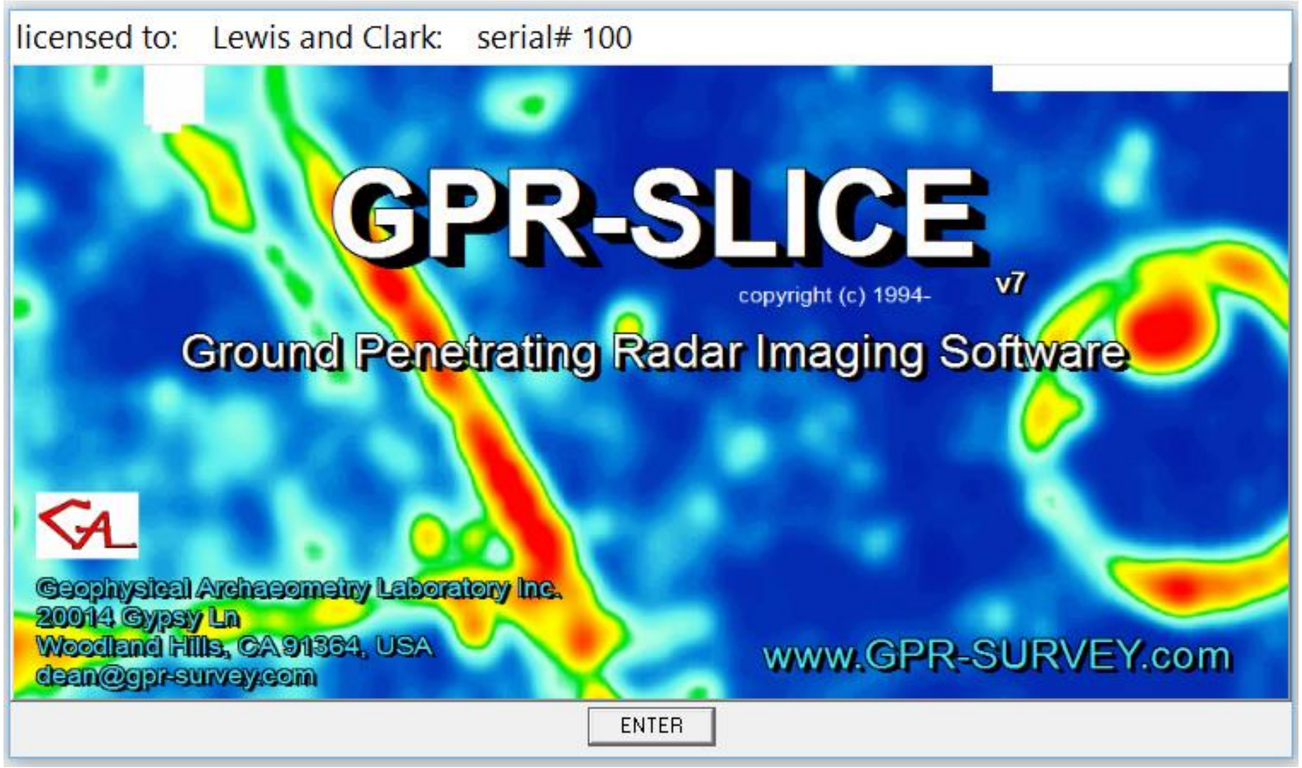
GPR-SLICE V7.0

Ground Penetrating Radar Imaging Software



User's Manual

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Introduction

GPR-SLICE is interactive software for processing and creating images of ground penetrating radar reflection data. GPR-SLICE integrates radargram profiles taken over a survey grid to produce horizontal time slice maps of radar anomalies in the ground. Time slice maps can effectively show the size, shape, location, and depth of buried targets. Subtle reflection features that are indistinguishable between adjacent radargram profiles can be imaged and detected on time slice maps created from 3D volume datasets. A recent book entitled GPR Remote Sensing in Archaeology (Goodman and Piro **ISBN** 978-3-642-31857-3) discusses the processes involved in making images from GPR data. Time slice maps of GPR data have greatly improved the quality and utility of this relatively new geophysical tool for a variety of applications.

GPR-SLICE provides a complete and single software package that interfaces directly with raw radar field data, processes the raw data, and creates a multitude of possible image presentations. A few of the main features of GPR-SLICE Software are:

- automated survey information file creation
- easy file/data management with quick controls to change between survey data
- resampling of radargrams from survey wheel or user inputted markers
- standard gridding menus for creating time slice maps and 3D volumes
- easy batch time slice creation and processing controls called BlueBox Batch runs from raw data to final 3D volume generation
- integration of all the multi-channel formats and navigation from the main GPR manufacturers
- plane pixel map menu for showing many slices on a single screen
- radargram batch processing and radargram and 3D radargram displays
- examine radargram processes quickly from up to 5 directories on a single screen
- 3D volume displays including:
- X, Y, or Z volume slices
- mouse control fence diagrams
- isosurface rendering and isosurface trajectory animations
- various standard volume cutaways
- static corrections for topography and the unique correction for antenna tilt-statics

- easy transform controls for enhancing time slice maps
- exportable animation menu
- staggering correction
- automated mosaic corrections for large scale / multi-grid surveys
- complete GPS navigation

GPR-SLICE was developed for need to have a comprehensive but easy way to quickly process the enormous amounts of radargrams collected in the field. GPR-SLICE makes it possible to quickly obtain 3D images of radargram profiles right in the field. Sites the size of 20m by 20m collected at 0.5m interval can have complete time slice analysis done in less than 20 minutes, making on site evaluations accessible and easy. Trajectory renderings and 3D volume displays are easy to create within GPR-SLICE allowing for animated movies of progressive transparent renders as well as a multitude of 3D displays.

Most importantly, GPR-SLICE is a user's software. The future directions of the developments in the software come from user's input. Many of the new features created in GPR-SLICE are what users need to image and provide that needed specific controls for their GPR datasets. Whenever the latest version for GPR-SLICE has been updated, it can be downloaded from the Subscribers Only page of the www.GPR-SURVEY.com.

What's New in V7.0 in 2017, 2016

- Google map import into OpenGL Volume
- Specialized vector volume addition menu to synthesize data taken on varying surface structures (such as a 4 side square column)
- Spreadsheet editing of OpenGL Volume drawn objects
- Spreadsheet editing of GPS track listings
- Combining up to 3 different antenna frequencies into a single radargram
- Vector imaging for rooms, walls and circular structures made simple with menus to automatically set the vector navigation files
- Compilation of 3D Vector xyza data volume from 3D vector radargrams after slice/resample operations
- GPS multi-radargrams display options: 1) GPS full scale 2)GPS equidistant scale and 3) GPS 1-scan per 1-pixel
- GPS post processing from master.gps file

- Independent axis labeling for depth and time now accommodates seismic reflection profiles and velocities
- Time to depth radargram conversion using the Horizon menu and layer interval velocities
- Shade color display
- Multiple instances of GPR-SLICE running from separate software folders
- Radargram thresholding and filtering
- FK (frequency-wavenumber) radargram filtering
- 32-bit radargram processing
- Customized trajectory animations in OpenGL
- OpenGL Volume XYZ-2D menu augmented with radargram displays on Zscan anomaly picking
- Roll/pitch/yaw added to direct compilation of multichannel data to 3D radargram volumes
- Negative/opposite – low amplitude isosurfaces
- Radargram differencing
- Auto hyperbola detection with a 3 & 5-point vertical search help button
- Advances in utility mapping functionality with anomaly picking on 2D radargram and 3D volumes to export to pipe features
- 2D-FFT processing of time slices to filter spatial frequency components
- Complete one button batch processing - BlueBox Batch processing from raw data to final 3D volume generation
- BlueBox Batch processing for XY decoupled grid generation useful in concrete and high density cross grid surveys
- Advances in Multi-Channel array integration for all the manufacturer – IDS Stream, 3D Radar, Mala Mira, Terravision along with BlueBox Batch processing with a special available menu for super large sites
- Direct 3D volume generation for multichannel GPS systems (or high-density single channel datasets) without slice/resample or gridding operations
- OpenGL XYZ-2D menu for tracking real time anomalies in Z planes directly onto the X and Y fence cuts in a volume all shown in a single dialog
- OpenGL Volume TSPoints operations for real time capturing of user defined anomalies and expanded drawing tool operations
- Vector Imaging and integration with accelerometers for mapping radargrams into their real 3D space
- Automated hyperbola detection and storage of peak responses of hyperbola for a variety of applications

- Zond, Mala X3M, CX11, CX12, GSSI SIR 4000, GeoScanners Akula, Transient Technologies, GeoTech, Loza, and UTSI Electronic multichannel, SEGY multichannel, Isung multichannel, Impulse Radar Raptor multichannel equipment added

GPR-SLICE v7.0 has complete 1 button BlueBox Batch processing from conversion to processed 3D volumes! The user can set a variety of parameters for processing in any menu, and then begin the complete batch processing. The settings can be easily saved or recalled to any new project, allowing the user to quickly and easily process a similar dataset with the same desired settings and batch filter processes. Batch processing is also available for all multichannel GPR systems as well.

GPR-SLICE v7.0 batch processing is referred to as "BlueBox" processing, since although a single button can be used to generate final results from raw radargrams, the user needs to learn what settings are needed to achieve the desired imaging. The concept of BlueBox processing is introduced to distinguish it from "black box" processing where the user has no direct interface with any of the steps in generating 3D volumes of GPR reflection data. Complete descriptions of BlueBox Batch processing is given in section XIII after the user has familiarized themselves with the basic flow of operations in GPR-SLICE.

Automated hyperbola detection has been integrated into the Hyperbola Search menu to assist investigators in their quest to map deterioration of bridge decks or other engineering sites constructed with rebar. The Automated hyperbola options can be used to tabulate and map amplitudes of hyperbolas which are necessary for evaluating concrete conditions and weathering. A complete description of the auto-hyperbola detection algorithms is provided in the special topic section I.

Road evaluation and mapping of road layers is becoming an important part of infrastructure evaluation. GPR is one of the most important geophysical techniques to assist in remote detection and mapping of road layer stratigraphy. GPR-SLICE horizon mapping and detection menus have been enhanced to report stratigraphic layers following the Caltrans-Standard. The California Dept. of Transportation (Caltrans) has a specified format for reporting of GPR surveys and to place these data into convenient form for integration with GIS software. GPR-SLICE was enhanced to meet the Caltrans requirements. In addition, GPR-SLICE was advanced to include metal plate calibration algorithms to help extrapolate and estimate subsurface thicknesses. The complete description of horizon mapping and detection is further details in the Static section of this manual.

Multi-channel imaging is becoming more frequent in GPR investigations. GPR-SLICE integration of multi-channel systems now includes the Mala Mira, IDS Stream, 3D Radar of Norway and the GSSI Terravision multi-channels systems. Navigation and integration of the multi-channel configurations are now completely seamless in GPR-SLICE and easy to import for starting BlueBox Batch processes. The complete details of enhances to multi-channel processing in GPR-SLICE is given in the supplemental manual to v7.0 available on the website.

Installing GPR-SLICE

The steps to install GPR-SLICE V7 are:

1) Create a folder c:\slice\v7.0\ directly on your local drive

2) Unzip the GPR-SLICE v7.0 New Users.zip file emailed to you.

3) Copy all the contents to the folder created in step 1.

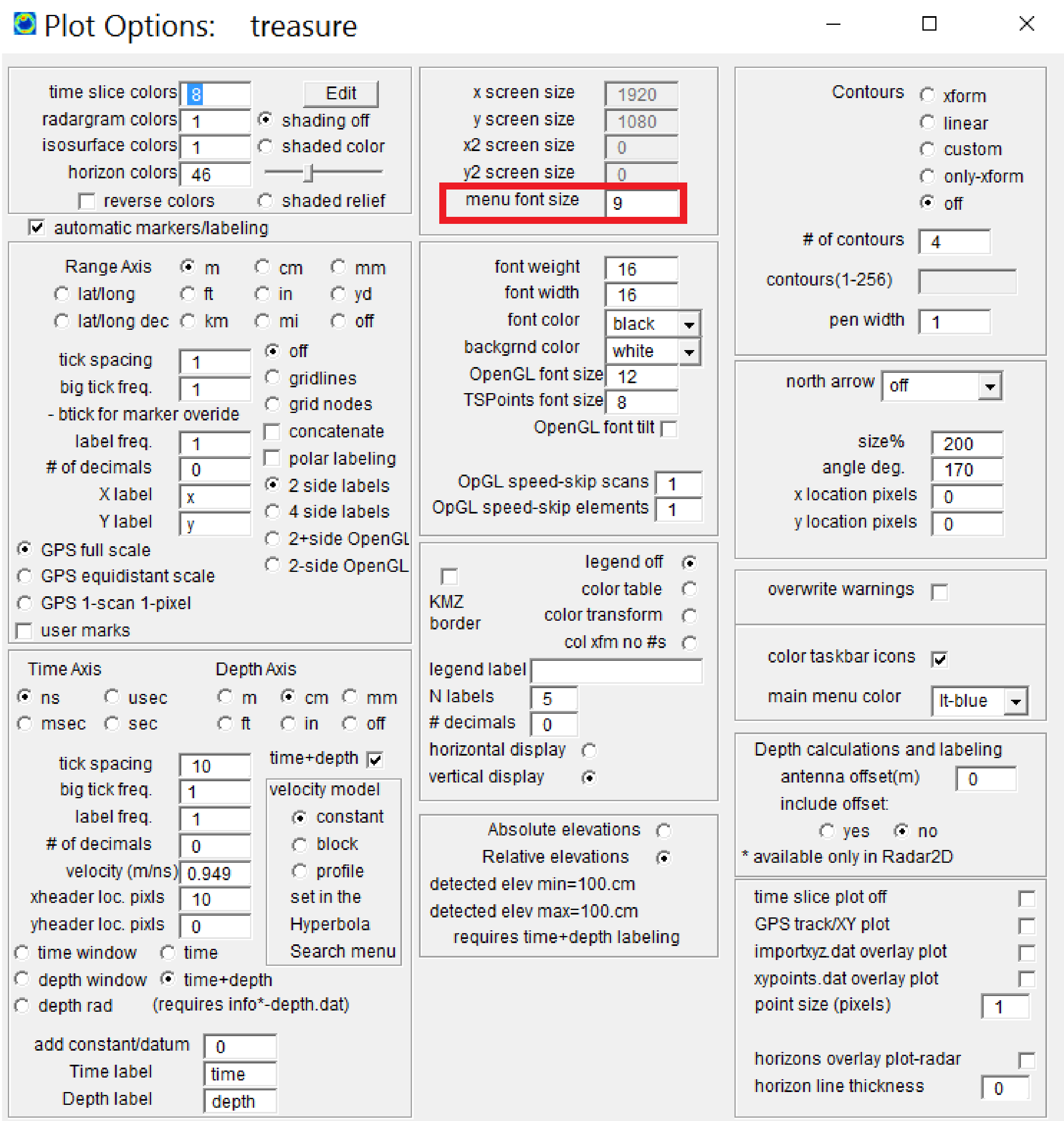
4) Run the CBUSETUP.exe in the V7.0 folder which will install the security device driver. CBUSETUP.exe can also be located on the www.marx.com website on the download support page, should the latest driver be needed.

5) Locate the application GPR-SLICEv7.exe and make a shortcut to it for convenience.

…. you now are ready to run the software.

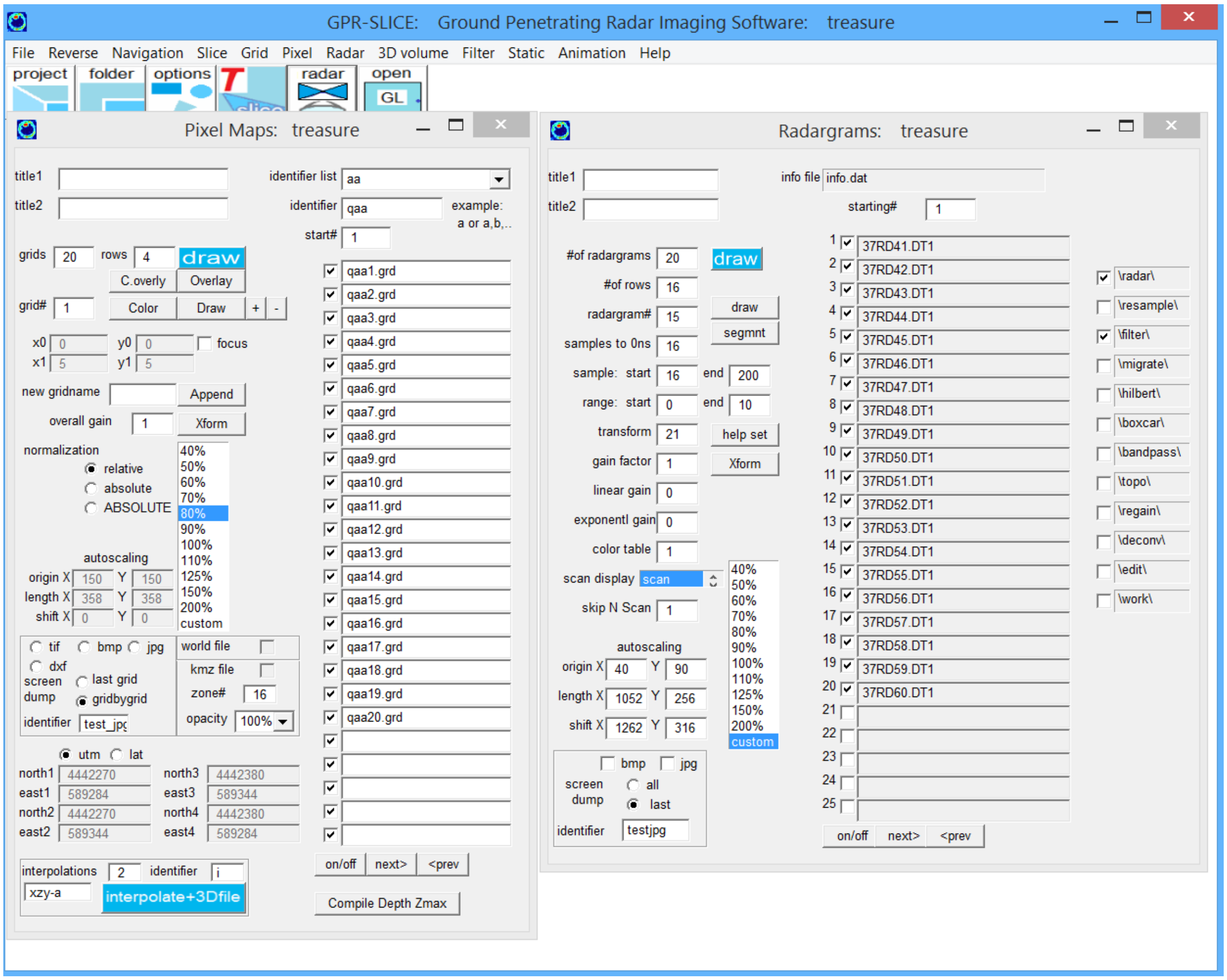
To test whether the software has been installed properly you will need to first create an initial project folder. Go to the Files menu and click on the Create New Project. Enter a name and then click New Survey. After this go to the Options menu and examine the menu (shown in the diagram on the next page. Look at the Range Axis settings. If you have labels next to all the radio buttons such as m, ft, yd etc…then you have properly installed the software. If any blanks appear next to the radio buttons, then the software is not installed properly. In this case, check the name of the folder to make sure it was created properly. If you still have problems contact dean@gpr-survey.com.

Note: GPR-SLICE software can also be run from any disk drive. Make sure that whichever disk drive is being used that the \slice\v7.0 folder has complete open access and that all the files in the folder do NOT have the read only checkbox engaged. To change the file access rights click on the v7.0 folder and go to properties list item. Uncheck the read only switch if it is engaged and then update the access in Windows.



The V7.0 Environment

The V7.0 environment has a lot of flexibility to adjust and place many different control menus on the screen at one time. Your ability to place and size controls on the menu is perhaps directly related to your eyesight. The user should adjust menu font sizes for their particular computer display so that the menu items are visible to them. To set the size of the control menus in V7, click the easy option taskbar button and adjust the menu font size. To see the changes, close the options menu and then reopen to see how the size has been adjusted.



Depending on the native display resolution detected, each of these screen sizes will have an optimum sizing for the menu font size setting. Typical values for the menu font size 8 can be used for many displays, but the user can change this value from 6 for small menus/fonts to about 11 or 12 for very large menus/font sizes. If your eyes are good, you can reduce the menu font size. Ultimately you will be able to have more control and graphic dialogs with less overlap the smaller you set the menu font size. Users can also run and make all the control and graphic dialogs full screen if they like. In the above example, 2 control menus, the Pixel menu and the 2D Radargram menu are all displayed simultaneously in V7. For most menus, after they are closed, V7 should remember the location the next time they are launched. The user can mix and match control dialogs with graphics dialogs.

Note: The user should destroy all processing dialogs before moving on to do other processes in the program. Graphic dialogs however, can be left up on the screen to compare with other graphic dialogs created. You can of course have other applications up and running while V7 is running.

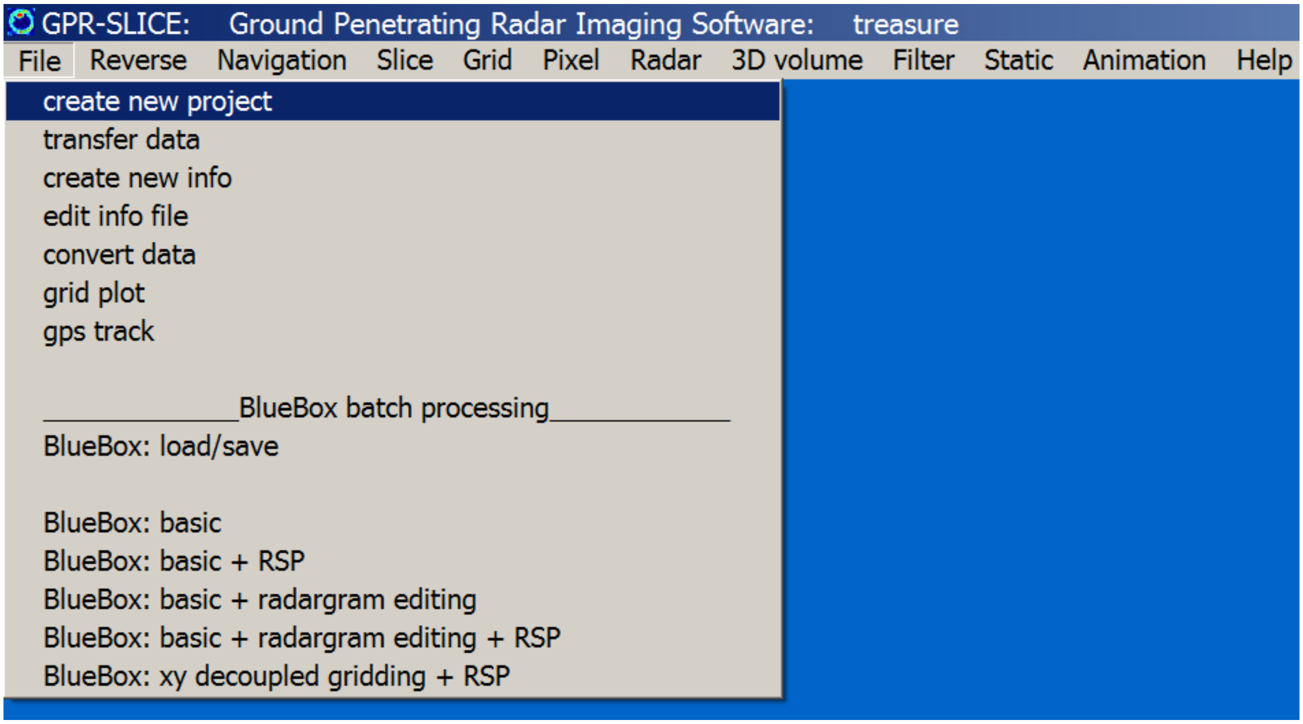
Multiple Instances of GPR-SLICE

Since the inception of GPR-SLICE for Windows in 2002, the software was required to be run through the c:\slice\v7.0 folder or other version folders since v4. This requirement has been relaxed and **GPR-SLICE can now be launched from any user defined directory**. This new features allows the user to run multiple threads of GPR-SLICE simultaneously as long as the project folders are different and multiple copies of the software installation are created in separate folders. There is no limit to the number of simultaneous threads of GPR-SLICE that can be run. This new feature in GPR-SLICE is particularly valuable for multichannel users or for single channel projects that take significant time to process, allowing the user to work on several projects at the same time. **To utilize multiple threads options for GPR-SLICE,** just copy the entire contents of the v7.0 folder t different unique folder (s) name. The software can be launched from any folder or from as many replicated folders as you like – you are not limited to two application threads running simultaneously. Running multiple applications of GPR-SLICE from different folders is thread safe as all log and work files during processing have been localized to the folder where the software is launched. Windows will probably decide what CPU core to use for additional threads.

Note: The active project folder name from the separate GPR-SLICE threads must be different and you should not run operations on the same project folder.

Note: GPR-SLICE is not thread safe for most applications from within a single instance of the software. This means, that if you running the filter menu for example and doing some batch process and then decide to run the radargram menu or some other radargram menu operation, the filter menu will be stopped, and control will go over to the radargram menu. This can also cause some confusion and unpredictable results. However, with the new relaxation of the folder where the software is run from in 2016, multiple instances of the software can be launched!!!

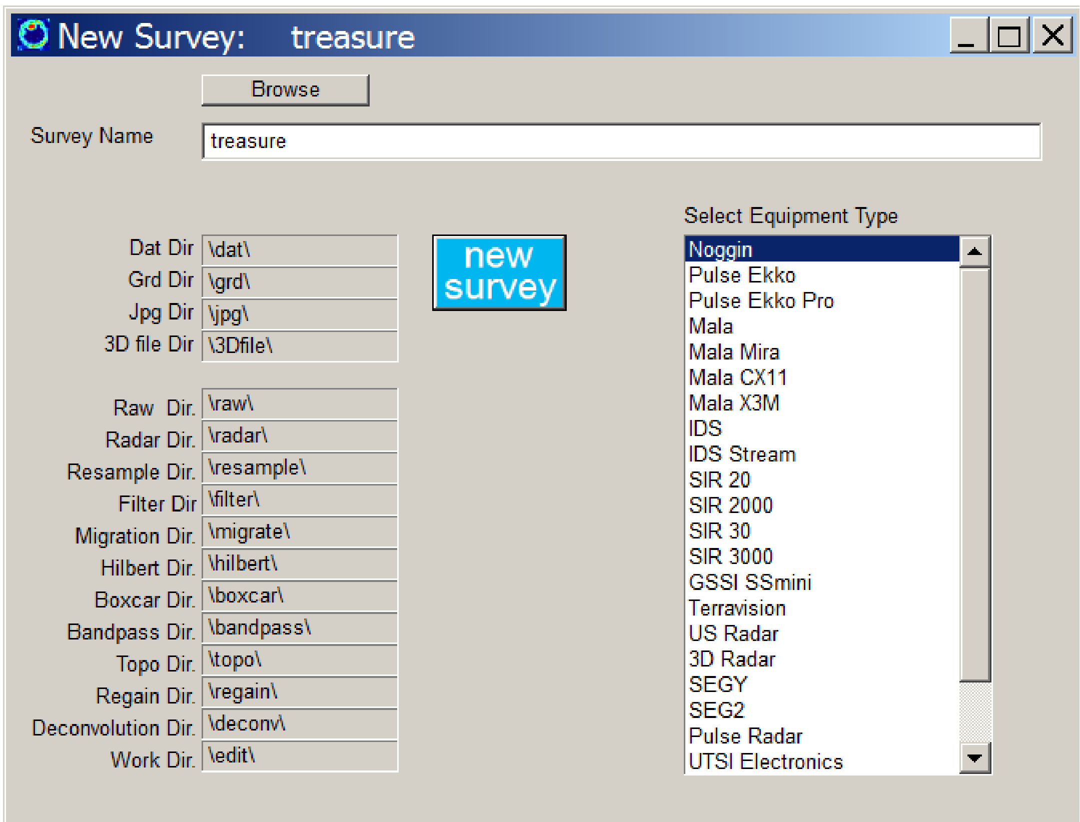
Quickstart Introduction: 2D Time Slices



In this quickstart introduction to GPR-SLICE V7.0 Software, we are going to go through all the elementary steps needed to create 2D and 3D time slices. V7 was written for the flow of control moving from top to bottom in the pull down menu, and then left to right. The 10 general steps to produce a series 2D time slices are:

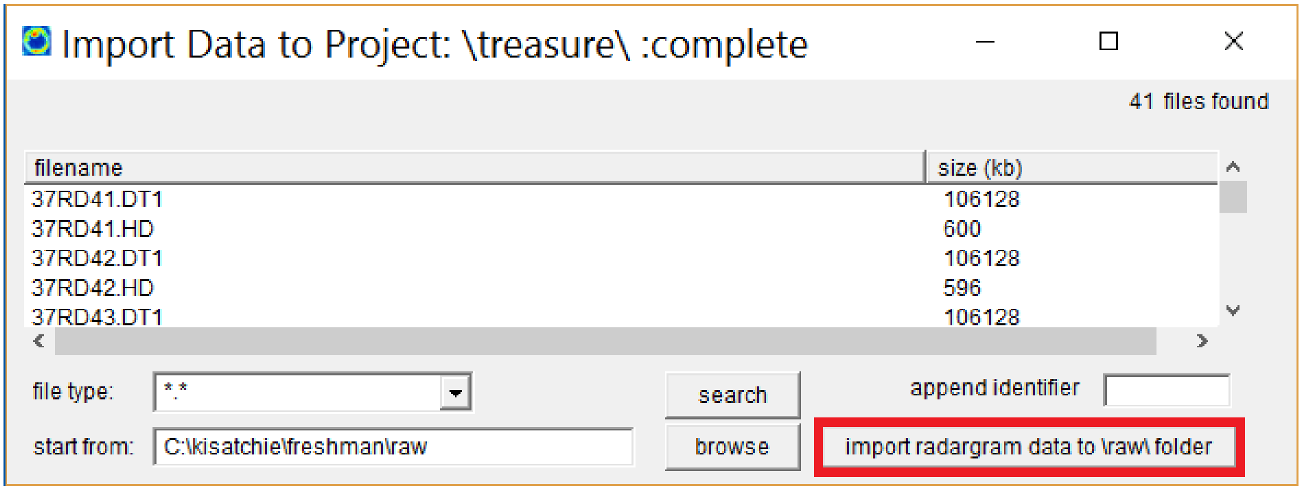
STEP 1. create new project
2. transfer data
3. create new information file
4. edit info
5. convert data
6. reverse data (if necessary)
7. set, correct, or assign navigation
8. slice/resample/xyz
9. grid xyz time slices
10. display time slices

The first 5 steps are all contained in order within the Files pull down menu. So if the user ever forgets what do next, just go down in the menu to the next step. (In the Files menu, the user can also show grid plots, GPS grid plots and other operations; however, these are not critical to making your 2d time slices. The user can retrieve projects in the Files menu by clicking on the select project item).



Step 1. Create New Project

Clicking the Create New Project button will launch a dialog asking for a new project name as well as the GPR equipment type used. The user can first Browse for any folder, then type in a name for project. In the example above a project called "treasure" is created directly at c:\treasure\ without browsing for any other main folder. Clicking the New Survey button will generate the project folder with 16 subfolders: 12 radargram folders for storing radargram signal processes and 4 other folders for imaging output. (In addition, two radargrams folders called work2 and work3 are made for future growth). The user can explicitly create projects on any separate external or internal hard drives.



Step 2. Transfer Data

After completing steps 1-3 the user needs to import data into the GPR-SLICE project folder. The transfer data option available in the Files menu is operated by:

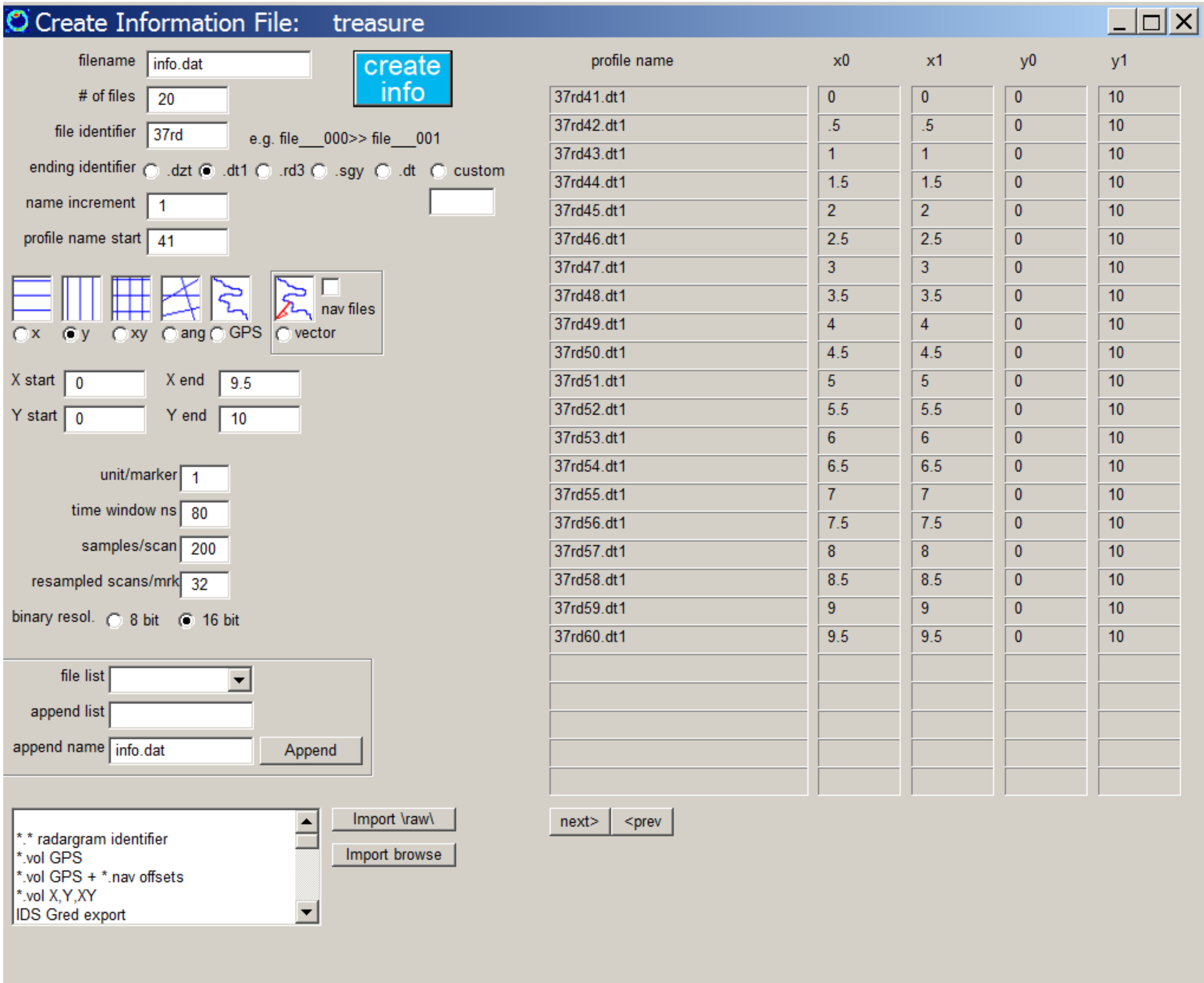
1) Click the Browse button to locate the root of the folder where the raw GPR data (and header files for Mala and Sensors and Software) reside.

2) Click the file type, e.g. *.dzt for GSSI, *.dt1 for Sensors and Software, *.rd3 for Mala. (For Sensors & Software, Mala equipment, one can also simply choose *. * which will insure that the *.hd or the *.rad files or any log files such as GPS are also transferred into the raw folder of the project).

3) Click the Search button to display the files into the dialog

4) Click the Import radargram data to \raw\folder button to begin transferring the raw data into the project.

Note: There is an option to import all the files from a survey with an Append identifier in the Transfer Data menu. This is useful when multiple grids nearby are to be combined into a single comprehensive process but when the separate grids might have the same filenames and unique names are needed



Step 3a. Create New Info

Turning on the Create New Info menu item will open a menu to help the user create a list of names and location of radargram profiles across a site (Figure 3). In the example, 20 profiles parallel to the y axis of a survey site are 10 meters in length and collected 50 cm apart from 0-9.5 meters. The filenames began with the 37rd41.dt1 and ended at 37rd60.dt1. The unit/marker is 1, the time window of the survey is 80ns, 200 samples/scan were used to digitize the radar scans, and a resampled scans/marker of 32 is set for resampling of radargrams. In this example the user wishes to process the data as 16 bit radargrams.

Clicking the Create Info button will make an info.dat file containing the names shown with the specified line lengths and starting locations. The user can insert other information file names, however, the names must all start with the prefix "info", thus info1.dat, infoall.dat, etc. are all valid information filenames.

All the names in the \raw\ folder of the project can also be quickly imported using the ***import*** button in the Create New Info menu. The button will read the user set radargram extension to see what filenames to propagate into the information file. The user will need to usually edit the locations on the ground from x, y, or xy survey import in the Edit Info File menu. For GPS surveys, the ***import*** button is the quickest way to generate the information file for the project.

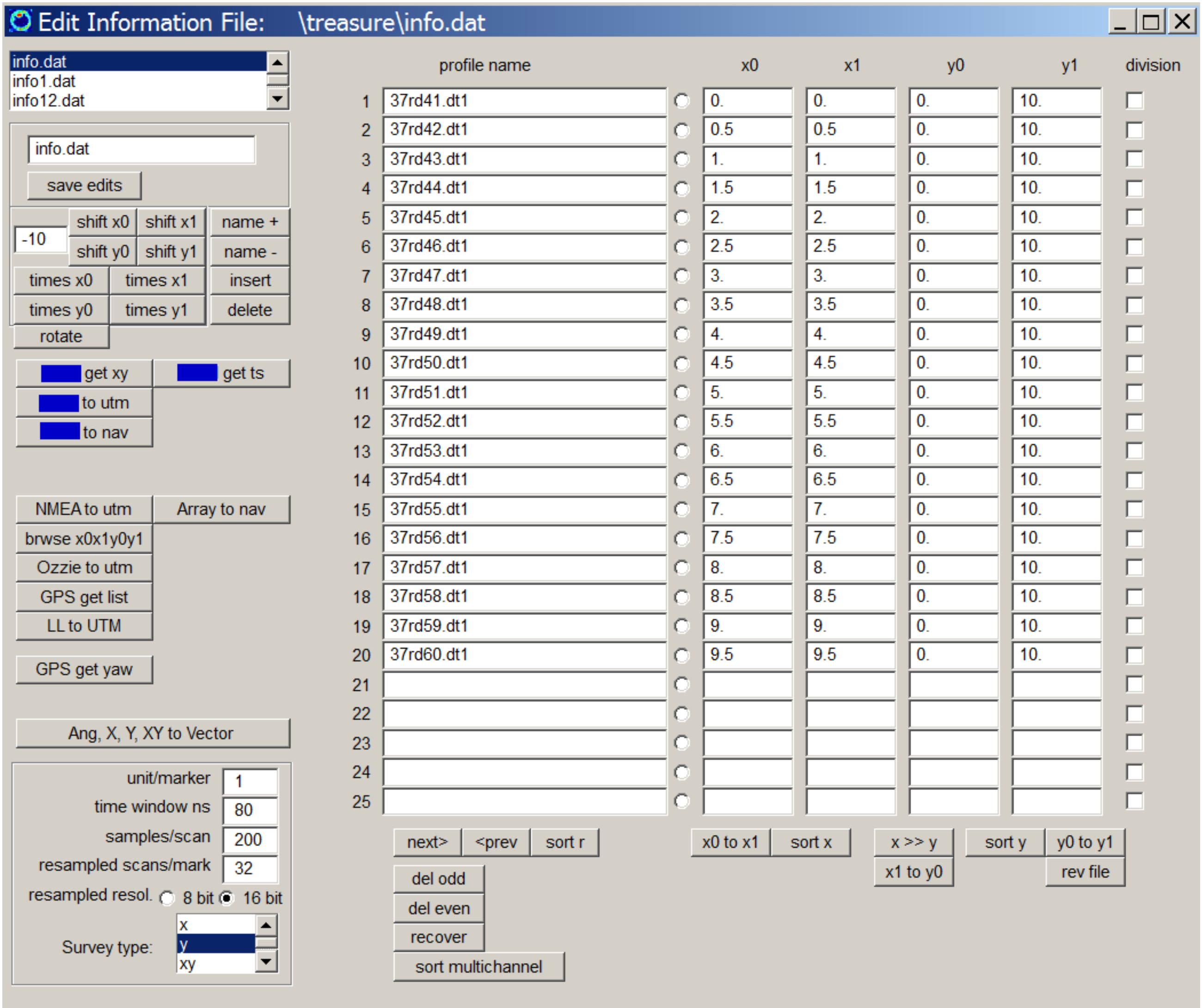
Additional Information:

The scans/mark is the number of scans to resample the radargrams to during the slice/resample process in the Slice Menu. This value should be set to a reasonable size. If it is set to small, radargrams will look pixilated and loss of information will occur. If the value is set to big, then the files will be increased in size unnecessarily and will slow down GPR-SLICE processes.

For example, if the user desires to have about 1 radar scan per 5 cm on the ground, then if the recording unit is 1 marker/meter, then setting this value to 20 will cause 20 scans to be resampled between meter marks within the radargrams. The user may also choose an appropriate value for showing smoother radargrams during the display to the screen if the radargrams are very short in length. The scans/mark are written to the header of the information file only – it does not cause any action to occur on the radargrams until processing in other menus is desired.

The unit/marker is the distance between user markers that has been placed within the radargram data. For instance, if survey markers were placed every meter, then the unit/marker would be set to 1. In the case of using English units and for an example where ft. is the unit of measure, then for a survey where markers were place every 2ft within the radargrams, then the unit/marker should be set to 2. For surveys conducted with a survey wheel, the user can use the markers placed in the data by the survey wheel. For a case where survey markers were placed every 5 meters in the data, the user would use a unit/marker of 5. (In the case of survey wheel use, because the data are evenly collected, the user can in fact use an arbitrary value for the unit/marker that they would like 'artificial' markers placed within the data. GPR-SLICE only shows range locations based on the actual markers written within the headers of the radargrams. This is done to help the user to make sure that resampling processes have been completed properly before higher order processes, such as migration, etc., are performed on the data. Thus for display of radargrams with a unit/marker of 5 for example, range labeling will only be written at 5m spacing. To get 1 meter displays between range values on the radargram displays the user will need to set the unit/marker to 1 for Survey Wheel operations only. GPR-SLICE will read the profile information from the survey information file and will tag the radargrams in the MARKERS MENU during operations in this section. Note: User inserted markers cannot have the unit/marker arbitrarily chosen as you can do with the Survey wheel – only the actual unit/marker should be used in this case.

The user has the option to set a radio button for either doing all processing in 8 bit or in 16 bit radargrams. If the raw data are 8 bit radargrams, then only 8-bit processing is available. 16 bit radargrams can be converted to 8 bit radargrams and all radargram processes after that will be in 8-bit resolution. Only 16-bit processing is recommended these days since disk space is not a problem! Currently, 32 bit radargram formats and converted down to 16 bit for processing in GPR-SLICE. Future version will have flexible format if 32 or even 64 bit radargrams become the norm. Currently only one manufacturer has 32 bit formats for a limited number of equipment.



*Only the buttons and menu items specific to the set GPR manufacturer will be shown in the runtime menu. Shown in the Edit Info File menu above, is a typical look of the menu. This can vary depending on the manufacture. The blue area is where either GSSI, SS, MALA, US Radar, GSF, Zond, UTSI, 3D Radar, SEGY, SEG2 etc. will appear depending on the equipment set for the project. There are also many navigation buttons for various operations and log file conversions that will appear. The typical ones are shown. A further description is given in the next section.

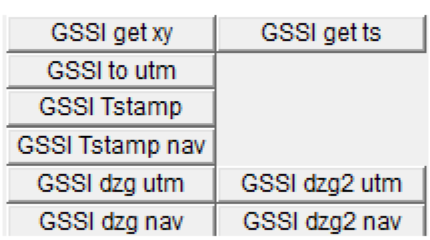
Step 4. Edit Information File

If some line lengths need to be edited, then the user can enter the edit info menu and adjust the line length or the starting locations. To save the editing changes the user needs to click the save edits button. This will update the info.dat file. The user can also save the edits to a different filename by typing in a name above the Save Edits button. By clicking the save edits button in this case, the changes will be written to the inserted filename. However, only the original information highlighted in the top menu item is active in the menu slots shown to the right.

The user can also insert or delete lines in the information file by click the radio button next to the profile name and then clicking “Delete” or “Insert”. Before clicking these buttons, if any other changes have been typed in manually, the user should click the “Save Edits” button before clicking the “Delete” or “Insert” button. Making a radargram name blank, and the clicking “Save Edits” will also remove a radargram to the updated information file.

If filenames have been skipped in the field data, then the user can quickly increment a name in the information file by clicking the radio button next to the profile file name that has been skipped, and then clicking the Name+ button to skip (and increment) that profile. For instance, if 37rd55.dzt was not collected in the field if this was a bad line, the user can click that radio button next to this file, then click Name + to increment the filename to 37rd56.dzt. All the radargram names will be incremented by 1 at this location. Hitting Name + several times will continually increment only the filenames. (Note: this feature will usually work if the file was initially created in the Create New Info menu, as settings there are being read in to this quick fix function).

There are various buttons in the Edit Info File menu that will extract header information and do various operations such as creating the GPR-SLICE navigation files *.*.gps. A partial list of the description of these buttons that occur with several of the manufacturers supported by GPR-SLICE is as follows:



GSSI get TS: Extracts the time window and samples stored in the GSSI header and places in the active information file.

GSSI Get XY: Extracts the survey wheel length stored in the GSSI binary header and places into the x or y columns of the active information file.

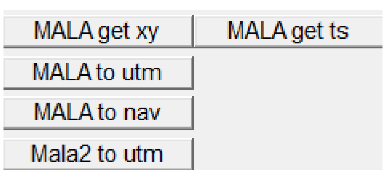
GSSI to UTM: Creates GPS log files for non-synced– older GSSI systems

GSSI Tstamp: Creates synced GPS log files for GSSI equipment supporting *.tmf time stamps file and *.plt/txt NMEA files

GSSI Tstamp Nav: Creates synced total station log files for GSSI equipment where *.tmf time stamp files and *.plt/txt files with standard NMEA formats

GSSI DZG,2: Creates GPS log files for older and newer GSSI equipment where trace numbers and NMEA strings are reported in the same log file.

GSSI DZG NAV,2: Creates total station log files for older and newer GSSI equipment where trace numbers and NMEA strings that have total station data in the lat/long position are reported



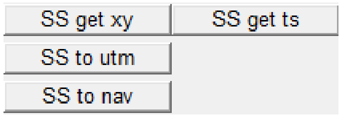
MALA get TS: Extracts the survey wheel line lengths for Mala Geoscience radargrams from the *.rad header files and updates this into the information file.

MALA Get XY: Extracts the survey wheel line lengths for Mala Geoscience radargrams from the *.rad header files and updates this into the information file.

MALA to UTM: Creates the *.rd3.gps files from Mala Geoscience *.cor files that have NMEA strings. The GPGGA NMEA string is used to convert latitude and longitude readings in these files into UTM coordinates which are used in GPR-SLICE operations.

MALA to NAV: Creates the total station log file from *.cor where the NEMA string lat/long are replaced with total station information.

MALA2 to UTM: Creates the GPS log file for an alternate *.cor log file

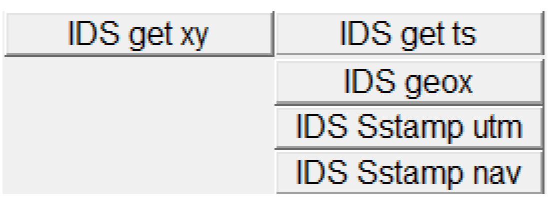


SS get TS: Extracts the time window and samples/scan for Sensors and Software equipment from the *.hd header files and updates this into the active information file.

SS get XY: Extracts the survey wheel line lengths for Sensors and Software equipment from the *.hd header files and updates this into the active information file.

SS to UTM: Creates the *.dt1.gps files from Sensors and Software *.gps files that have NMEA strings. The GPGGA NMEA string is used to convert latitude and longitude readings in these files into UTM coordinates which are used in GPR-SLICE operations. (More discussion is given in the GPS section of this manual).

SS to NAV: Creates the total station log files from Sensors and Software *.gps files that have the NMEA string formats containing the total station information in the lat/long position.



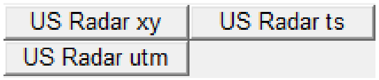
IDS get TS: Extracts the time window and samples/scan for IDS of Italy equipment.

IDS get XY: Extracts the survey wheel line lengths for IDS of Italy equipment and updates this into the active information file.

IDS get GEOX: Compiles GEOX manufacturers navigation files

IDS Sstamp UTM: Reads native GPS and corresponding scan stamps stored in the radargram headers to create synced navigation files

IDS Sstamp NAV: Reads native GPS formatted files where lat/long are the total station X,Y to create synced navigation files



US Radar TS: Extracts the time window and samples/scan from the US Radar header and places in the active information file.

