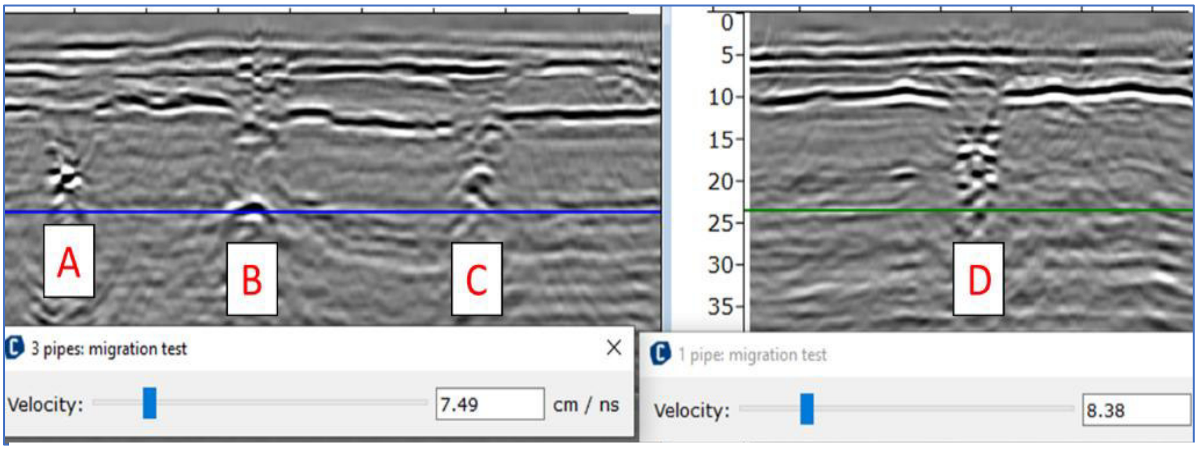


Figure 117 Test migration of the two radargrams from figure 1, left migrated with 75 m/µs and right with 84 m/µs

It's possible to delve into a lot of detail concerning the correct velocity adjustment. For example, the profile doesn't cross each target perpendicularly. However, there's often a compromise to be made, which is not very crucial, if migration velocity is treated separately to the velocity used for depth calculations and awareness of the compromise is kept.

Figure 118 shows the result of 3D-migration with velocity set to 80 m/µs and the targets compress nicely, regardless of their directions. The latter is the strength of true-3D migration based on proper channel spacing, good positioning, and practical software able to stitch/bin the data into a 3D volume.

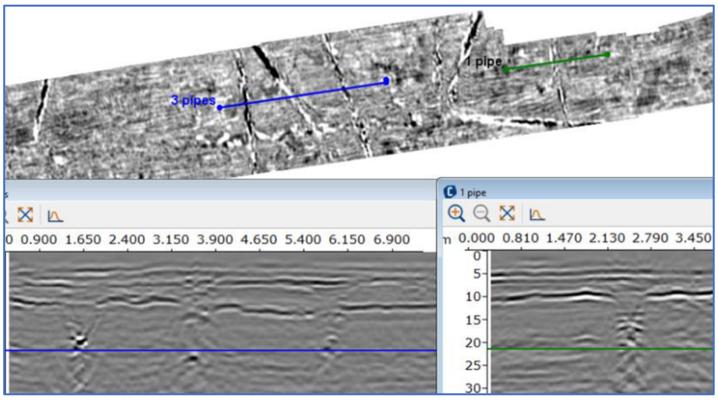


Figure 118 Result of 3D-migration with velocity set to 80 m/µs

Takeaway

In 3D-applications, the migration procedure shines when it comes to visualising targets in the top-view because when working with interpretation, it's the view most utilised. There's no deep expertise needed for applying it correctly when modern, interactive software makes the process swift and intuitive. In this example, we did not show the full strength of it, and that will be more obvious when we come to AVI-exports and deep-slice processing (Figure 119), and those discussions will follow in subsequent notes.

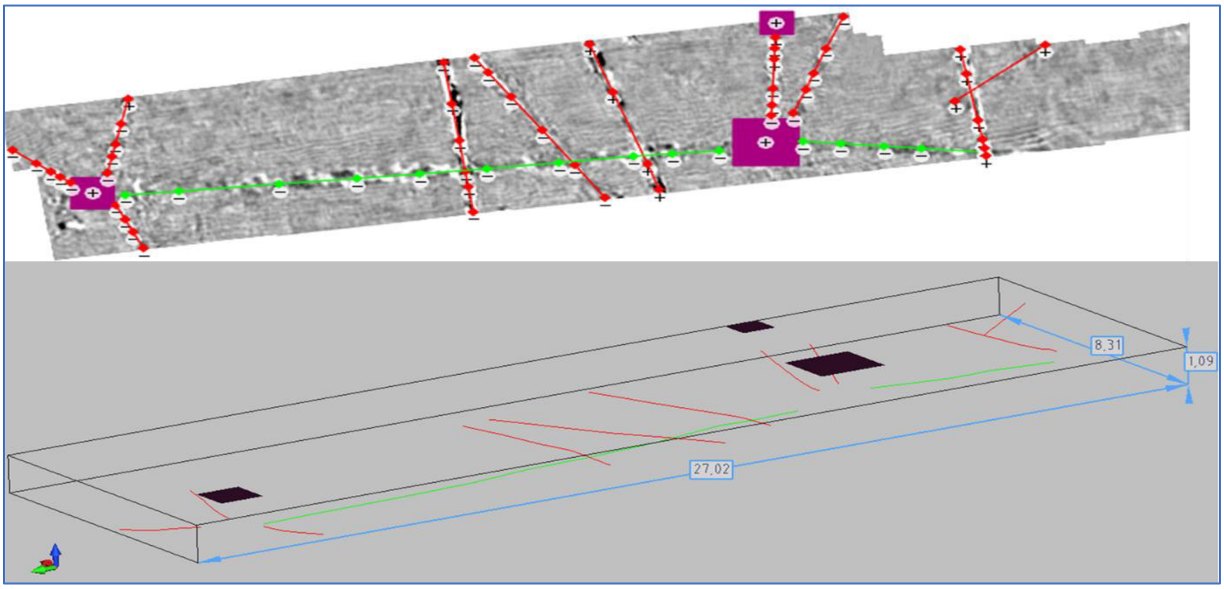


Figure 119 Final interpretation as it might look in the radar software, top. Exports to a dxf-viewer, bottom.

5.7. Interpretation of Raptor Data

In the previous note we briefly covered data collection and the most common processing steps. We concluded that if the raw data is of good quality, especially when it comes to positioning, the following processing can be swiftly done with modern software. That brings us to the most time-consuming step in managing 3D GPR data – interpretation. This stage is a real bottleneck and where good software can make a significant difference. In this note, we look at the simplest, but a reliable, way of interpreting Raptor data.

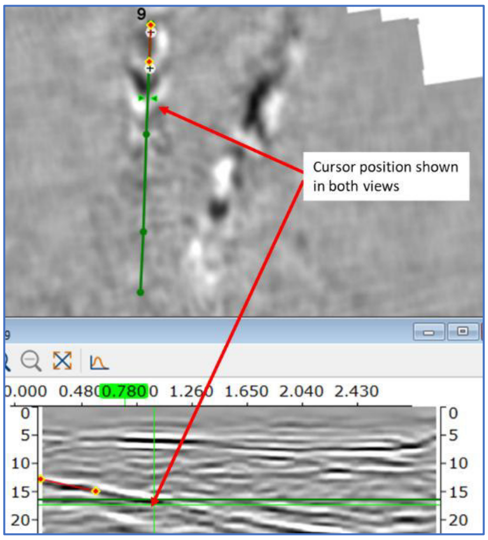


Figure 120 picking of a dipping target. A cursor shows the actual position of the cursor along the cut line and a horizontal line in the 2D-view show the actual depth slice.

Top-views are probably the most common when it comes to interpreting 3D GPR data. However, they are not that useful for the precise picking of target depths. Instead, their strength lies in giving the user an overview and the perception of the target layouts. Having 3D data at hand provides us with the ability to view any 2D cut in that data volume. If those cuts are made properly, then picking a target in the 2D view, combined with views and picks in the top-view, makes the process more accurate.