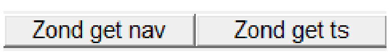
US Radar XY: Extracts the survey wheel line lengths from the US Radar radargram and places in the x or y menu slots of the active information file.

GSF get TS: Extracts the time window and samples/scans from the GeoScanners header

GSF Get XY: Extracts the start and end points of the radargrams from *.gsf GeoScanners header.

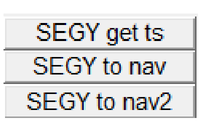
GSF to UTM: Creates the GPS log files for GeoScanners equipment by reading the *.gsf header

GSF to NAV: Create total station log files for GeoScanners equipment



Zond get TS: Extracts the time window and samples/scans from the Zond file header

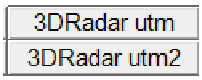
Zond get NAV: Extracts the start and end points of the radargrams for the Zond radargram header.



SEGY get TS: Extracts the time window and samples/scan from SEGY seismic data tape headers

SEGY get NAV: Extract the navigation from the SEGY trace headers

SEGY get NAV2: Extracts the navigation from SEGY trace headers that are written in alternate group coordinate locations.



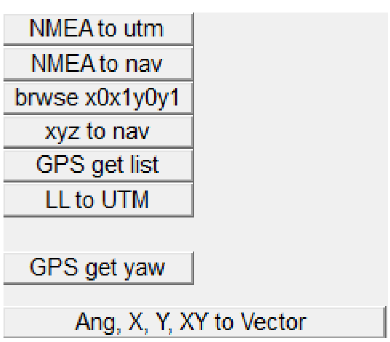
3D Radar UTM: Convert 3D Radar GPS log files into GPR-SLICE log files.
3D Radar UTM2: Alternate 3D Radar GPS log file format convert to GPR-SLICE log file format

UTSI get TS: Extracts the time window and samples/scan from UTSI Electronic radargrams

UTSI get XY: Extracts the survey wheel length and places into the active information file

UTSI to UTM: Creates the *.dat.gps file from a UTSI Electronic *.gpt files that have NMEA strings listed.

There are several button operations that will appear in the Edit Info File menu no matter what the manufacturer is:



NMEA to UTM: A button that will read a GPGGA NMEA string GPS file and convert this file to standardized GPR-SLICE format with UTM coordinates.

NMEA to NAV: A button that will read a total station GPGGA NMEA string total station x and y written into the lat/long position and convert to GPR-SLICE log file format.

BRWSSE X0X1Y0Y1: Imports an external file with 4 columns and comma delimited of x0,x1,y0,y1 and inserts this into the active information file. The number of lines in this external file must correspond with the number of files in the active information file.

XYZ to NAV: Launches a menu to set custom imports for navigation log files associated with each radargram where the columns and skipped header lines and file extensions are set.

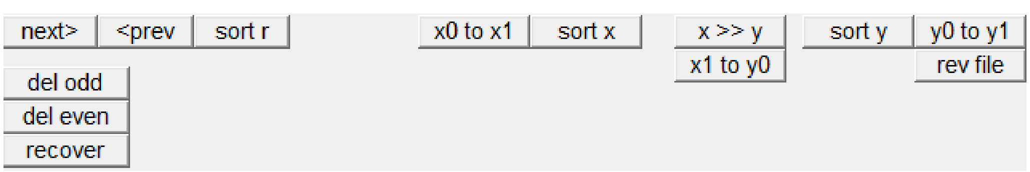
GPS Get LIST: Updates the number of GPS/total station readings in the GPR-SLICE log navigation files and inserts these numbers (less one) into the y1 slot of the active information file.

LL to UTM: Imports an external file of with 4 columns and comma delimited of Latitude0, Latitude1, Longitude0, Longitude1 for the start and end points of radargrams and will convert to easting0, easting1, northing0, northing1 in the information file.

GPS GET YAW: Will launch a menu for setting read formats for customized *.*.gps file and *.yaw file and will make calculations to place the scan vector into columns 9,10, and 11 of the *.*.gps. (Please see extension discussion of this in the Vector imaging section of the manual).

ANG, X, Y, XY to VECTOR: Converts ANG, X, Y, or XY surveys to Vector surveys (see Vector imaging for more information on this conversion and its purpose).

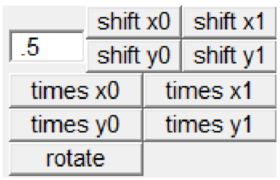
There are a variety of buttons on the bottom of the Edit Info File menu.



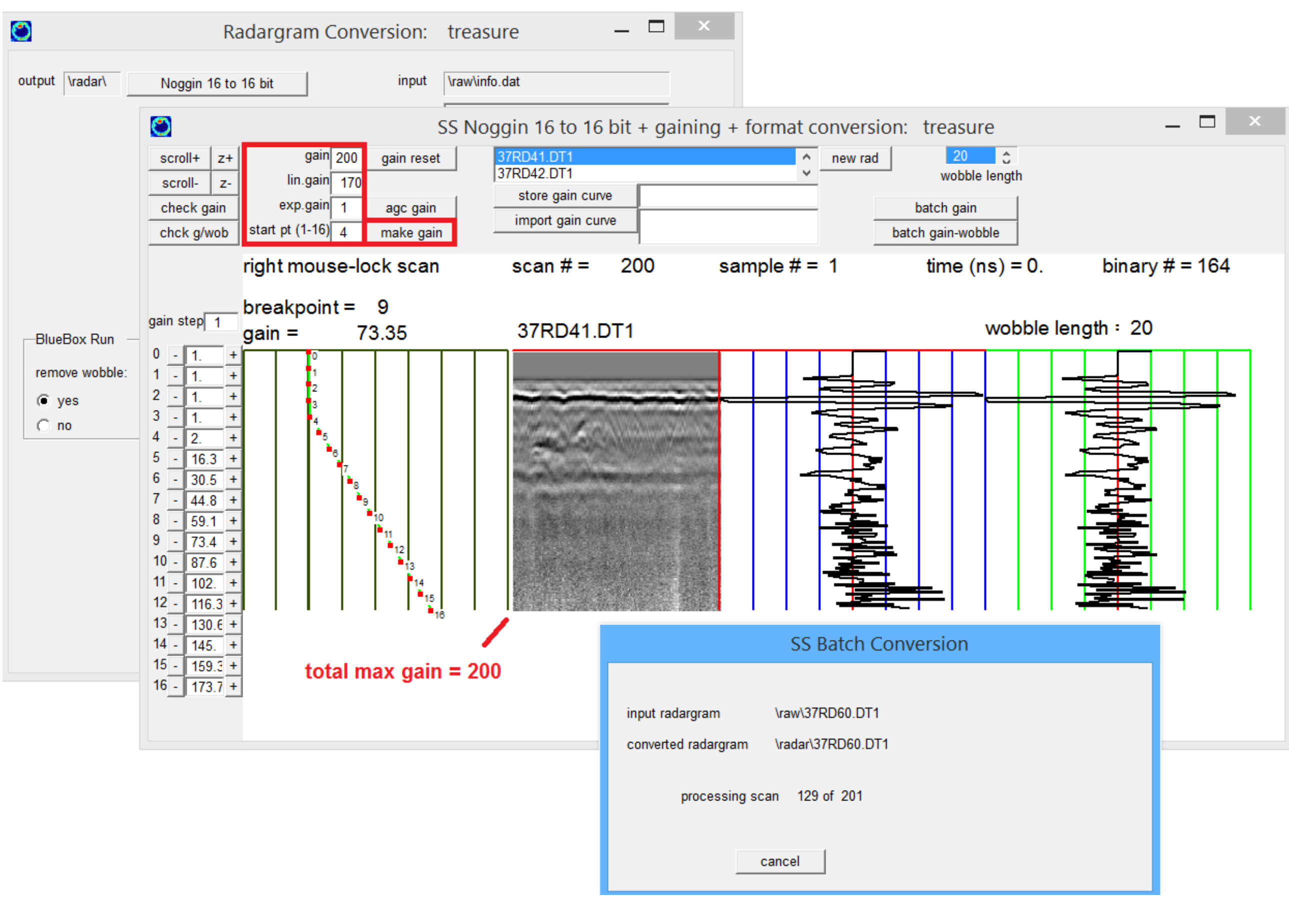
Rev File: This operational button will read the reverse file information and interchange either the y0/y1 or x0/x1 slots to note the direction of the recorded radargram. (Note this option should usually not be used if the radargrams are reversed in the Reverse menu).

X0 to X1 – interchange columns
Y0 to Y1 – interchange columns
X>>Y – interchange X0, X1 with Y0, Y1

SORT X – sort x via the smallest to largest
SORT Y – sort y via the smallest to largest
SORT R – sort the information file based on the name
DEL ODD – delete every odd profile from the active information file
DEL EVEN – delete every even profile from the active information file
RECOVER – recover any edit changes



Independent shifting/multiplication of individual columns in the information file using a user set value. The Rotate button will adjust the current information file and write an inforotate.dat file with X, Y, XY or Ang surveys rotated to the new coordinates.

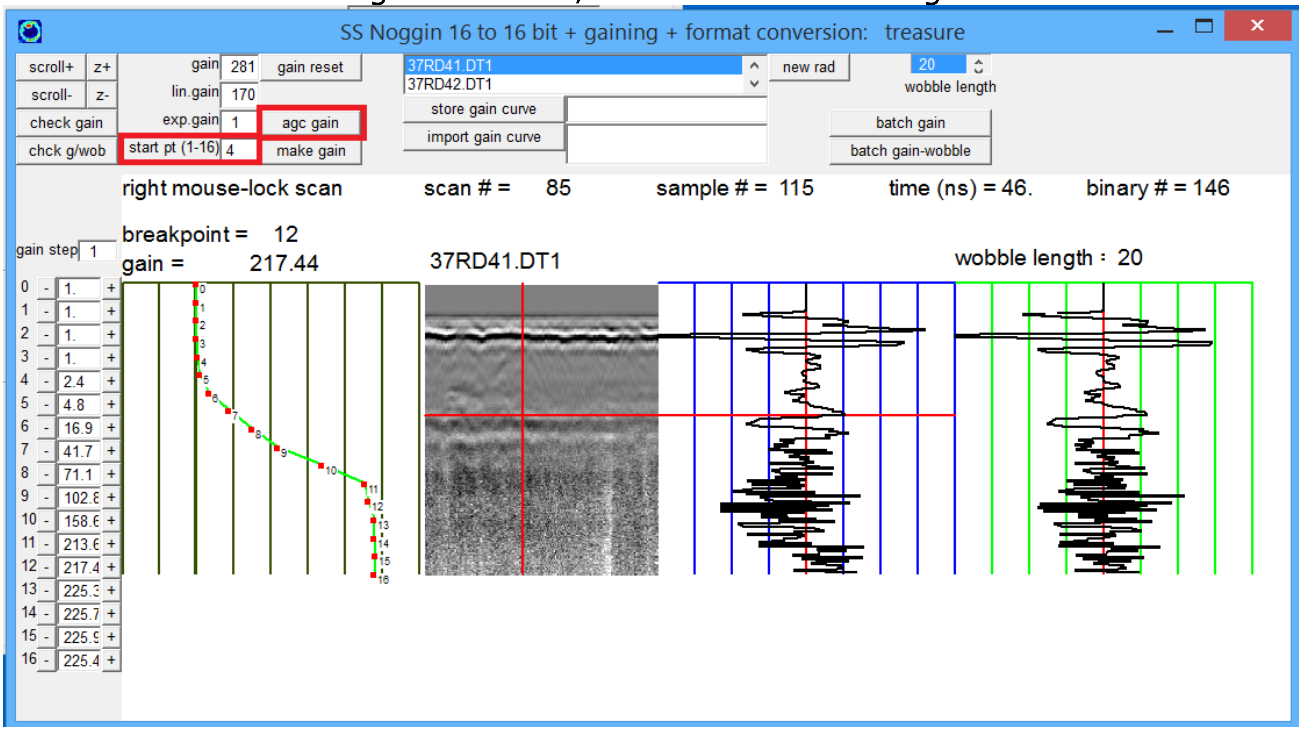


Step 5. Convert Data

All GPR manufacturers' data needs to be converted to GPR-SLICE format. GPR-SLICE v7.0 currently provides for conversion of radargram formats for Geophysical Survey Systems Inc. of New Hampshire, Sensors and Software of Canada, and Mala Geoscience of Sweden, US Radar, IDS of Italy, 3D Radar of Norway, GeoScanners, Zond Radar, UTSI Electronics from the UK, and SEGY/SEG2. The primary features of each of the company's data formats are that GSSI radargrams have gains applied to the data during field collection, whereas Sensors and Software, Mala Geoscience, IDS of Italy and most other manufacturers record 16/32 bit ungained data. If the data are ungained in the field, then 16-bit recording is necessary to store the information. 16/32 bit ungained radargrams or 16/32 bit gained radargrams can be converted to 16/32 bit gained radargrams. Raw recorded 8 bit radargrams from older GSSI systems are also supported.

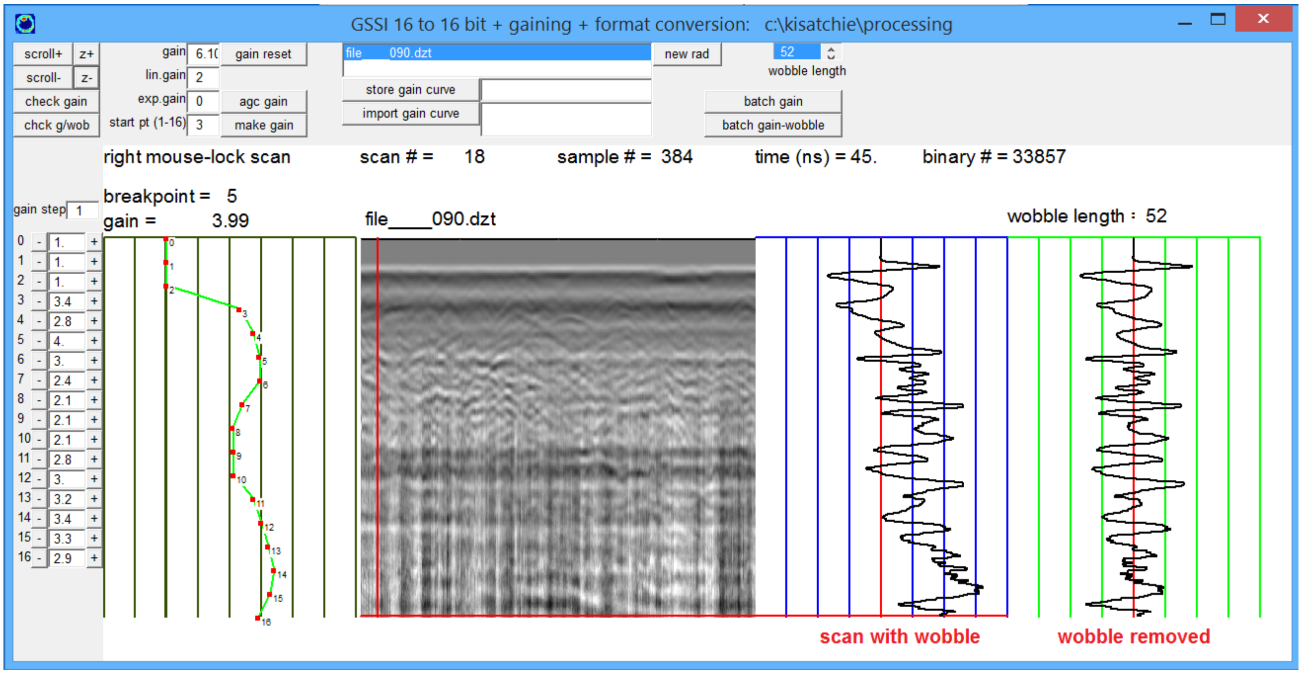
Shown in the previous example is a radargram from a Sensors and Software equipment. A gain curve was designed on the left hand drawing menu and is shown applied real time to one scan. The user can redefine and set the total gain to be applied in the graphic window for applying the gain curve. In the example, the total gain is set to 200. In some instances, more gain may be needed to properly gain the signal. Setting the gain to 300 or even more and then clicking the Reset Gain button will allow the user to apply more gain to the raw recorded radargrams. In addition to drawing the gain curve manually, there are also options to automatically generate a gain curve using the linear gain, exponential gain, and the gain start point setting and then clicking the Make Gain button. The example shown has a linear gain of 170, and exponential gain of 1. The gain is started from the 4^{th} point down since above this corresponding point the ground wave is already properly gained and no more gain is needed here. In this example, the linear gain would increase linear from the 4^{th} point to the last break point in the gain curve. The exponential gain curve would further gain faster with depth to a value of (exp(i/z)-1) where i is depth along the scan and z is the total depth. The value of 1 is subtracted such that if exponential gain is turned off, the total exponential gain contribution is 0.

The scan shown with blue lines is the raw radar scan with the gain applied. Notice that the signal at depth drifts away from the red line which is the 0 value. This radar scan shows what is commonly called "dc–drift" or "wobble" noise. This dc-drift from the 0 location can be removed. The scan plot at the far right with the green line uses what is called a wobble filter to remove the dc-drift in radar scan. The wobble filter computes a running average over a user defined wobble length, i.e. sample scan length, and subtracts this value from each value in the radar scan. In the example below for a SS radargram, wobble lengths of 20 scan samples are used in the running average to subtract the wobble. The default wobble length used is 1/10 the total scan length.



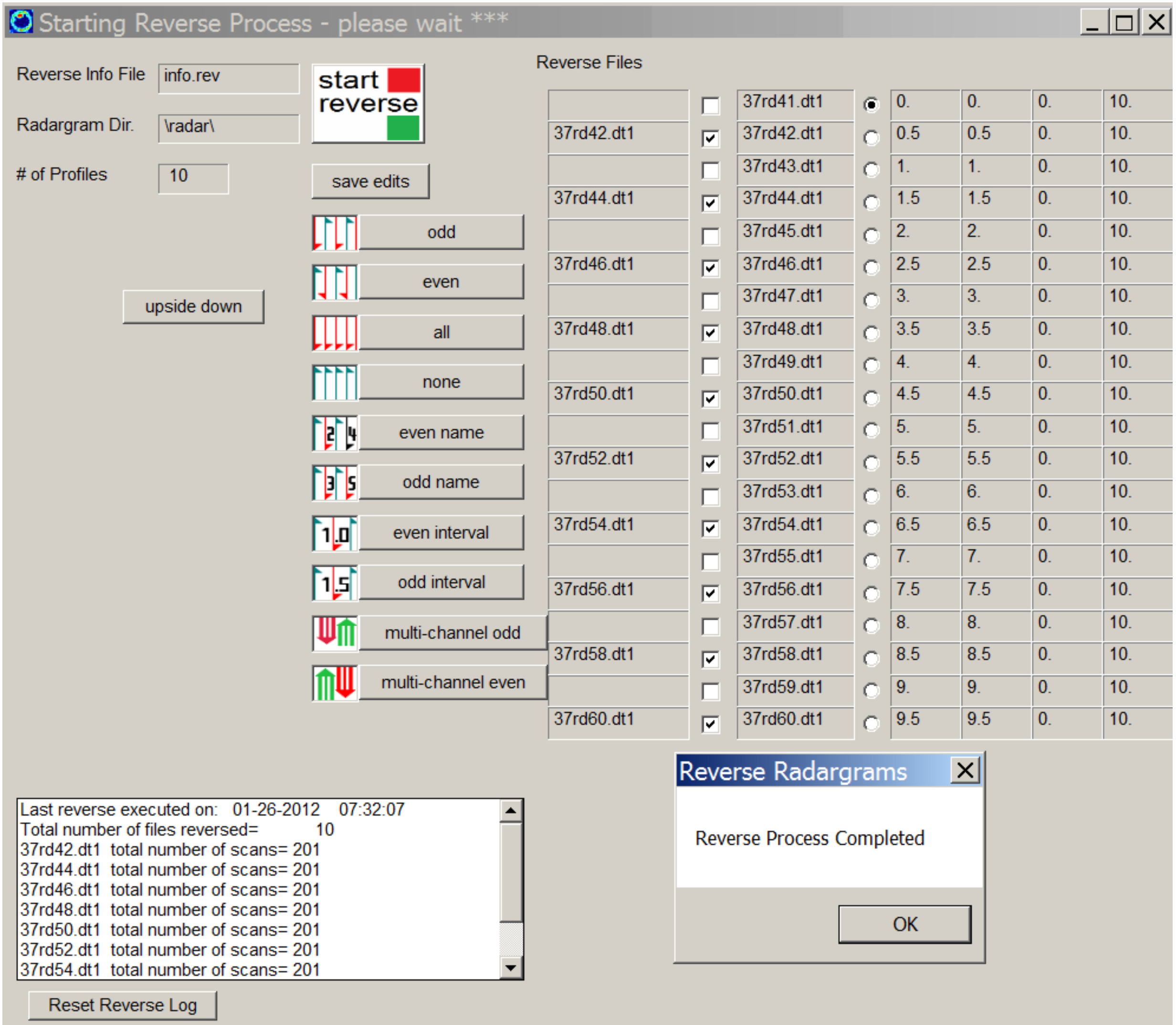
An AGC – automatic gain button also exists for all convert menus as shown in the previous figure. The AGC will try to fit a gain curve to the data to automatically enhance the lower reflections without trying to clip the data. The AGC operation can sometimes create what looks like large jumps or jagged gain curves. If the user does not like this the AGC curve can also be re-adjusted manually to get a more favorable looking for conversion.

The dc-drift or wobble noise is seen in all radargrams from all the manufacturers and is not just in Sensors and Software raw radargrams. An example of this noise in a GSSI radargram is shown in the next figure for a GPS collected radargram. The gain curve was generated using the AGC – automatic gain curve operation. In this radargram the large dc-drift in the signal can be seen changing from scan to scan which causes the alternating gray tones to appear on the bottom of the radargram where the low frequency drift noise exists.



To convert the data, the user can click batch gain-wobble. This will convert all the radargrams in the \raw\ folder to 16 bit radargrams, subtracting out the dc-drift in the data, and at the same time adding a gain with time.

The drawn gain curves are stored during either draw/editing or by clicking the Make Gain button for automatic gain generation. To store a desired gain curve for retrieval later, the user can type in a name and then click the Store Gain Curve button next to this menu item. This will generate a stored file with the appended name "gain-"so that it can be identified and filled into the import listbox the next time the menu is entered. Up to 100 different gain curves can be generated if desired (although such operations should usually never be needed).



Step 6. Reverse Data

If radargrams in the field were collected in the reverse direction, the reverse process can be used to un-reverse them. This is the next process that needs to be done on our way to get out a time slice. The Reverse Menu is kept in a separate item on the main GPR-SLICE command menu. In this menu the user can choose radargrams automatically that need to have the radargram binary files reversed. Several buttons, such as Odd, Even, All, None, Even Name, and Odd Name can be used to automatically choose radargrams for reversing. For instance, the button Even will automatically set the 2nd, 4th, 6th.... radargrams in the info.rev file for reversing. The button Even Name, for example will choose those radargrams that end in an even number. This is convenient when multiple grids have been appended to a single info.dat file, and the user had always kept even or odd names as the names for files that were collected in the reverse direction.

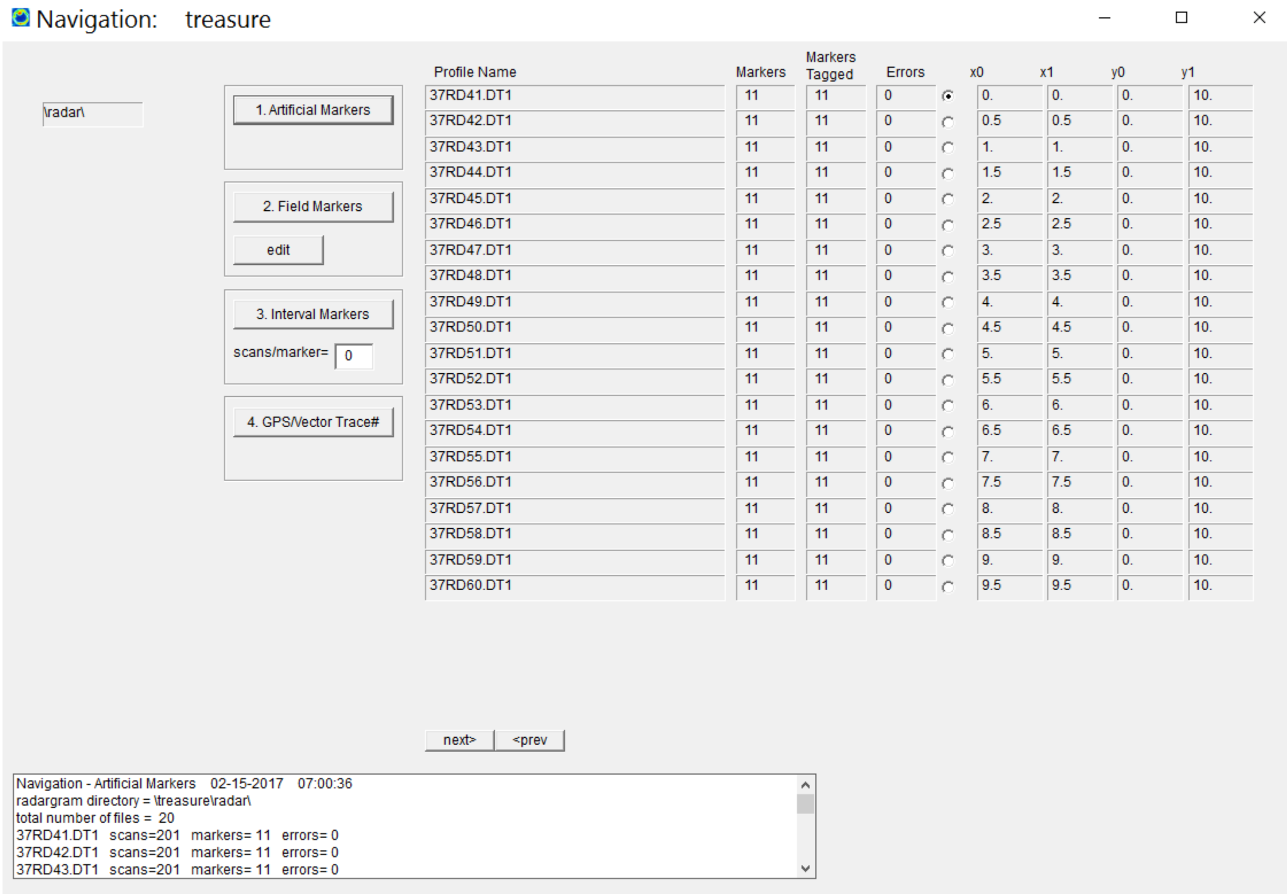
The button Odd Interval can be used to automatically tag the radargrams for reversing that were collected at in between locations, e.g. 0.5, 1.5, 2.5, 3.5 etc. or if the profile interval were say 0.25m, clicking the Odd Interval would tag radargrams at 0.25, 0.75, 1.25, 1.75 etc. etc. The Even Interval button will tag the radargrams at the 0, 1.0, 2.0, 3.0 etc. if the profile interval spacing was 0.5, or at 0, 0.5, 1.0, 1.5 et if the profile interval spacing were say 0.25.

All of these quick setting buttons are for convenience, however, many times customized reverse files are needed for lines that are broken or for other reasons. In this instance, the user will need to keep good field notes and then they can set those radargrams which need to be reversed by clicking the checkbox next to these files.

Clicking the start reversing button will begin the reverse process. Radargrams to be reversed in the \radar\ folder will be rewritten into the \radar\ folder**.**

Note: In this process the binary files residing in the \radar\ folder were reversed – thus they are no longer the original raw recorded data. A log file is kept for the records so the user can know whether or not they applied the reverse process to the project.

Note: Several buttons are available for multi-channel surveys when forward and reverse surveys were done. The operation will read the number of channels to alternately reverse these consecutive listings.



*Only the buttons and menu items specific to the set GPR manufacturer will be shown in the runtime menu will be shown in the blue box location

Step 7. Set Navigation

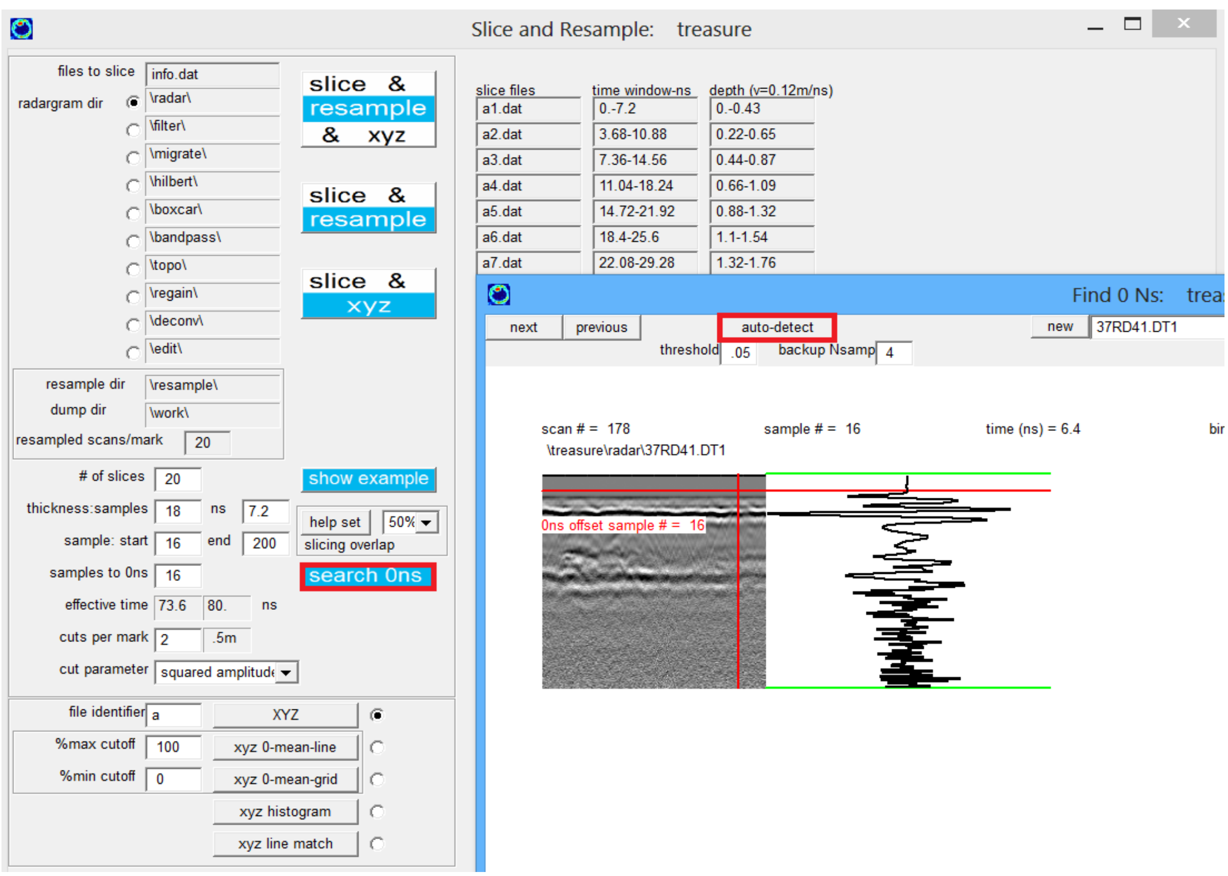
The next step to get 2D time slices is to set the navigation. This particular dataset was collected with a Sensors & Software survey wheel. The SS survey wheel radio button is clicked. Next the user will click the artificial marker button, which will generate marker tags equidistantly across the radargram based on the total number of scans. If for example there are 1000 scans in the radargram, clicking the artificial marker button will place navigation markers every 100 scans for these files since they are all 10 meters in length. Artificial markers should always be used with survey wheel data.

If the user clicks the field marker button for navigation, GPR-SLICE will detect the marker headers written into the radargrams. During conversion, GPR-SLICE stores marker information in the 2nd sample of the radargram. When running the field marker option, if any errors occur such as an extra marker which had inadvertently having been inserted in the field, the user could edit out this extra marker by entering the edit menu. Note: if a dataset if collected with Field Markers and the Artificial Marker process is run, this will destroy the markers in the radargrams and replace them with the artificial markers. To fix this issue, the user will need to rerun the convert menu to get the original field markers back into the \radar\ folder radargrams.

Step 8. Slice and Resample and XYZ

Step 8 is the heart of GPR-SLICE operations where time slice datasets are created from radargrams. The user can apply time slice analysis to any radargram folder for which they have done processing. In this example, time slicing will be applied to the \radar\ folder containing the raw radargrams which have only been converted with a gain curve. There general processing steps are:

- search 0ns
- set the number of time slices, slice thickness
- set bin parameter (usually abs(amplitude))
- set bins per mark
- start the slice/resample process



Step 8a. Search 0 Ns

To discover the location of the ground surface reflection, the user should launch the search 0 ns menu in the SLICE/RESAMPLE menu. There is an auto-detect button which will automatically discover the 0ns offset. The auto-detect works by examining a change in the wave amplitude that is more than the set threshold of the mean pulse. In the screen shot, the threshold is set to 0.05 which is equivalent to a 5% rise from the average response. This value may need to be changed depending on the equipment and if there is digital noise before the first ground wave pulse. Once the triggering threshold is set, there is also an option to backup or move forward N samples from the threshold trigger sample.

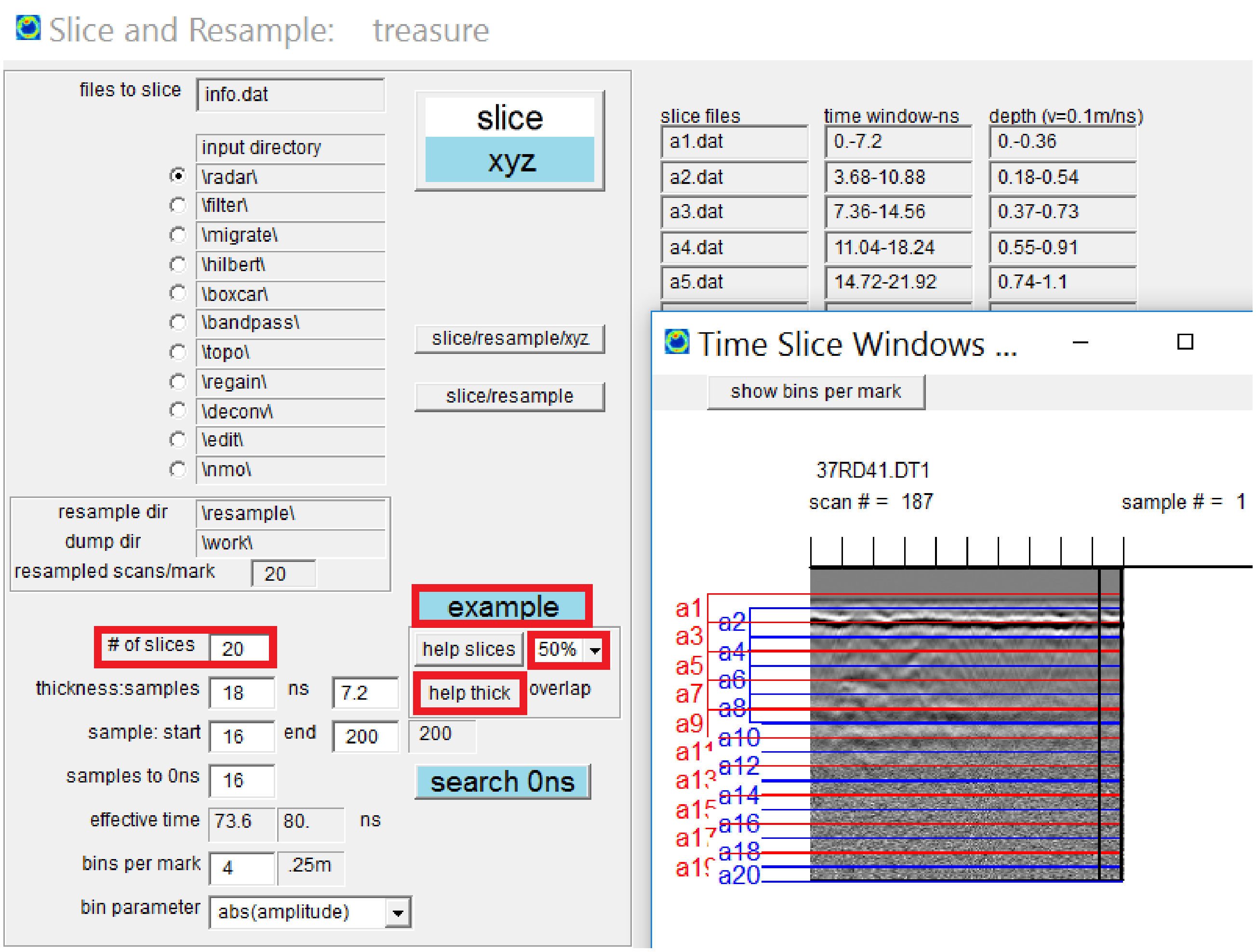
The user can also set the 0ns offset by hand by clicking the left mouse button at the desired depth sample. The user should find where the radar wave just begins to rise from the 0 line and choose this as the 0ns offset. If data was recorded with a large offset, the actual depth of penetration is less than that given in the GPR control unit. The effective time window is given by

Effective time window (ns) =T(N-N0)/N

where T = recorded time window
N = recorded samples/scan
N0 = sample of the 0ns position

If the 0ns offset is 0, then the recorded time window is the same as the effective time window. If the 0 ns offset is 1/10 the length of the radar scan, then the effective time window is only 90% the recorded time window. The user should make sure not to record data with too large of an offset in the field.

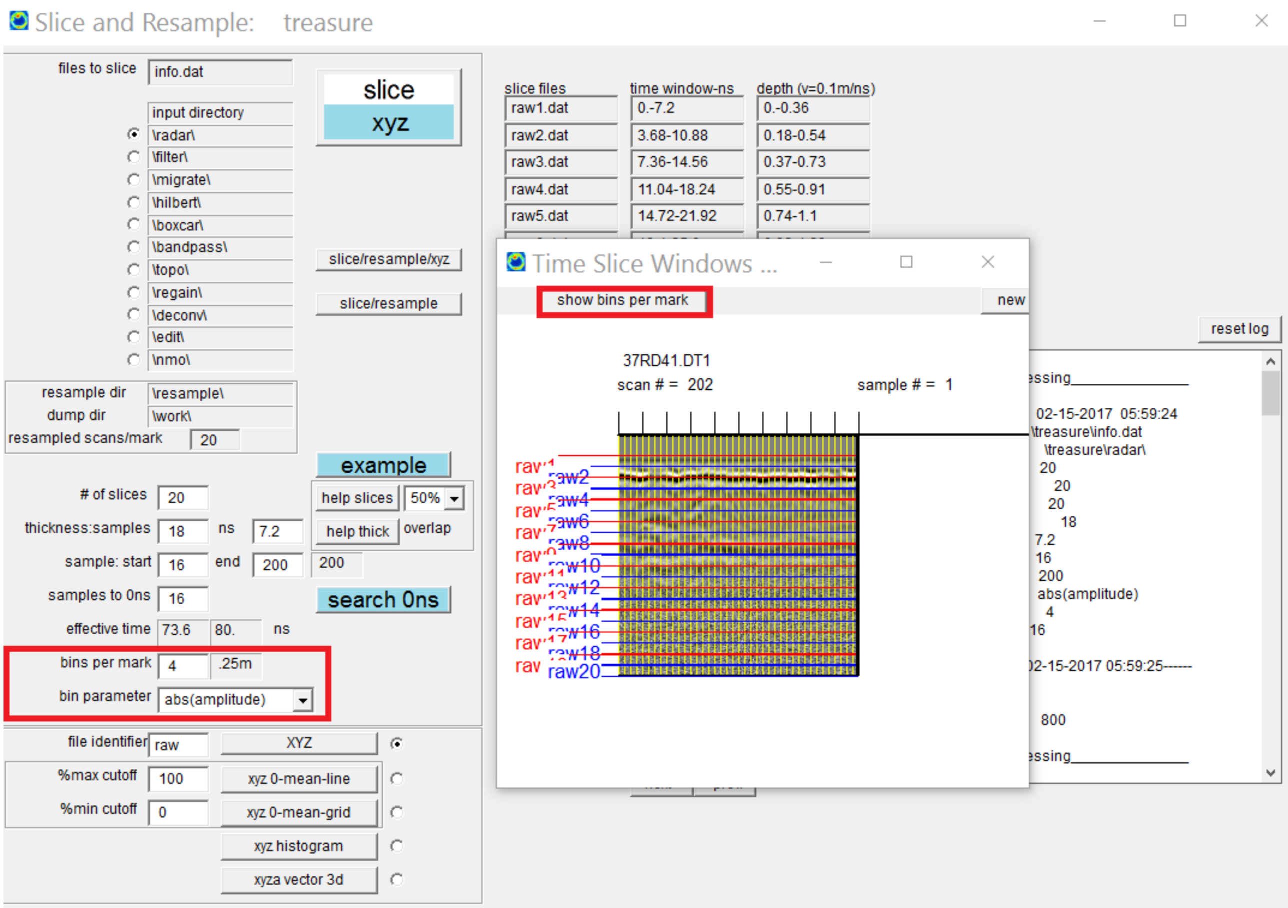
Note: In the Search 0ns offset menu there is an option for auto-detect-all. This option generally is not being used unless the user has changed offset positions in parts of their data or if there is significant drift in the ground surface reflection over a survey site. The line-by-line option is currently reserved for working with array datasets where antenna pairs can have different offsets. Single channel licenses will not see the line-by-line option appear in their Slice/Resample menu.



Step 8b. Set # of Slices, Slice Thicknesses

The next step is deciding how many slices and how thick to create the time slices. In the top example the user has set the # of slices to 20 The overlap between the slices is chosen and for this example 50% overlap between slices is desired (and recommended). Clicking the Help Thick button will automatically adjust the slice thickness for the # of slices and the desired overlap. The sample start is set the same as the samples to the 0ns offset which was found to be located at the 16th sample, and the end (bottom) of the radargram is located at the 200th sample.

Generating overlapped time slices can be very useful for creating subsurface images. Overlapping of time slices can also to help connect anomalies which may be at slightly different depths and as well as to see the transitions between depths better. It is also useful in many applications to create time slices that are at least the thickness of one or two wavelengths of the radar pulse that is sent into the ground



Step 8c. Set Cut Parameter

This setting determines what kind of time slice information to be used to create XYZ datasets. Three setting are currently available in GPR-SLICE:

- squared amplitude – averages the square of the amplitude of the recorded reflection over the time window – A^2
- absolute amplitude – averages the absolute amplitude of the recorded reflection - |A|
- amplitude – average the real amplitudes of the recorded reflection – A

The squared amplitude is a rectified - positive domain - measure of the reflected radar scan. The absolute amplitude is also a positive domain measure. The third setting of just the amplitude of the radar scan will average both positive and negative amplitudes to compute an average. If the Slice Thickness chosen is very large, the cut parameter using just the amplitude will be close to zero since positive and negative amplitudes will cancel each other.

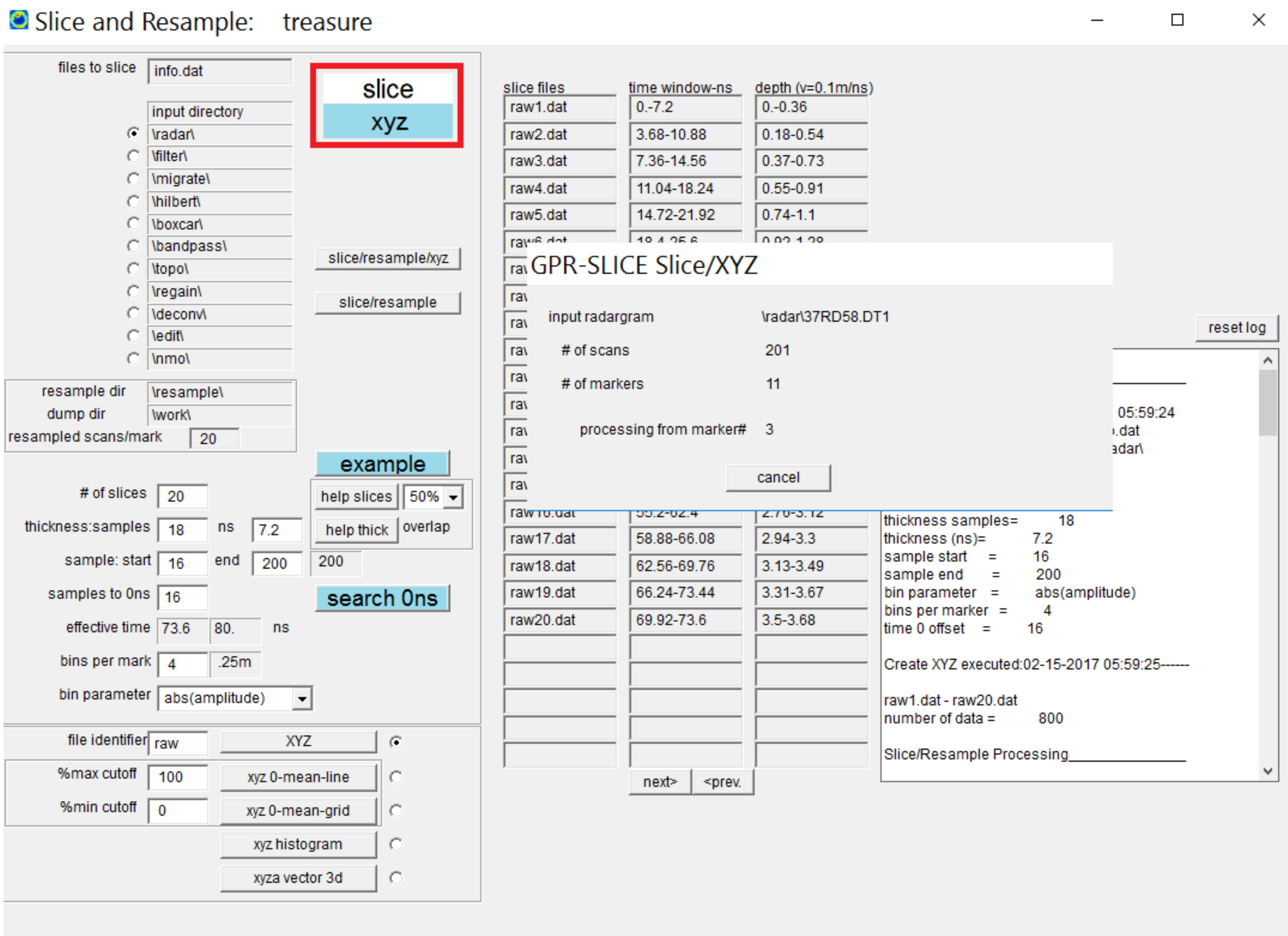
The squared amplitude of the radar scan – i.e. a simple rectified measure of the radar scan works very well for many imaging task. (GPR-SLICE provides radargram processes such as Hilbert Transforms, which will also rectify the radar scan. These kinds of processed radargrams can also be used to create time slice datasets).

The user should set the bin parameter to the recommended absolute amplitude - abs(amplitude) - for most operations.

Step 8d. Set Bins per Mark

Next, the user should choose a reasonable cut per mark value. This value tells GPR-SLICE slicing outines how often to create an average between navigation markers. For this particular site, the navigation markers are inserted every 1 meter. Setting a bin parameter to 4 will in effect cause slicing routines to create 4 averaged values between markers, or at 25 cm intervals. To see the effect of how one is binning or setting horizontal and vertical windows across the radargram, the user can click the show bins per mark button. Yellow vertical lines (top diagram) will appear showing the density of horizontal averages to be made along the radar tract.

The recommended slicing parameters for this example are not necessarily the optimum settings for any site or set of data. Some applications may require thinner or much thicker slicing to solve a particular problem. As a general rule, it is recommended to create averages that are no more than twice as dense along the lines as between lines. For instance, if the profile spacing is 50 cm, then using a cut parameter of 2 will make averages along the line at 50cm intervals. In this way you will have a square grid of xyz points to be used for creating time slice pixel maps. You can however, use a value of 4 to create averages at 25cm, which would give twice as much data along the line as between lines. This is also ok to do. Creating averages which might yield averaging at maybe 10 to 20 times the profile spacing is not recommended. In these kinds of grid maps, the effects of striation noise can become pronounced. In some fine scale engineering applications, such as searching for narrow rebar, having smaller averages along the line can sometimes yield better imaging results.



Step 8e. Slice and XYZ

The next step is to begin the slice/xyz processing. During slice/xyz operations the time slice data are generated from each radargram and time slices are generated. The process will automatically compile the ASCII time slices. (Optionally, slice/resample/xyz operations can be run to create resampled radargram to a constant number of scans per marker; in this case 20 new scans are made between meter markers. This is usually the preferred button to click for surveys made with fiducial markers. The processing dialog that would come to the screen tells the user how many original scans exist in the radargrams in the \radar\ folder. It also tells how many new scans are generated from resampling operations. For datasets collected with user inserted markers, the resampled radargrams will have all the extraneous radar scan data before the first marker and after the last marker cut off).

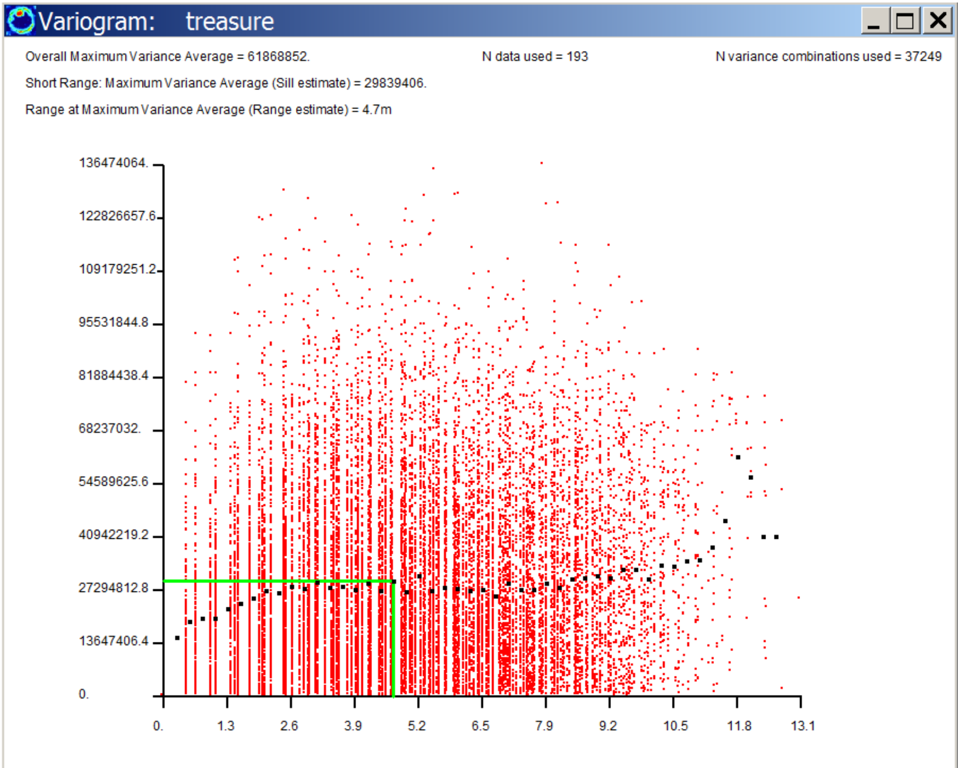
In the final step where the xyz slices are made, this xyz part of the process will read the info.dat file stored in the FILES menu and then merge the time slice values computed for each radargram with the navigation. The correct information file must always be active in the FILES menu before clicking the create xyz button.

Step 10. Grid the Time Slice *.dat Files

The next step to create time slice pixel maps is the gridding process. The grid processing will interpolate between the xyz data to make time slice grids/pixel maps. The time slice grids that get created can be made with very fine or coarse cell sizes. In above example inverse distance interpolation is highlight. The gridding steps are:

1. Choose inverse distance interpolation with a smoothing factor of 2
2. Click the help set which will automatically choose some gridding values such as the start and end values for the grid, the cell size, search and blanking radii - draft/fine grid cell size and standard/broader search radius can be used and chosen automatically)
3. Clicking the start gridding will begin the gridding process.

The user has options in V7 to show the gridding results as the software processes. If processing graphics is clicked on then each time slice map will get drawn to the screen as it is made. The user cannot adjust the display of color transforms during the gridding process.



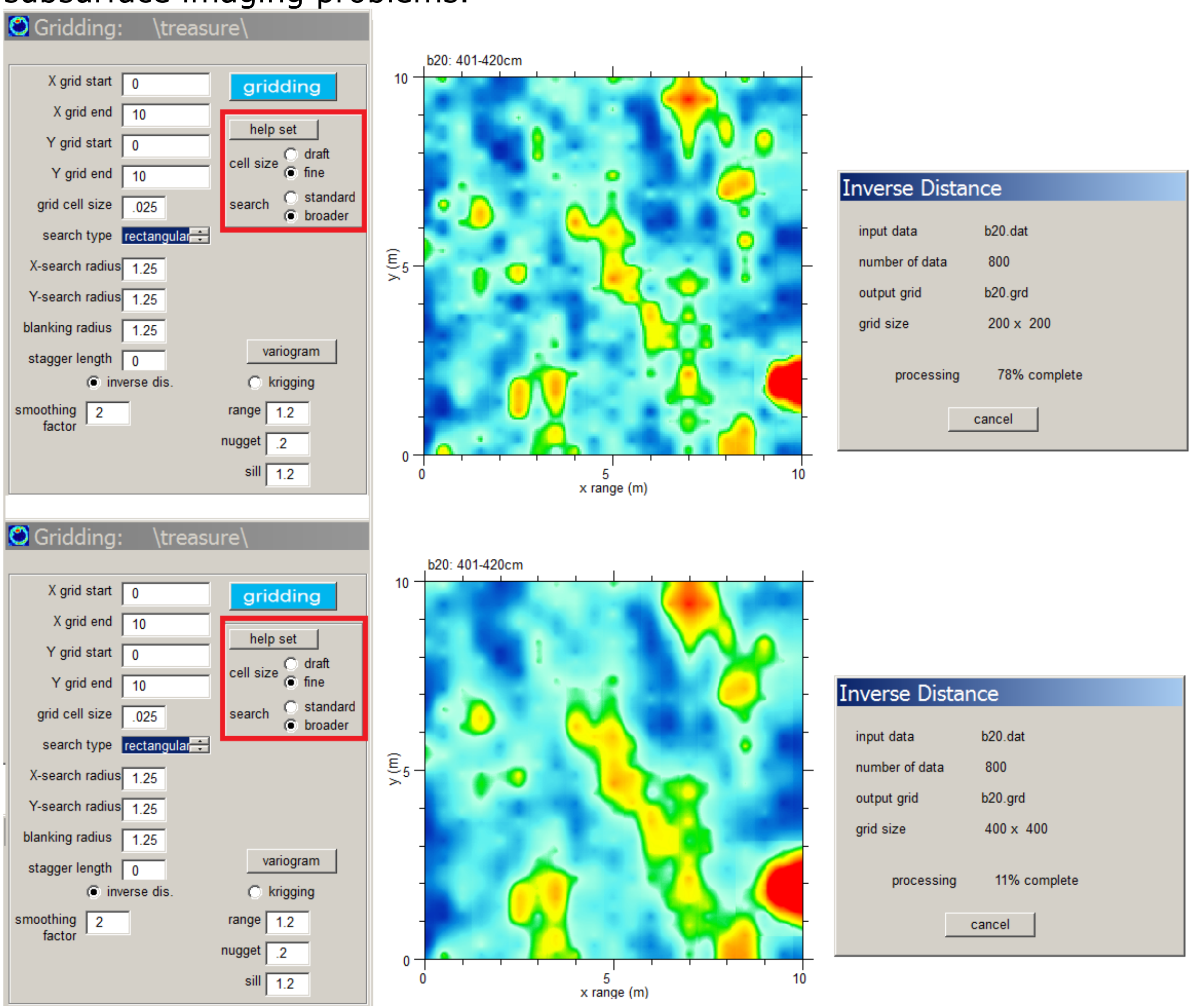
Optional: For the kriging interpolation option the user can click the variogram button and the software will automatically find some values for the kriging range and sill for the first grid.

Optional: Step 10e. Set Variogram Parameters, Range and Sill

The variogram calculation will automatically get updated if the user chooses this method for grid estimation. If the user wants hi-resolution kriging as their method for calculating their grids, then they may want to first click the variogram button. Doing so will cause a variogram plot showing the variance between all the combinations in the data, along with a generalized fit for the sill and range. These values chosen may or may not be represent optimum statistics for the data to be gridded. They are only recommended values. The estimate comes from an attempt by the software to find a local maximum in the variogram at short ranges. If a local maximum in the variogram is not detected, the range and sill values at about 1/3 the maximum range in distance is selected. GPR-SLICE V7 currently does not estimate the nugget used in the kriging grid estimation. The default value is 0.2.

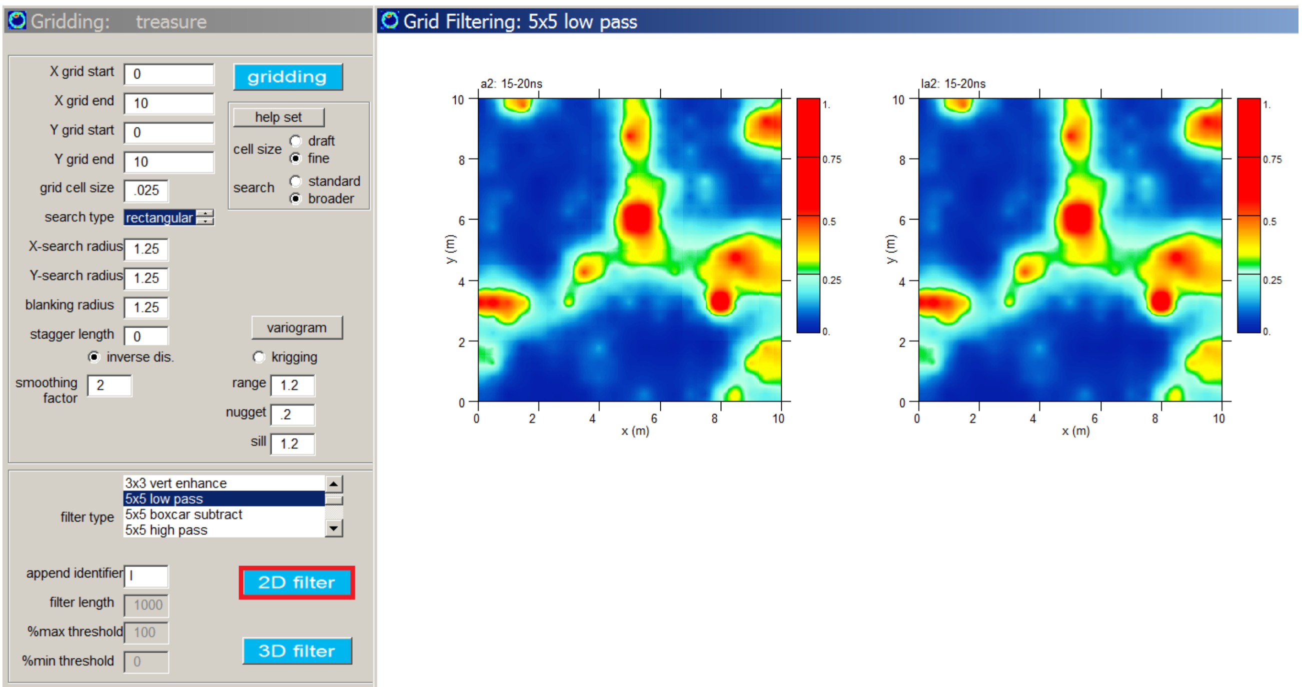
On exiting the variogram, a dialog will inform the user that the range and sill have been updated. The user has the option to adjust these parameters, however, a whole dataset can usually be gridded using one set of kriging parameters estimated from one of the time slices (usually the top slice).

Inverse distance gridding can also be effectively used with most datasets. One of the tradeoffs between ordinary kriging and inverse distance is the processing time for gridding. Kriging takes much longer processing times but can often give slightly better resolution. Inverse distance takes the least amount of processing time, but can also generate overly smoothed time slice maps. A comparison of using broader versus narrower search radius is shown. The broader search radius (found by clicking the help set button) is 2.5 times the profile spacing; standard search radius is 1.5. For this example, the broader search appears to have more coherent anomalies imaged (at the expense of less resolution of individual anomalies). One must decide for themselves what kinds of maps with the appropriate interpolation is needed to solve their subsurface imaging problems.



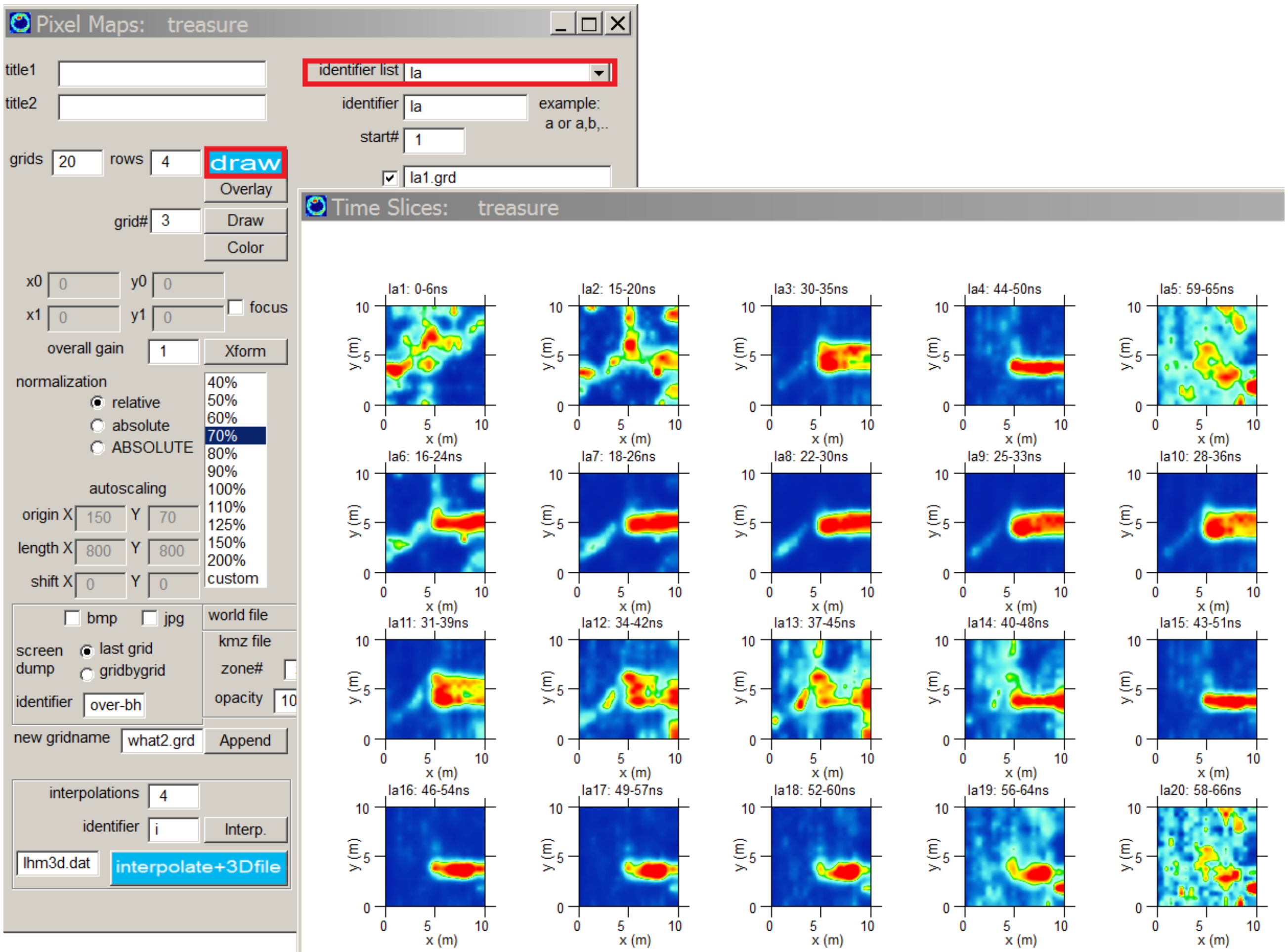
Step 10f. Grid XYZ Time Slices

Clicking the start gridding button will initiate the batch processing for kriging (or inverse distance). V7 has the added feature of real time graphic display of the time slices as they are generated. The overall size of the graphic display can be changed in this menu; however, the user cannot change any plotting features such as the transforms or colors as batch processing proceeds.



Step 10g. Smooth Time Slices

To remove gridding noises a 3x3 or 5x5 low pass grid filter can be applied the raw time slices. Click the desire filter in the Filter Type listbox, set the append identifier (e.g. to "l" for low pass) and click the 2D filter button. The filtering process will append the letter "l" to all the smoothed grids.



Step 11. Display Time Slices

The final quickstart step is to display the 2d time slice dataset created in the GRID menu. The user can enter Pixel Map, which is conveniently available on the task bar at ***T*-slice** as well as in the PIXEL pull-down menu. The following can be used to display the 20 slices

1. Choose the desired grid set identifier listbox
2. Set the starting grid # to 1
3. Set the total number of grids to display on the screen e.g. 20
4. Set the number of rows to break up the display into to 4, e.g.
5. Toggle and click on the auto scaling size to display all the time slice data (in this example it is set to 70%)....
6. Click the "draw" button at the top - you have drawn 2D time slices in GPR-SLICE V7!!

The transform menu can now be brought up by clicking the left mouse button over the time slice maps, allowing the user to adjust image contrasts and colors.

Auto-gaining with the Transform Menu

It is very simple to automatically gain a large time slice dataset. The new procedures which requires clicking only a few buttons for auto-gaining an entire time slice grid set are to first display all the grids to the screen, then

1) Click a transform, e.g. linear.

2) Click Save-All.

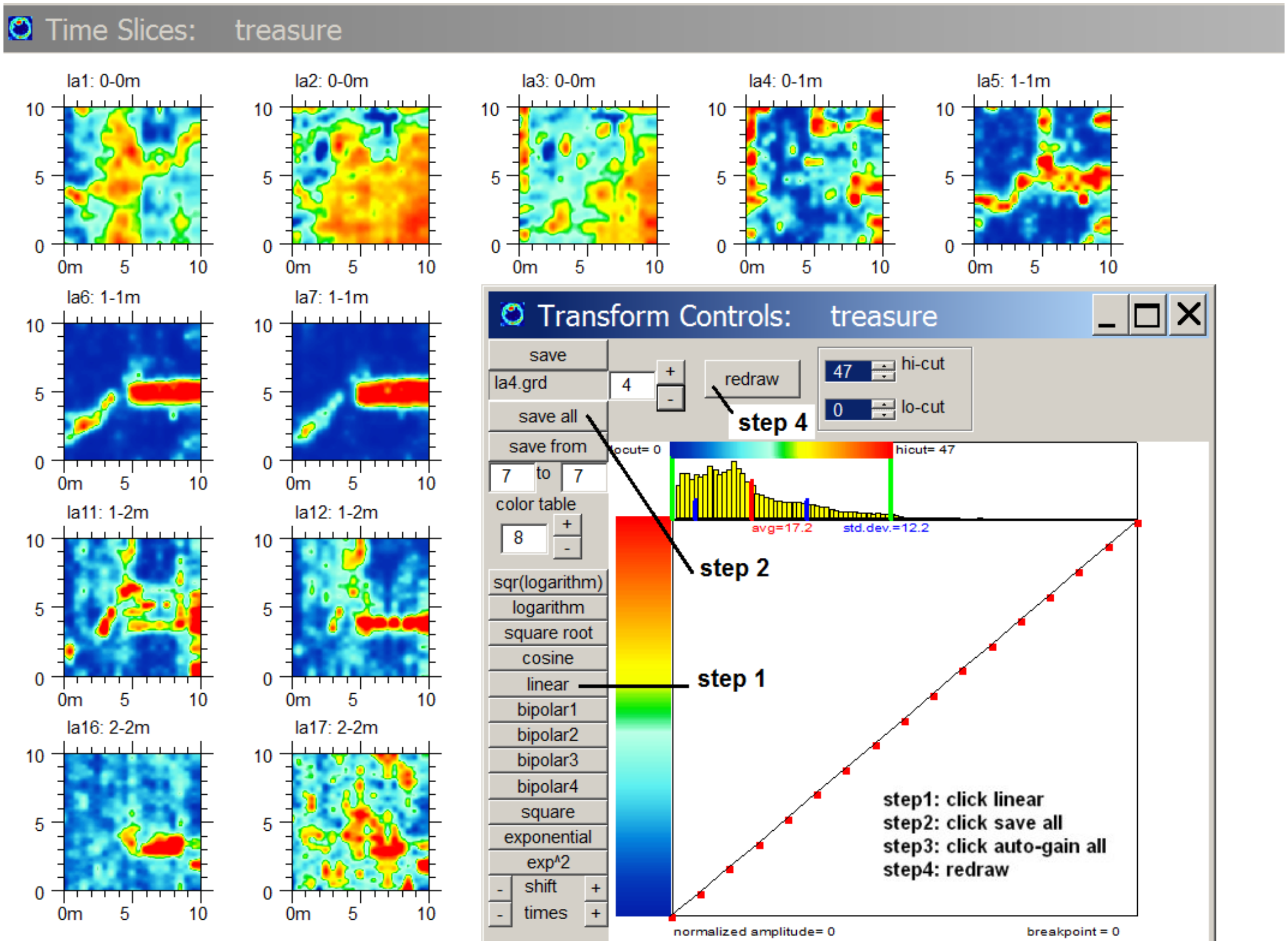
3) Click the auto-gain all. This will automatically set all the lo-cut and hi-cut off settings (the green little bars on the histogram) to the 3 standard deviations to each side of the mean. The user should **not** click the Save or the Save All buttons after clicking the Auto-Gain-All as this will replicate the active transform and the lo-cut/hi-cut settings for every grid.

4) Click Redraw to see the changes.

Notes: To display interpolated time slices, one should reset all the transforms back linear and also make the lo-cut and hi-cut threshold settings 0 and 100. This can be accomplished by using the “Save All" button to reset this for all the interpolated grids. By resetting the transform to linear and the thresholds to 0 and 100, this essentially removes all re-contrasting of the time slices and allows recovering the exact colors that were used to interpolate between the time slices.

Notes: Clicking the "Auto-Gain-All" or "Auto-Gain" button in the transform automatically discovers and saves the individual lo-cut and hi-cut settings. If one wants to globally adjust the transform, but then to have the unique lo-cut and hi-cut settings also be active for the maps, after clicking the "Save All" button to globally store the transform shape and lo-cut and hi-cut settings, you will need to go back and click "Auto-Gain-All" to rediscover the individual map lo-cut and hi-cut settings.

Some of the procedures are shown in the following diagram to better help the user discover these important features within the software:

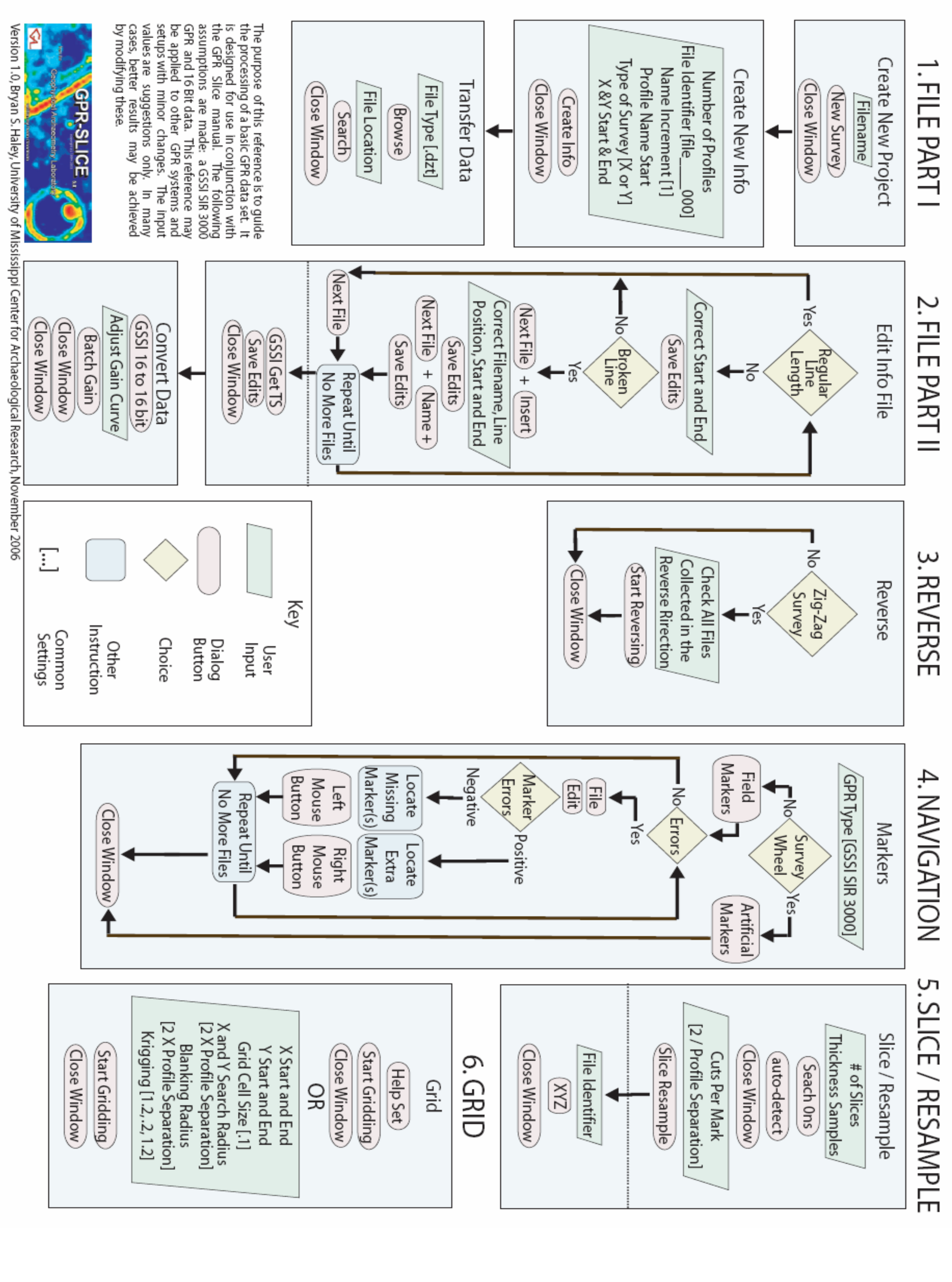


Note: Step1 and step2 insure that you have linear transforms set throughout. Linear transforms can also be set individually or globally to any canned transform as well.

Note: Step 3 will automatically detect the lo-cut and hi-cut thresholds to apply the color table over. These are the green bar settings shown on the histogram plot. Clicking the auto-gain-all button will automatically save these threshold settings - the user usually does Not need to click the save-all buttton.

2D Quickstart Flow Chart

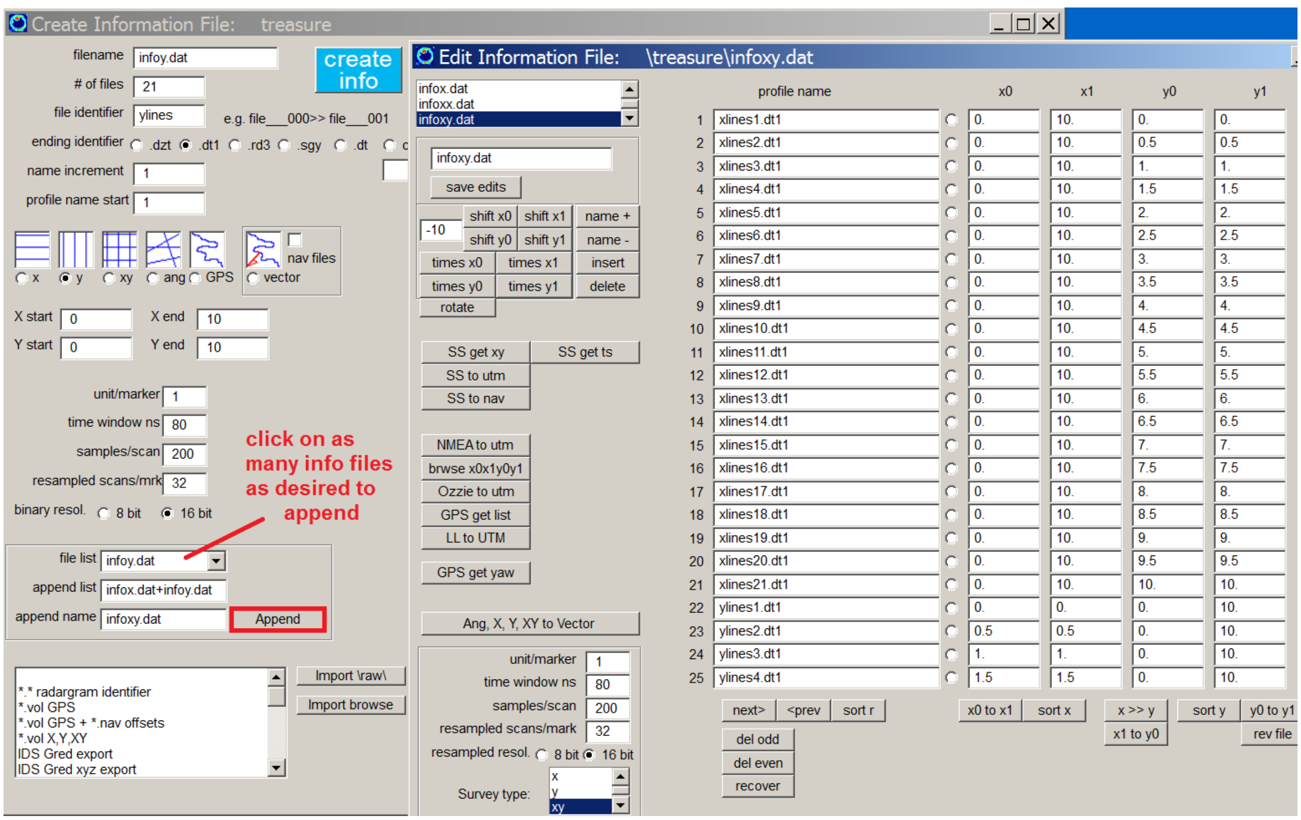
(Flowchart Courtesy of Bryan Haley, University of Mississippi)



Making XY Cross Survey Information Files

GPR-SLICE can handle any kind of survey navigation as long as the information file is properly set. Commonly, XY surveys are made. The easiest way to create the information file from cross surveys is to generate an infox.dat file and separately create an infoy.dat file. These 2 files can then be appended at the bottom of the Create Info File menu. Shown below are some of the steps outlined in the Create Info File menu:

Combining/Appending Information Files



Any combination of information files can be appended together in the Create Info File menu. For instance, for cross grid XY survey, first the infox.dat and the infoy.dat files are made independently in the menu and then appended together. These files are then clicked on in the File Listbox, after which the Append button is clicked on with the name of the output filename, e.g. infoxy.dat. The operations here were modified in 2011 to enable up to 500 information files to be appended in one operation by consecutively clicking on the desired info files in the File List. An example of cross surveys can be seen in section XIX of the manual.

Quickstart Introduction: 3D time slices

To make 3D time slices and other volume display such as isosurface rendering, a 3D binary file must first be compiled. The 3D binary file is compiled from a series of 2D grid files. The instructions for creating 2D time slice grids are discussed in section III. There are several possible ways to create 3D binary files.

In one method, we can create a limited number of time slices and then interpolate between time slices. The interpolation process will normalize the grids based on relative values (e.g. color) rather than absolute values. This will help to create a continuous and visually smoothed 3D volume. Interpolated time slices are normalized. The normalization effectively causes automatic gains to be applied at each level in the time slice dataset.

In a second method, we can initially create a lot of slices from the original raw data and compile these to a 3D binary file. This file will then contain the original and absolute values contained in the radargrams. If large dynamic range exists in the 3D binary file, in the current version of GPR-SLICE, the user will have less flexibility in controlling gains across the data with depth during display.

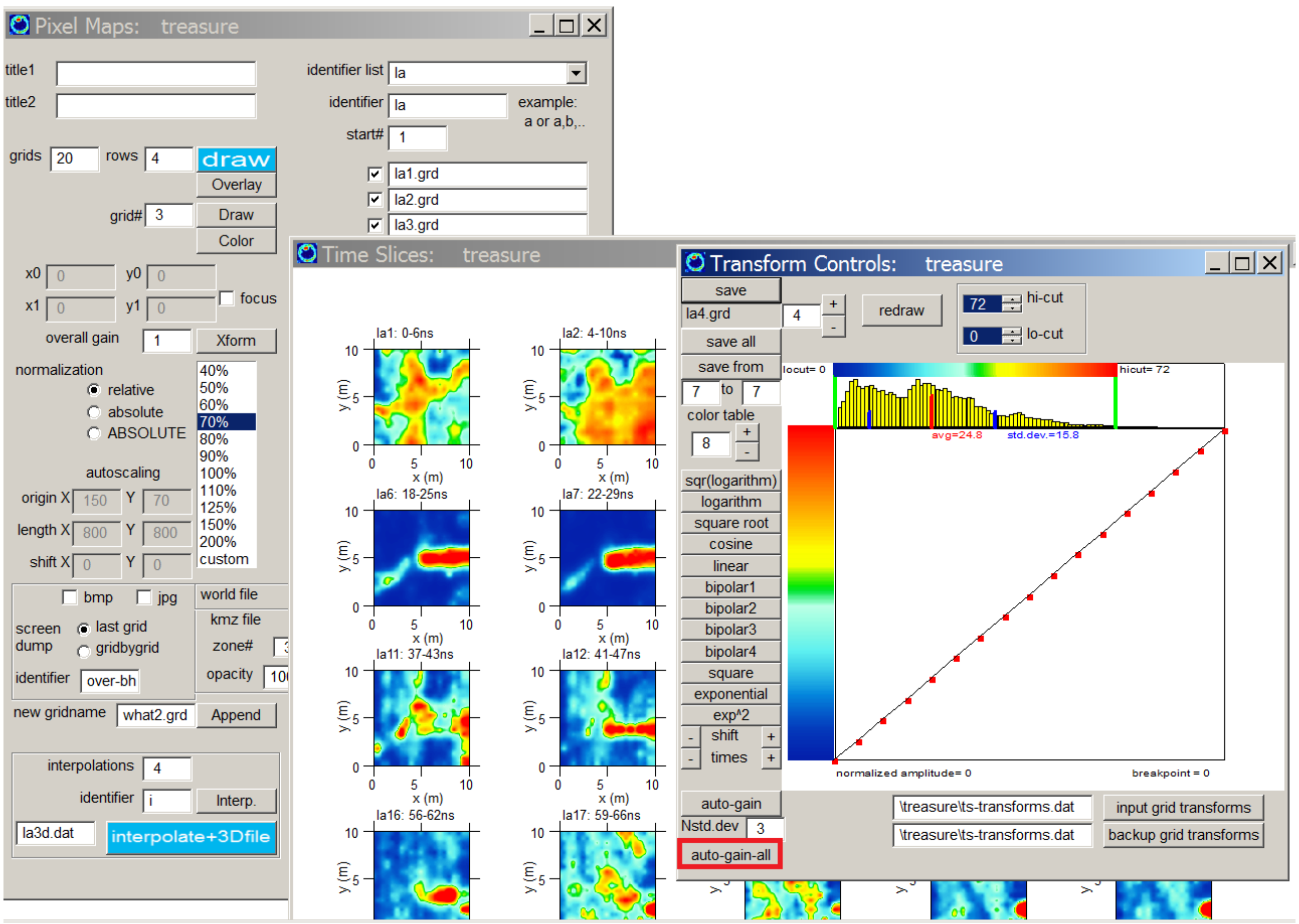
Note: For most imaging applications or for surveys in which data are noisy, creating a limited number of time slices (say maybe 20 or 25 slices) across the radargrams and then interpolating between the time slices 3-4 times will generally create visually more useful and stimulating images and animations. The user is welcome to experiment what is best for their imaging applications however. Most users that become familiar with GPR imaging agree that relative normalization is generally much more useful than absolute normalization in colorizing the time slices. Relative normalization allows one to amplify subtle changes in reflected energy at each discreet depth to show the whole horizon of reflected changes. However, some applications may require absolute normalization. To create volumes of absolute amplitudes that replicate the energy in the reflected pulse one should never use interpolated time slices. The steps necessary to generate an absolute amplitude volume is to first create a large series of time slices, maybe more than 70 or so in the Slice/Resample menu, followed by gridding and then 3D file compilation. One should never use interpolated time slices if they want to generate absolute amplitude volumes. To generate normalized 3D volumes, one should always use interpolated grid files that are compiled to the 3D volume.

We will begin by outlining the general steps for creating an interpolated dataset which is normalized:

Step 1: Make a series 2D time slices.
2: Adjust the transforms of the individual time slice maps
3: Interpolate the time slice grid set + compile to a 3D binary file
4: Create 3D time slice displays in Open GL Volume

Step1. Make a Series of 2D Time Slices

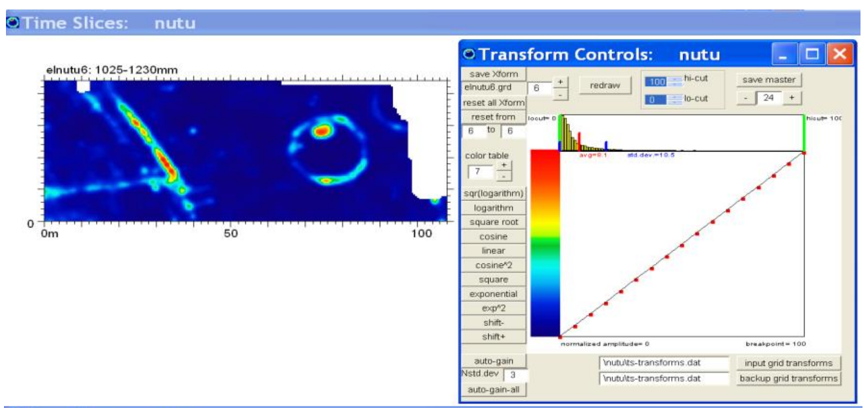
To make a series of 2D time slices follow all the steps in section III. The time slice grid set that was generated in section III contains a total of 20 time slices across the radargrams.

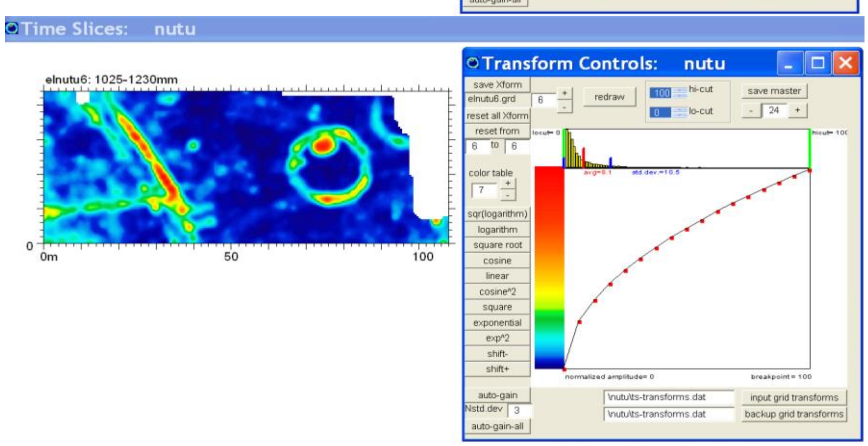


Step2. Adjusting Time Slice Transforms

The series of time slices can be quickly and automatically adjusted for color enhancing. The user will draw all the time slices to the screen, left click the time slices to bring up the transform menu, then click autogain all button to automatically adjusted all the colors in the maps.

Sometime individual maps in the time slice dataset may need to be enhanced separately to create contrasts desired contrast. Clicking the left mouse button when the time slice pixel maps are on the screen, the user can adjust the individual transforms. It is often best to create a nice blending between color contrasts between adjacent maps so as to create visual smoother 3D volumes from interpolated and normalized grids. The transform menu allows for adjusting individual transforms or globally resetting all transform to a common transform by clicking the "reset all Xform" button in this menu. The user can also change transforms from a range of time slices in the dataset. Often the top few time slices require different transform settings than for deeper slices. Various transform buttons with canned settings are available such as linear, cosine, exponential, log etc. The user can also manually draw the transforms by hand to create different contrasts in the data. An example of an image with 2 different transforms in shown in the following diagrams:

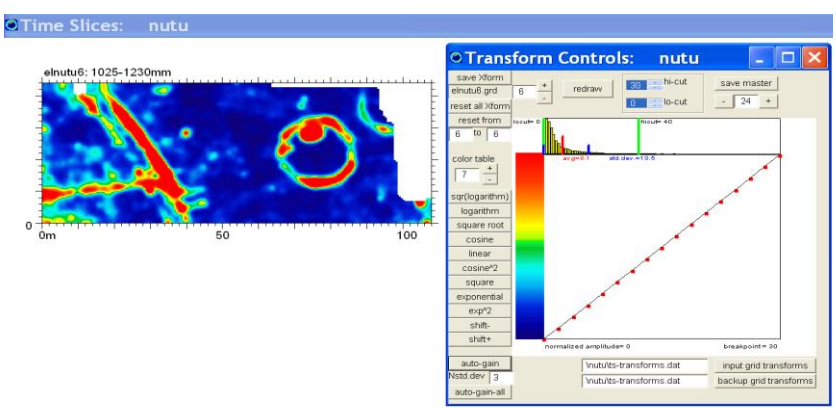




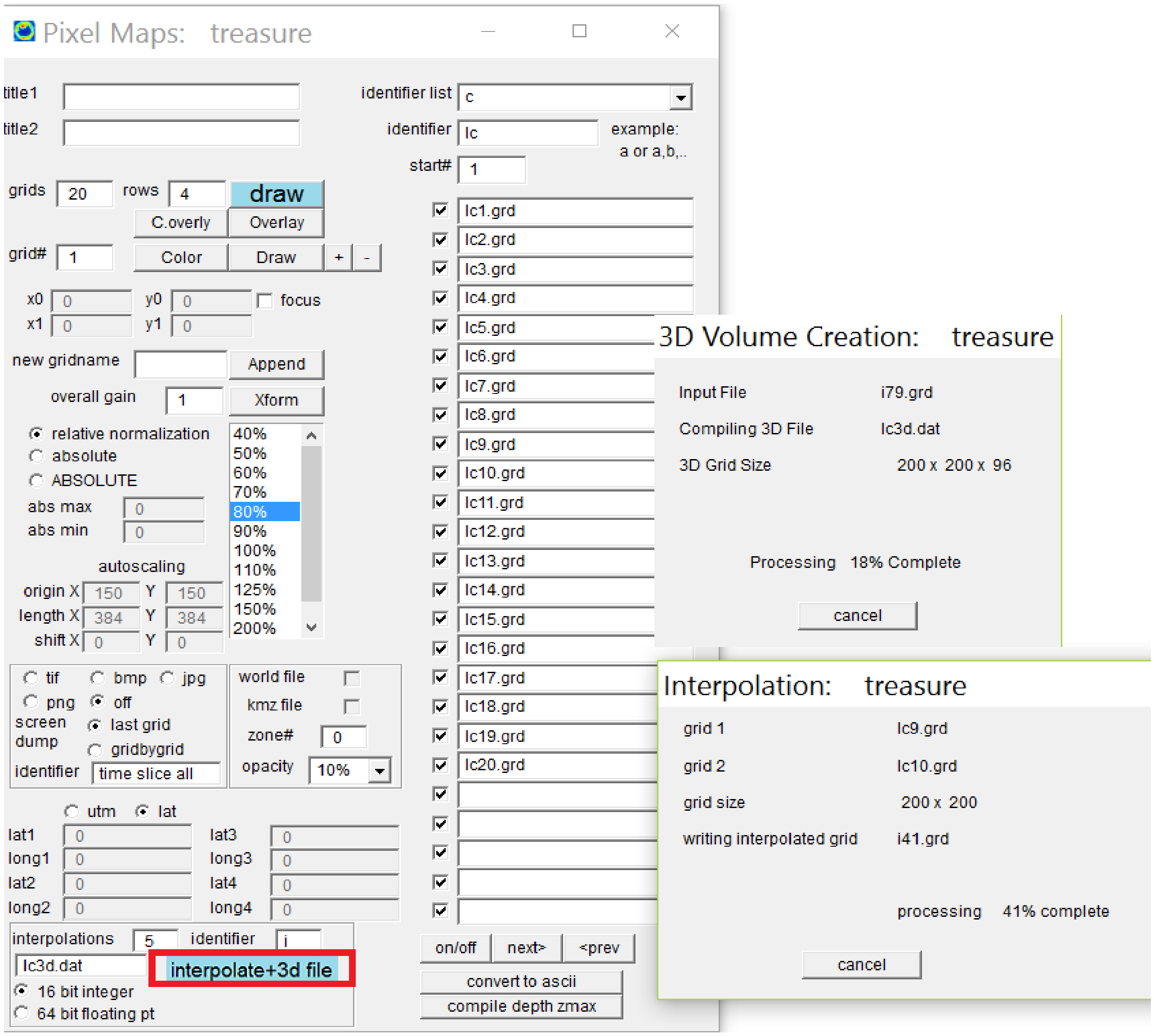
Note that the linear transform on the top image will apply the rainbow colors at equal amplitude intervals across the time slice data values, whereas the square root transform shown in the bottom diagram, will preferentially create contrast across the weaker reflectors in the map.

Another way to adjust the transforms is to use the lo-cut and hi-cut settings in the Transform Menu and manually adjust these with the left and right mouse button. The lo-cut and hi-cut settings are seen as green bars on a histogram plot for the current active grid. The left green bar is the lo-cut and the right green bar is the high-cut. These settings tell over what range the color table will be applied to. If for instance, the hi-cut setting was put to 70%, then the color table would be applied from the lowest amplitude in the time slice map to amplitudes that are 70% of the maximum. Values in the time slice map that are greater than 70% will be pegged to the last color in the color table – in this instance it would be red. The lo-cut and hi-cut settings can be set either by hand using the left/right mouse button, or by using the auto-gain (or auto-gain-all) buttons on the bottom of the transform menu. The auto-gain buttons will set the lo-cut and hi-cut settings to a default of 3 standard deviations on each side of the mean reflection. The standard deviation can be set to any customize value as well.

The lo-cut and hi-cut option is often useful in creating equal coloring on the time slice maps, particularly with images that are not well distributed in their reflection values or where the dynamic range of just of few data points prevent seeing weaker reflection. The settings can be used in a way to de-spike data if this desired, to remove the prominence of very isolated and strong reflections in a time slice image. The same dataset in the previous diagrams is shown with a linear transform, and a resetting of the hi-cut value to in this case 40%. Note that more red color appears in the map since, all values above 40% of the maximum reflection are assigned red.



Step 3. Interpolate the Time Slices + Make 3D File

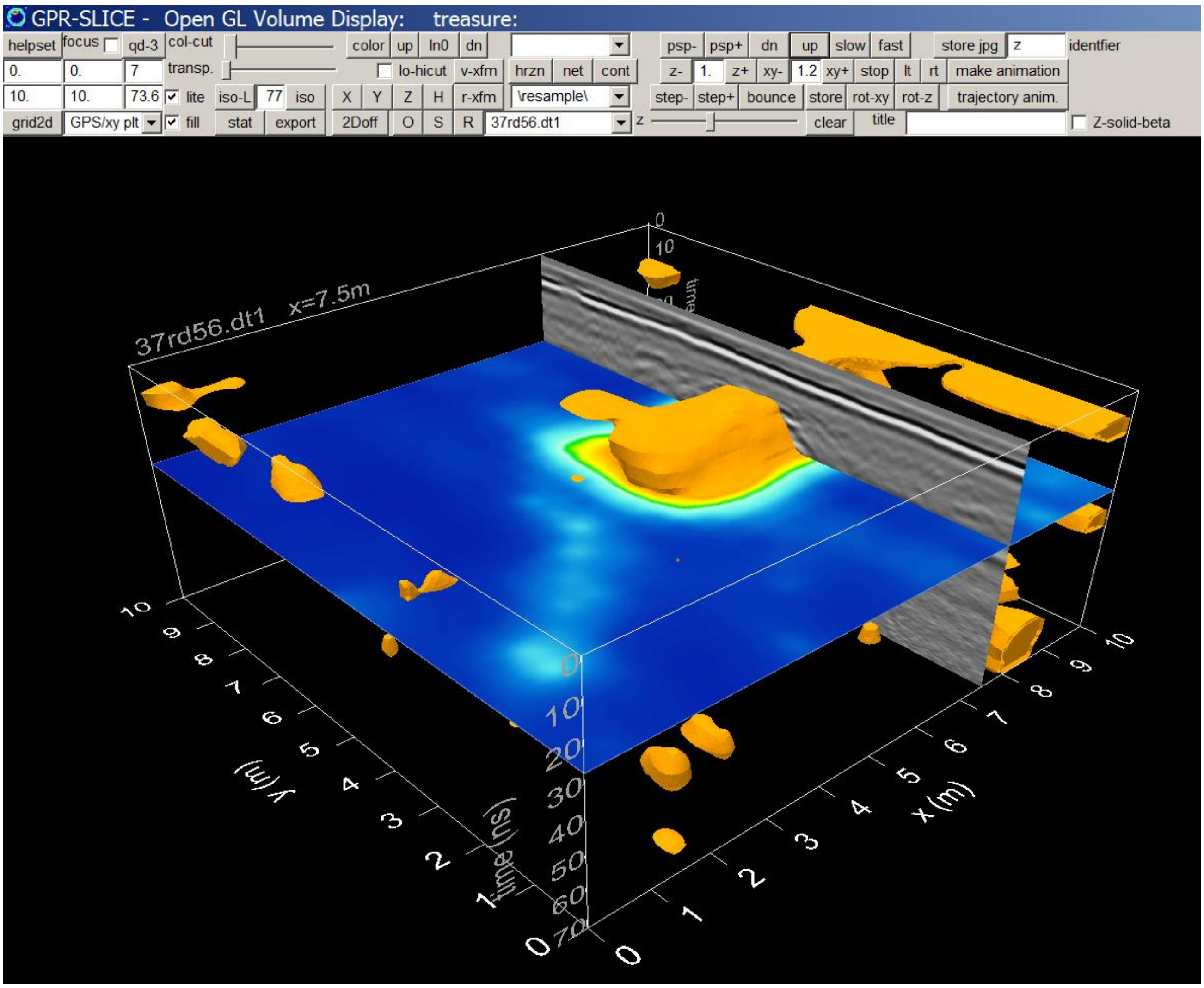


Once the time slices are generated, it useful to interpolate the time slices to generate normalized grids based on the colors of the grid maps being used rather than actual binary values. The time slice dataset can be interpolated in the Pixel Map menu after the user has made adjustments to the transforms. The user should set the number of grids and grid identifier to interpolate in the top setting of the menu, in this case 20 and the identifier "a", and then set the number of interpolations to make, in this case 4. Setting the interpolations identifier to i, the user will create (20-1)*4+1 or 77 interpolated grids called i1-i77.grd. The identifier can also be customized. Often users like to show where the interpolated grids came from, so using an interpolation identifier like "ia" to create the ia1-77.grd dataset is also possible. Once the interpolation process is complete, another process will start automatically to compile the interpolated grids to a 3D binary file. To make 3D volume datasets, it is useful to have at least 70-100 2D grid files to compile. This will insure that 3D volumes displays will not look pixilated along the z axis of the volume. 2D time slices are currently ASCII files whereas 3D files are binary. Binary files are much easier to work with for 3D imaging applications.