In Figure 120, the picking of a dipping target is shown. The horizontal line in the 2D view keeps the user aware of where the depth slice is in the top view, with the cursor positions shown in both aspects. Modern software must allow interpretation in all the available views, without restrictions.

Figure 121 shows a top view where many targets are visible at the same depth slice. The cut-lines suitable for target picking are shown below. Laying out these cutlines is intuitive, and the ability to scroll up and down in the time-slices makes it straightforward to place them correctly, centred on the targets. Once in place, it is possible to pick a straight utility line in a 2D view in a matter of seconds. Curved and dipping targets will be a little more time consuming to pull out.

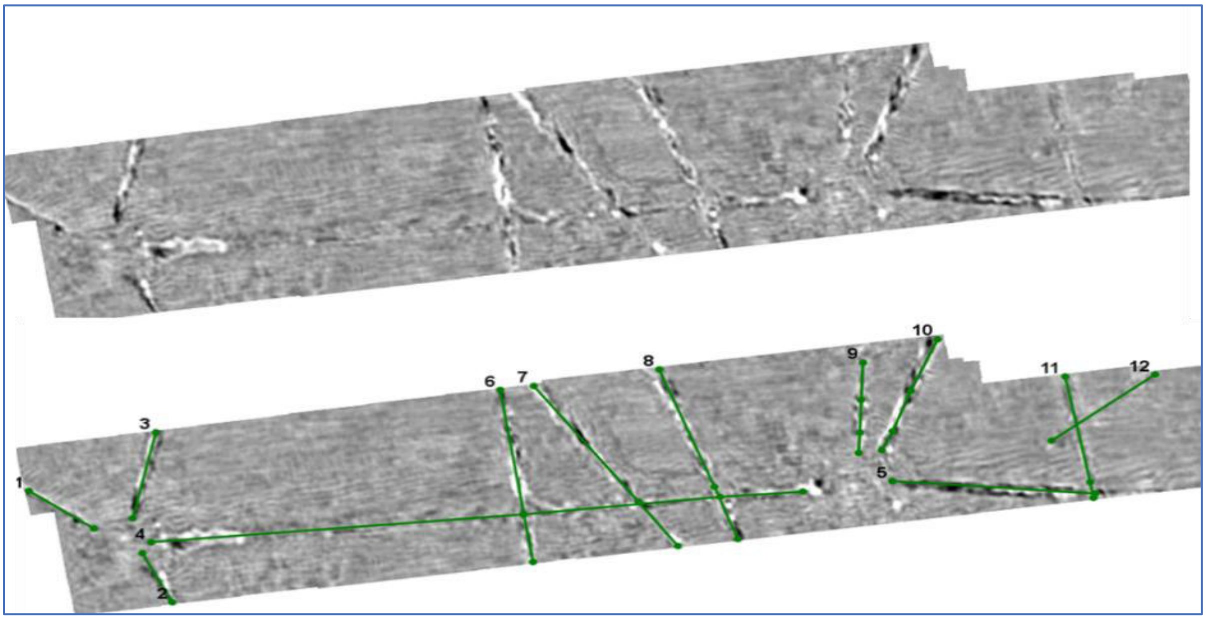


Figure 121 Clean top-view at depth slice showing most targets and laid out cutlines (green), bottom

During this process, the software must support an effective workflow, because, in a complex project, the screen can quickly become cluttered and confusing to understand. Things which may not seem significant, when working a small project, now reveal their importance. For example, having clear positioning indicators, minimizing keyboard inputs, auto-naming, auto-colouring, short-cuts, the ability to switch between different processing instances and views easily, a simple tool for measuring distances, and a straightforward means to turn such tools on and off, are but a few to mention.

In Figure 122, a slightly more complex situation is shown. Here we are marking a target which crosses under another line. In cases like this, and even more complex ones, the software must give the user practical tools for navigating through the data to manage the views and interpretation features.

A user might want to add manholes or other infrastructure visible in the data, assuming they did not bring them into the project as surface features during data collection. This ability can add value for the final touch up, likely done in a CAD environment; it may also be a useful QA/QC of the results. A final interpretation may look like the upper part of Figure 123, where for clarity, we also show a dxf-export with a bounding box.