Note: For users that want to compile grid sets which are not normalized, they can do this by using the absolute or ABSOLUTE normalization settings in the Pixel Map menu. This option is generally set aside for applications when users want to generate 3D volumes of radargram (binary) pulses, but can also be used when the absolute reflection energy in the radargrams is desired for displays without local enhancements. This can be useful for geologic mapping where a direct translation to the energy volumes shown in the radargram without equalization of reflections at each level, is generated.

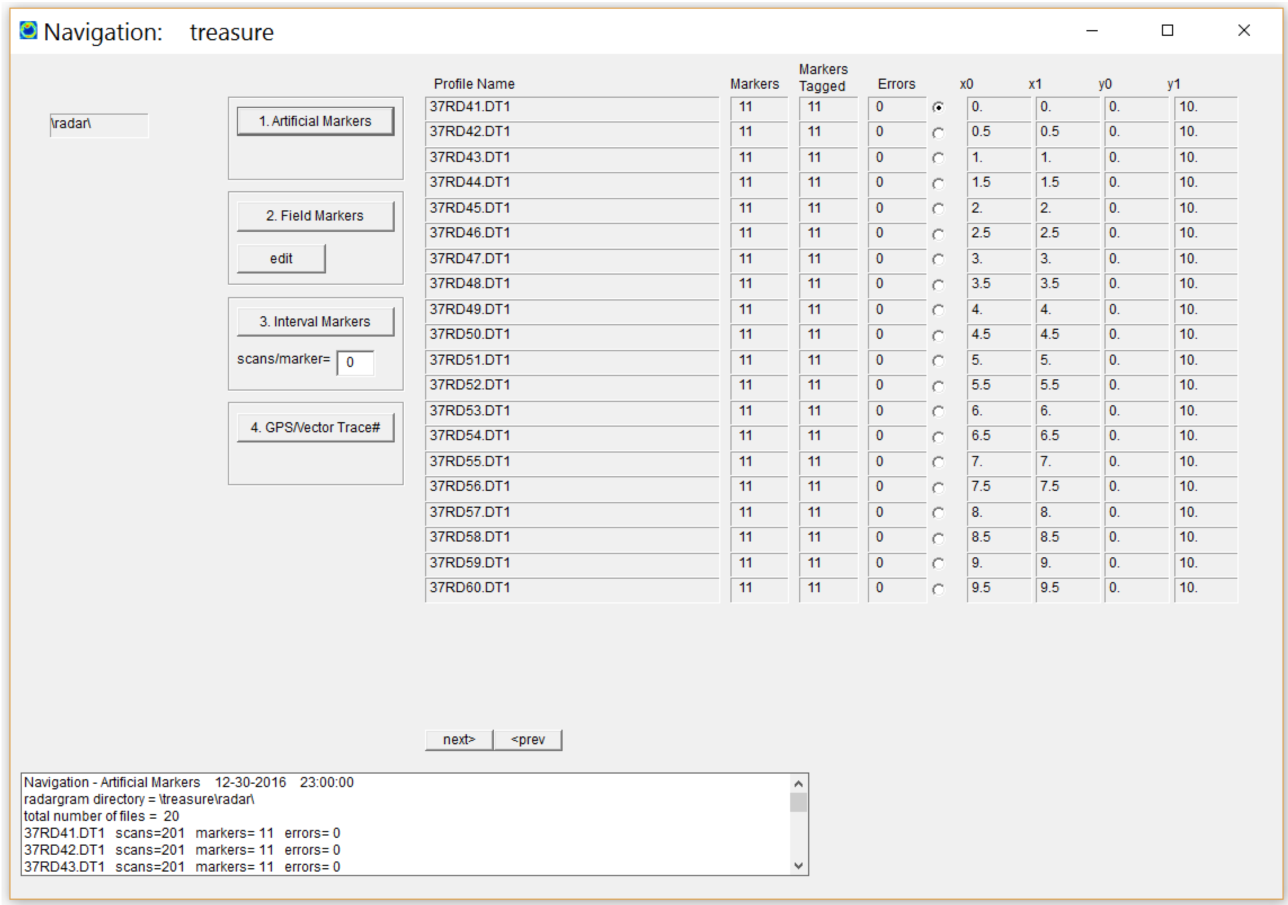
Step 4: Create 3D Time Slice Displays

After the 3D volume is generated the user can use the Open GL menu for a variety of visualization displays:



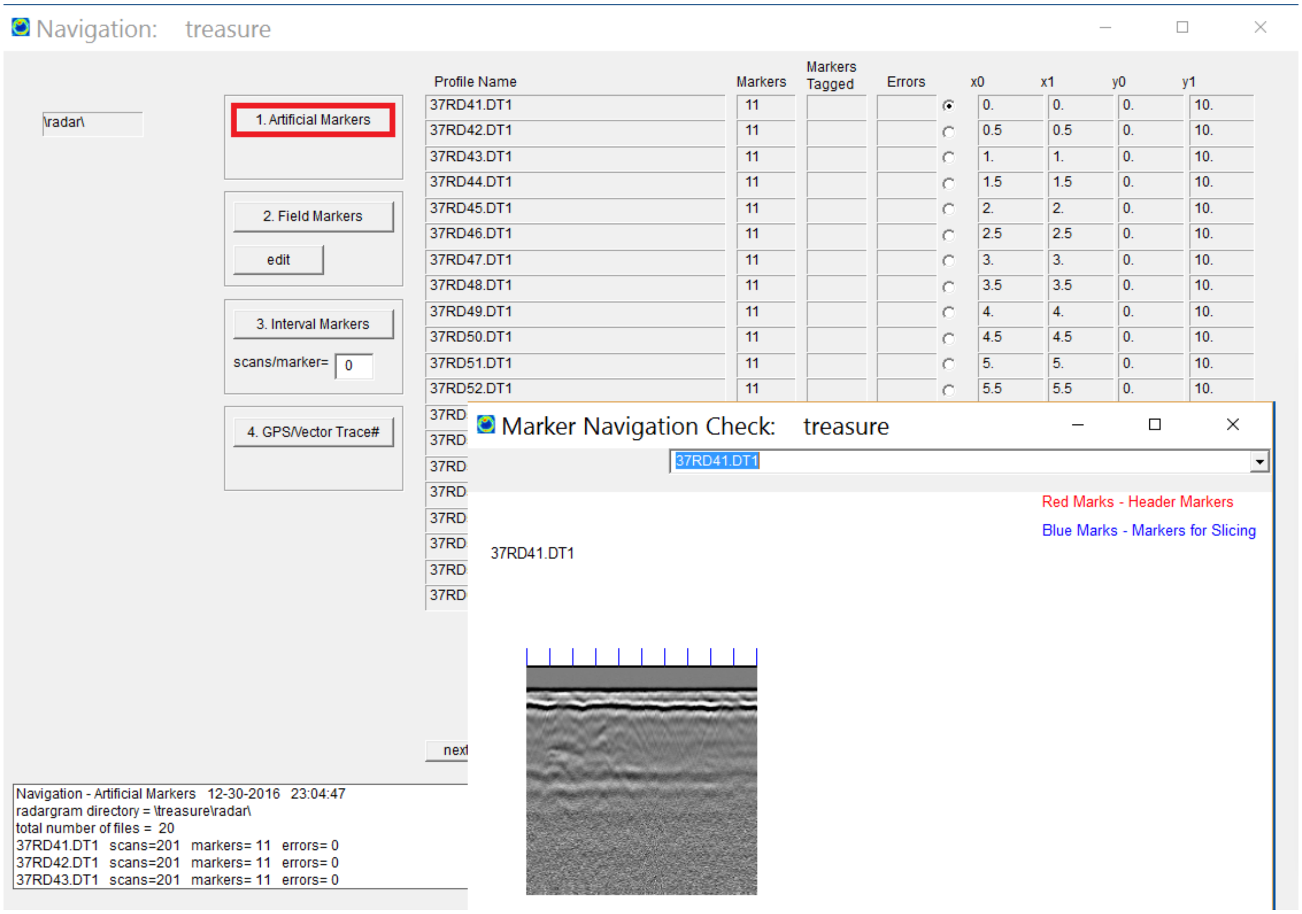
Open GL routines in GPR-SLICE provide the most advanced 3D imaging visualization tools. A separate section on Open GL 3D imaging is provided for which shows all the capabilities in this state-of-art software visualization option in GPR-SLICE.

V. Navigation Menu: Overview



The Navigation Menu is used to assign locations to the radargrams and all time slice images. GPR-SLICE V7.0 can implement navigation in a variety of different ways. These methods are discussed under the headings of:

1. Artificial Markers
2. Field Markers
3. Interval markers
4. GPS Trace #



1) Artificial Markers

The Artificial Marker process, which is a button seen in the Navigation Menu, will create navigation marks based on the total number of scans recorded within a radargram. This is a very useful way to handle radargrams collected with a survey wheel. Survey wheels always have some slippage in them even on very flat and smooth surfaces. For this reason, the total number of scans recorded will vary between lines, sometimes as much as several % on bumpy surfaces. (Note: a survey wheel may not be the appropriate device to use to navigate the antenna across the ground on very irregular surfaces).

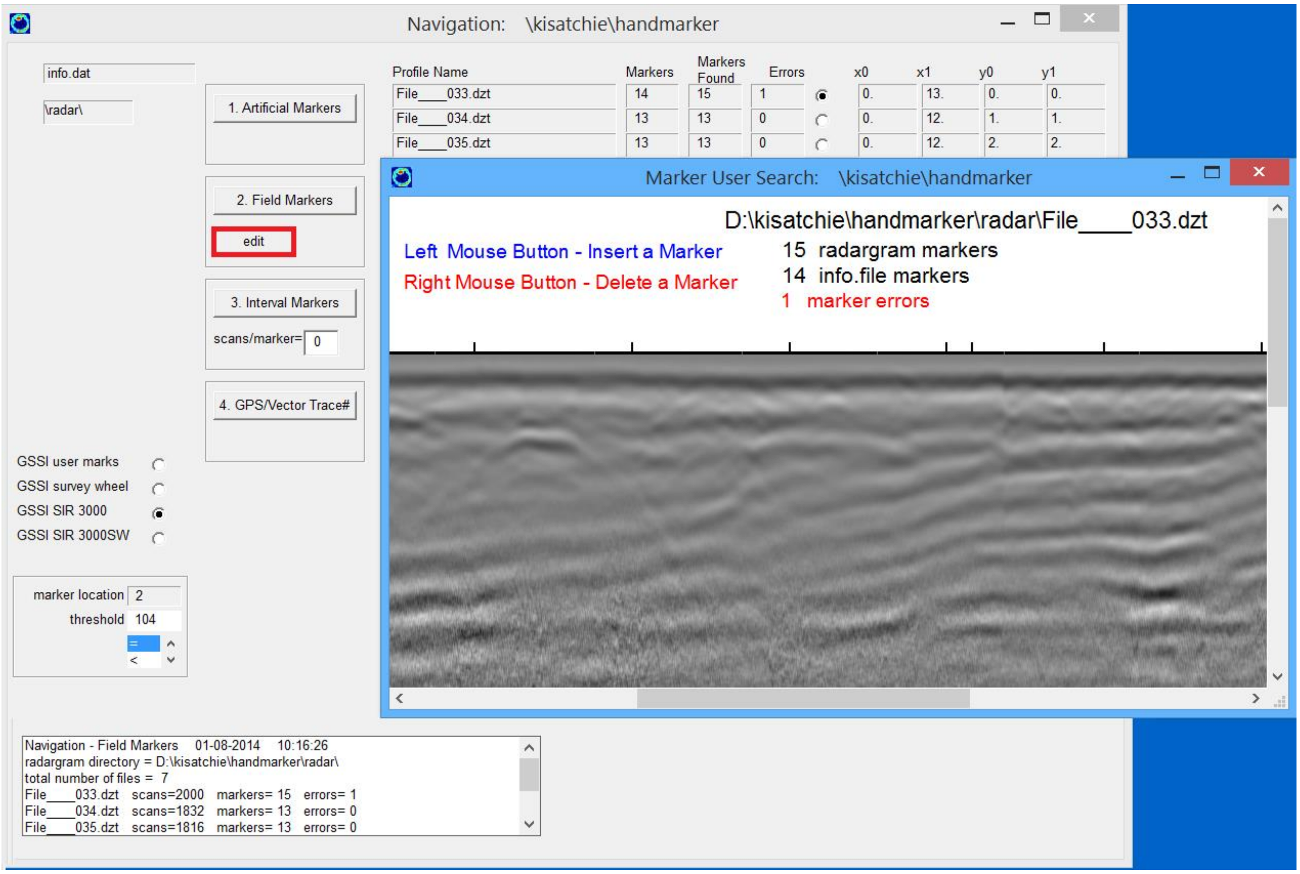
The artificial marker process can be used to create the navigation information across the entire collected number of scans. For instance, if a radargram has 201 scans and the information file for this radargram suggests that it is a 10m long line, then the artificial marker process will write 11 markers including the beginning and at every 20 scans along the radargram. The artificial marker process assumes the radargram begins and ends at the desired locations along the grid. For data collected with a survey wheel some equipment manufacturers such as

GSSI writes a survey wheel mark within the radargram scan on the second sample. Even so, with slippage these markers should probably be avoided in doing the navigation.

Artificial markers should also be used if the user is doing a GPR-GPS survey. In this case, if the GPS information files contain equally spaced readings in time or in distance, then GPS radargrams can be quickly assigned navigation by clicking the "Artificial Marker" button. What this process assumes is that GPS readings are made at equidistant readings across the radargrams and for each point in the GPS navigation file, is assigned a scan location in the radargrams. In the case when there are fallouts – locations of missing GPS information in the GPS file – the GPS Trace # option can be used and is discussed in a following section.

When one clicks the "Artificial Markers", the software will place navigation tags in the 2nd sample of the radargram scan pulse. This tag will correspond with an exact known location on the ground. Not every scan needs to be tagged in GPR-SLICE since the scans between two known navigation points will be dead reckoned and properly positioned between these two points.

The user can click on the "Show Markers" option in the main Navigation pull down menu, and see exactly where the navigation has been set across the radargram. The last example shows a radargram which is known to be collected with a survey wheel and is 10 meters in length. When the Artificial Marker process is applied, the profile information file is read to find out the length for that line, and then assigns the markers equidistantly across the radargram.



2) Field Markers

The Field Marker process will automatically search for the navigation markers in all the radargrams listed and will display the number of detected marker tags in the radargram in the menu. Field markers for some manufacturers are inserted directly into the binary radargram trace headers in the field and other manufacturers have the field markers and their associated scan numbers placed into separate ASCII files. On conversion, GPR-SLICE places the field markers into the 2nd sample of the radargram trace header for all the different manufacturers.

Running the Field Marker process will show the results of the number of markers determined from the survey information file with those actually found in radargram. Any errors in user field markers will be shown in the error column in the Navigation menu. If there are any errors, the user can launch the Edit Menu (as shown in the previous diagram), by first clicking on the radio button for the appropriate radargram, and then clicking the Edit button.

During a survey, marker errors will occur from a variety of reasons. Hopefully, the number of errant lines can be minimized with good field practices. The user can insert or delete markers for a radargram that has a navigation problem. The left mouse button will insert a marker; the right mouse will delete a marker on the radargram.

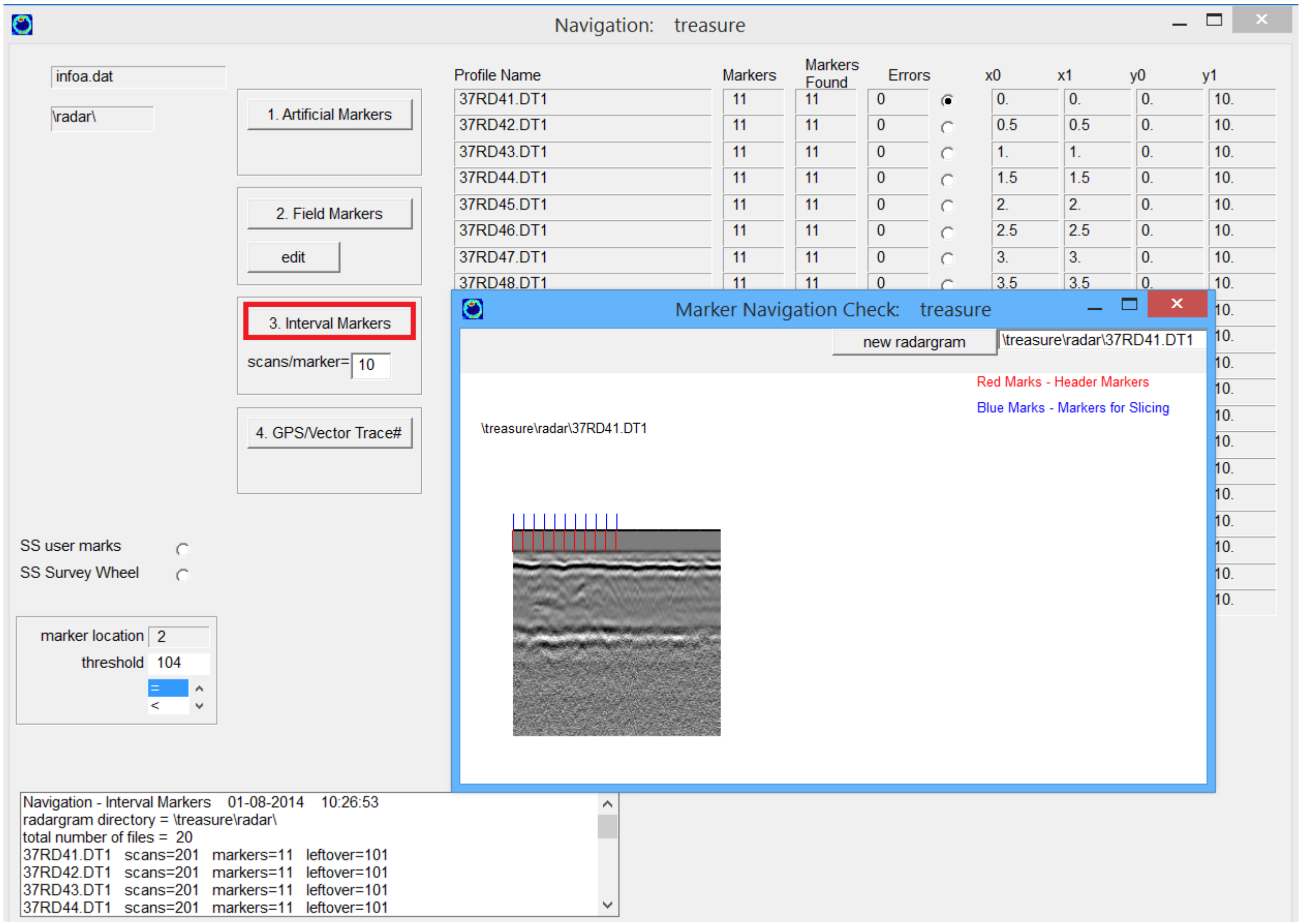
Note 1: Sometimes the user may need to guess where the marker error exists in the radargram because it is not obvious where marker is needed to add or delete. In this case, the user should also check that line start and end locations are typed in correctly in the survey information file.

Note 2: In the case when many marker errors occur within a single radargram and the navigation cannot be adequately determined, it may be useful for the user not to include this radargram in the survey grid by deleting it from the information file.

Note3: Careful note taking is required to properly document the navigation of the radar over the ground if user markers or survey wheels is to be used. Before any time slice analysis is applied to the radargram dataset, the marker information for that set of radargrams must be created in this menu and no errors between the number of markers given by the information file and those found in the radargram must exist.

Note4: If a user has not used hand markers and they have not used a survey wheel, nor GPS or total station navigation, there are **NO** accurate operations that can be used to apply/detect/assign navigation to the data.

Note 5: If the user accidentally runs any other navigation operations such as artificial markers etc., the original field marker tags will get over written in the radargram scan headers. The user must re-convert the data from the raw folder to recover the original marker tags.



3) Constant Interval Markers

An optional process to assign navigation marks using a constant number of scans across the radargram is also available, which is likened to using a survey wheel that never has any slippage. This navigation method can be used when a specific survey requirement in which the antenna in a survey wheel application was not stopped at the end of the line but continued on recording past the desired end line. Then using a constant interval marking, and assuming no slippage, the user can recover navigation to a location somewhere before the last scan was recorded. This option may be justified to correct these kinds of (sloppily) collected datasets. This navigation assignment is not recommended for most applications with the survey wheel, as the surveyor should only normally collect data to the start and stop baselines for each profile.

In the above example and just to show the Interval Marker navigation assignment, an interval of 10 scans between markers is assigned. For this radargram, which is 10 meters in length, the marker locations assigned are shown. (The total number of scans is 201 for this radargram. The interval marking only tag the radargram to the 101st scan. If this navigation were later used, the whole right half of the radargram would not be included in any part of the processing). The navigation log box for Interval Markers will indicate the number of "leftover" scans which are beyond the last marker tagged.

4) GPS/Vector Trace #

GPS random navigation requires separate GPS files for each radargram contained in the information file. This GPS Trace # process will extract the corresponding scan locations for each GPS reading that is in the 5th column of *.*.gps files and place a marker tag in the 2nd sample of that scan pulse. During the creation of the *.*.gps files from each manufacturer's native GPS log files, GPR-SLICE stores the scan/trace number in the 5th column of those files. These scan numbers will be tagged on those scans in the radargram during application of the GPS navigation. Generally, all the recent manufacturers will have the lat/long or UTM location associated with a scan number in the radargrams. The GPS scan numbers – locations where GPS information UTM exist - can be randomly located and do not have to be equidistantly identified across the radargrams.

Note: Older GPS equipment may not have scan numbers. If so, for those non-synced GPS radargrams, this navigation option will not work and the only alternatives may be artificial markers (e.g. rubber banding all the GPS equidistantly across the radargrams)

General Notes for Navigation Assignment

Note 1: Whatever last type of navigation assignment is run, will be the active navigation information. Marker information is overwritten every time a new navigation process in this menu is run. Markers should be recreated each time when the user is about to do slicing on any resampled or processed radargrams such as migrated or filtered radargrams to insure that the proper navigation is assigned, etc.

Note 2: The user can view the markers assigned across a radargram by clicking the Show Marker button in the pulldown Navigation Menu, and should always do so to insure the navigation looks correct.

Note 3: The actual navigation tag is recorded in the 2nd sample of the radargram. This is identified in the Navigation menu along with a threshold that is set for different kinds of navigation types, such as user field markers or survey wheel markers. For GSSI equipment, the 2nd sample in the radar scan contains information on the marker and is set to 232 for user markers, 228 for survey wheel markers, and 104 for SIR 3000 equipment. Sensors and Software user markers are set to the value 32 for user and survey wheel markers. MALA navigation tags are set to 232. Other manufacturers may have just a dummy threshold value that is used. Three kinds of marker threshold tests can be used to distinguish a marker, >, =, <. For most modern radar equipment, the threshold type should be set to "=". In earlier radar equipment, the marker was actually written into the (analog) radar scan and the amplitude threshold of the marker was usually high but not a constant value after being digitized. The threshold type of greater than or less than the threshold value was useful for identifying markers in older radar records which were digitized from analog systems.

Note 4: A good reason to use artificial marker tagging based on the total number of scans is shown above. In the above example, the last marker from a survey wheel survey was not put into the radargram during the survey. This may have happened because either the equipment did not go all the way to the end of the line and/or there was slippage and the survey wheel did not trigger recording the last marker even though the end of the line was encountered.

GRID Menu: Overview

The Grid Menu will take XYZ time slice *.dat datasets that are created at (sparse) grid nodes across a site and generate denser *.grd grid datasets using standard geospatial interpolation routines. The Grid Menu features are:

Inverse distance interpolation
Kriging interpolation
Grid filtering
Grid expansion
Grid rotation/translation
Grid Appending (Pixel Map menu)
Grid Math
Grid Blanking
2D Fast Fourier Transform - Time Slice Filtering
Creation of a 3D binary volume
Conversion to Surfer *.grd

The user can create dense time slice grids showing high-resolution maps of recorded reflection amplitudes across survey sites using several interpolation methods: inverse distance and kriging.

Inverse Distance Interpolation

Estimation between surrounding data points using a distance weighting exponent is given in the equation, i.e.

estimated data = w1*z1+w2*z2+....wn*zn

where wi = 1/h^a
h = distance between nearby point and the point on the grid to be estimated
a = smoothing factor (commonly set to 2)
z = radar reflection strength at the point in the interpolation

The inverse exponential factor – or often called the smoothing factor - is used in weighting data by their distance to the desired point to be gridded. A lower value will more closely weight all values within the search radius equally; a higher value will more strongly weight data within the search radius that are closer to the desired grid point to estimate.

Kriging Interpolation

Kriging provides the best estimate of interpolated data based on inversion of the covariance matrix of distances. The general equation describing kriging is:

data weights = $c^{-1}d$

where cij = c0+c1 if h=0
= c1 exp(-3h/a) if h>0
a = range at which covariance value remains essentially the same
h = distance between points
c0 = nugget effect which provides a discontinuity at the origin
c1+c0 = sill which describes the value of the estimate at large distances
cij = covariance matrix of formula(1) between points in the estimate
cij^{-1} = inverse matrix of cij
d = vector containing values from formula(1) between points in the estimate and the point to be interpolated

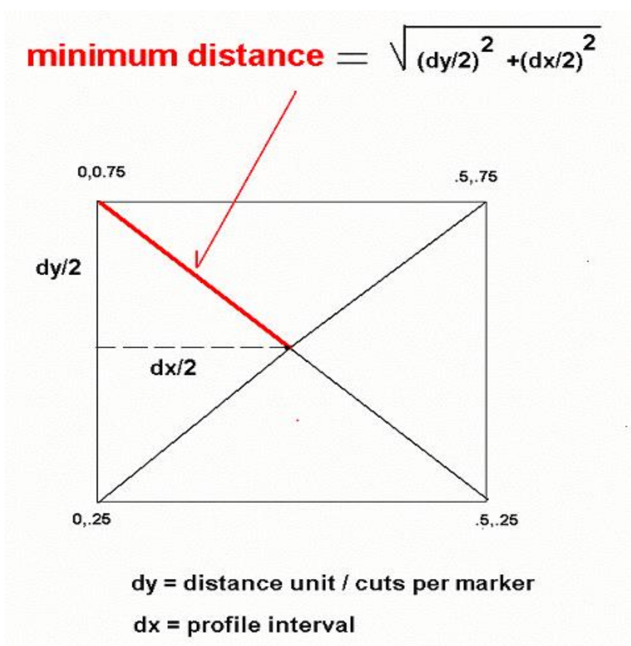
(see Applied GeoStatics, E.H. Isaacs, R.M Srivastava, Oxford Press, 1989)

The menu has options to predict amplitudes within blanked out areas within a survey grid if so desired, or the ability to automatically identify blanked out areas in a grid without having to create separate blanking files. Options to apply filters to the grid datasets in the GRID menu can be done in a batch mode with a single mouse click; gridding processes are also handled in batch mode as well. The use of identifiers can help the user to recall the different processes applied to different datasets. The user can use larger or smaller grid start and end locations than those recorded in the actual dataset to either look at just a region within the recorded grid, or to create a larger grid which can be combined with other areas in the large grid. Combining parts of a larger grid to create a comprehensive grid is finalized in the PIXEL MAP menu.

Notes on the Blanking Radius

The blanking radius is the maximum distance to perform interpolation into the grid from searched data points. If a point in a grid map is being interpolated, and no nearby data is at least within the blanking radius, then this point is left blank. Often in archaeological application many areas cannot be surveyed because of various obstructions. Sometimes it is desired to estimate grid values from areas that could not be surveyed. In this case, using large search radii and large blanking radius will interpolate into blank areas that can give estimates of the reflected amplitudes. In the case when users want to conserve the areas not surveyed with the GPR equipment in the field, then smaller blanking radius (slightly larger than the minimum distance between XYZ data points) should be used.

Note: There will always be some slight interpolation within blanked out areas for a survey grid. By using the smallest possible value for the blanking radius, areas that have not been surveyed within the site can be conserved and will be shown automatically within GPR-SLICE time slice maps. To compute this minimum distance a diagram is shown describing the calculation of the minimum distance:



The minimum distance that one can set the grid searching without creating holes in the map and at the same time preserve as much of the blank areas of the grid that were not surveyed is given by the above formula. For example, in the case when one uses a profile interval in the field of 0.5m, and has a cuts-per-marker of 2 and a distance unit per marker of 1 meter, than the minimum distance to create a solid grid of data would be

sqr[(.5/2)^2+(.5/2)^2)=0.354 m.

Users normally set the blanking radius equal to the search radius, which defaults to one and a half times the profile spacing or 0.75 meters for this particular example.

Grid Filtering

A total of 22 different kinds of filters can be applied to gridded time slice *.grd datasets. 20 of the filters are matrix filters and the last two filters are linear background filters to remove noise parallel to either the x (horizontal) or y (vertical) axes of the time slice grids.

The matrix filter descriptions are given for a 3x3 matrix as follows:

1) 3x3 Low Pass -

```
1 1 1
1 1 1
1 1 1
```

2) 3x3 Boxcar Subtract -

```
1/9 1/9 1/9       0 0 0
1/9 1/9 1/9   -   0 1 0
1/9 1/9 1/9       0 0 0
```

3) 3x3 Hi Pass-

```
-1 -1 -1
-1  9 -1
-1 -1 -1
```

4) 3x3 Laplacian-

```
-1 -1 -1
-1  8 -1
-1 -1 -1
```

5) 3x3 Vertical Enhancement-

```
-1 2 -1
-1 2 -1
-1 2 -1
```

6) 3x3 Horizontal Enhancements

-1	-1	-1
2	2	2
-1	-1	-1

The same filters can be translated into larger matrix filters with 5x5, 9x9, and 17x17 grid elements.

1) Low Pass filter: For very noisy time slices the user may want to apply 5x5 or 9x9 lo pass filter which will take a boxcar average over the filter size. For instance, a 5x5 will take an average of 5 grids in each direction about the center of the filter and output this averaged result. This is useful for smoothing noisy time slices, and is essentially just an average.

2) Boxcar Subtract filter: This filter takes and average over the entire (rectangle – boxcar) and subtracts this value from the center of the filter. This is somewhat like a High Pass filter in that local changes are magnified in the grid and background reflection features are removed.

3) Hi Pass filter: This filter will amplify very strong amplitude changes across a grid. This filter will often remove too much essential information and is usually not the most useful filter for most application.

4) Laplacian filter: These filters will amplify linear features. This filter is also not useful for most imaging problems, except in cases where only linear features are desired to be extracted from a time slice map.

5) Vertical Enhancement filter: This filter will amplify linear features parallel to the y axis of a grid.

6) Horizontal Enhancement filter: This filter amplifies linear features parallel to the x axis of a grid.

7) Vertical Background filter – This filter is a threshold line filter that is applied individually to lines within the grid that are parallel to the y axis. The filter works by computing an average value of the gridded data over a filter length that the user sets. This value is then subtracted from the value of the center of the line filter. This filter is useful in removing striations noises in the time slice grids. The filter is also useful in removing the mosaic patterns caused by connecting adjacent grids collected at different times or during different ground conditions. The vertical background filter requires the user to set the upper and lower thresholds for which data will be included within calculating the moving filter. For instance in the case of strong reflections from target features along the line, the user can set the threshold to a value just below the

target amplitudes. By doing so, the data from the targets will not be included as the moving line filter is applied. This will insure that strong reflectors do not get 'smeared' as the filter is applied. The lower setting can also be used in the same way. The minimum and maximum threshold settings are given as a percentage of the relative strongest reflector along each individual line.

8) Horizontal Background – This filter is identical to the Vertical Background line filter just described, however, the filter is applied to the grid lines in the X directions.

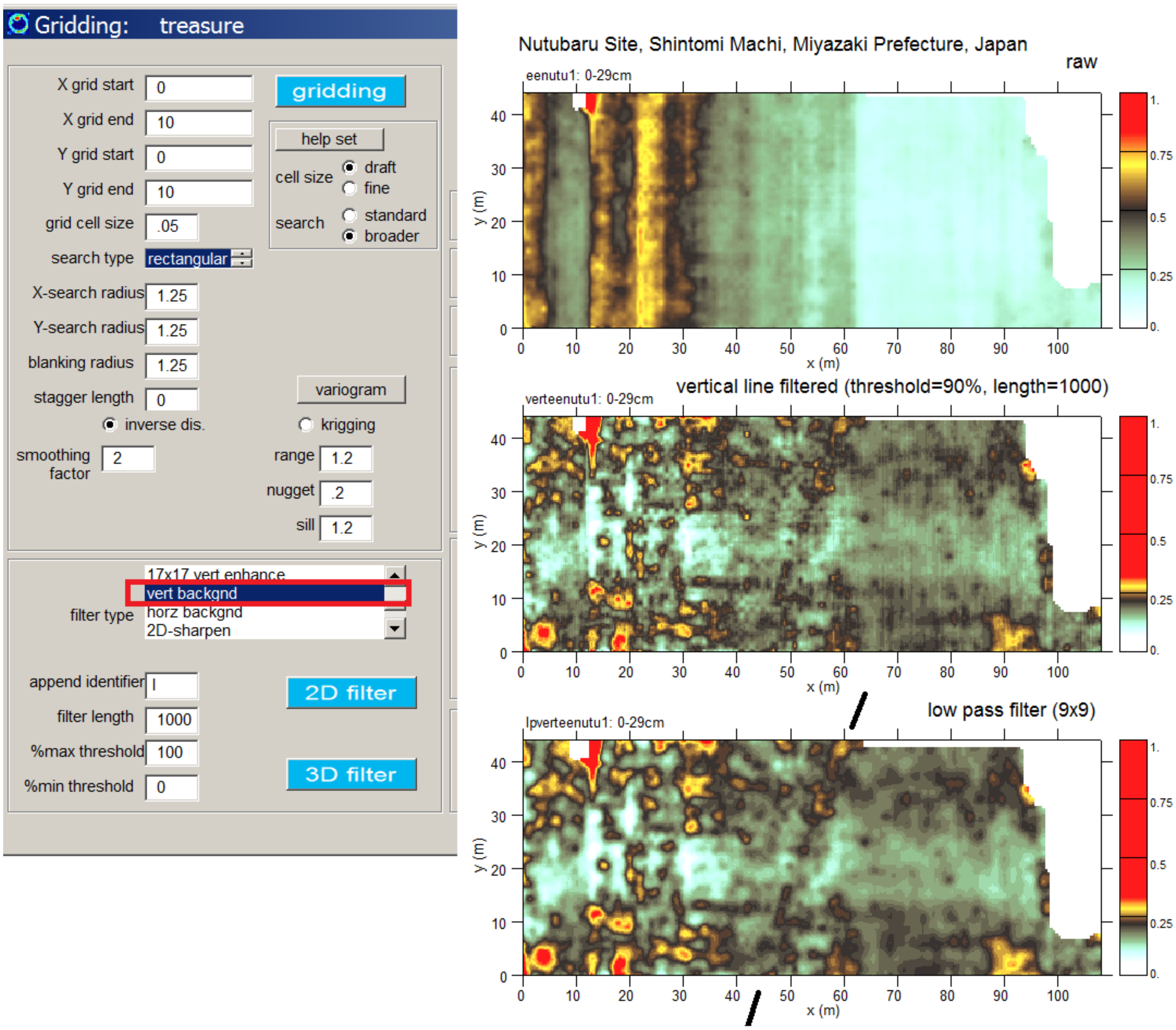
Note 1: If the grid was acquired along the y direction then in the case that the user needs to do some background filtering, the Vertical Background filter should be used; likewise, if profiling was done along the x direction then the Horizontal Background filter should be used.

Note 2: An overall gain can be applied to the filtered grids. Regaining is usually necessary for Laplacian filtering as grids with weak target reflections will require an increase in the dynamic range of the data. Normally, the gain can be set to 1.

Note 3: The Filter Length setting only applies to Vertical Background and Horizontal Background filtering. The user will need to try several setting to see which filter length provides the right amount of filtering to the data. A Filter Length set to the total length of the grid cells in either the vertical or horizontal direction will essentially subtract a single – averaged - value from each grid line individually.

Note 4: Background filters can filter out real signals that are recorded within the data. For instance, if a buried wall reflection was recorded parallel to the x direction of a survey area, then a Horizontal Background filter with maximum thresholds set above these reflections may cause complete or partial removal of these target reflections from the time slice maps. Thresholds can be used to not exclude data above or below these values in the filter.

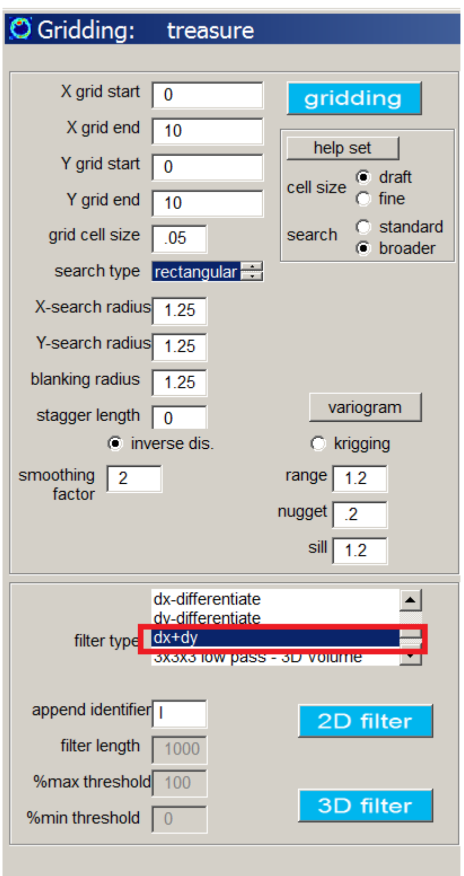
Example of (vertical) grid line filtering

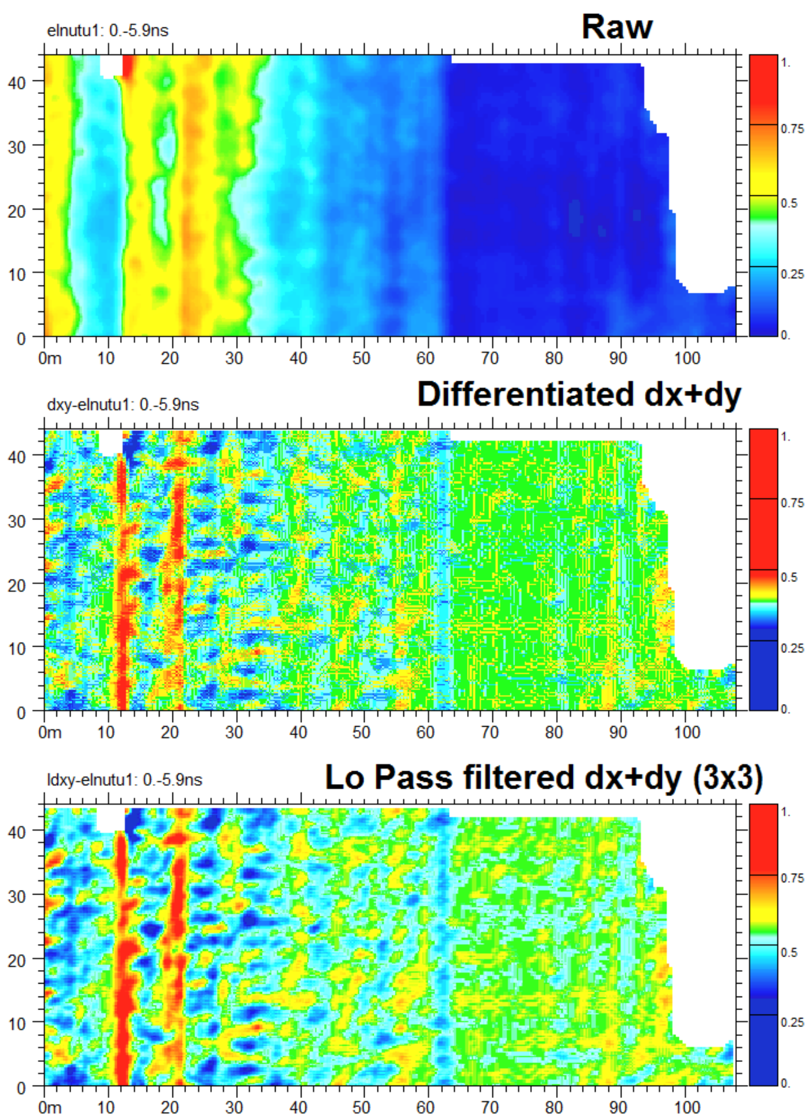


Using the vertical filter in the Grid menu, linear features parallel to the profile lines (top diagram) in this example dataset are removed. The line filtered grid (middle diagram) is also smoothed with a 9x9 lo-pass boxcar filter (bottom digram). After filtering hidden features are shown in the image that could not be seen in the original raw time slice.

Example of differentiation of time slices added to Grid Filter Menu

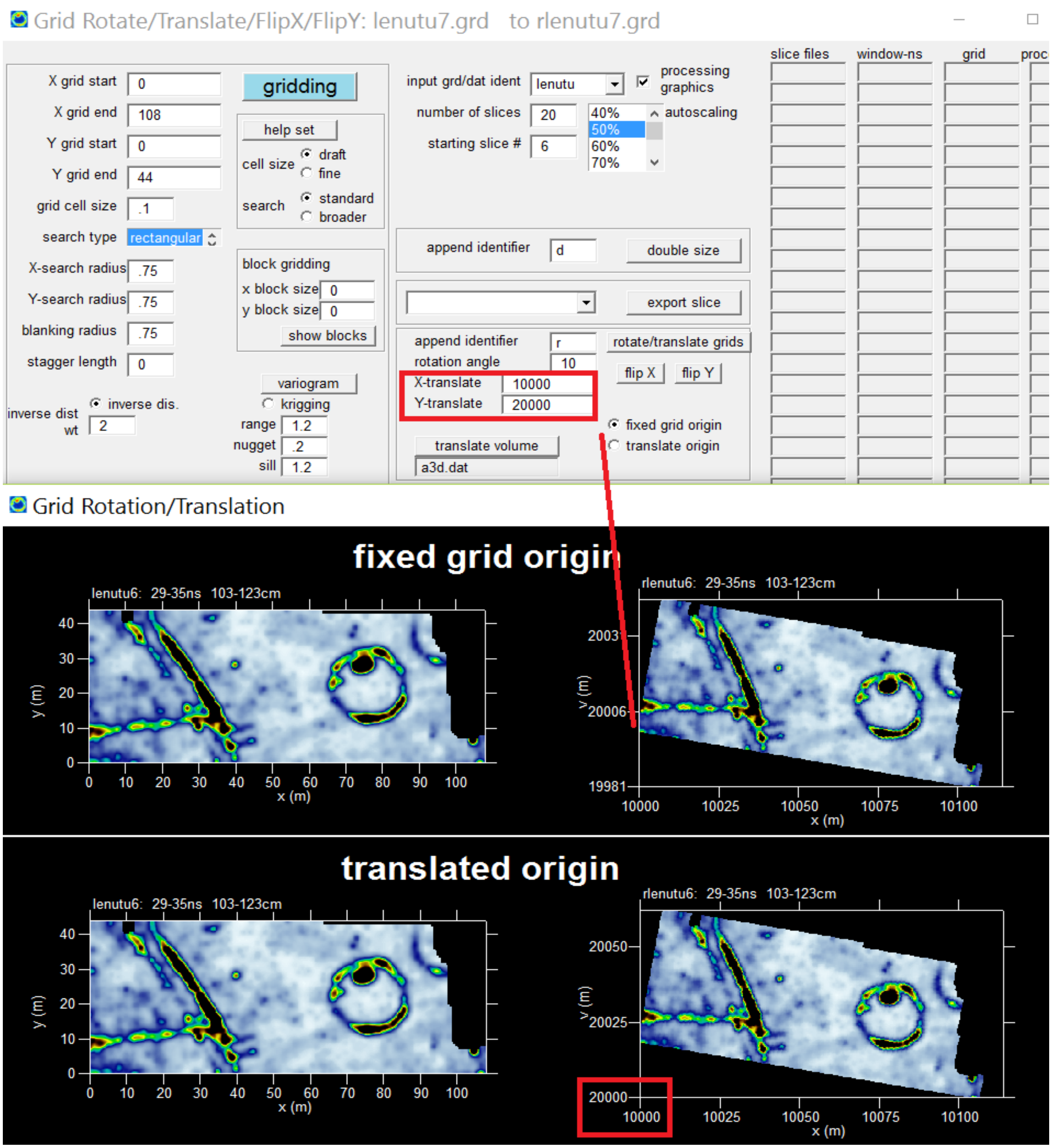
Another filter of the time slice images can sometime be to differentiate the image in both x and y directions. A grid filter option which differentiates the time slices is available in the Grid menu - filter listbox. The process looks at nearest neighbor differences, squaring the differences in both x and y directions, and presenting the square root of this sum. An example of a time slice that was differentiated using the dx+dy filter. is shown with the original data, the differentiated time slices, and a small lo pass filter applied to the differentiated time slice. Very subtle structures which are not illuminated in the regular time slice are apparent. Individual differentiation filters in both the x and y directions are also available as well in the Grid Filter listbox. Processing with hi-pass grid filtering can also achieve similar results.





Rotating/Translating/Appending Grids

In the GRID Menu an option to translate and rotate grids is available. Two options are available for rotating and translating grid: 1) fixed grid origin or 2) translate origin. Fixed grid origin refers to fixing the origin of the local grid or the southwest corner after grid rotation. The x and y



translate values in the menu are the values used to set the origin of a rotated grid. The fixed grid origin option can be useful in georeferencing a local grid to a UTM grid for instance, where only the southwest corner is given. The second option -translate origin will simply fix the southwest corner of the new grid after rotation. The translate origin is useful to reference a new set of grids to a common origin so they might be combined or appended if needed in the Pixel Map menu.

In the example, a grid is rotated 10 degrees and translated to x=10000, y=20000 at the origin. With the "fix data origin" clicked on the southwest corner of the old grid will be rotated/translated so that the original southwest corner is now at 10000, 20000 in the new grid. This rotate/translate process will work in batch and will create a whole new set of grids called with the append identifier.

Appending Gridsets

Often independently created time slice grid sets are needed to be put into a single encompassing grid files. If the user then wants to append several grid sets together, they can do so in the Pixel Map Menu. The general steps for appending grids together are:

Step 1: Use the multi-grid identifier and type in the grid names separated by commas. In this example, there are 2 grids written as a, b

Step 2: Set the starting grid number (in this example the starting grid is 5 to append the 5th and 6th files together)

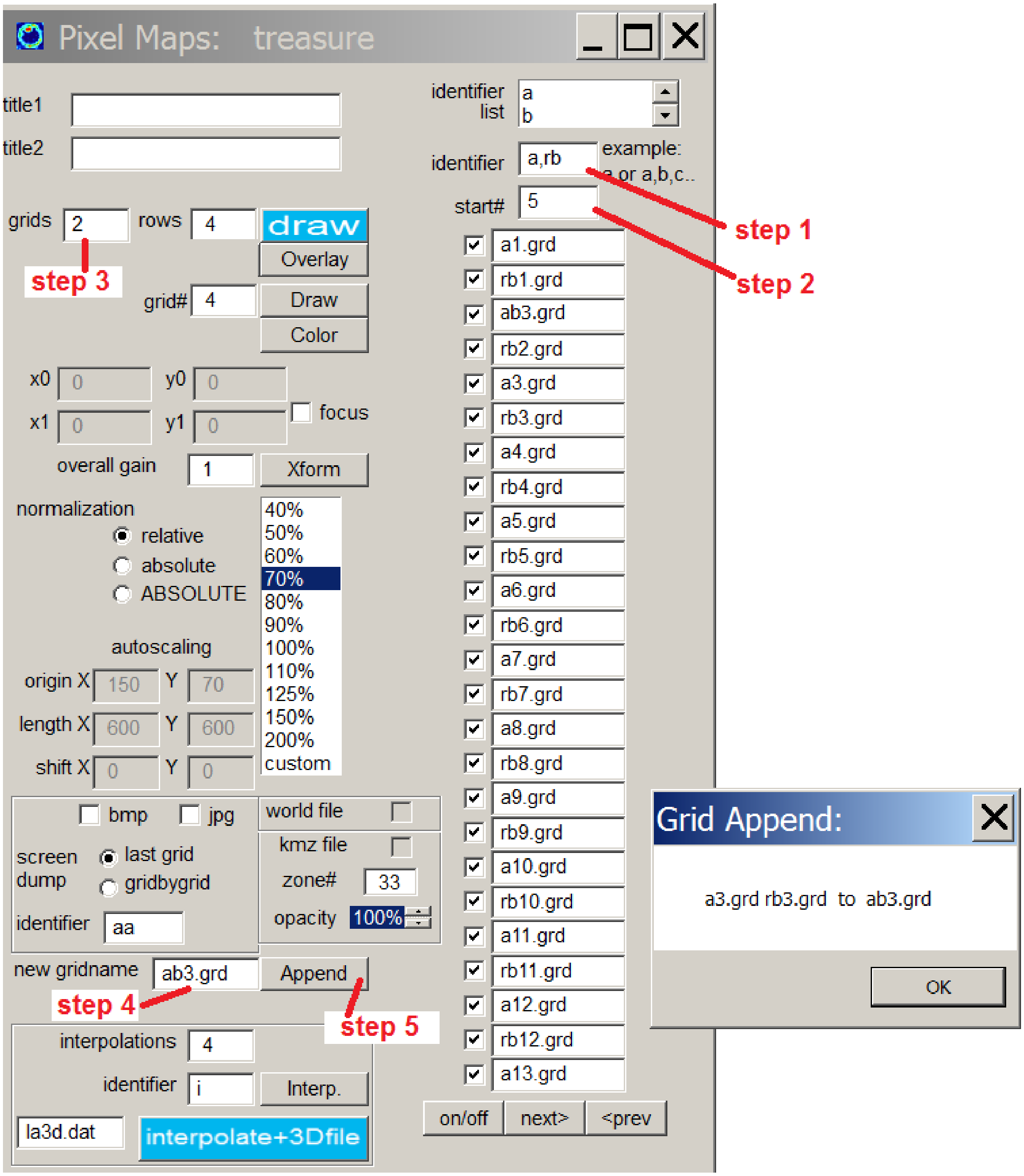
(Alternately steps 1 and 2 can be accomplished by explicitly typing the names of the grids to append in the grid file slots in the menu)

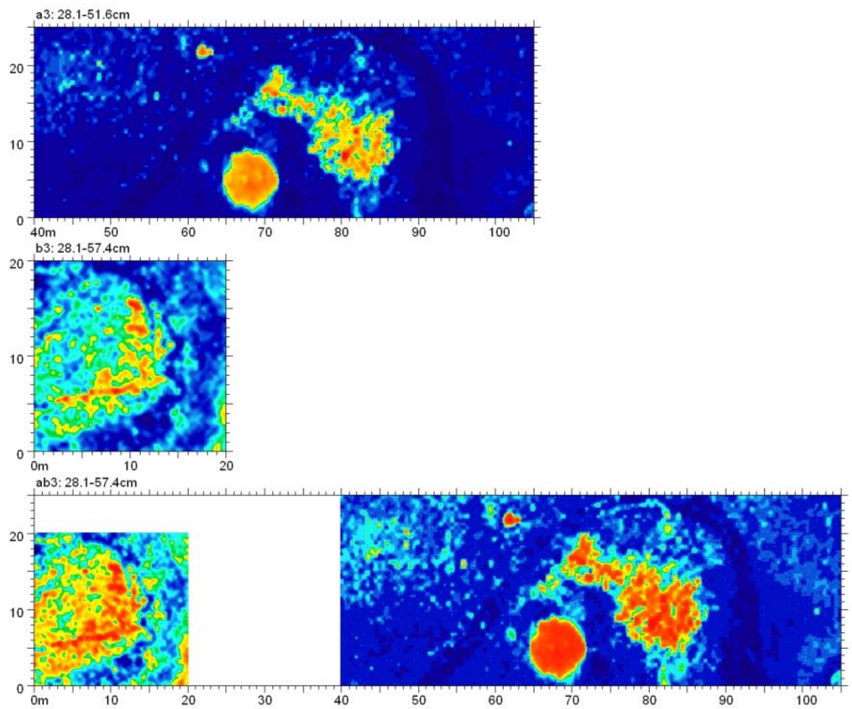
Step3: type in the total # of grids to append together

Step 4: type in a new name for the appended grid.

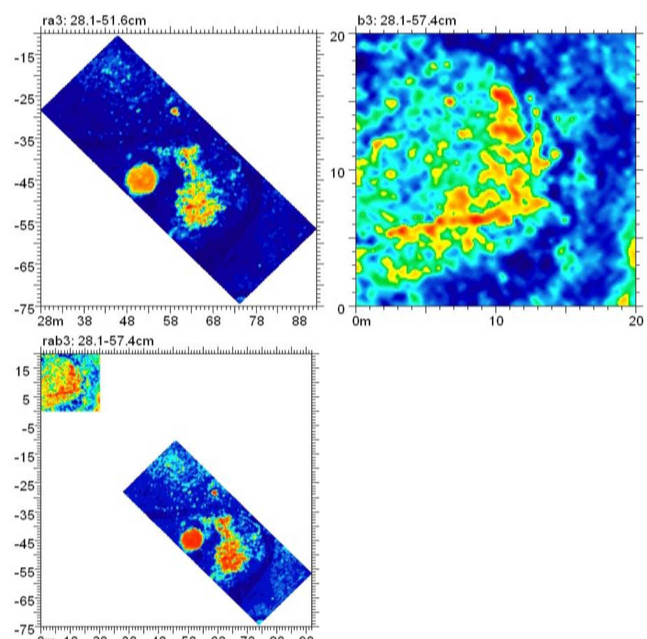
Step 5: click the Append button and up will come a dialog telling you what you are appending together and the new grid name.

Note: the cell size – grid density – must be the same for all the grids to be appended together, if not, an error message will appear.

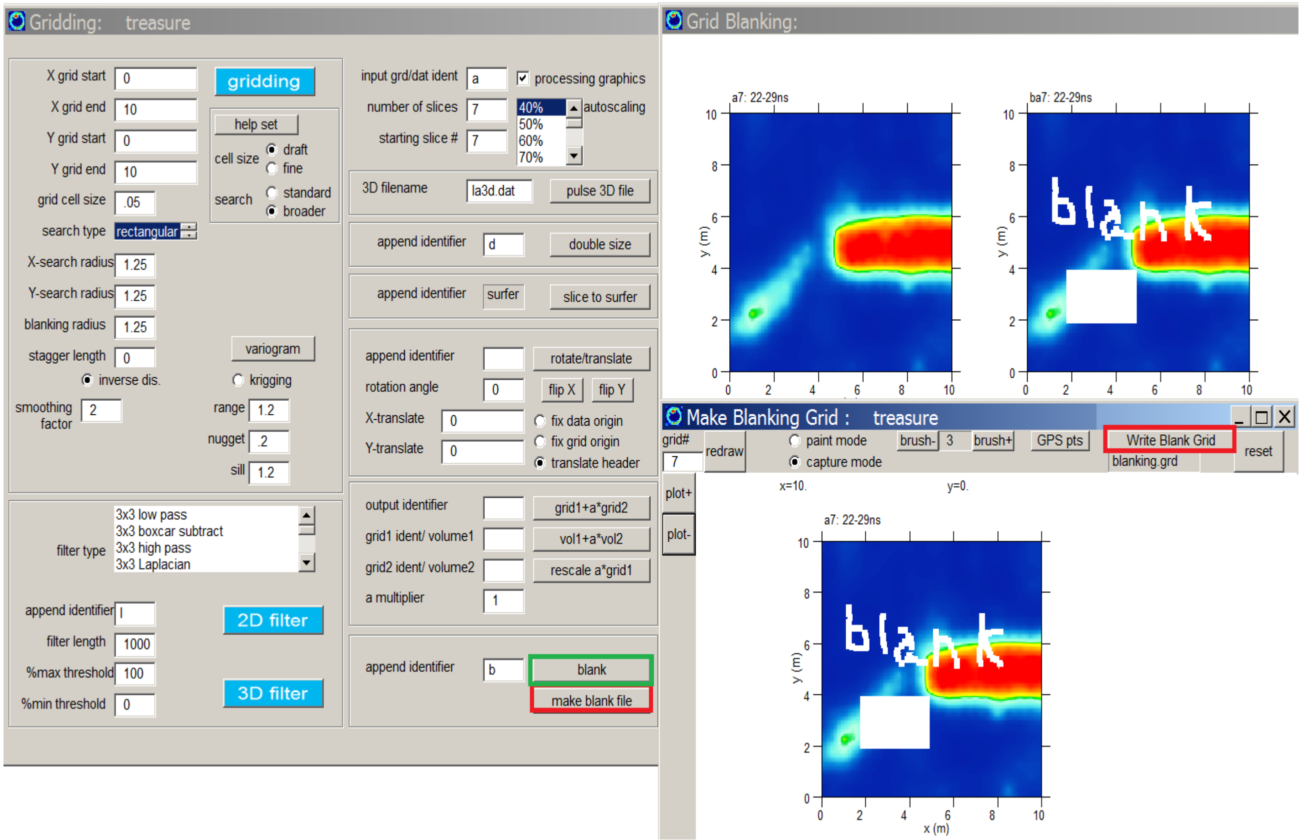

Pixel Maps: treasure
title1
title2
identifier list
a
b
identifier
a,rb
example:
a or a,b,c..
start#
5
step 1
step 2
grids
2
rows
4
draw
Overlay
step 3
grid#
4
Draw
Color
x0
0
y0
0
x1
0
y1
0
focus
overall gain
1
Xform
normalization
relative
absolute
ABSOLUTE
40%
50%
60%
70%
80%
90%
100%
110%
125%
150%
200%
custom
autoscaling
origin X
150
Y
70
length X
600
Y
600
shift X
0
Y
0
bmp
jpg
world file
kmz file
screen dump
last grid
gridbygrid
zone#
33
identifier
aa
opacity
100%
new gridname
ab3.grd
Append
step 4
step 5
interpolations
4
identifier
i
Interp.
la3d.dat
interpolate+3Dfile
a1.grd
rb1.grd
ab3.grd
rb2.grd
a3.grd
rb3.grd
a4.grd
rb4.grd
a5.grd
rb5.grd
a6.grd
rb6.grd
a7.grd
rb7.grd
a8.grd
rb8.grd
a9.grd
rb9.grd
a10.grd
rb10.grd
a11.grd
rb11.grd
a12.grd
rb12.grd
a13.grd
on/off
next>
<prev
Grid Append:
a3.grd rb3.grd to ab3.grd
OK



An example showing the results of the Rotate/Translate and Append processes is given in the figure above. Two grids were appended, one of which was translated 40 meter. The resulting appended grid is shown in the bottom diagram. All these grids were shown in a single GPR-SLICE process by individually typing these names into the grid menu items, and then displaying the first 3 grids. An example of the same processes with a rotation added to one of the grids during the Rotate/Translate process is shown in the diagram below:

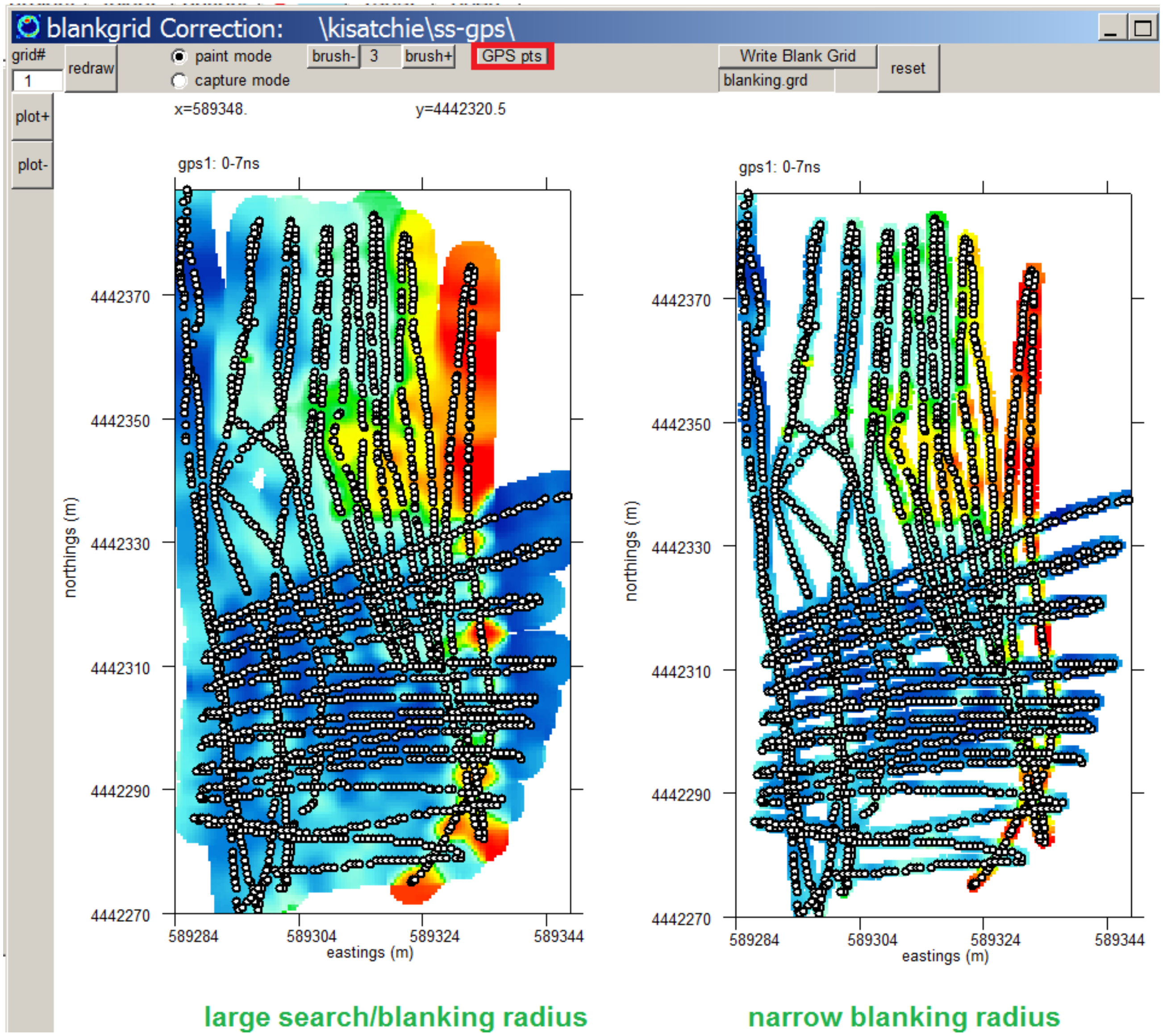


Grid Blanking



During grid creation, time slice values are interpolated into areas. The amount of interpolation is a function of the search radius and the blanking radius. In some small scale sites, areas which are desired to keep blank and to remove interpolated information, the user can customize a blanking grid.

To implement grid blanking, the user can click on the Make Blank File button in the Grid Menu. This will launch a drawing program which will allow the user to draw blank areas within the displayed grid map. There are adjustments for the size of the brush, which stores regions as the left mouse button is clicked. Also, rectangular screen capture blanking option can also be engaged. Once the desired area to blank is drawn, the Write Blank Grid button in the drawing menu is clicked. This will store the blanking information. The blanking information can then be applied in a batch process to all the grids by clicking the Blank button in the Grid menu.



An option to show the location of GPS collected over a time slice grid in the Make Blanking Grid menu is available in Grid menu. For a GPS collected survey grid, clicking the GPS pts button shown above, will draw the GPS navigation points over the GPS time slice. In the examples above, a narrow and large search radius and blanking radius were used to create the time slices. The purpose for putting the GPS track map on the time slice information is for the user to better see how much interpolation is being done, particular for random data collection. Some areas where there are very thin GPS locations or errant locations the user may want to remove these areas from the time slice maps. Correlating the GPS locations will allow the user to create a customized blanking grid to run in batch which will preserve additional areas the user wants leave blank in the time slice maps. The user can better visualize those areas that may need to have grid values removed.

2D Fast Fourier Transform - Time Slice Filtering

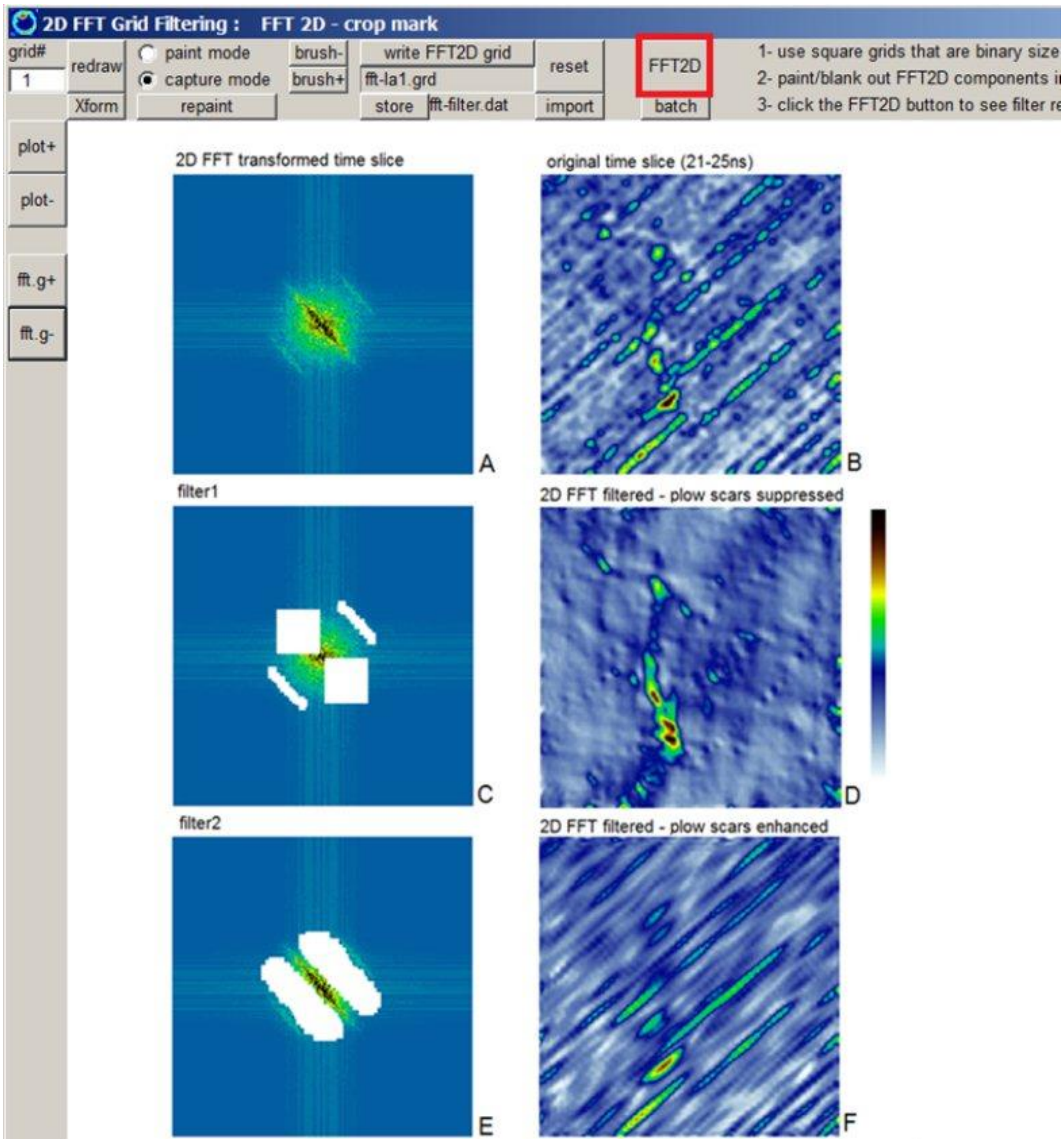
An extremely powerful method for filtering and removing noises seen on time slice datasets is 2D Fast Fourier Transform filtering. In this method the time slices are converted to the spatial frequency domain using Fast Fourier Transforms:

$$F(\mathrm{x},\mathrm{y}) = \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} \mathrm{f(m,n)e}^{-\mathrm{j}2\pi(\mathrm{x}\frac{m}{M}+\mathrm{y}\frac{n}{N})}$$

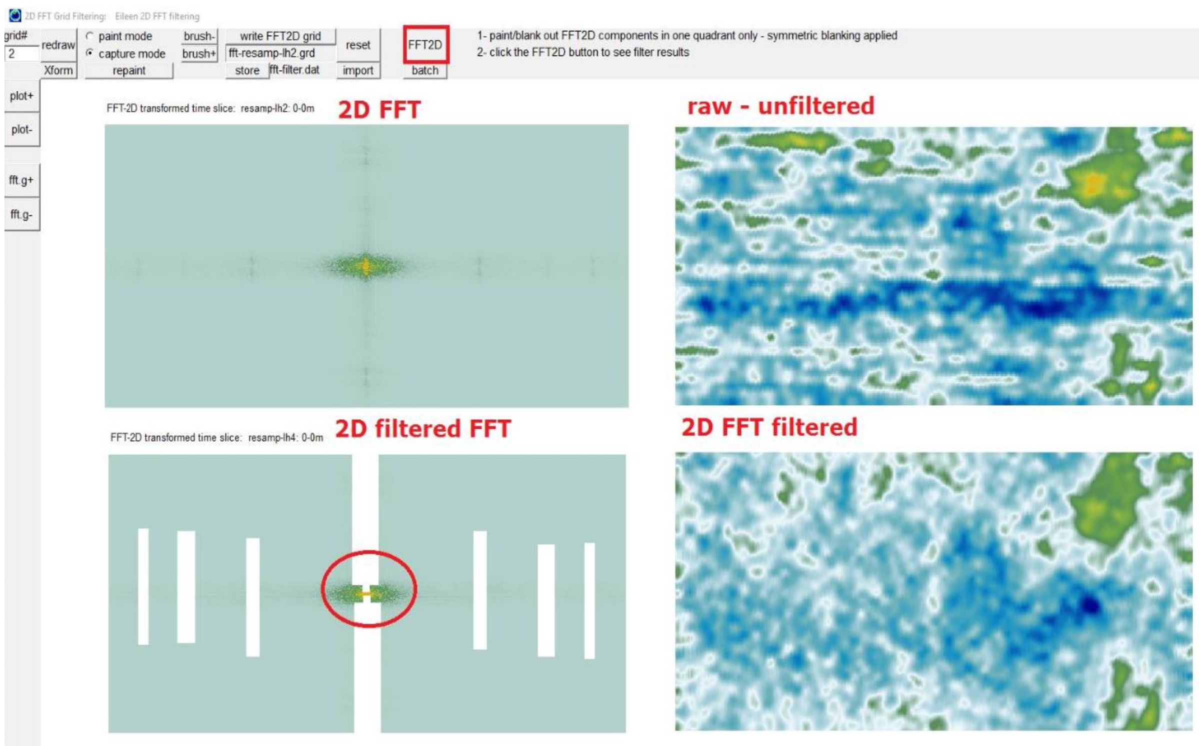
$$f(\mathrm{m},\mathrm{n}) = \sum_{m=0}^{M-1} \sum_{n=0}^{N-1} \mathrm{F(x,y)e}^{\mathrm{j}2\pi(\mathrm{x}\frac{m}{M}+\mathrm{y}\frac{n}{N})}$$

where x and y are the coordinate location, M and N the grid dimensions, f(m,n) is the 2D Fast Fourier Transform of the time slice data F(x,y). Noises in the time slice can be selectively filtered by setting those desired spatial frequency components in the transformed data f(m,n) to 0 before computing the inverse Fourier Transform F(x,y).

An example of using 2D-Fast Fourier Transforms to remove noise from plow scars on time slices is shown in the next figure. In the original time slice from 21-25ns plow scars can be observed at approximately a 45-degree angle to the radar profiles and the grid. Transforming the time slice with a 2D-Fast Fourier Transform (FFT), the spatial frequency components comprising the plow scars can be clearly seen (a). The spatial components of the plow scars in frequency space are identified as linear features that have a direction that are normal to the plow scars seen on the time slices. Selectively blanking out these spatial frequency components (c) and taking the inverse 2D-FFT the plow scars can be nearly completely suppressed in the filtered time slice (d). In addition, just the contribution of the plow scars can be visualized by leaving in the relevant spatial frequencies and blanking other components (e, f). The 2D-FFT filtering is very sensitive to low frequencies near the center of the image. For blanking operations either a screen capture mode or painting mode where the user sets blanking brush size can be used. If an area that is blank does not look good after running the FFT operation, the area can be un-blanked by clicking the ***repaint*** button and un-drawing. Blanking out the low frequency spatial components, which are near the center of the plot, can dramatically alter the final image. The user should be careful not to completely blank out the central portion of the transformed dataset. Because the 2D-FFT data is symmetrical between the 1st and 3rd and between the 2nd and 4th quadrants, blanking operations only need to be applied to any single quadrant - the software will automatically blank out the negative (or positive frequencies) in the other quadrant.



2D-FFT filtering requires binary grid sizes to implement Fast Fourier Transforms (M=N); however, grid resampling is done when the native grids are not binary sizes. GPR-SLICE will automatically do resampling of the grid for import to the filtering process and will back sample to the original size and dimensions after the filter is applied. Another example of a site with a rectangular grid with linear and slightly off parallel crop noises near 5-10 degrees is shown. A customized filter is applied to the 2D spatial components. The 2D FFT filtered time slice shows suppression of the linear noises which are non-parallel stripping noises due to agricultural activity on the survey site. (data courtesy Eileen Ernenwein, East Tennessee University).



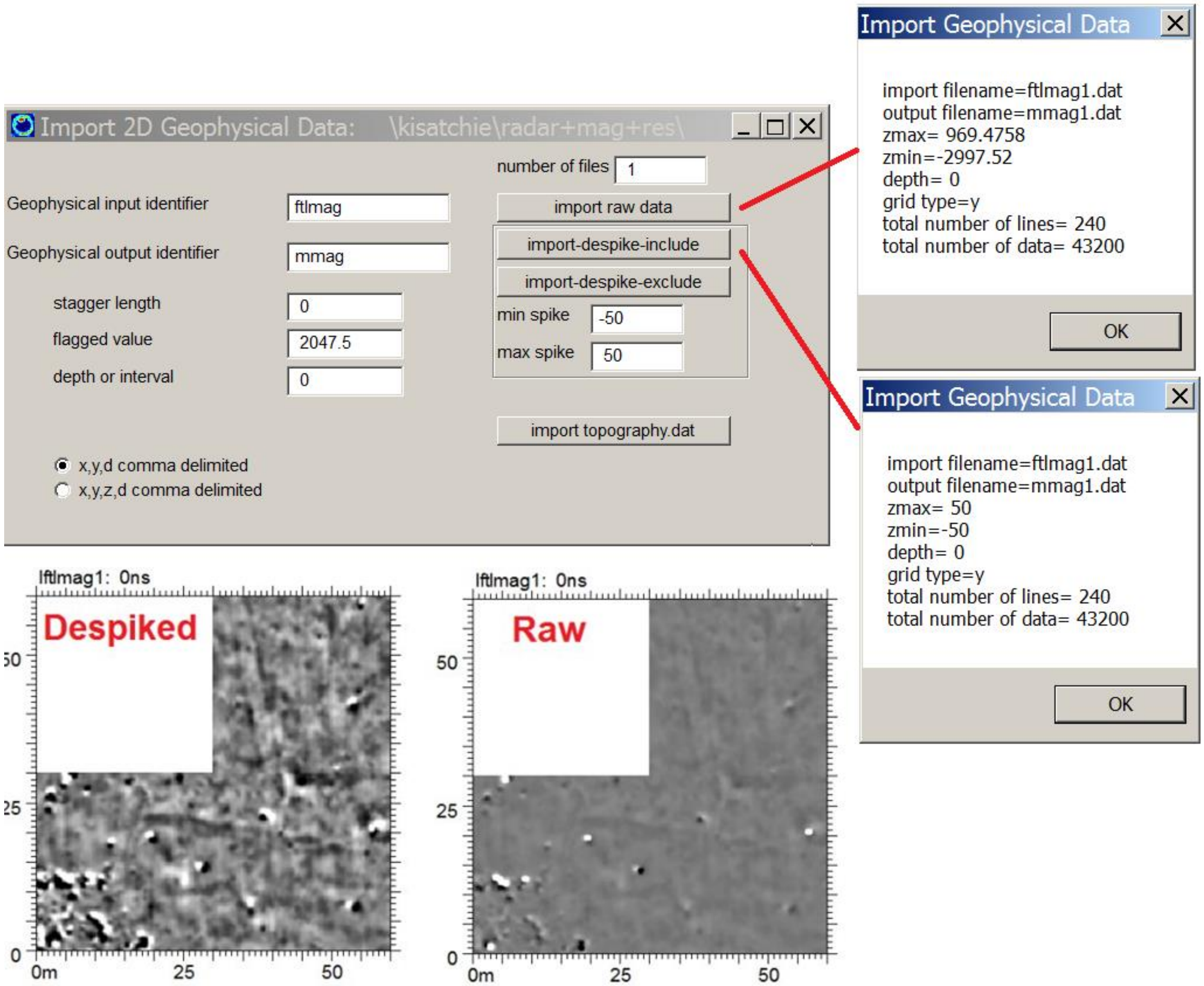
Note: The 2D-FFT filtering process is very sensitive to the central – low frequency portions of the transformed data. For this example, a small vertical ellipse of data near the center of the transformed time slice was zeroed – and which helps to remove the crop noises more effectively.

Import 2D Geophysical Data

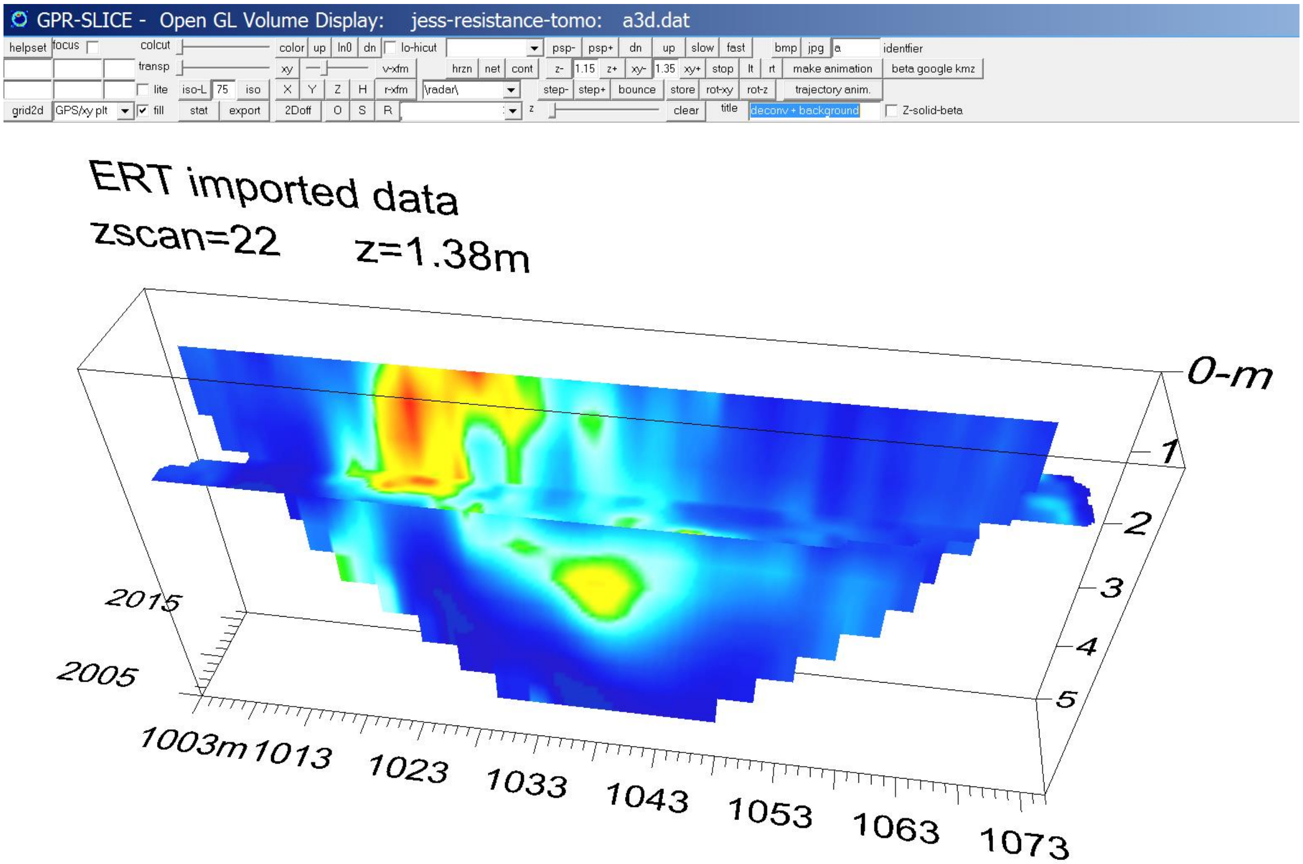
GPR-SLICE has capabilities of gridding any 2D and 3D data. Options were placed into the software at the requests of users that wanted to be able to grid other geophysical data. The import option located in the Grid pulldown menu launches a dialog which asks for a filename which contains the data. The files must have the *N.dat extension where N must start with 1 to N number of files to be imported, and be written as a simple x, y, z comma delimited file with no header. GPR-SLICE requires the *.N.dat format since users that import ERT data for example often have a series of files and not just 1. The user should also make sure that the very last line has a proper carriage return. Some programs such as Excel etc, may not properly place the end-of-file carriage return properly – please check this. Converting the data to **CSV MS-DOS** from Excel for example will ensure that a readable file can be imported. The *N.dat data must reside in the \dat\ folder of the project.

There are options to import the data as raw or de-spiked. Two options for de-spiked data are to include the data by resetting to the min/max spike levels, or to exclude points that fall outside of de-spiked ranges. Also, the user can set data values which are flagged values (e.g. empty values) in the imported data. In addition, the user can import the data and shift every other line by the stagger length to compensate for staggering errors, which is common from zig-zag surveys.

An example of a magnetic dataset is imported from a file called ftlmag.dat. The Import button will create a GPR-SLICE *.dat file called ftlmag1.dat with the correct header and format information. This file ftlmag1.dat can then be gridded in the Grid Menu and displayed in Pixel Map menu just as a regular time slice is (see the following diagram). One important point regarding importing geophysical data is that the absolute values of the data are preserved. In GPR data the "real" values of the electric fields are currently never known, just the digitized value of the reflection which is a function of the gain and the binary resolution. For importation of real geophysical data, the absolute values of the data range must be preserved. GPR-SLICE tags the imported data grid files differently than GPR grid files so that these values can appear on the color legend.



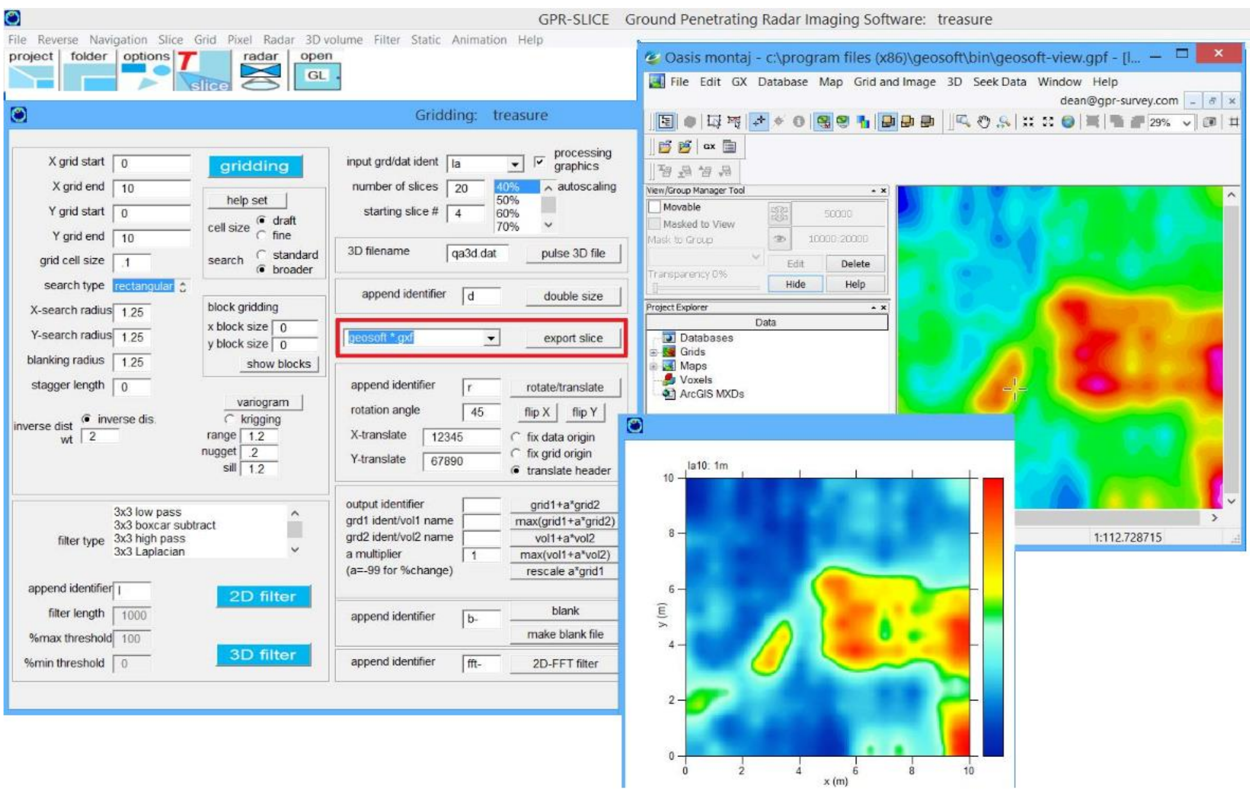
This magnetic anomaly map made from data collected at the Ft Lewis archaeological site in Washington State, was historic farm site. The GPR-SLICE operations of enhancing any imported geophysical data such as histogram transform adjustments are available. Although currently only 2D files are importable in GPR-SLICE v7.0, it is possible to generate 3D files of non-GPR data in the software. Using Electrical Resistance Tomography data collected by Jessica Ogden at the British School of Archaeology in Rome, 3D volumes could be generated after interpolation in the Pixel Map menu. An example display is shown below.



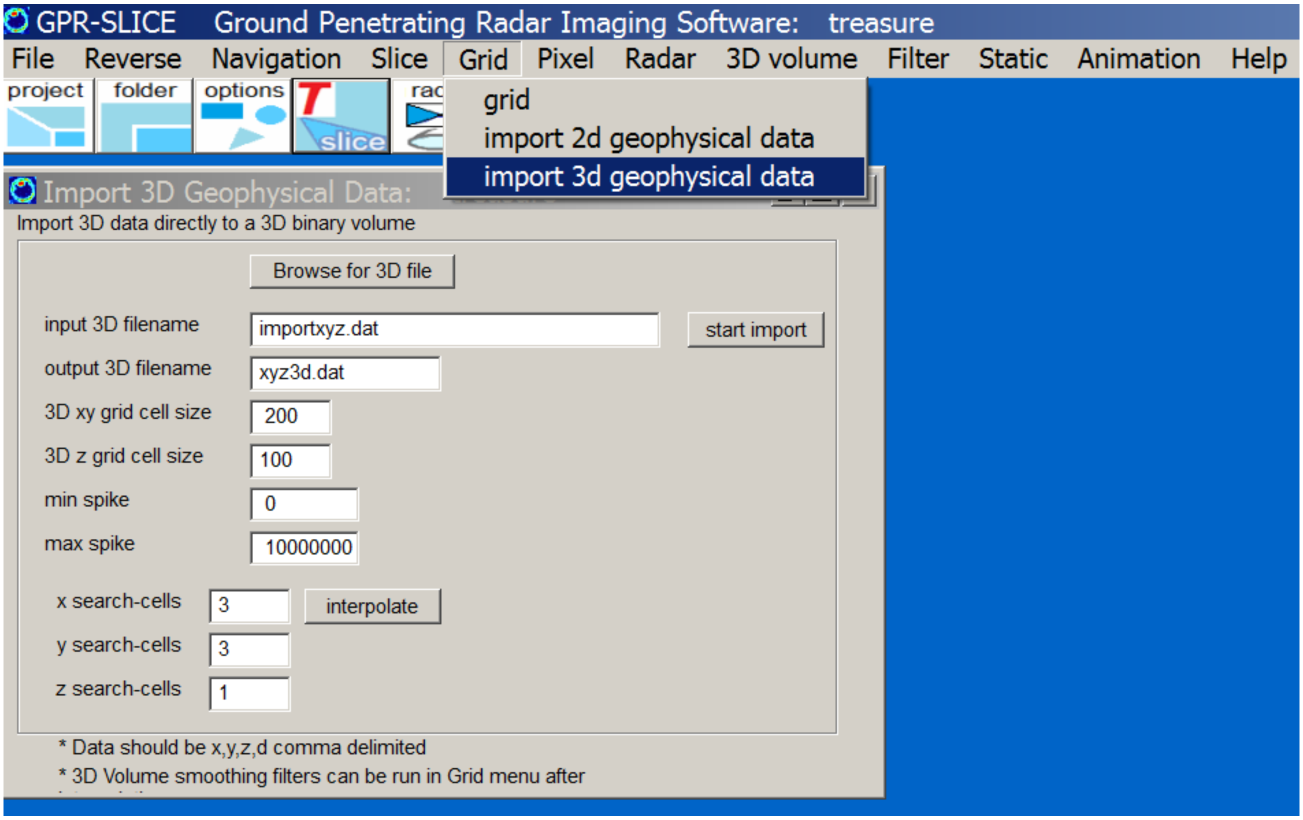
In this ERT 3D volume, 12 resistivity inversion layers were imported in batch by setting the number of files to 12 in the Import 2D Geophysical Data menu. A total of 12 files res1-12.dat from the ERT data were placed in the \dat\ folder before they were imported and gridded. After gridding, typical Interpolate+3D file generation available in the Pixel Map menu was applied.

GeoSoft Oasis Montaj *.gxf Export Format

A new export format for import of GPR-SLICE 2D *.grd grid files has been created for import into Geosoft's Oasis Montaj Software. In the Grid menu, there is a listbox for choosing different formats including the first export option for making Surfer grids (Figure 5). The *.gxf (Grid Exchange Format) is an ASCII format that can be directly imported into Oasis Montaj Software. The *.gxf format was in fact developed by GeoSoft for sharing grid files with other software. The exported grid files are written to the \grd\ folder. An example of a grid file in GPR-SLICE and its counterpart *.gxf format displayed in Oasis Montaj viewer is shown in Figure 5.



Import 3D Geophysical Data

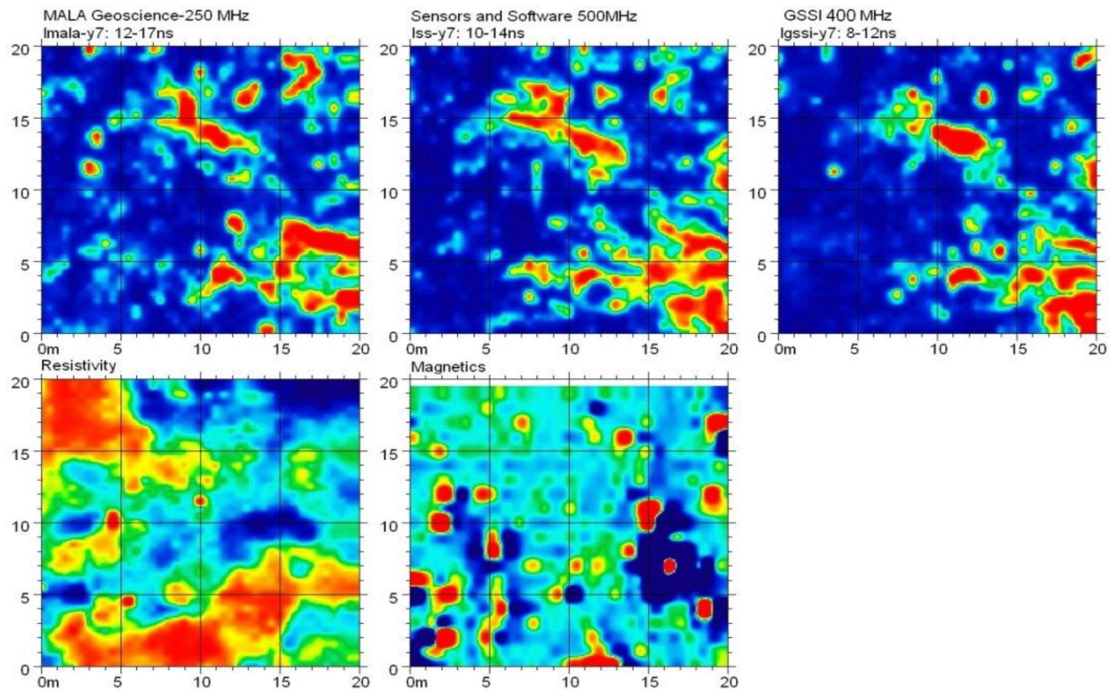


A 4 column ASCII file with a comma delimited format of x,y,z,d of external geophysical data can be imported, interpolated, and directly written to a 3D binary file. In the import option the maximum number of desired grid cells in either the XY and the Z direction are independently set. The number of cells to search for interpolation in X, Y and Z directions can also be independently set.

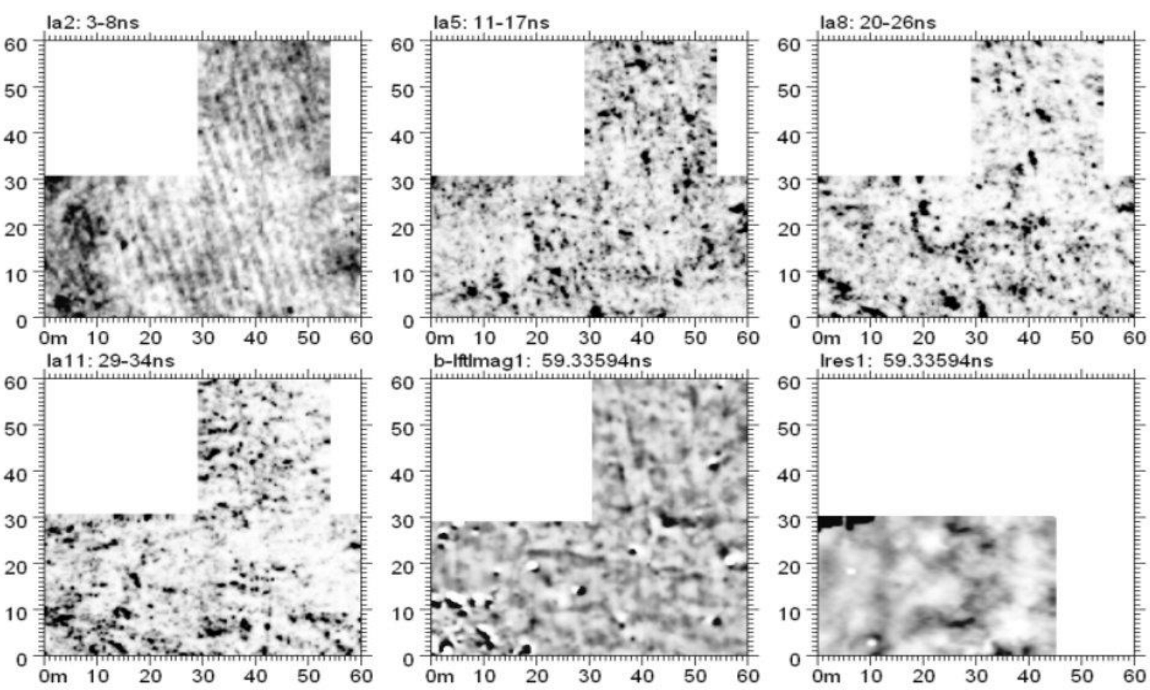
Note: Depending on the number of grid cells and the number of cells to search as well as the density of the imported data, the resulting volume may have many empty cells. Examining the volume in Open GL Volume can also magnify the gaps in the volume since color blending options need adjacent cells with data to illuminate surrounding cells. If there are many blanks either reduce the number of grid cells, or increase the number of cells to search out.

Comparison of GSSI, Mala, Sensors and Software, Resistivity and Magnetics

A comparison of GPR time slices computed from 3 different equipment manufacturers, GSSI, Mala and Sensors and Software, is shown below for the Ft Frederica surveys. This survey was made as part of the National Park Service workshop on GPR. The time slices made from a Mala 250 MHz, Sensors and Software 500 MHz, and the GSSI 400 MHz antenna all show remarkably the same general feature. The data are also compared in the following diagram with resistivity and magnetic data from the same site there collected. Examination of magnetic map shows little correlation for this particular site. Magnetic lows seem to be inversely proportional to areas of high reflections. Some regions of high resistivity are correlated with recorded GPR reflections.