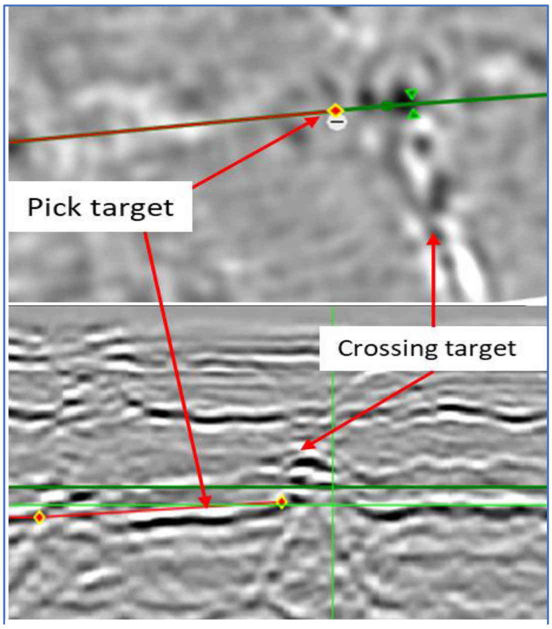


Figure 122 Picking a target along the horizontal cutline in top view while crossing under a target coming in from 90 degrees.

Takeaway

The combination of 3D GPR array data and modern software removes many of the ambiguities often faced by users of simpler 2D systems. The dense data makes it possible to view the subsurface from any direction and thereby secure a reliable interpretation. Nevertheless, in larger projects, it is probably the most time-consuming part of the whole mapping process, which makes the user-friendliness and workflow support of a modern software critical.

We have shown here the most straightforward approach and left out more advanced tools and methods, which we will cover in the next part of this note.

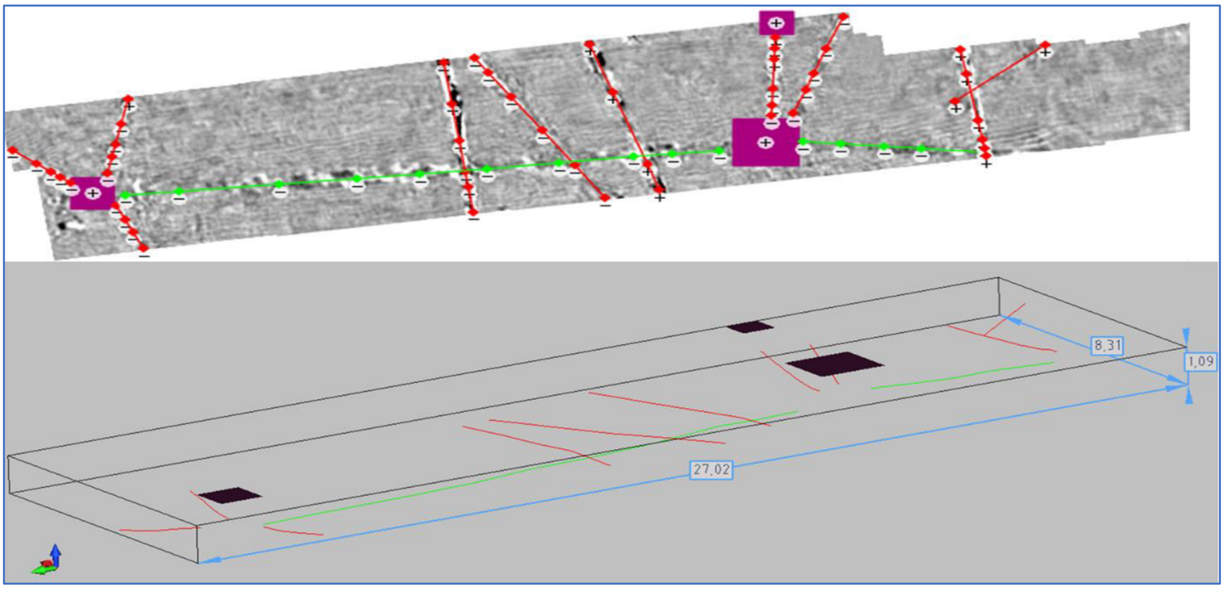


Figure 123 Final interpretation as it might look in the radar software, top. Exports to a dxf-viewer, bottom.

6 Appendix C: Software Licence

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