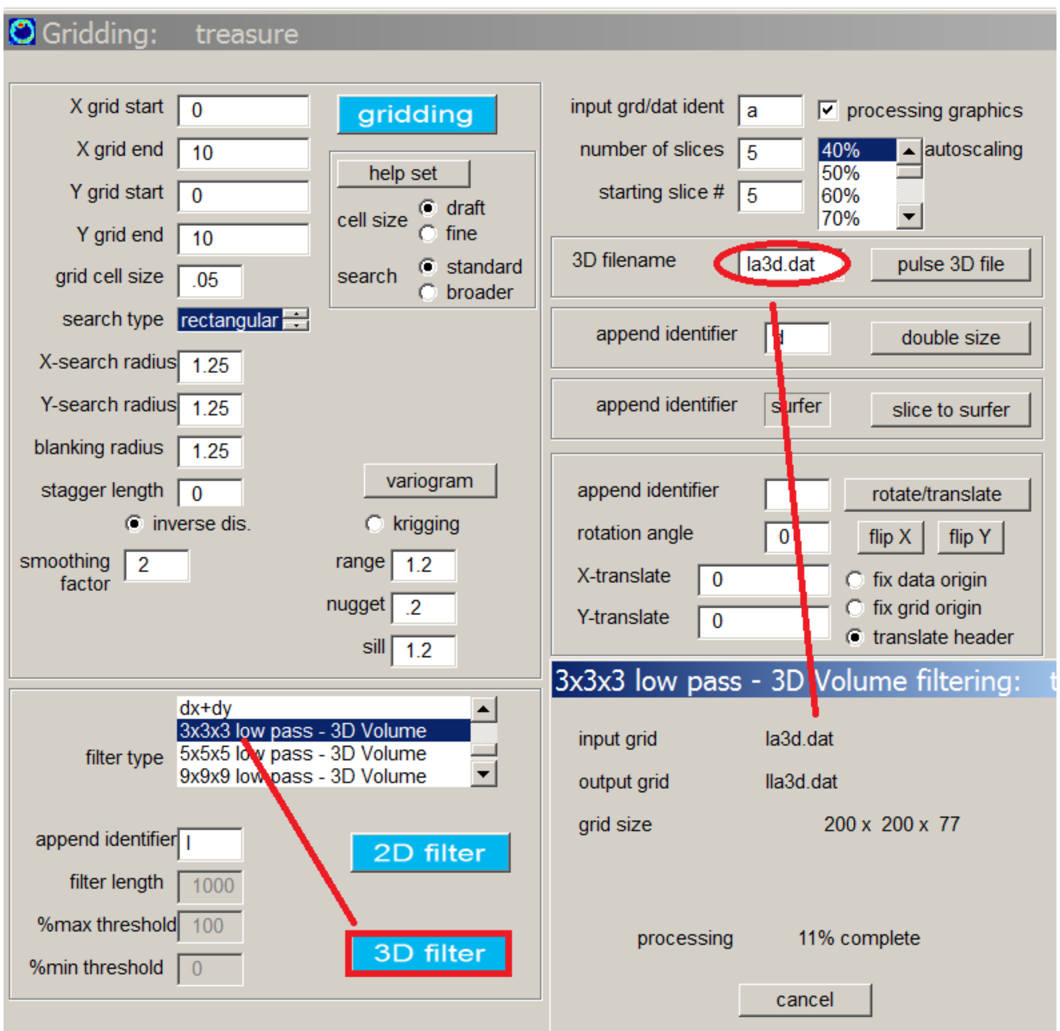


A second example is shown for the Ft Lewis archaeological site in Washington State. Here only one GPR instrument was used along with a resistivity and magnetics. The resistivity survey was not as extensive as GPR and magnetics.



Smoothing of 3D Volume files

3D volumes generated in GPR-SLICE can have boxcar smoothing applied in 3 dimensions. The option is available in the GRID menu with the button identified as 3D Filtering. Currently 3x3x3, 5x5x5, 9x9x9, and 17x17x17 boxcar smoothing is available (and listed in the bottom of the filtering listbox as seen in the following diagram). In addition, 3x3x1, 5x5x1, 9x9x1, and 17x17x1 3 volume filters are also available. These smoothers are particularly useful for 3D volume generated for the full radar pulse and do not include time slice smoothing from sample other than the same level. The option can also be effectively applied to topographically adjusted 3D volumes. This filtering helps to alleviate some noises caused by the vertical shifting of normalized grid cells to adjusted topography levels in the volume.



PIXEL MAP Menu: Overview

This menu is designed to enhance and display time slice grids created in GPR-SLICE. Many functions can be performed in this menu, including:

- drawing multi-time slice displays
- adjusting time slice transforms
- interpolating time slices
- creating 2D time slice animations
- appending/concatenating grids
- overlay analysis

For those topics not included or need further description than given in the Quickstart section, they are presented here.

Drawing Multi-Time Slice Displays

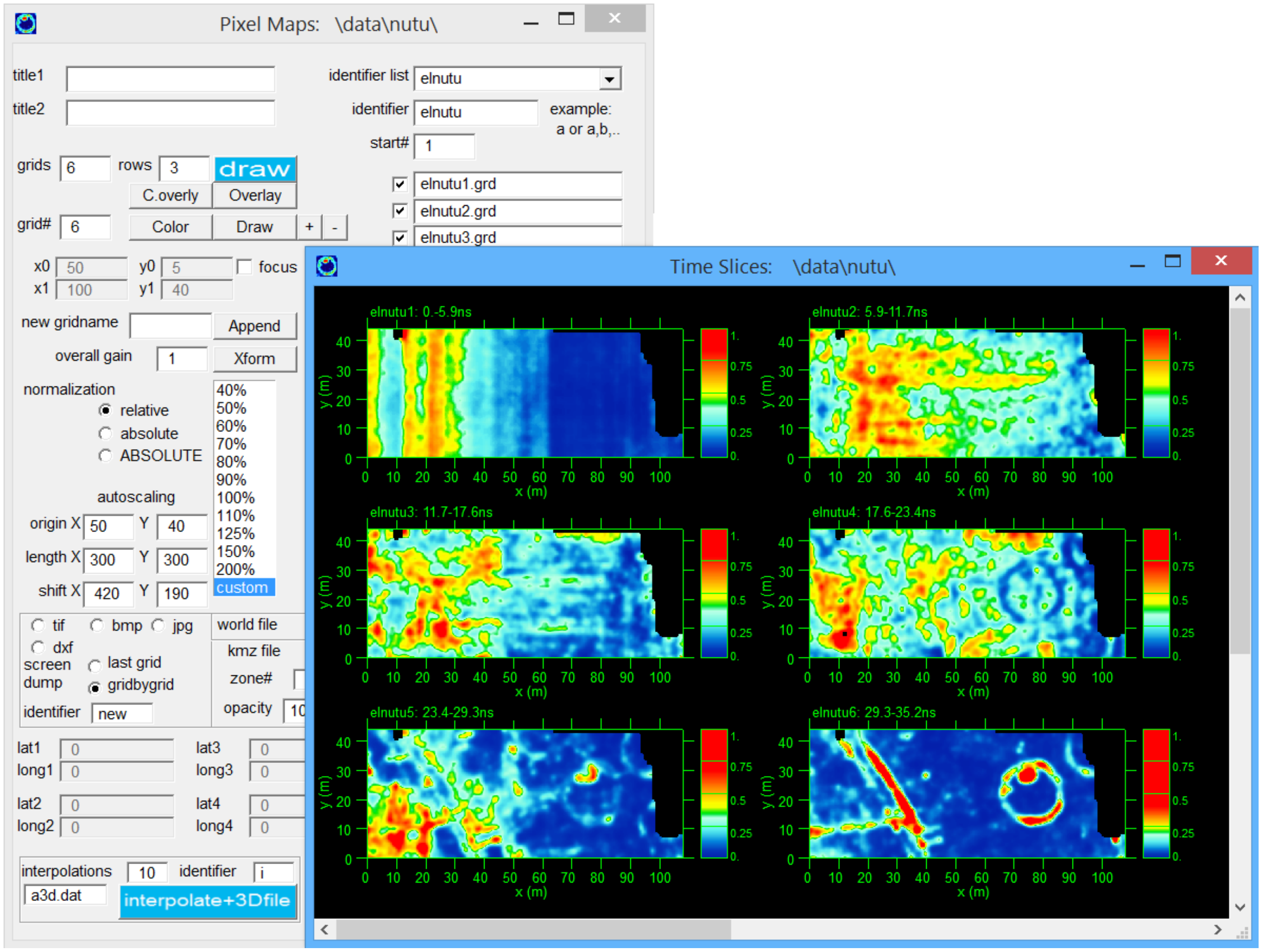
As shown in the Quickstart section for 2D time slices, the user can display as many time slices in one screen as they so desire. If the user chooses automatic sizes for the screen displays, then they will have the autoscale switch engaged to some value other than "custom". If the autoscale switch is set to 50% for example, all time slices drawn to the screen will fill up only about half the computer screen. The user normally will choose how many time slices plus the number of rows they will want to display maps at. The Pixel Map Menu will find appropriate sizes and locations for the time slice maps based on the number of slices and rows set. The user can also manually set the sizes and the shifting between plots by turning on the custom option in the auto scale listbox. For custom sizes, the user will need to specify explicitly the:

X, Y origin of first map measured from the upper left hand corner of computer screen

X, Y pixel lengths of the individual time slice maps

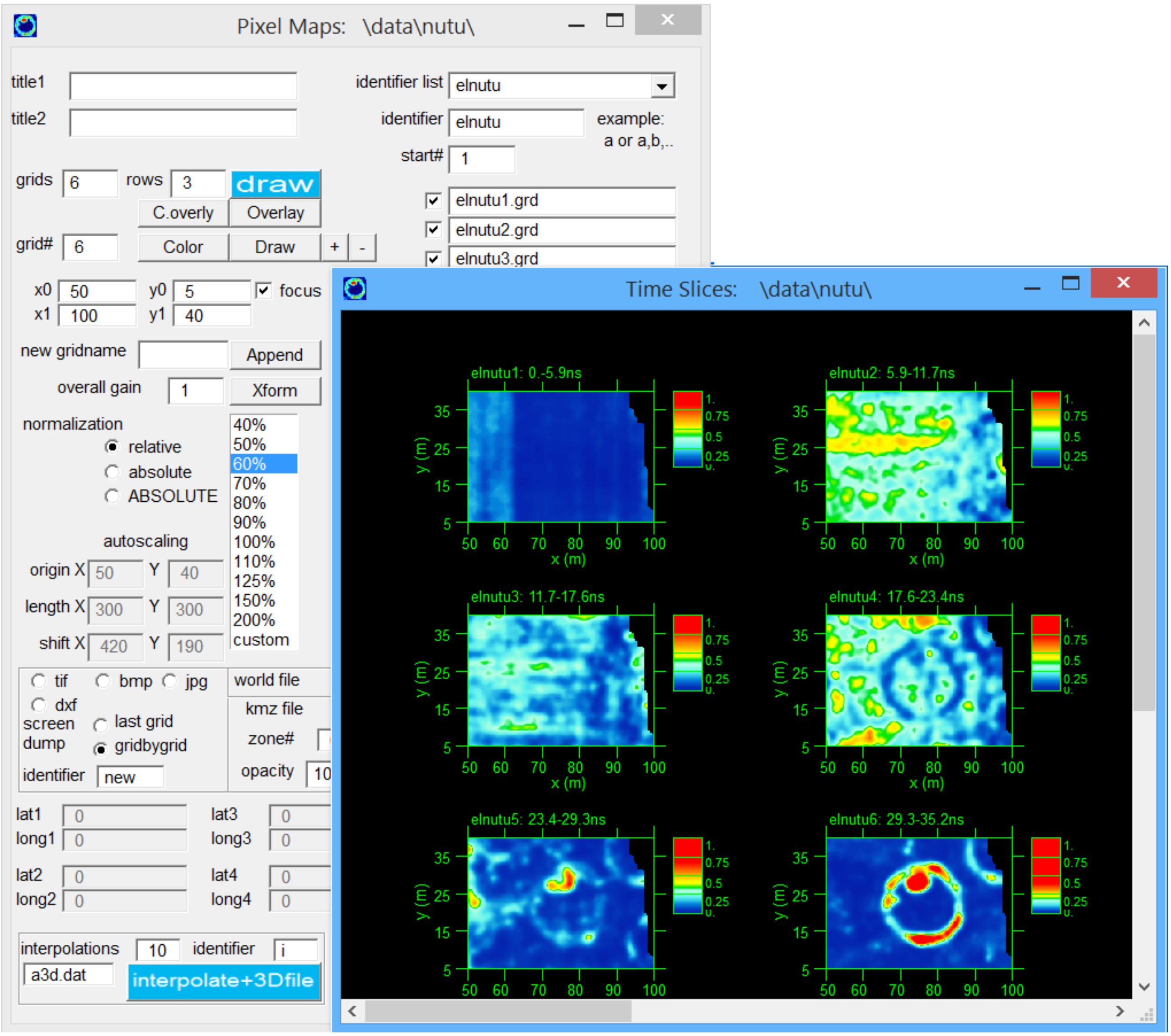
X, Y pixel lengths to shift between adjacent plots.

With the custom setting engaged, the user can make multi-time slice displays which are actually bigger than the computer screen. When images bigger than the computer screen are drawn, GPR-SLICE will automatically put scroll bars on these displays to allow viewing the entire image.



In this example above, the number of time slice grids to display is set to 6 with 3 rows. The auto scaling function is engaged to custom. The multi-time slice displays are drawn 70 pixels from the left and right from the top left hand corner. The pixel lengths for the plots are set to 300 pixels each. The plots are also shifted 360 pixels in the horizontal X direction, and 200 pixels in the vertical Y direction. (Also, the background color is set to black and the font color to white in the Options menu).

There is an option to only show a portion of a time slice grid to the display. Checking the focus option on and then setting the x and y start/end locations to the desired portion of the time slice grid, will generate separate time slice maps with just the focused region. This option is very valuable for large scale time slice grids when only a portion is needed for examination. This could be a very easy way to also remove



GPR edge effects found at the ends of lines, where noises due to the collection methods can sometimes occur.

Three types of normalization can be used to display time slice maps: relative, absolute or ABSOLUTE normalization. Relative normalization will display each time slice map based on each individual grids own maximum and minimum grid values. Thus each grid displayed to the screen will have a red area (assuming a rainbow color table) as its strongest reflector progressing to blue for its weakest reflector. In the case of absolute normalization, GPR-SLICE will find the maximum and minimum within the entire set of grids to be displayed to the screen first, and then will find the appropriate color for each grid to be display based on these overall maximum and minimum grid values found. The third option called ABSOLUTE normalization will colorize the time slice based on the binary resolution collected with raw GPR data. For instance, if 16 bit radargrams are being processed with the square amplitude, then the maximum values in the time slice grids can be 2^(15-1)^2, which are really huge numbers. One can display the color legend with the corresponding numbers depending on the normalization by clicking this on in the Options menu.

Note: Absolute normalization will generally overweight the top time slices as this is the area where typical ground reflections reverberate within the antenna to usually create the strongest recorded reflections within the dataset. For absolute normalization to be effective, the user will generally use a single color transform for all the time slice maps to be displayed to the screen.

Creating 2D Time Slice Animations

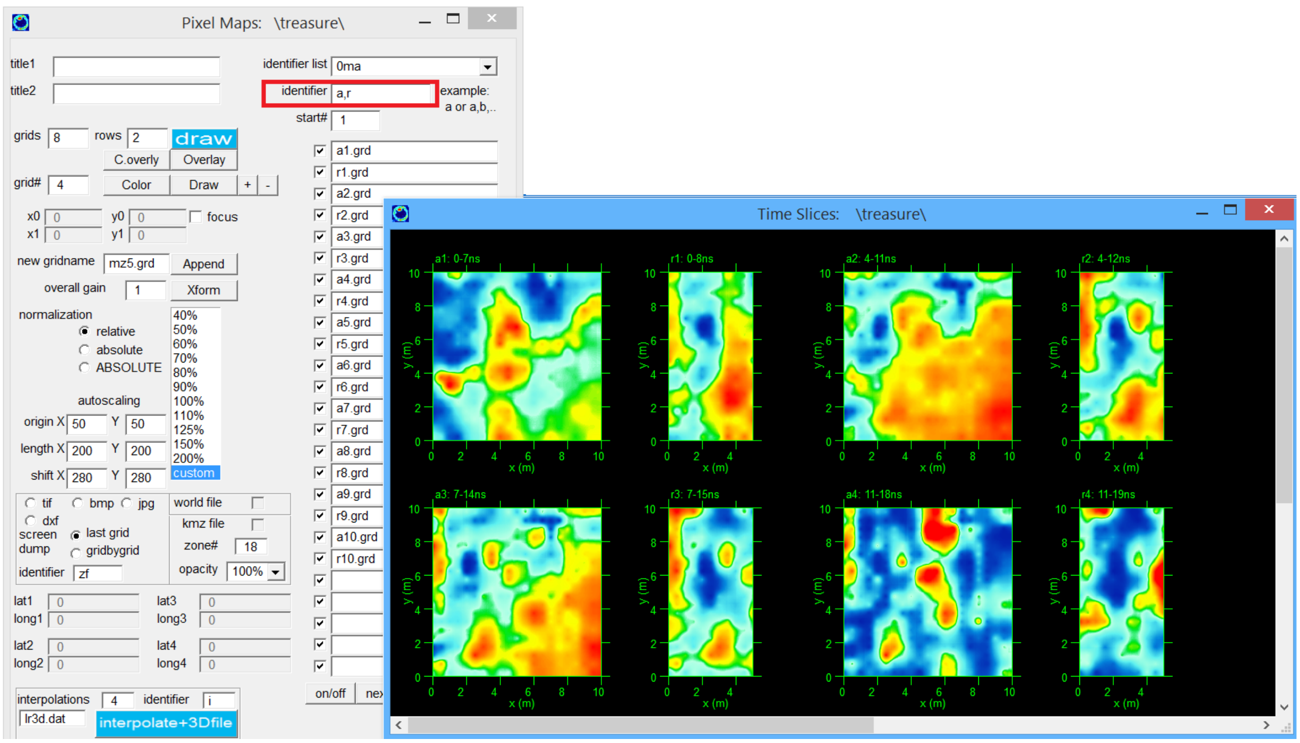
JPG or BMP outputs can be created while time slice maps are being drawn to the screen. Two types of output control of screen displays can be set: last grid or grid-by-grid. Last grid will output only 1 bitmap/jpeg after the entire number of time slices is displayed to the screen. Grid-by-grid will output a picture file after every single grid is drawn to the screen.

Before starting the drawing to create an animation, the user should insert an output identifier for creating JPGs, located next to the screen dump setting in the Pixel Map menu. If the jpeg output control is clicked on, and the identifier is "a" for example, a series of JPG names called, a1.jpg, a2.jpg…aN.jpg, will be created when the drawing is started. In the case when only the last grid option is desired, the single JPG filename will be given the name aN.bmp, where N is the number of grids that are actually drawn to the computer screen.

Note: Various resolutions of are available for jpeg outputs, but for GPR-SLICE only the highest resolution is used.

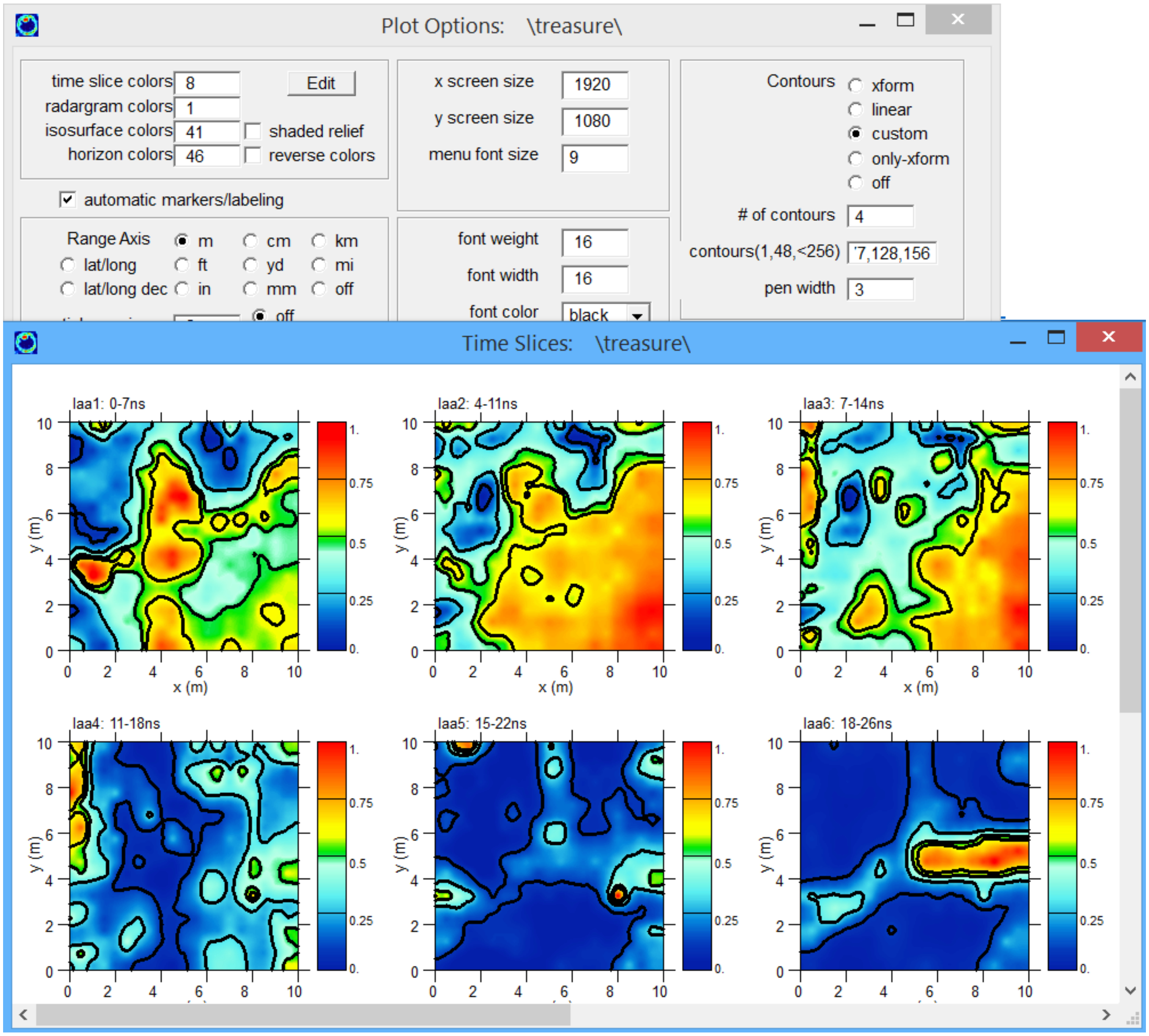
Displaying 2 (or more) Different Grid Sets

The user can display two different grid sets on the screen. This is useful in comparing different analyses that may have been applied to each grid set on the same computer screen. In the example on the identifier for each of the grids is inserted – comma delimited - as "a, r" in this example. Grid sets with different processing on the same site can also be shown. More than 2 different datasets can be shown by continuing the comma delimited identifier.



Pixel Maps + Contour Lines

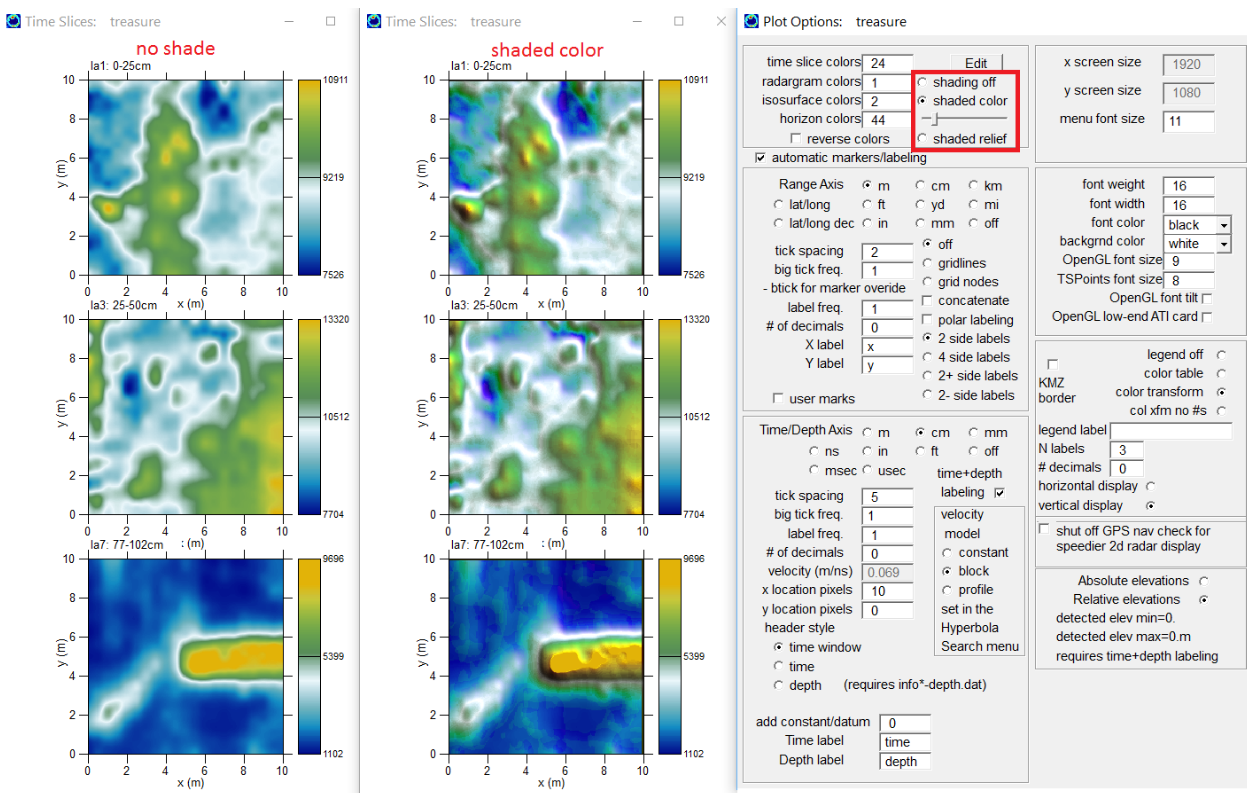
Pixel Maps can be shown with contour overlays. The contours can be applied using either the transform, linear or custom option. Using transform, the contours will be applied followed the active transform for the displayed time slice. Linear, will place contours at a constant threshold between contour lines. Custom allows the user to explicitly set at what threshold values the contour overlays are displayed. For custom the user can enter any values, **separated by commas**, between 1 and 255.



Shaded Color Displays in the Pixel Map Menu

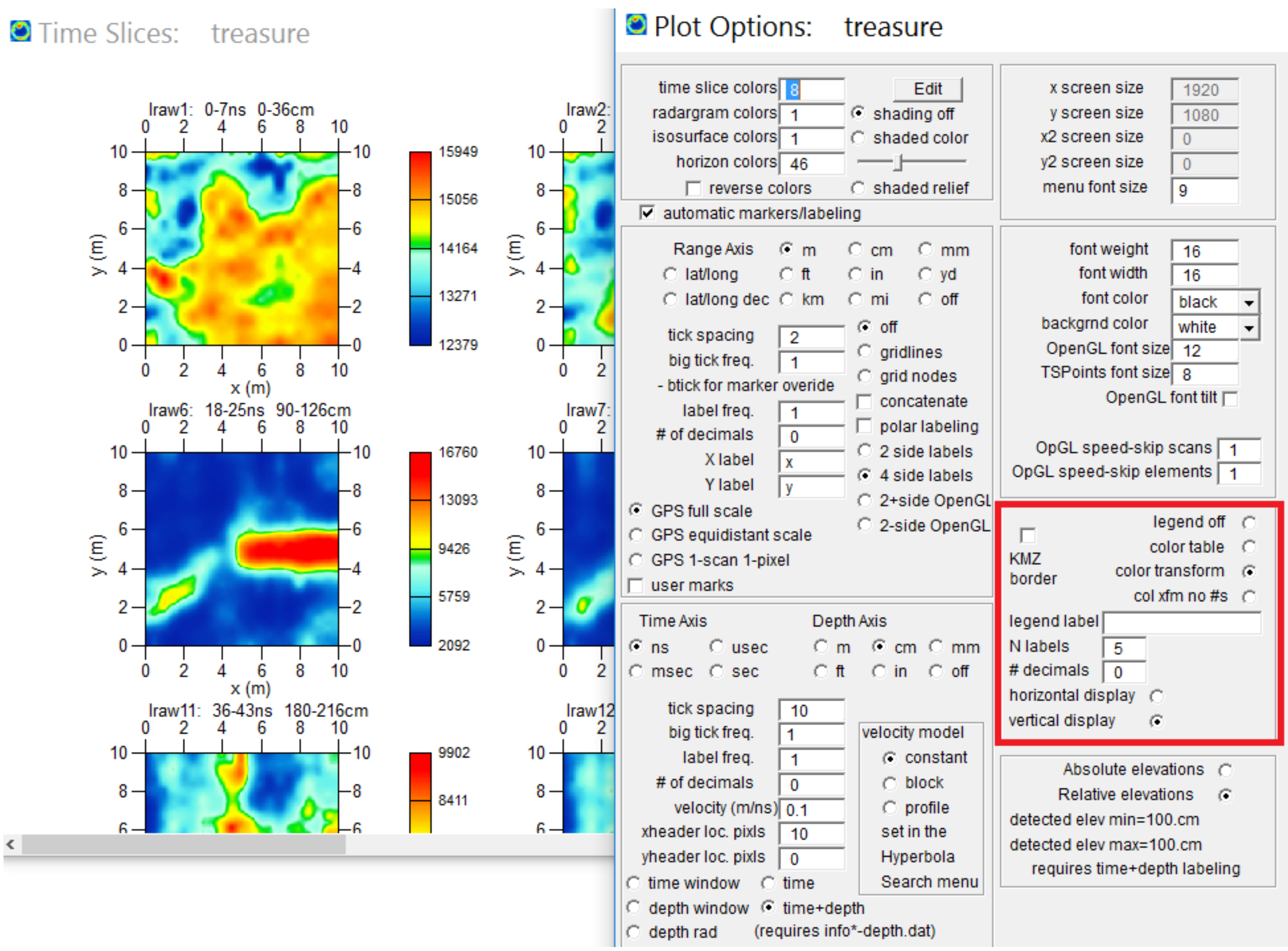
Shading of 2D pixel maps can be used in displays to give an artificial 3D appearance in the drawn time slice imagery. Shown in Figure 6 is an example comparing normal – unshaded and shaded color time slice images. This displays preference is currently available in the Options menu. A slider bar can also be used to adjust the level of shading in the images. Some color tables lend themselves better for shade coloring then others. To assist the user in choosing a good color table with the option, the standard GPR-SLICE color tables have been expanded. On the Subscribers Only page of the website, the new color table for software have been upgraded. The typical standard rainbow color table is still table #8, however, color table #9 was added and appears to be a perfect palette to enhance shade color imagery. Other color tables and ordering of the color tables in the list have been adjusted. Color tables from 21-30 for instance have bipolar appearance and these can be useful for radargram displays. For shade relief displays color tables from 41-50 are useful. From 31-40, color tables with less than 256 continuous colors, such as 32 or 16 colors are provided to help represent colored contouring imagery.

Note: Shade color displays are currently only available in the Pixel Map menu.



Customizable Legend Display

Color legends in the 2D Pixel Map menu can be customized to display labels at any desired frequency (see screen shot). In addition, horizontal or vertical displays of the legend can be set. The legend size is maxed out to 512 pixels or shorter depending on the axis size that the legend is output to. The number of decimals for labeling can also be adjusted. As all 2D grid data are now recorded as double precision floating point numbers and not strictly integers, all grid maps have decimal data included. For time slice images where the squared amplitude or time slices made from 32 bit radargrams are being used, the numbers are quite large and the display of numbers on the legend can be shut off with col Xfm no #s radio button.



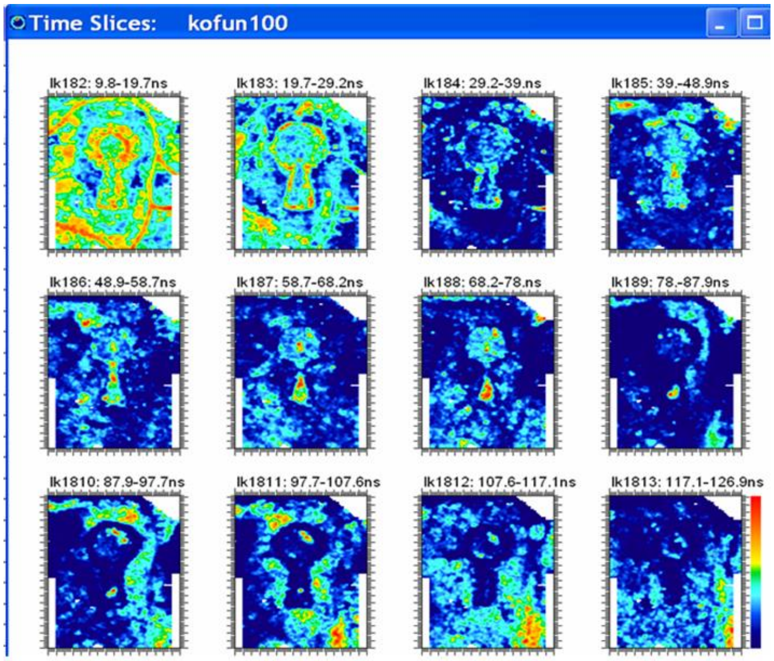
Overlay Analysis

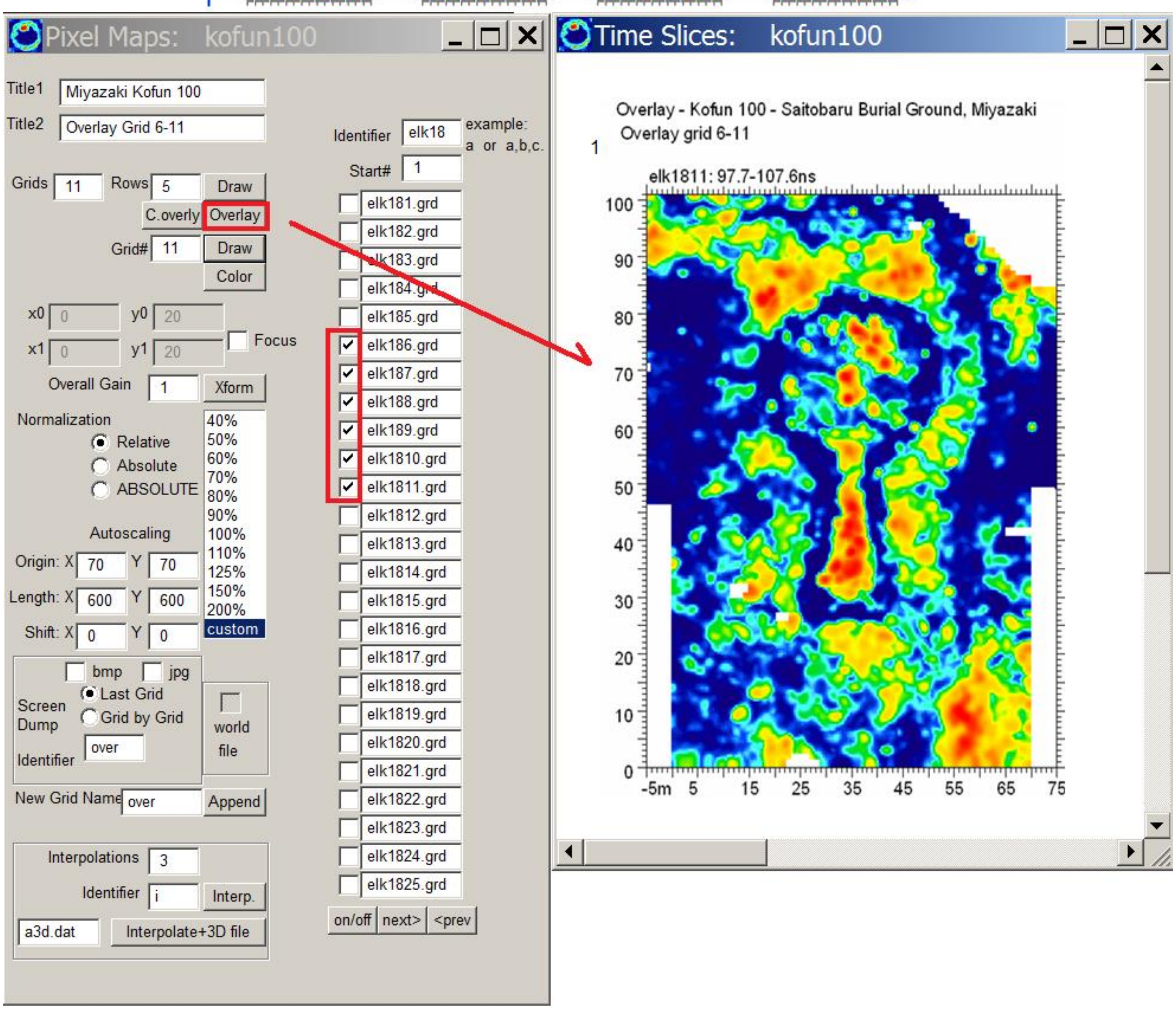
Because structures are often not buried at equal depths, making thin slices may only show parts of these structures on the time slice maps. To make a comprehensive image of reflections at different time/depth levels, Overlay Analysis can be implemented. In this process, the user can choose a range of depths to overlay the relative- strongest-reflectors onto a single map. The shallowest time slice map is first drawn and then deeper time slice maps which have stronger colors (e.g. stronger relative reflections at any grid locations) are plotted onto a single 2D map. GPR-SLICE Software allows individual transforms to be applied at each level to be overlaid into the final image, which allows for greater control in emphasizing important levels in the combined time slice image map. In the cases when continuous archaeological features are at varying depths in the ground, the overlay analysis will accumulate reflections from these different depth ranges and help to create a useful map containing all the relevant reflections on a single image.

Show in the Pixel Map Menu on the following page is a series of time slices made across a burial mound site in Miyazaki, Japan. The purpose of the GPR survey was to determine the shape of a buried moat surrounding the mound which might give information on the construction period, either late or early sixth century A.D. In the individual time slice maps, several levels show reflections which have some information reflecting from the moat regions. These were identified as time slice maps 6-11.

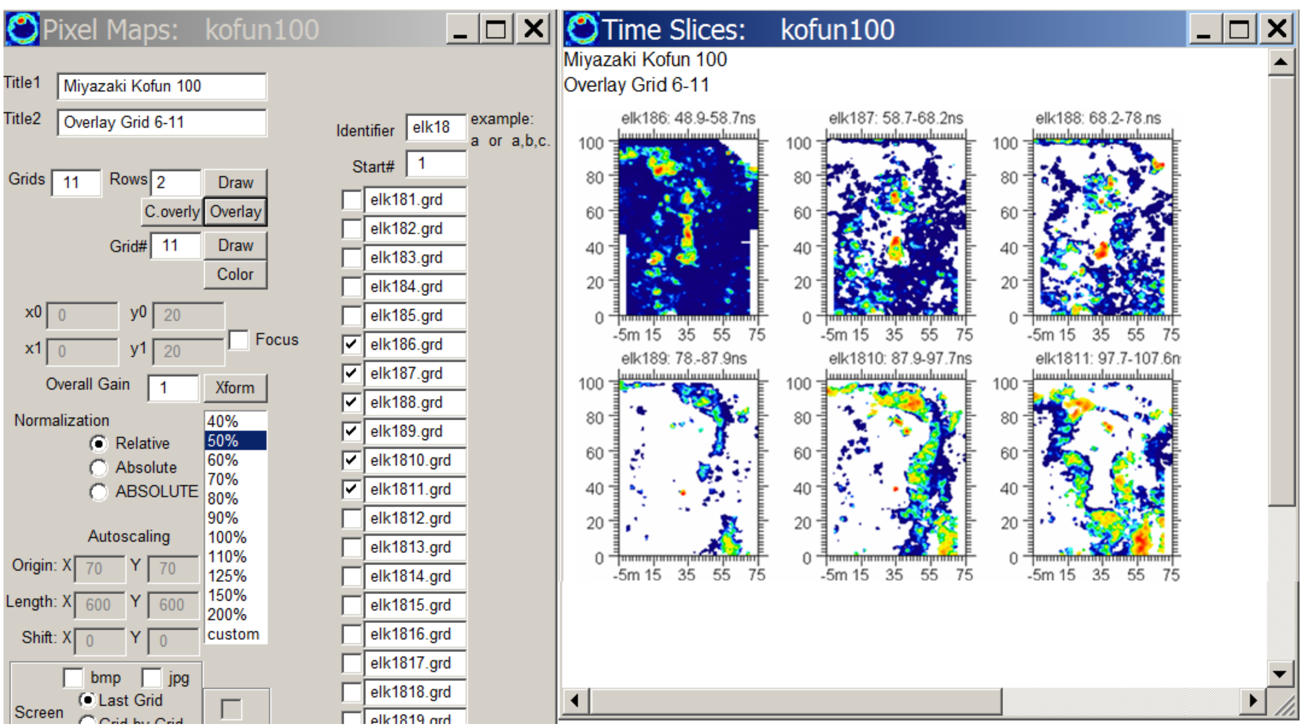
To start the overlay process, only those maps which are desired to be included in the overlay are clicked on (as shown Pixel Menu on the next page). The user has buttons on the bottom of the menu to click all the checkboxes next to the grids on or off. The auto scaling option should be set to custom and the shifting in x and y plots are set to 0. Clicking the "Overlay" button will start the overlay process. After the results are displayed the user may sometimes have to "lighten up" the general transforms for the time slice maps to prevent overdrawing the maps with too strong of colors. The resulting overlay image for the example was used to discover a "keyhole" shaped burial moat which indicated a early 6^{th} century construction for the mound.

Animations of the overlays operation can also be made by turning on the Screen Dump for JPGs and setting the grid-by-grid radio button.


Time Slices: kofun100
lk182: 9.8-19.7ns
lk183: 19.7-29.2ns
lk184: 29.2-39.ns
lk185: 39.-48.9ns
lk186: 48.9-58.7ns
lk187: 58.7-68.2ns
lk188: 68.2-78.ns
lk189: 78.-87.9ns
lk1810: 87.9-97.7ns
lk1811: 97.7-107.6ns
lk1812: 107.6-117.1ns
lk1813: 117.1-126.9ns


Pixel Maps: kofun100
Title1 Miyazaki Kofun 100
Title2 Overlay Grid 6-11
Grids 11 Rows 5 Draw
C.overly Overlay
Grid# 11 Draw
Color
Focus
Overall Gain 1 Xform
Normalization
Relative
Absolute
ABSOLUTE
Autoscaling
Origin: X 70 Y 70
Length: X 600 Y 600
Shift: X 0 Y 0
40% 50% 60% 70% 80% 90% 100% 110% 125% 150% 200% custom
bmp jpg
Screen Dump
Last Grid
Grid by Grid
Identifier over
world file
New Grid Name over Append
Interpolations 3
Identifier i Interp.
a3d.dat Interpolate+3D file
Identifier elk18 example: a or a,b,c.
Start# 1
elk181.grd elk182.grd elk183.grd elk184.grd elk185.grd elk186.grd elk187.grd elk188.grd elk189.grd elk1810.grd elk1811.grd elk1812.grd elk1813.grd elk1814.grd elk1815.grd elk1816.grd elk1817.grd elk1818.grd elk1819.grd elk1820.grd elk1821.grd elk1822.grd elk1823.grd elk1824.grd elk1825.grd
on/off next> <prev
Time Slices: kofun100
Overlay - Kofun 100 - Saitobaru Burial Ground, Miyazaki
Overlay grid 6-11
elk1811: 97.7-107.6ns

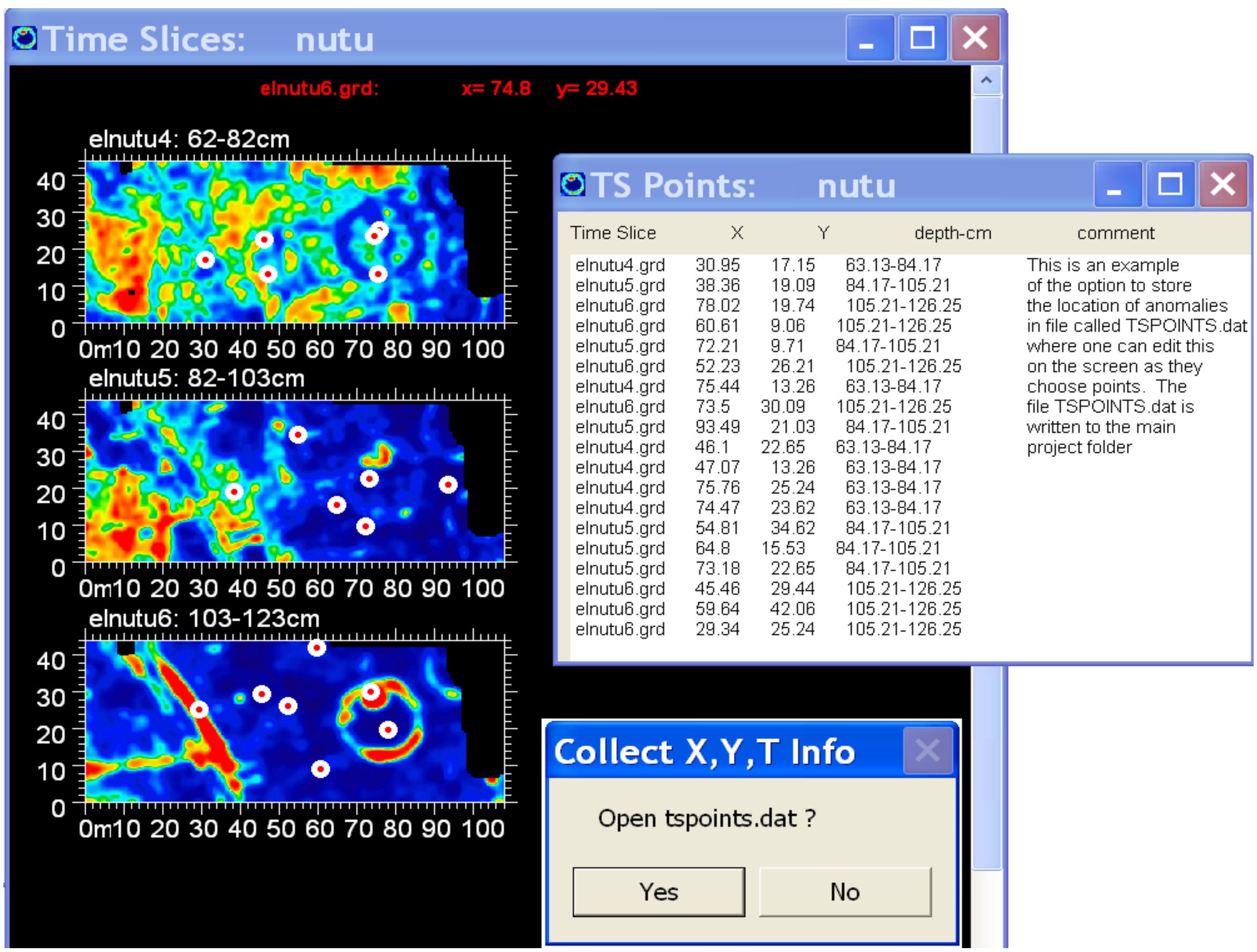
If the shifting of the individual time slice plots is made, then the user can display the contributions from each map that will become part of the overlay. This can be visualized in the Pixel Map Menu below. The auto scaling was taken off custom and the plots were shifted automatically (at 50% scale). The first time slice was drawn fully. The next time slice in the series shows areas on its map that are stronger in color than the first map. The 3rd map and so on progressively shows what regions have stronger reflections (colors) than all the previous maps that were drawn. This technique of overlaying the relative-strongest-reflectors is not the same as making simple composites or adding the colors or maps together. The overlay analysis is a binary process to show the relative-strongest-reflectors over the range of time slices chosen. The nomenclature relative-strongest-reflector is used to distinguish the overlay process which analyzes the individual maps with their relative color transforms made at each level and overlays the strongest colors – not strongest absolute reflection amplitudes - at each location. The strongest colors which are mapped are at the control of the user in setting transforms at each level in the overlay analysis.



Note: Overlay analysis displays are written to a hardwired grid file named **overlay-analysis1.grd**. The overlay-analysis1.grd file can be redisplayed in the Pixel Map menu and world files also can be generated from this specially compiled grid file.

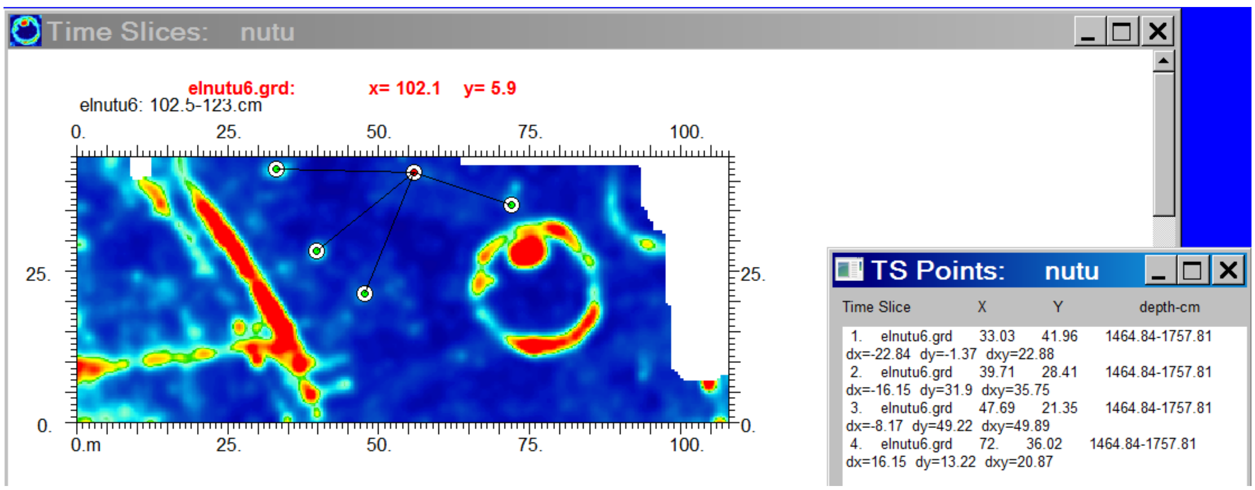
TSPOINTS.dat Anomaly File

A feature was added to GPR-SLICE which allows the user to store a file containing mouse clicks of anomalies. To access this feature, the user needs to display a series of time slices to the screen. Then, right clicking the mouse will launch a message box asking the user if they wanted to store X, Y and T information which contains their mouse location and the corresponding time slice information. Saying yes will open up an on screen dialog which will get filled for every left mouse click that is made on a time slice. The time slice name, the X and Y location, and the time or depth location of the anomaly is stored in the on screen dialog. This dialog is written to a file called TSPOINTS.dat and the end of the operation. In this example, the time slices are being displayed in centimeters and thus centimeters are written to the depth column. If time in nanoseconds were chosen, the depth column would convert to time rather than depth. The user can also type in a comment as they store anomaly information.



The TSPoints option in Time Slice displays is also programmed for right mouse clicks after initial launch – reporting of dx, dy, dxy between the last left clicked point in TSpoints.dat file. An example of this new TSPoints option in GPR-SLICE v7 in the Time Slice display is shown below. The request for this option was made by a user that was working in a forensic survey and they needed to quickly report distances between selected points.

Initially the left mouse is clicked to store a bull's eye of the first point, then subsequent right mouse clicks will draw separate chords from the first selected point to all the locations where the right mouse is clicked.

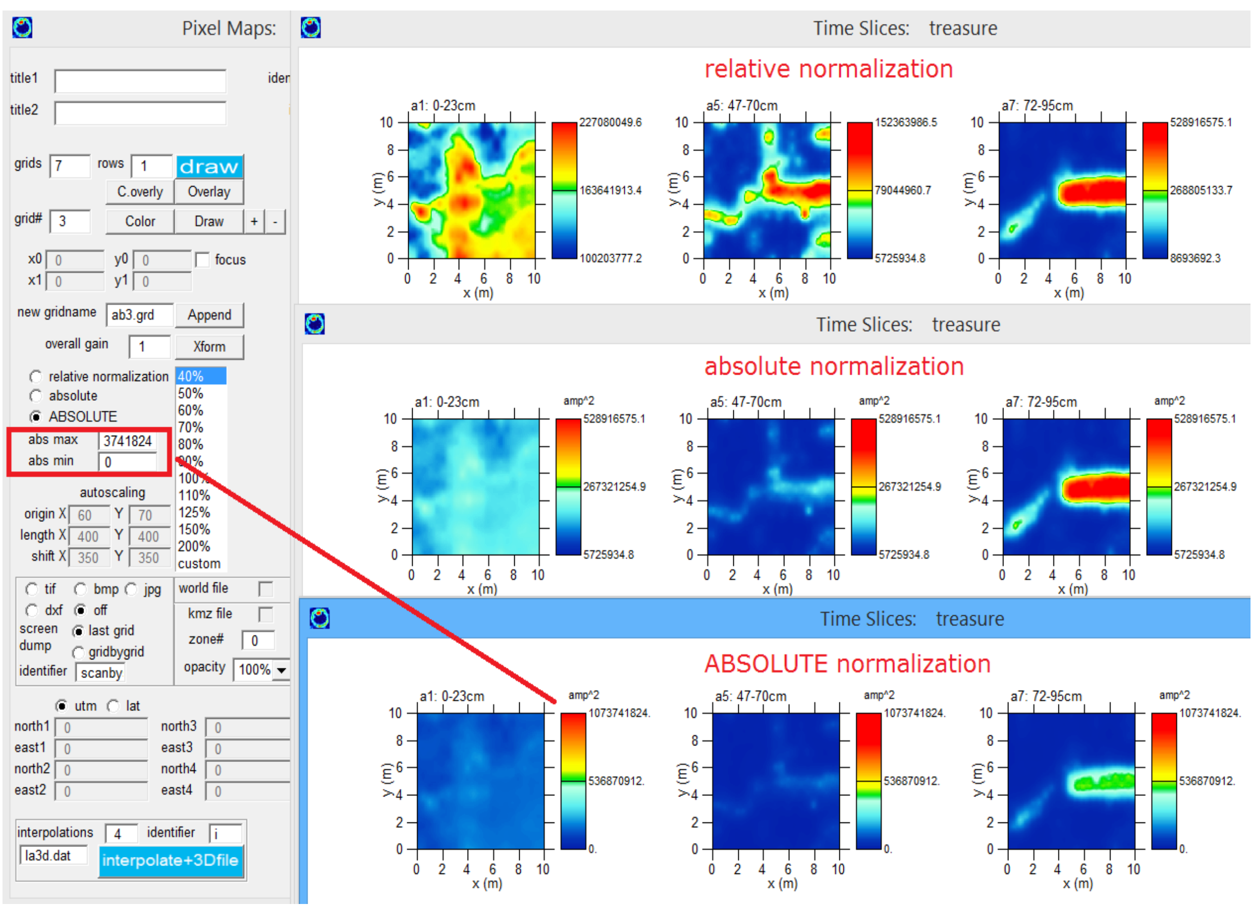


ABSOLUTE Normalization Customizable Settings

The display of time slices with ABSOLUTE normalization now have customizable inputs for the minimum and the maximum values (see next screen shot). ABSOLUTE normalization will set the peak value and the minimum value across an entire set of time slices and colorize the data based on the values. Lower case absolute normalization – where the minimum and maximum between all the time slices displayed is searched first prior to display - is the same as upper case ABSOLUTE normalization display if the user set values are identical. The customization here is to allow users investigating 4-D measurements of GPR to "re-colorize" data collected and to investigate changes in the signal over time. To do this requires fixing the minimum and maximum values before colorization.

Note: For those using the Grid Blocking function for either the Multichannel menus or the Grid menu, when displaying multiple blocks at the same level in the Pixel Map menu, ABSOLUTE or absolute normalization should be used. This will insure that all the blocks are colorized with reference to one set of min/max values – whereas on relative normalization each map is independently normalized and could cause mosaic changes between blocks when looking at the data as a whole.

Note: In the example the absolute minimum and maximum were set to the maximum abs (amplitude) time slice parameter of 32768^2 = 1073741842 which is the largest possible time slice value that can exist in a grid map for 32 bit radargrams. This value is unlikely and can only come in the case of an area that has a completely strong reflection. However, over gaining of a radargram, creating clipped regions could possible create a time slice parameter in grid map with this value.

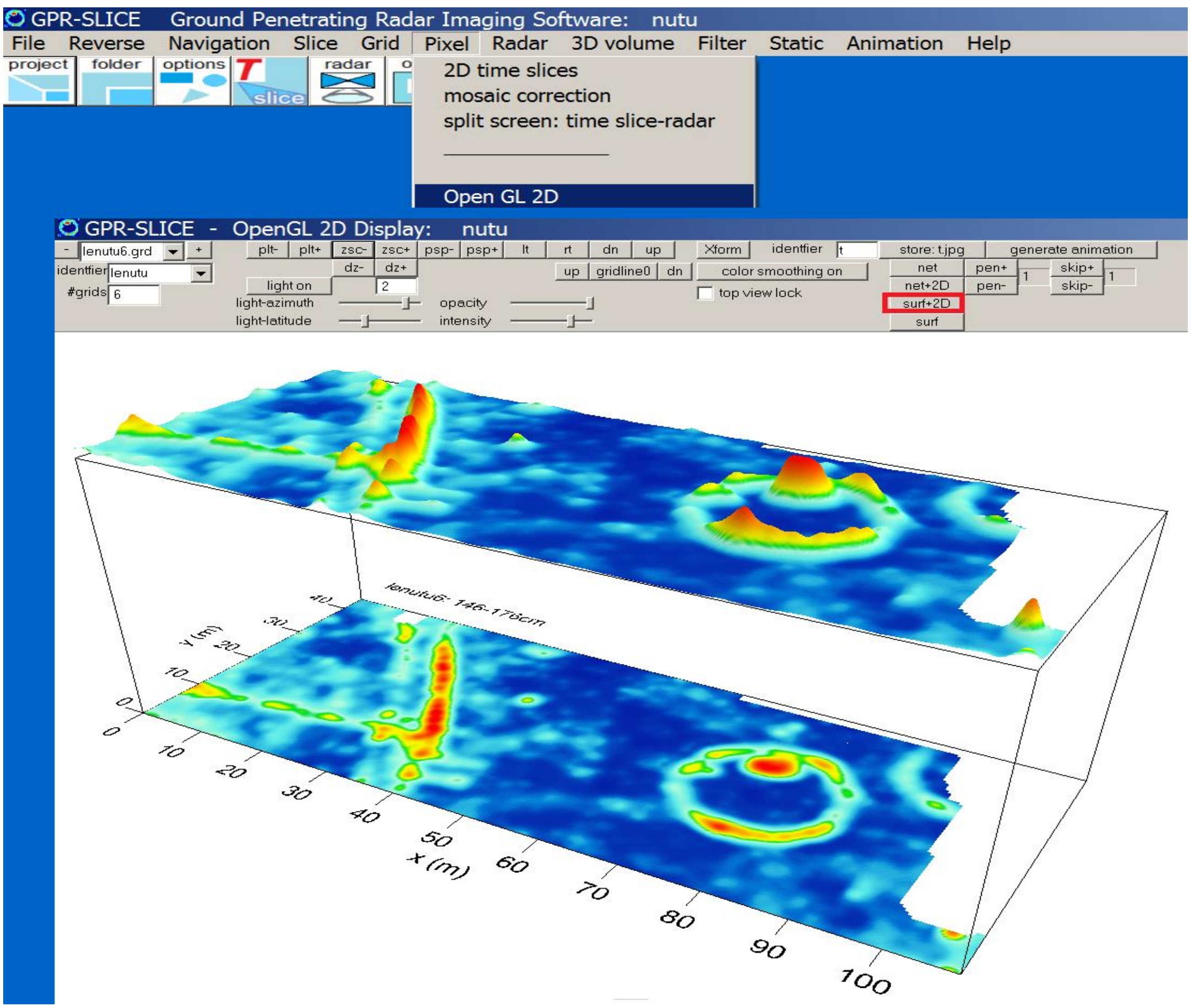


OpenGL 2D Surface Plotting Menu

A menu to draw 2D time slices as 2D surface relief maps is now available in the Pixel Map 2D pulldown menu. In the menu there are 4 possible displays:

1. net plot
2. net plot + 2D
3. surface + 2D
4. surface

The example shown is a surface + 2D image. There are Z scaling buttons to reduce or increase the surface anomalies. Clicking the **Z scl-** button several times will make 2D flat displays which can be rotated and



tilted real time. The time slices can be incremented by clicking the **+** and **-** buttons.

Elemental lighting options have been added to give various effects where the azimuth, light latitude, intensity and transparency can be changed with a slider bar. Several control buttons to adjust the separation between the surface plot and the time slice can be handled with the dz-/+ buttons. There is also a Top View Lock checkbox which when engaged with just the surf will give a normal 2D time slice image. We hope to expand this menu in the near future to also have some additional features such as multi-time displays.

The Open GL 2D menu has options to output a single jpg or a series of jpgs for input to the animation menu. There is a **Store jpg** button which will create one jpg. To generate an animation, the user can click the **Generate Animation** button. This will cause the OpenGL 2D routine to display all the time slices set in the Pixel Map menu and create an animation with the jpgs automatically incrementing their stored named.

Note: Currently to generate an animation, the OpenGL 2D window should remain **maximized**. Any changes to the graphic window that are made as the animation is being generated, will cause those screen changes to appear in the outputted jpgs.

Multichannel 2D time slices from 3D volume - unlimited survey size

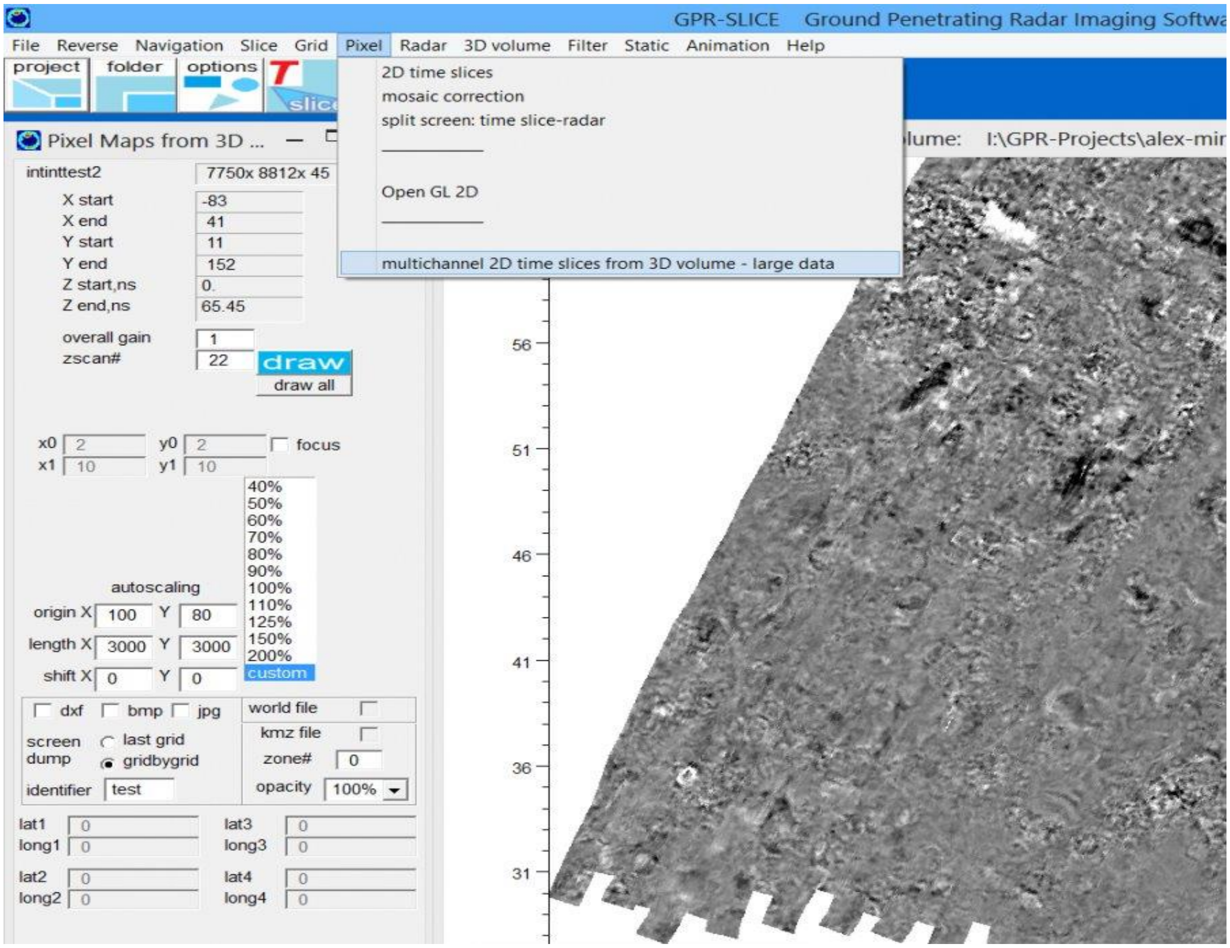
Compilation of the 3D volume from large surveys was limited by the size of the volume. Volume sizes under about 500mb could be handled and generated in the software. Recently, our users at GeoStudi in Italy surveyed an area encompassing 12 hectares that comprised over 9000 radargrams! GPR-SLICE was not equipped to be able to handle these large sites. Not only could the 3D volume not be compiled, there were no options to be able to display such large sites.

New software was written to solve the problems of data compilation of super large sites and for display of super large sites. The enhanced 3D radargram volume generation menus - available to only multichannel users - now can read any size survey and compile this data to a volume. The operations will initially test the size of the survey and if it is greater than 500mb, special disk writing procedures which do not use any array space will automatically be implemented, allowing for unlimited compilation capabilities. However, for these large super sites, because compilation is being written sample-by-sample to the disk and not in blocks, the compilation operations can be upwards of 10-15 times slower than normal speeds.

With the first part of the problem solved – being able to compile super large volumes for large area surveys – the next task at hand was being able to display this large data. A new menu was written that also does not use memory arrays and this is now available. The new menu allows the multichannel user to display any Zscan from a large volume in 2D. An example of a dataset where 5cm cells over a test volume, which is equivalent to 17 hectares, is shown in Figure 5. The volume compiled for this site is 6.2gigabytes! The 2D menu allows only a single Zscan from the volume to be displayed on the screen. Batch buttons however, are available for outputting jpg,/bmp/kmz files from the entire volume, frame-by-frame.

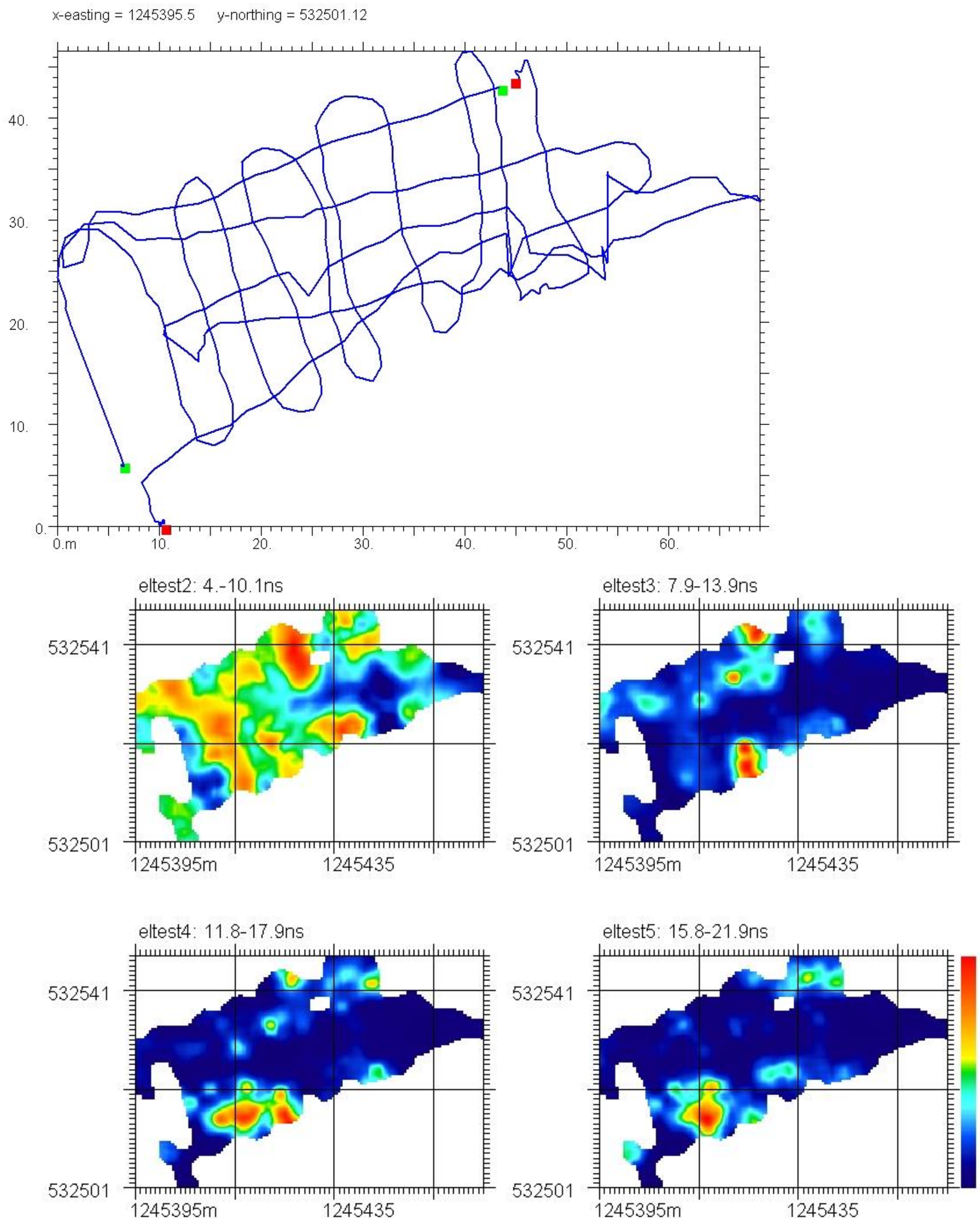
The example site studied in Switzerland with the processing in GPR-SLICE run by Gianluca Catanzaritti from 3D GeoImaging in Italy reported that the 9200 radargram – 12 hectare site could have all data processes run within 15 hours of batch operations! The processing included conversion, 0ns radar editing, spectral whitening, background filtering, Hilbert transform, and 3D volume compilation.

OpenGL Volume menus for such large dataset, to visualize everything real time with isosurface etc, is of course not available at this time. In addition, Overlay Analysis can also be used since this would require memory operations with these large datasets.


GPR-SLICE Ground Penetrating Radar Imaging Softwa
File Reverse Navigation Slice Grid Pixel Radar 3D volume Filter Static Animation Help
project folder options
2D time slices
mosaic correction
split screen: time slice-radar
Open GL 2D
multichannel 2D time slices from 3D volume - large data
Pixel Maps from 3D ...
lume: I:\GPR-Projects\alex-mir
intinttest2
7750x 8812x 45
X start -83
X end 41
Y start 11
Y end 152
Z start,ns 0.
Z end,ns 65.45
overall gain 1
zscan# 22
draw
draw all
x0 2 y0 2 focus
x1 10 y1 10
40%
50%
60%
70%
80%
90%
100%
110%
125%
150%
200%
custom
autoscaling
origin X 100 Y 80
length X 3000 Y 3000
shift X 0 Y 0
dxf bmp jpg
world file
kmz file
screen dump
last grid
gridbygrid
zone# 0
identifier test
opacity 100%
lat1 0
long1 0
lat2 0
long2 0
lat3 0
long3 0
lat4 0
long4 0
56
51
46
41
36
31

GPS-GPR Surveying and Imaging: Introduction

GPR-SLICE was equipped to do 3D imaging from GPR/GPS surveys beginning in 2003. An example plot of the first GPS track and time slices generated in 2003 in the software and published in the SAGEEP (Soc. for the Application of Geophysics and Engineering for Environmental Problems) 2004 proceedings is shown below (data courtesy of Matt Barner, URS Corporation):



Since this first early operation of GPS imaging in the software, many new options over the years to completely automate the process have been added to GPR-SLICE. GPR-SLICE is completely compatible with all the unique GPS formats from Sensors and Software, Mala Geoscience, and GSSI, US Radar, IDS, 3D Radar, Radarteam, Geoscanners and UTSI Electronics as well as SEGY recorded GPS radargrams. GPR-SLICE will take all the raw and unique GPS log files that the major manufacturers generate, and convert these files to GPR-SLICE format. GPR-SLICE will read:

- Sensors and Software *.gps log files and convert these into UTM coordinates and write a standardized GPR-SLICE formatted navigation file called *.dt1.gps used for time slice operations,

- GSSI *.tmf timing files to get the start and end times for a given *.dzt radargram, and then extract the necessary and contemporaneous GPS logging information given in the *.plt, after which a standardized GPR-SLICE formatted navigation file called *.dzt.gps is generated for time slice operations – both Time Stamped and non-Time Stamped log files are converted. GSSI SIR30 has different extension names and formats, e.g. *.dwg files which are read an automatically converted to UTM. These files also have the scan number stored and conveniently given in the native log files which are written into the GPR-SLICE *.dzt.gps log files. *.dzw log files read was also added in 2013.

- Mala Geoscience *.cor or *.gga log files and convert these into UTM coordinates and write a standardized GPR-SLICE formatted navigation file called *.rd3.gps used for time slice operations.

- US Radar *.gps log files and will convert these into UTM coordinates and will write the standardized GPR-SLICE formatted *.rad.gps files.

- IDS *.gps or native *.geox files are imported directly and converted to UTM coordinates to make the *.dt.gps files navigation files

- 3D Radar *.positions.txt or *.nav are read and converted to *.vol.gps files with the standardized GPR-SLICE navigation format.

- UTSI Electronics *.gpt files are read and converted to *.dat.gps files with the standardized GPR-SLICE navigation format.

- Zond or SEGY/2 have the GPS information written into the scan headers which are similar to the SEGY locations. Zond has however has changed the location of the standard SEGY to accommodate higher navigation precision. These location are automatically inserted into the GPR-SLICE written log files.

- GeoScanners *.gsf GPS information is written into the scan headers of these radargrams and this is extracted and placed into the *.gsf.gps navigation files by GPR-SLICE operations.

GPR-SLICE v7.0 uses a 20 column format for GPS files. This 20 column format contains:

> ***Eastings, Northings, Elev(m), Time, scan#, GPS quality, N satellites, HDOP, vector x, vector y, and vector z, + 9 columns for future growth.***

The *.*.gps files are automatically generated by clicking the various manufacturer's buttons in the Edit Info File menu. In most cases, the manufacture has either written the $GPGGA NMEA string or have provided eastings and northings values in their log files. For those manufacturers that only provide the NMEA string, the latitude and longitude are converted to eastings and northing using the WGS – 84 values:

Equatorial_Radius: Semi-Major Axis (WGS-84 value = 6378137.0 meters)
Polar_radius: Semi-Minor Axis (WGS-84 value = 6356752.3142 meters)
Flattening: f = (a-b)/a (WGS-84 value = 0.00335281066475)
First_Eccentricity_Squared: ecc = 2f - (f^2) (WGS-84 value = 0.00669437999013)
Inverse_flattening: Reciprocal Flattening (1/f) (WGS-84 value = 298.257223563)

There are utility buttons in the Edit Info File menu call "SS to UTM" or "Mala to UTM" or "GPS to UTM" where the $GPGGA NMEA strings which contain latitude and longitude information, are automatically converted in GPR-SLICE to UTM coordinates. UTM coordinates are much more useful for processing then latitude and longitude, because the actual absolute ranges in metric units in east and north are assigned.

The scan # does not necessarily have to be written into the file. If there are no skipped GPS readings – e.g. no GPS fallout - and the readings are all equidistant in time and/or spatially equidistant in scan number across the radargrams, then the Artificial Markers can (and must) be used to generate the navigation tags across the radargrams. If there are fallouts or the GPS readings are not equidistant in scan # across the radargrams, the GPS Trace # process in Marker menu to extract the scan # from the GPS files **must** be used for navigation. In this case, the scan # must exist in the 5th column.

Sensors and Software, Mala Geoscience, US Radar, Geoscanners and Radarteam for example currently output the scan #. Having the scan # associated with each GPS reading insures the best and most accurate navigation. Some users are finding customized solutions to generate the GPR/GPS files particularly for older equipment that was not set up to do GPR/GPS collection automatically.

As a review, the two possible navigation steps that are unique to creating a time slice from GPS navigated data are:

a) run the Artificial Marker process in the MARKER menu to place navigation tags equidistantly across the radargram corresponding to the total number of GPS recorded and when the corresponding scan number is not known

b) run the GPS Trace # process if GPS navigation has been recorded with the corresponding scan number.

After applying the navigation, the dataset then goes through the normal operation followed in the Slice/Resample menu. One special note, if the user slices the data with a bins per mark in the SLICE menu of 2, then the XYZ dataset will be comprised of averaged readings made twice between GPS readings. If the GPS data were collected for instance every 1 second, then a bins per mark of 2 would mean the data are binned every ½ second. If the data were gathered based on the survey wheel, say every meter on the ground, then a value of 2 would correspond to making 2 time slice parameters between consecutive GPS readings on the survey wheel at ½ meter. The user will need to decide what is a reasonable spatial sampling along the GPS radargram and this is done with the cut per mark setting.

GPR-SLICE is capable of handling any density of recording of GPS readings. GPS log files with NMEA or log information collected on every recorded scan – or for navigation logged on some regular or random place along the recorded scan are all handled within the software properly.

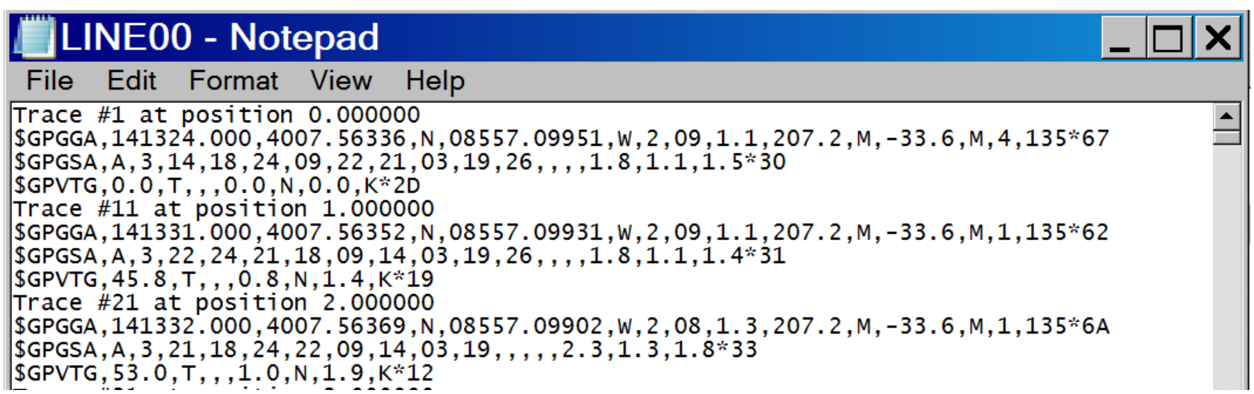
With this basic information, it is useful to review examples of GPR/GPS imaging using each of the major manufacturer's datasets. We would like to extend are thanks to: Allen Gontz of the University of

Massachusetts for providing the Mala Geoscience dataset, Amzie Wenning of the Indiana Geological Survey for providing the Sensors and Software dataset, Andy Kathage for allowing us to use the GSSI GPR/GPS dataset, Ron LaBarca of US Radar for SPR Seeker equipment, Egil Eide from 3D Radar of Norway for *.vol data, and Erica Utsi for the UTSI Electronic GPR system of the UK.

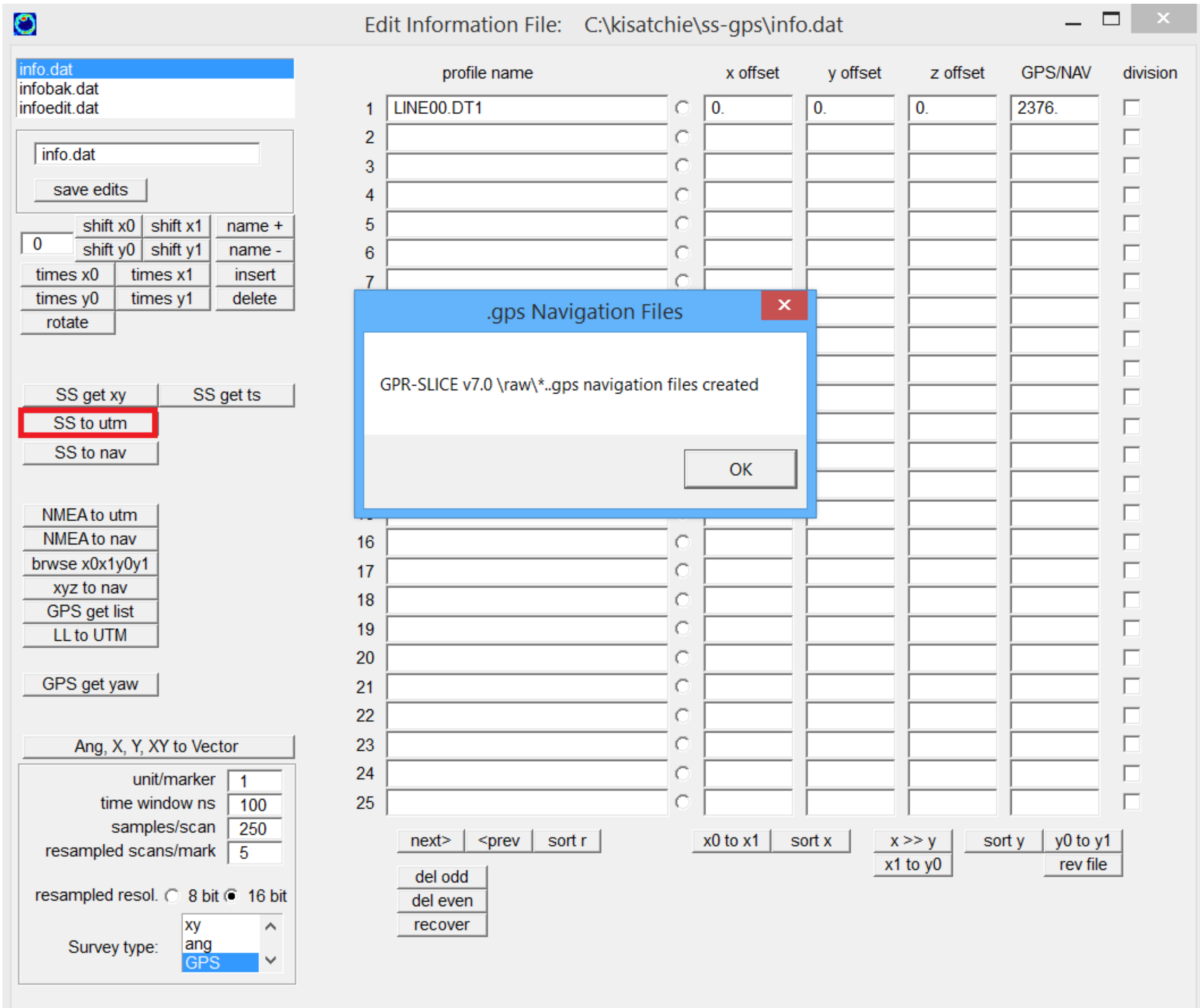
Sensors and Software GPS Navigation

Purpose: To introduce how Sensors and Software GPS surveys are integrated into GPR-SLICE software and to show all the steps from using raw GPS tracks to creating time slice datasets.

Basic Information: With every Sensors and Software GPR/GPS survey, a GPS log file with the extension *.gps is created for every radargram. This log file which must reside in the \raw\ folder of a project contains the trace # (in GPR-SLICE referred to as the scan #) followed by a NMEA string.

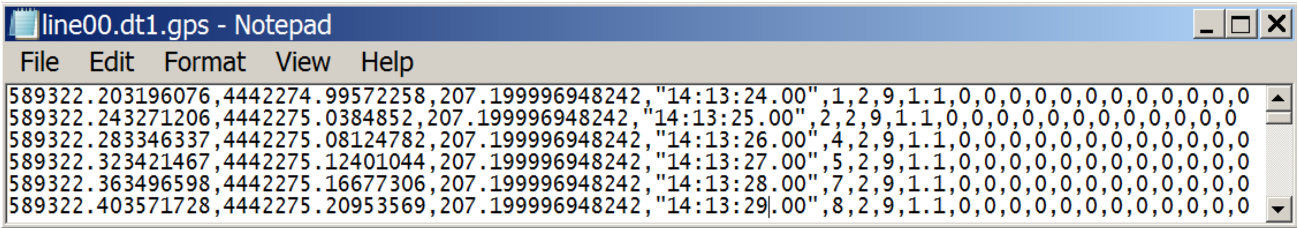


In this example log file for one radargram, every 10 traces and its corresponding NMEA strings are given. There are various NMEA strings available; however, GPR-SLICE uses the GPGGA one for navigation operations. To convert this file to GPR-SLICE format, various quick utility buttons are available in the Edit Info File menu. For this Sensors and Software example GPS dataset, the user will click on the SS to UTM button in the Edit Info File menu (shown in the next menu screen shot). The SS to UTM button will convert the entire *.gps log file for each radargram and generate a *.dt1.gps file which is a 20 column format and is:

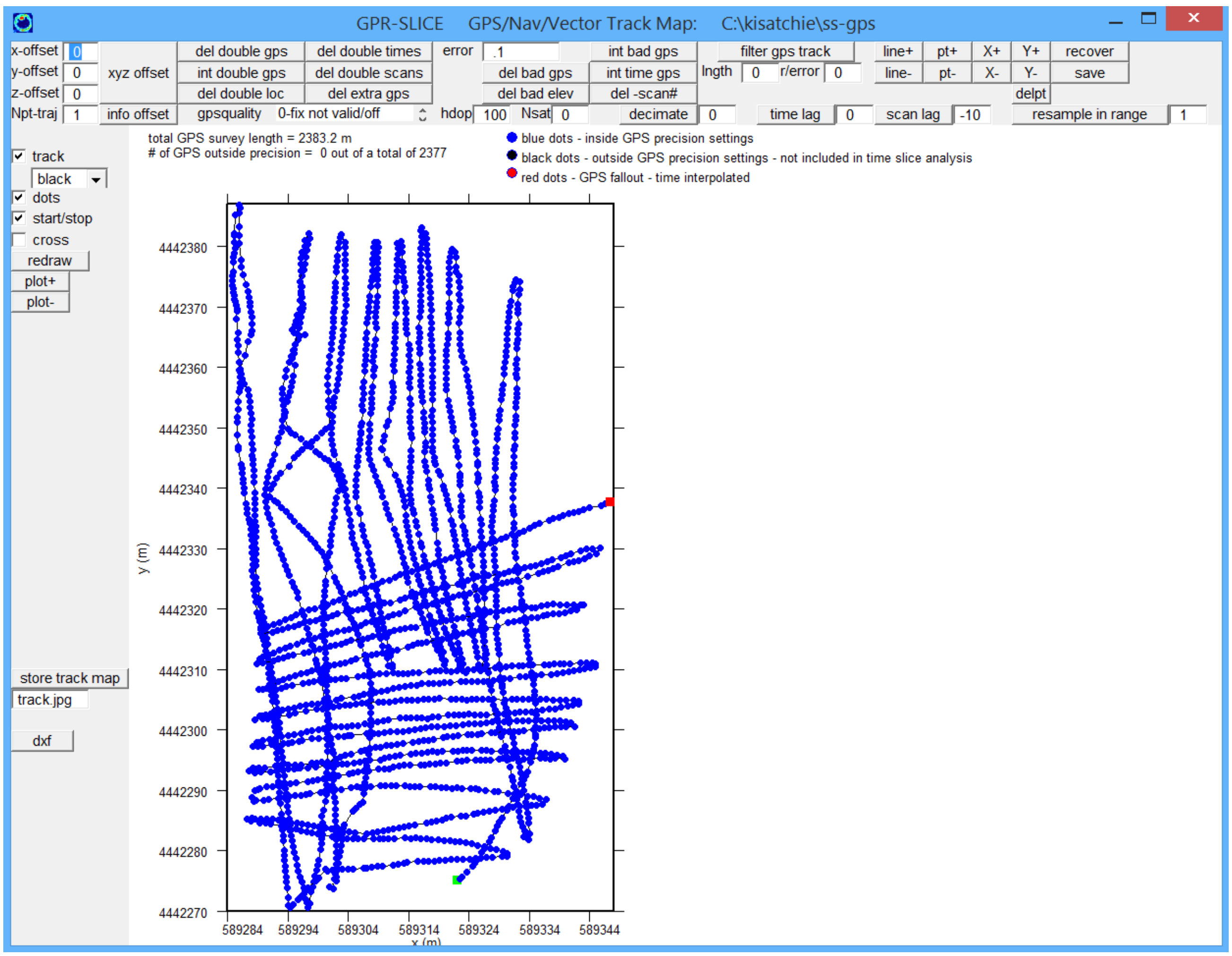


Eastings, Northings, Elev(m), "time", Scan#, GPSquality, Nsatellites, HDOP, vector x, vector y, vector z, + 9 reserved columns

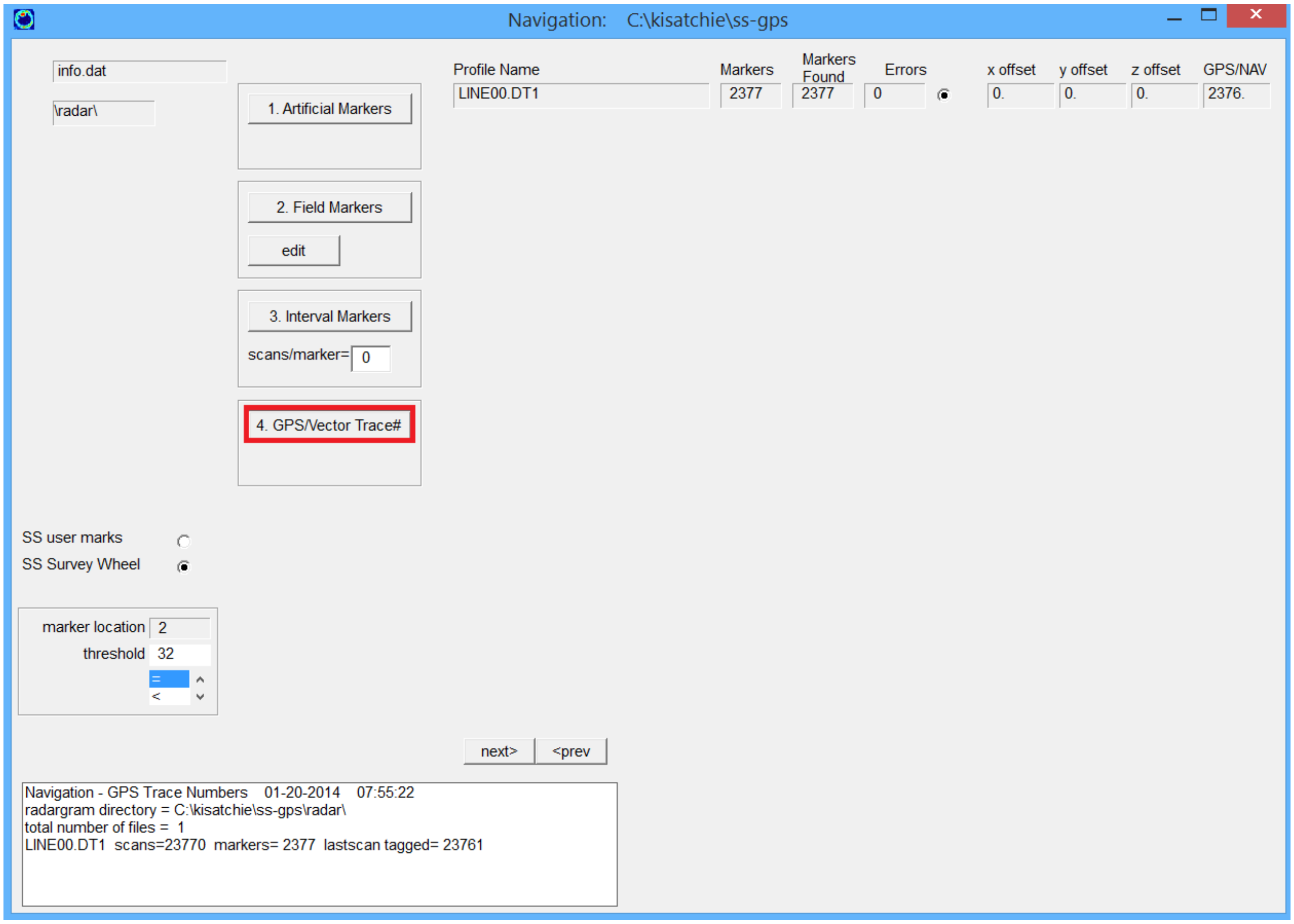
GPR-SLICE reads the GPGGA NMEA string and converts the latitude and longitude to UTM. The number of GPS listings in the log file that are converted are store in the 4th column of the information file. In this example 2376 GPS readings are compiled. (The actual number is 2377 for marker navigation). An example of the *.dt1.gps file which is written into the \raw\ folder of the project and showing the 20 column navigation file is given:

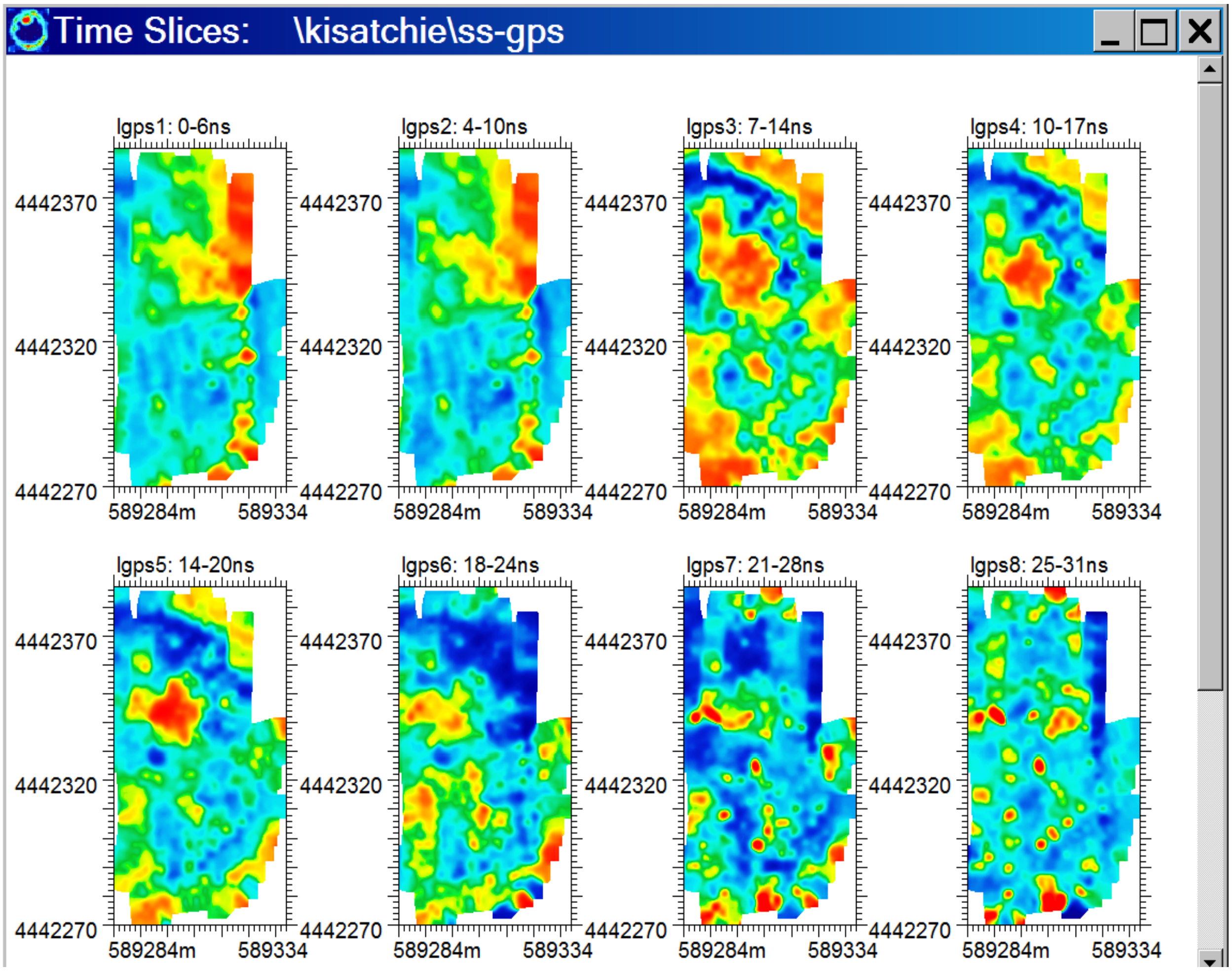


The \ss-gps\ example is a single continue GPR/GPS survey in which only one radargram was collected over a site at the Indiana Purdue University Strawtown Archaeological site. The GPS track is shown below:



To continue GPR-SLICE processing with this dataset, one continues to the Navigation menu, then uses the option GPS Trace # navigation option (see next screen shot). The GPS Trace # operation, will read the *.dt1.gps files and extract the 5th column scan # as the location where navigation markers are located and where navigation exists. After this, the user continues on to do normal slice/resample operations. An example of some 2D time slices for this site is also shown in a screen shot following.

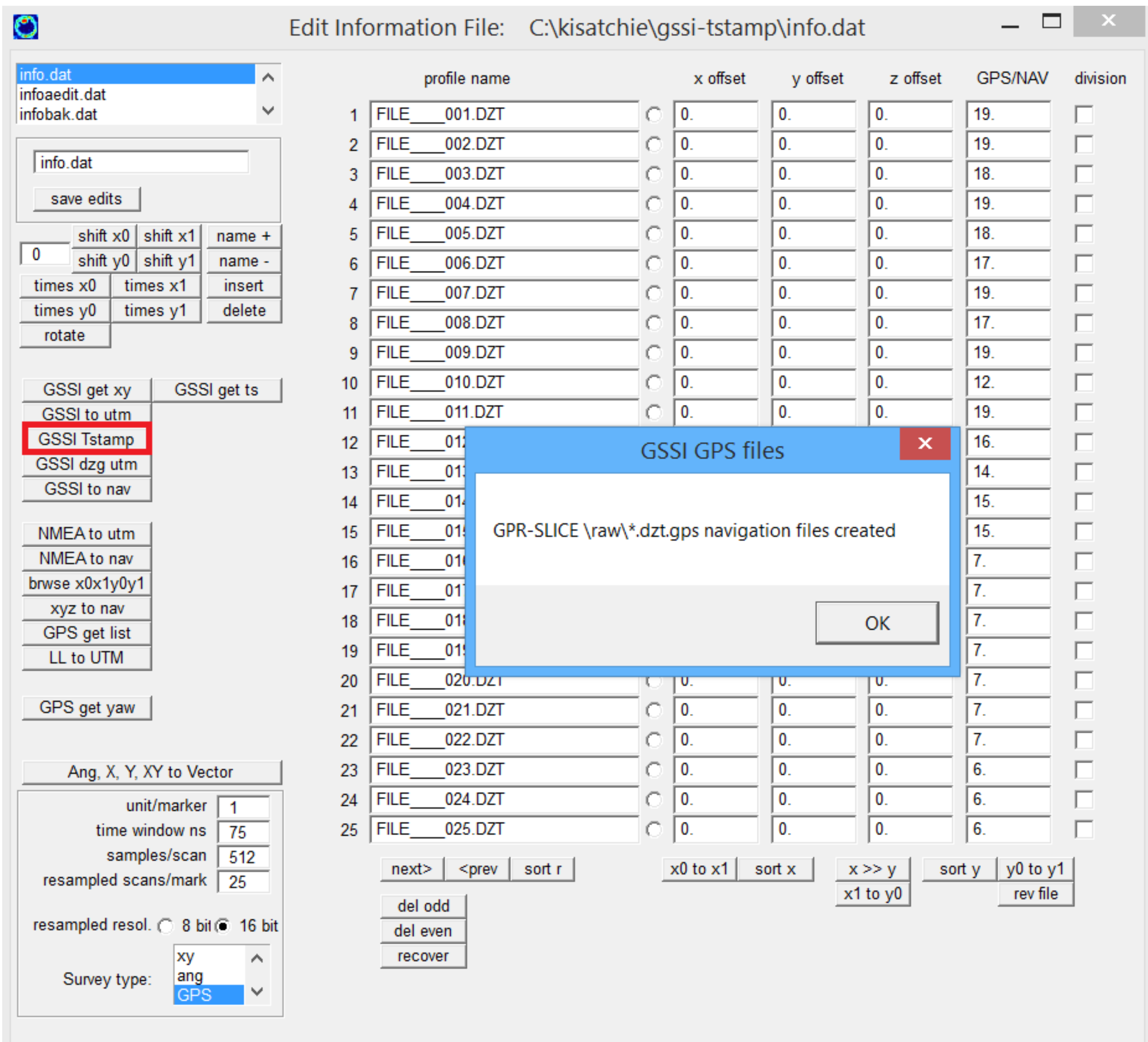


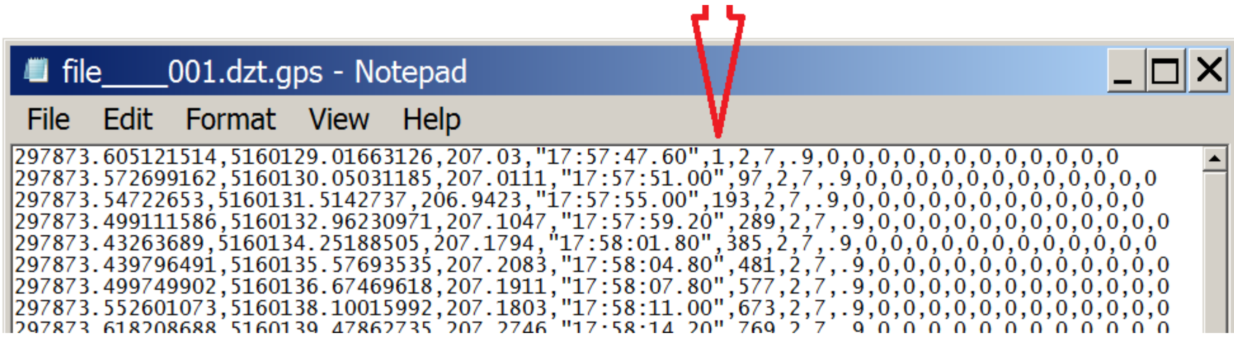


GSSI (SIR 3000) – Time Stamp - Method 2 – GPS Navigation

Purpose: To introduce how GSSI GPR/GPS surveys are integrated into GPR-SLICE v7.0 software and to show all the steps from using raw GPS tracks to creating time slice datasets. This method is the recommended method when time stamps are recorded in the TMF file.

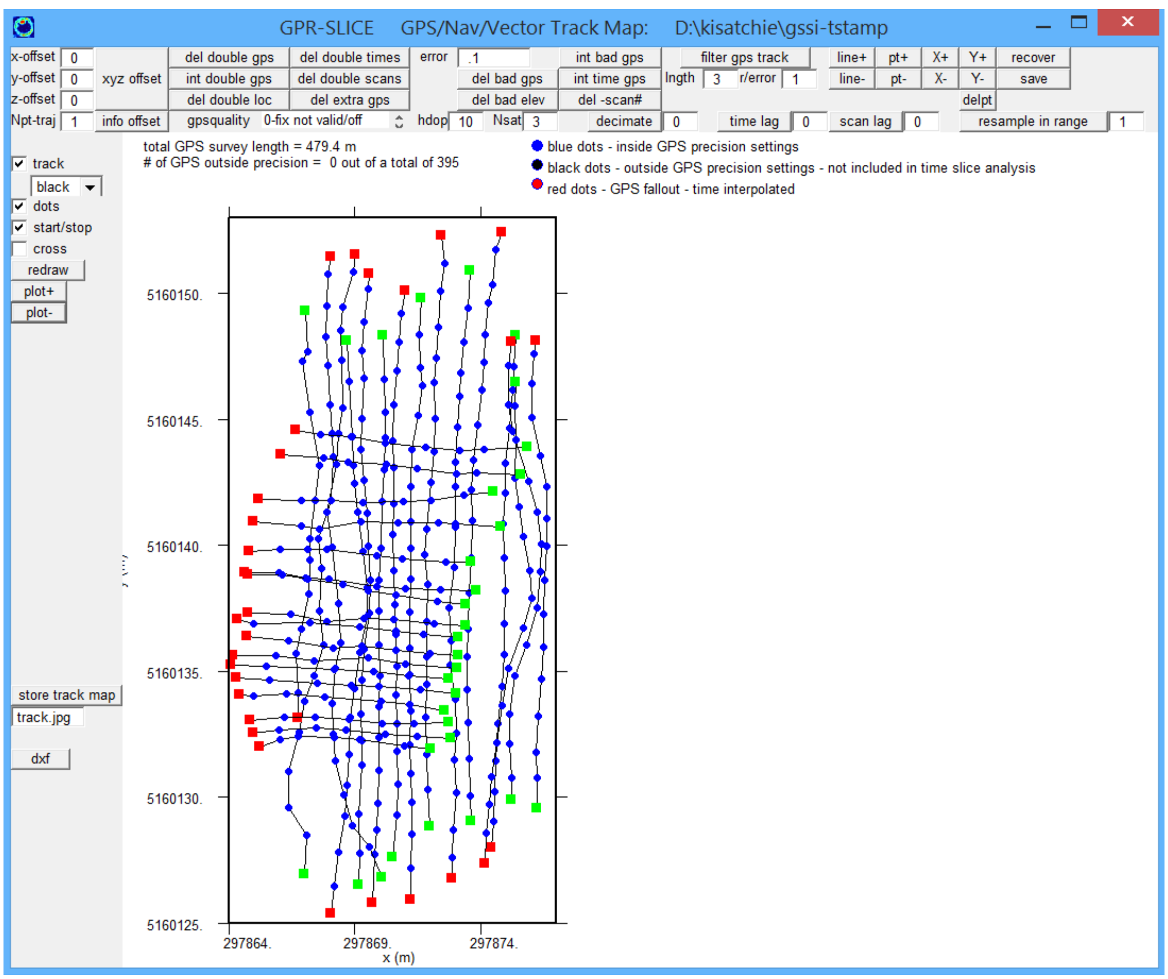
Basic Information: With every GSSI GPR/GPS survey, 2 GPS log files, a *.plt file and a *.tmf extension is created for every radargram. The *.tmf file contains timing information when the radargram started and stopped. GPS log files here are also recorded with time stamps that are stored in the *.tmf file. The time stamps are read and converted to corresponding scan numbers. The locations of the time stamped scans are then found between two neighboring NMEA strings reading their times. The time stamped scan's lat/long/elevation are read and linearly interpolated between the two bordering NMEA strings. The operation GSSI Tstamp will do all the UTM conversions, linear interpolations between bordering NMEA strings and will compile the *.dzt.gps files. An example of the button operation is shown below:



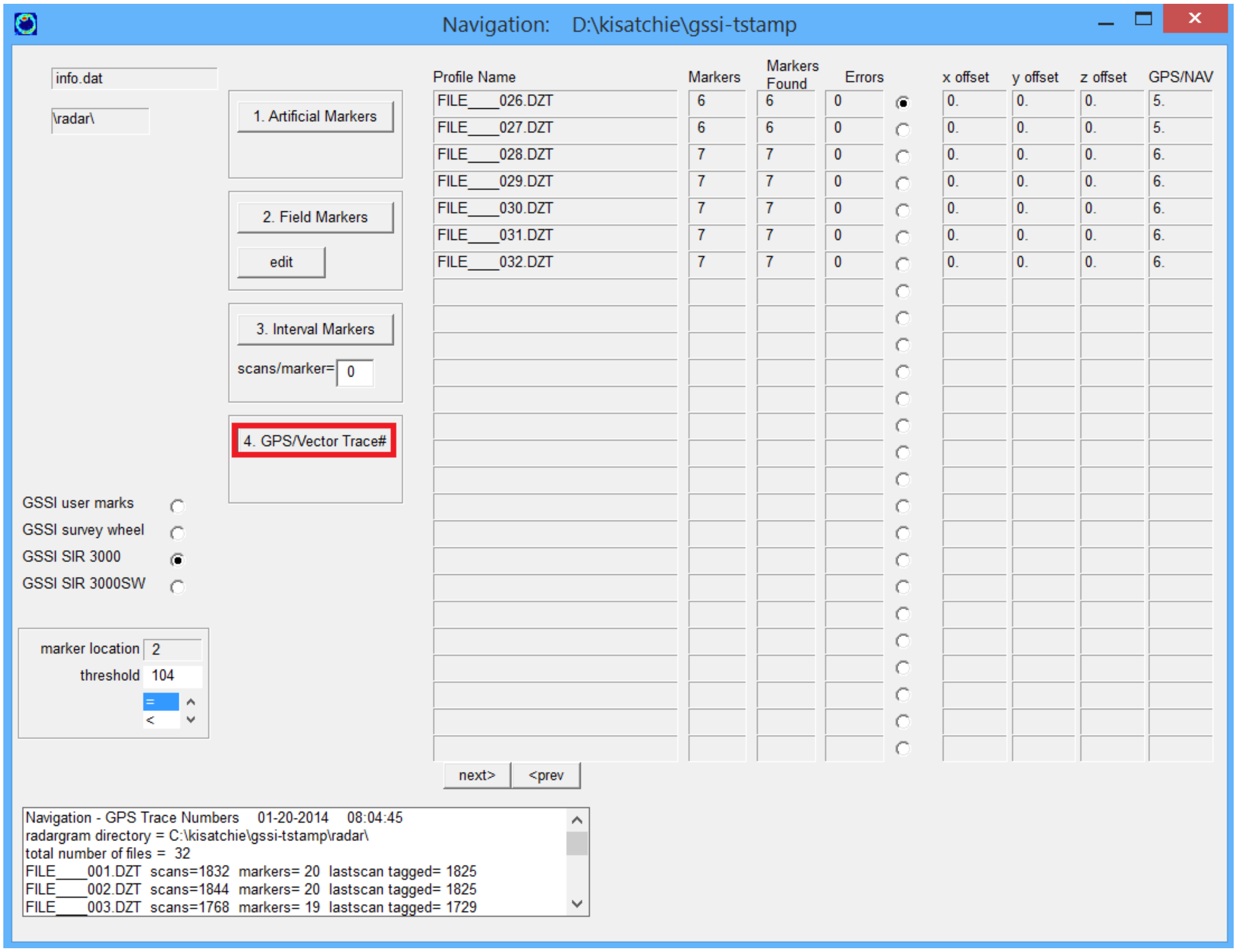


An example of the *.dzt.gps file generated is shown above. The key operation with the GSSI Tstamp button is that the scan numbers associated with the converted UTM readings is stored in the 5th column of the navigation files! This provides the best possible navigation and most accurate navigation when time stamps are recorded.

The GPS track map associated with this dataset is shown in the next diagram:



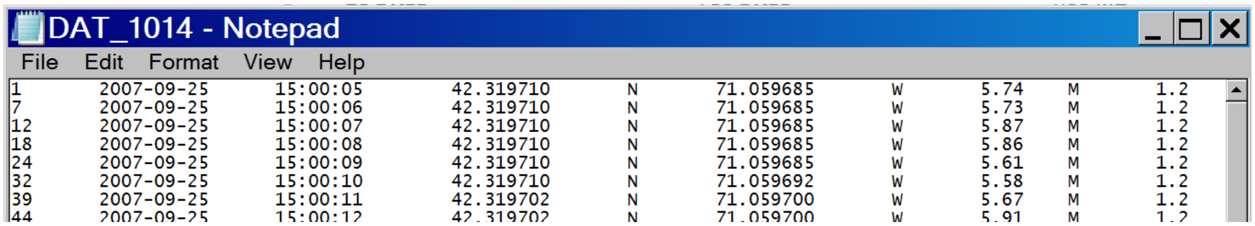
It is critical with the GSSI Tstamp that navigation **option #4: GPS/Vector Trace #** is used.



MALA Geoscience GPS Navigation

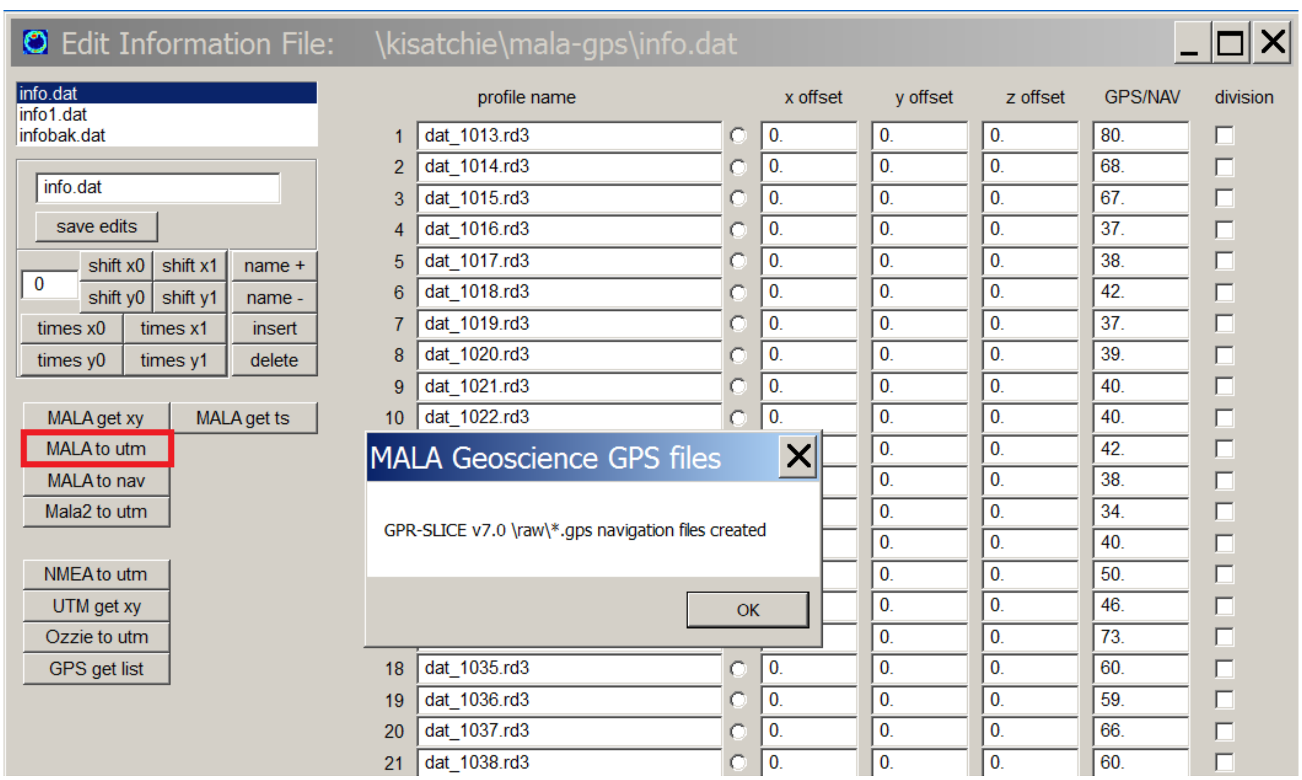
Purpose: To introduce how MALA Geoscience GPR/GPS surveys are integrated into GPR-SLICE v7.0 software and to show the essential steps from using raw GPS tracks to creating time slice datasets. Also to show the options for doing basic filtering of GPS tracks.

Basic Information: With every MALA GPR/GPS survey, a *.cor GPS log files is created for every radargram. An example of a *.cor file which resides in the \raw\ folder is shown:

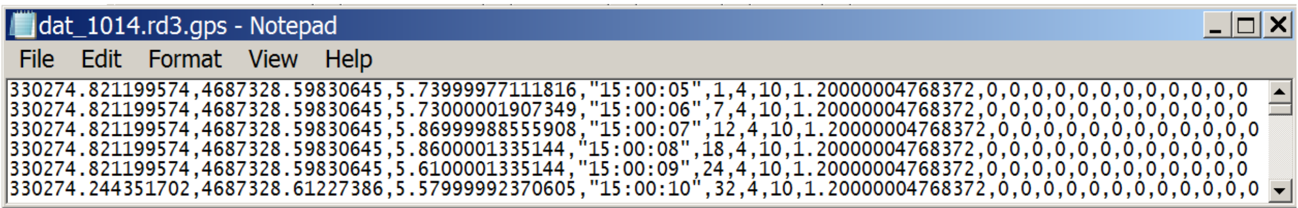


1	2007-09-25	15:00:05	42.319710	N	71.059685	W	5.74	M	1.2
7	2007-09-25	15:00:06	42.319710	N	71.059685	W	5.73	M	1.2
12	2007-09-25	15:00:07	42.319710	N	71.059685	W	5.87	M	1.2
18	2007-09-25	15:00:08	42.319710	N	71.059685	W	5.86	M	1.2
24	2007-09-25	15:00:09	42.319710	N	71.059685	W	5.61	M	1.2
32	2007-09-25	15:00:10	42.319710	N	71.059692	W	5.58	M	1.2
39	2007-09-25	15:00:11	42.319702	N	71.059700	W	5.67	M	1.2
44	2007-09-25	15:00:12	42.319702	N	71.059700	W	5.91	M	1.2

The *.cor file contains the scan # in the first column along with the date, time, latitude, longitude, elevation and other information. Clicking the Mala to UTM button in the Edit Info File menu will generate a *.rd3.gps files containing the converted 20 column standard format file with UTM used for GPR-SLICE processing:



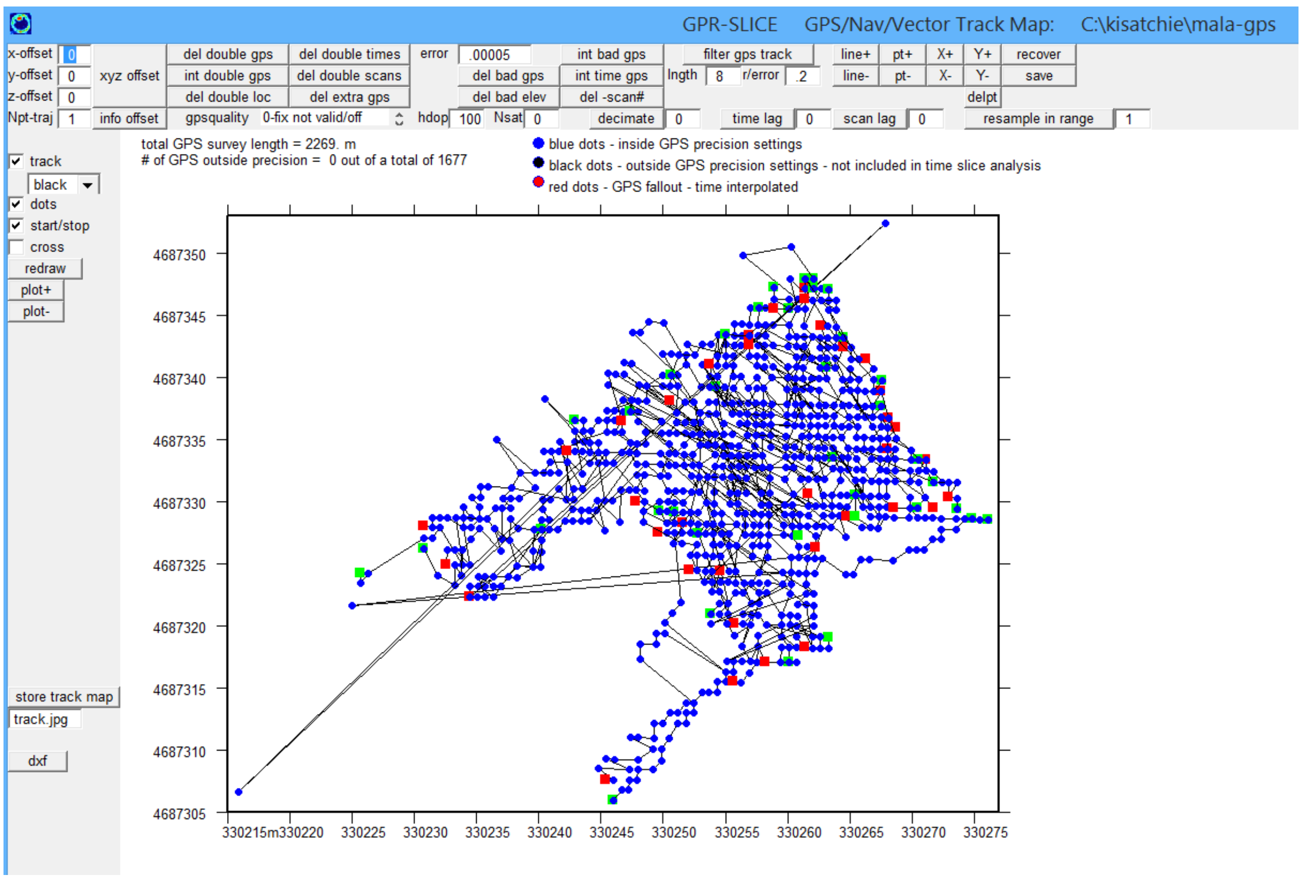
An example of a *.rd3.gps file generated for GPS processing in GPR-SLICE is shown:


dat_1014.rd3.gps - Notepad

File Edit Format View Help

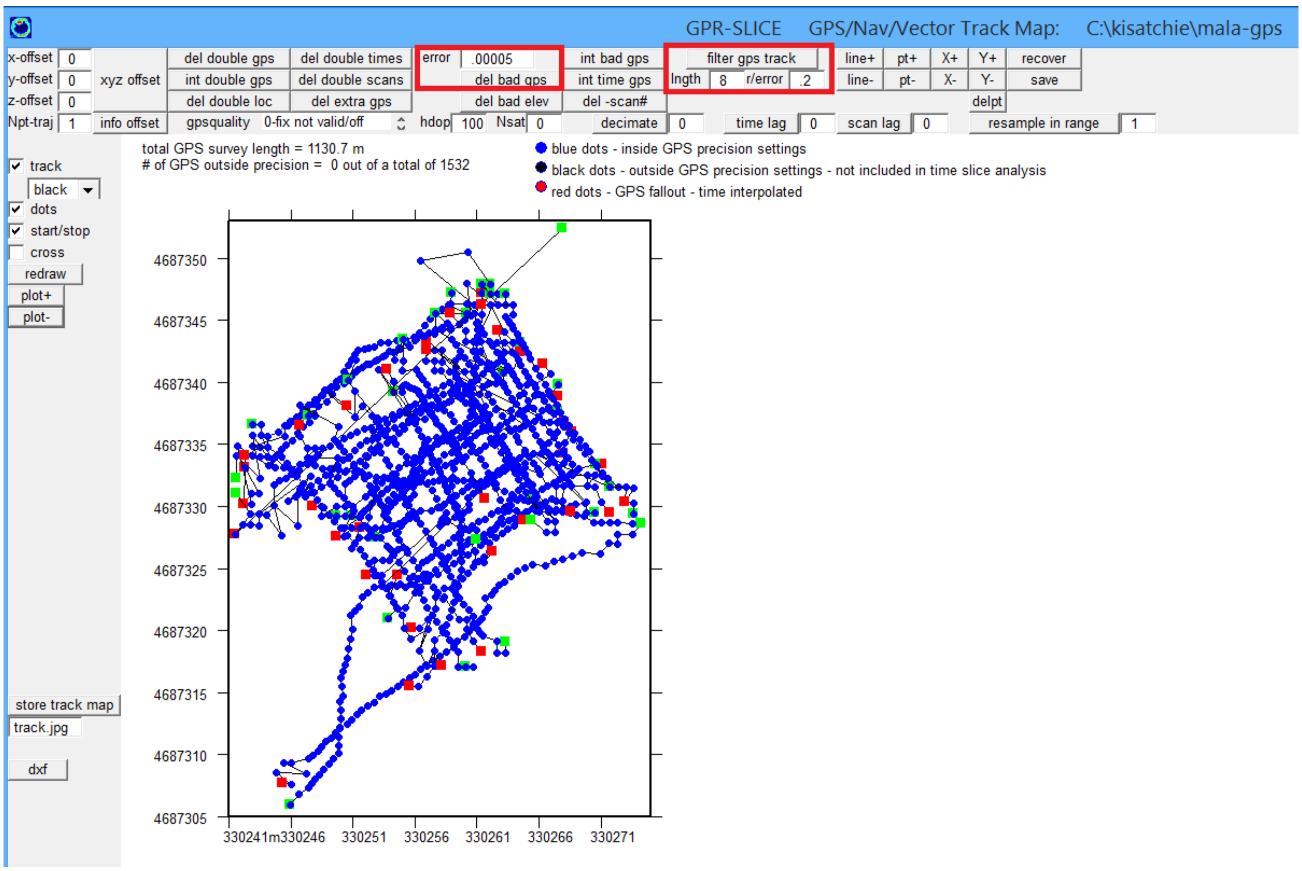
```
330274.821199574,4687328.59830645,5.73999977111816,"15:00:05",1,4,10,1.20000004768372,0,0,0,0,0,0,0,0,0,0,0,0,0
330274.821199574,4687328.59830645,5.73000001907349,"15:00:06",7,4,10,1.20000004768372,0,0,0,0,0,0,0,0,0,0,0,0,0
330274.821199574,4687328.59830645,5.86999988555908,"15:00:07",12,4,10,1.20000004768372,0,0,0,0,0,0,0,0,0,0,0,0,0
330274.821199574,4687328.59830645,5.8600001335144,"15:00:08",18,4,10,1.20000004768372,0,0,0,0,0,0,0,0,0,0,0,0,0
330274.821199574,4687328.59830645,5.6100001335144,"15:00:09",24,4,10,1.20000004768372,0,0,0,0,0,0,0,0,0,0,0,0,0
330274.244351702,4687328.61227386,5.57999992370605,"15:00:10",32,4,10,1.20000004768372,0,0,0,0,0,0,0,0,0,0,0,0,0
```

The corresponding GPS track map for this dataset is:



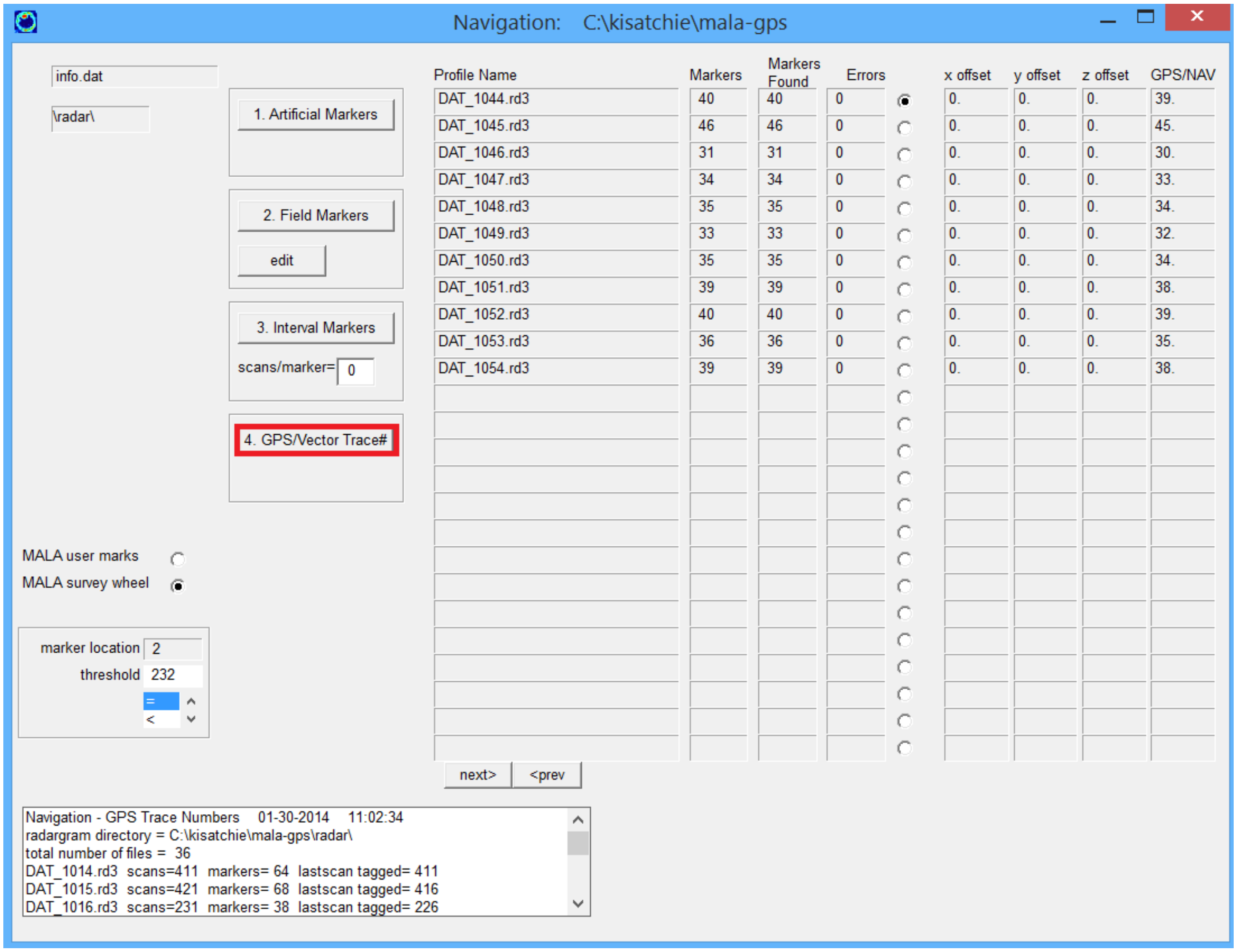
This GPS track map shows some error in ground locations, and this was a result of the accuracy of the number of latitude and longitude decimals outputted in the raw GPS log *.cor file for this over-the-counter grade GPS unit. (Much higher quality GPS equipment should normally be configured with the GPR system to get the most accuracy in subsurface imaging – preferably RTK GPS). This track can be filtered by choosing an appropriate error to Del Bad Points as shown in the next screen shot.

Reducing the acceptable error below this will begin to remove some good points. Where to stop the error process may be left up to the user to determine the acceptable track errors for imaging. After bad points are removed, one can continue to do navigation and the slice/resample operations normally. The track can also be smoothed using the Filter GPS Track operation. This has a length setting which is the number of GPS points to have a running average; if the error is above the set r/error then the moving average will replace the local GPS point. The following figure has both wayward points and filtering applied:

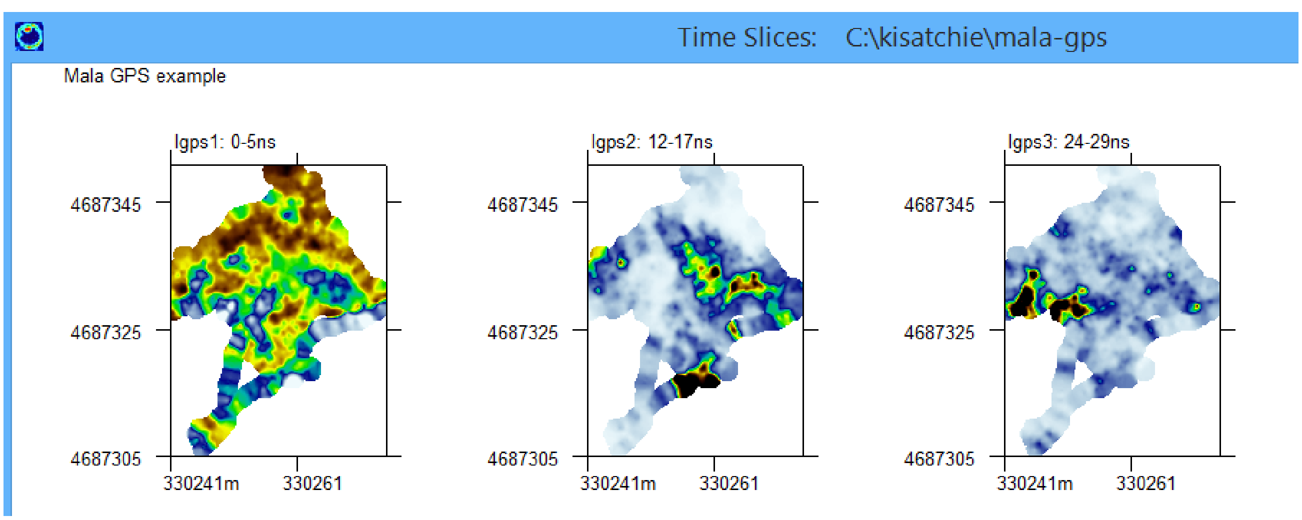


A complete description of GPS track filtering options is given in the next section.

Because MALA GPR/GPS *.rd3.gps files have the scan number in the 5th column, the GPS Trace # navigation option should be used to continue the slicing process:



Example of MALA GPR/GPS 2D time slices are given in the following image using the filter GPS track:



IDS GPS Navigation

Purpose: To introduce how IDS GPR/GPS surveys are integrated into GPR-SLICE v7.0 software.

Basic Information: With every IDS GPR/GPS survey a *.gps log file should exist for every radargram. An example of an ID raw gps log file is shown below:

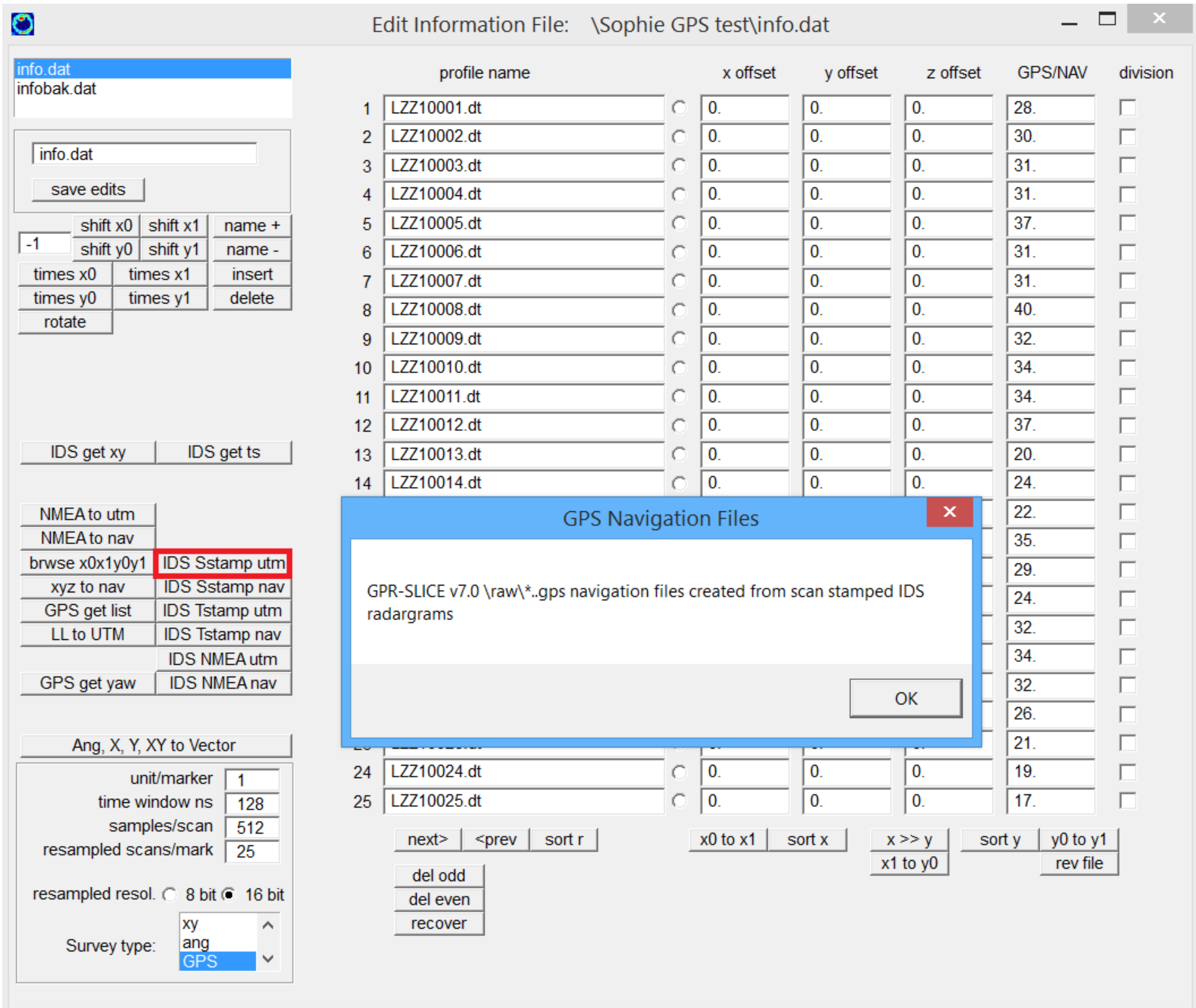
LZZ10046.GPS - Notepad

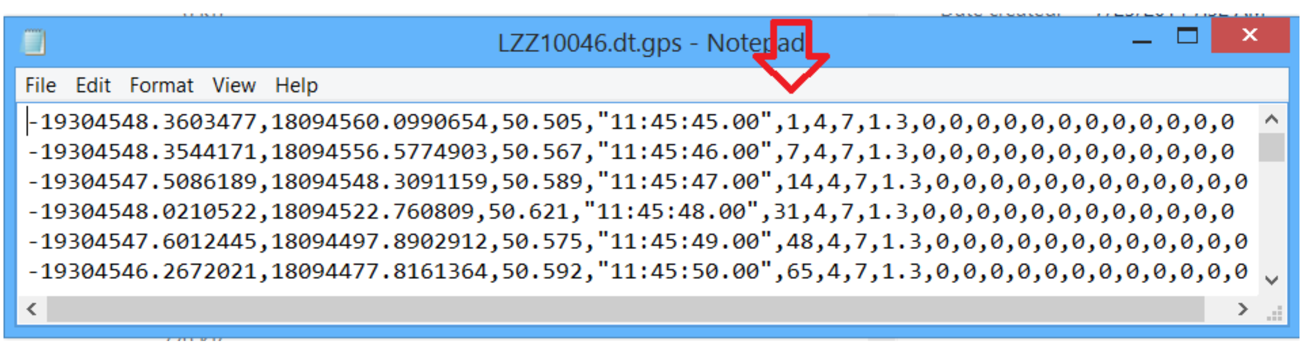
```
$GPGGA,114545.00,5209.76053118,N,00816.65447586,W,4,7,1.3,50.505,M,57.833,M,1.0,0023*5E
$GPGGA,114546.00,5209.76060350,N,00816.65446613,W,4,7,1.3,50.567,M,57.833,M,1.0,0023*59
$GPGGA,114547.00,5209.76077478,N,00816.65450641,W,4,7,1.3,50.589,M,57.833,M,1.0,0023*53
$GPGGA,114548.00,5209.76129846,N,00816.65439367,W,4,7,1.3,50.621,M,57.833,M,1.0,0023*58
$GPGGA,114549.00,5209.76180988,N,00816.65435363,W,4,7,1.3,50.575,M,57.833,M,1.0,0023*53
$GPGGA,114550.00,5209.76222444,N,00816.65439683,W,4,7,1.3,50.592,M,57.833,M,1.0,0023*53
```

The log file is a standard NMEA string without any scan number information written into the file. IDS currently places navigation tags on the 2nd sample in the raw radargrams. To assign the GPS to their associated NMEA string the button IDS SScanStamp is available in the Edit Info File menu as seen in the next Figure. The IDS ScanStamp button will search out the 2nd sample to find the tagged scans and then it will write this into the 5th column of the *.dt1.gps files that GPR-SLICE makes (see screen shot next page).

Note: If the total number of listings in the GPS files does NOT agree with the number of tagged scans in the radargram, a message warning will come to the screen to inform the user that there are missing or too many tags in the radargram etc.

Note: The user should use the GPS/Vector Trace # navigation option in the Navigation Menu since the IDS GPS solution has unique scan numbers assigned to the recorded GPS.

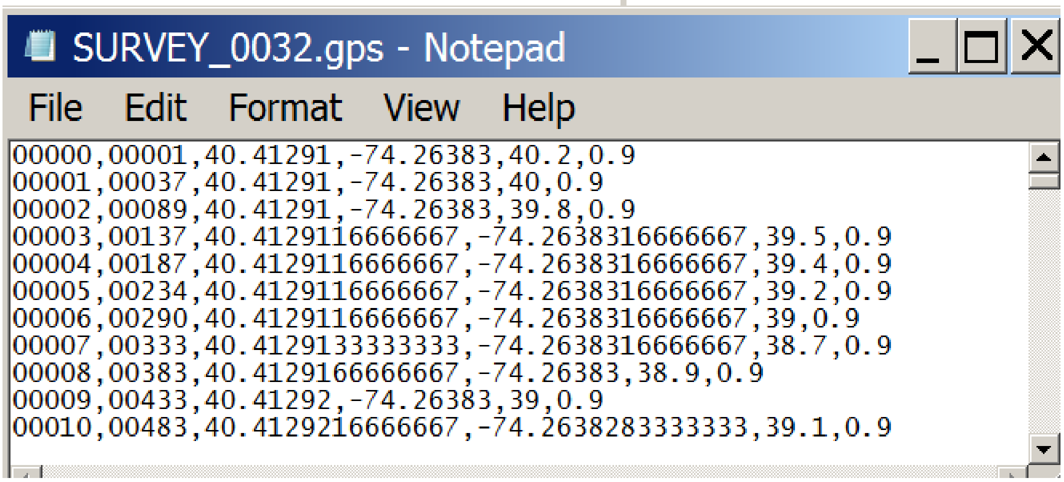

Edit Information File: \Sophie GPS test\info.dat
info.dat
infobak.dat
save edits
shift x0 shift x1 name +
shift y0 shift y1 name -
times x0 times x1 insert
times y0 times y1 delete
rotate
IDS get xy IDS get ts
NMEA to utm
NMEA to nav
brwse x0x1y0y1 IDS Sstamp utm
xyz to nav IDS Sstamp nav
GPS get list IDS Tstamp utm
LL to UTM IDS Tstamp nav
IDS NMEA utm
GPS get yaw IDS NMEA nav
Ang, X, Y, XY to Vector
unit/marker 1
time window ns 128
samples/scan 512
resampled scans/mark 25
resampled resol. 8 bit 16 bit
Survey type: xy ang GPS
profile name x offset y offset z offset GPS/NAV division
GPS Navigation Files
GPR-SLICE v7.0 \raw*..gps navigation files created from scan stamped IDS radargrams
OK
next> <prev sort r x0 to x1 sort x x >> y x1 to y0 sort y y0 to y1 rev file
del odd
del even
recover


LZZ10046.dt.gps - Notepad
File Edit Format View Help
-19304548.3603477,18094560.0990654,50.505,"11:45:45.00",1,4,7,1.3,0,0,0,0,0,0,0,0,0,0,0,0
-19304548.3544171,18094556.5774903,50.567,"11:45:46.00",7,4,7,1.3,0,0,0,0,0,0,0,0,0,0,0,0
-19304547.5086189,18094548.3091159,50.589,"11:45:47.00",14,4,7,1.3,0,0,0,0,0,0,0,0,0,0,0,0
-19304548.0210522,18094522.760809,50.621,"11:45:48.00",31,4,7,1.3,0,0,0,0,0,0,0,0,0,0,0,0
-19304547.6012445,18094497.8902912,50.575,"11:45:49.00",48,4,7,1.3,0,0,0,0,0,0,0,0,0,0,0,0
-19304546.2672021,18094477.8161364,50.592,"11:45:50.00",65,4,7,1.3,0,0,0,0,0,0,0,0,0,0,0,0

US Radar GPS Navigation

Purpose: To introduce how US Radar GPR/GPS surveys are integrated into GPR-SLICE v7.0 software.

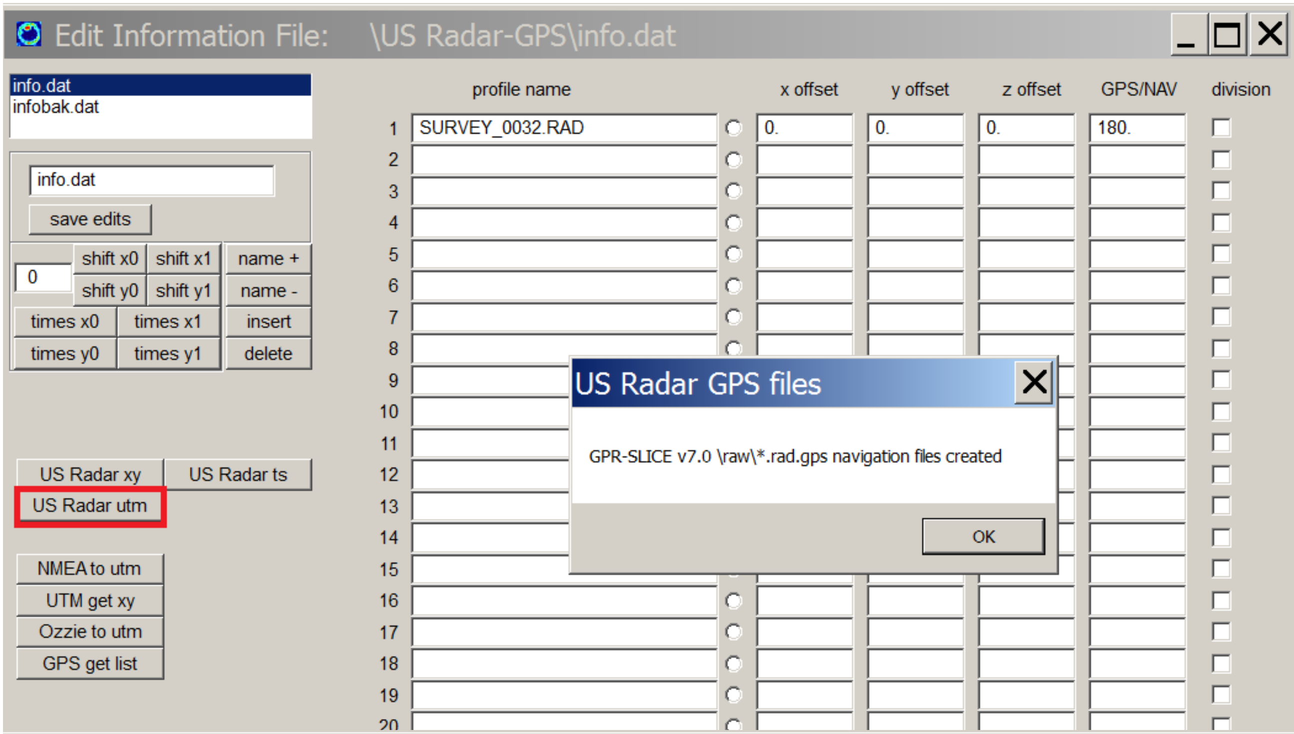
Basic Information: With every US Radar GPR/GPS survey, a *.gps log files is created for every radargram. An example of a US Radar raw gps log file is shown below

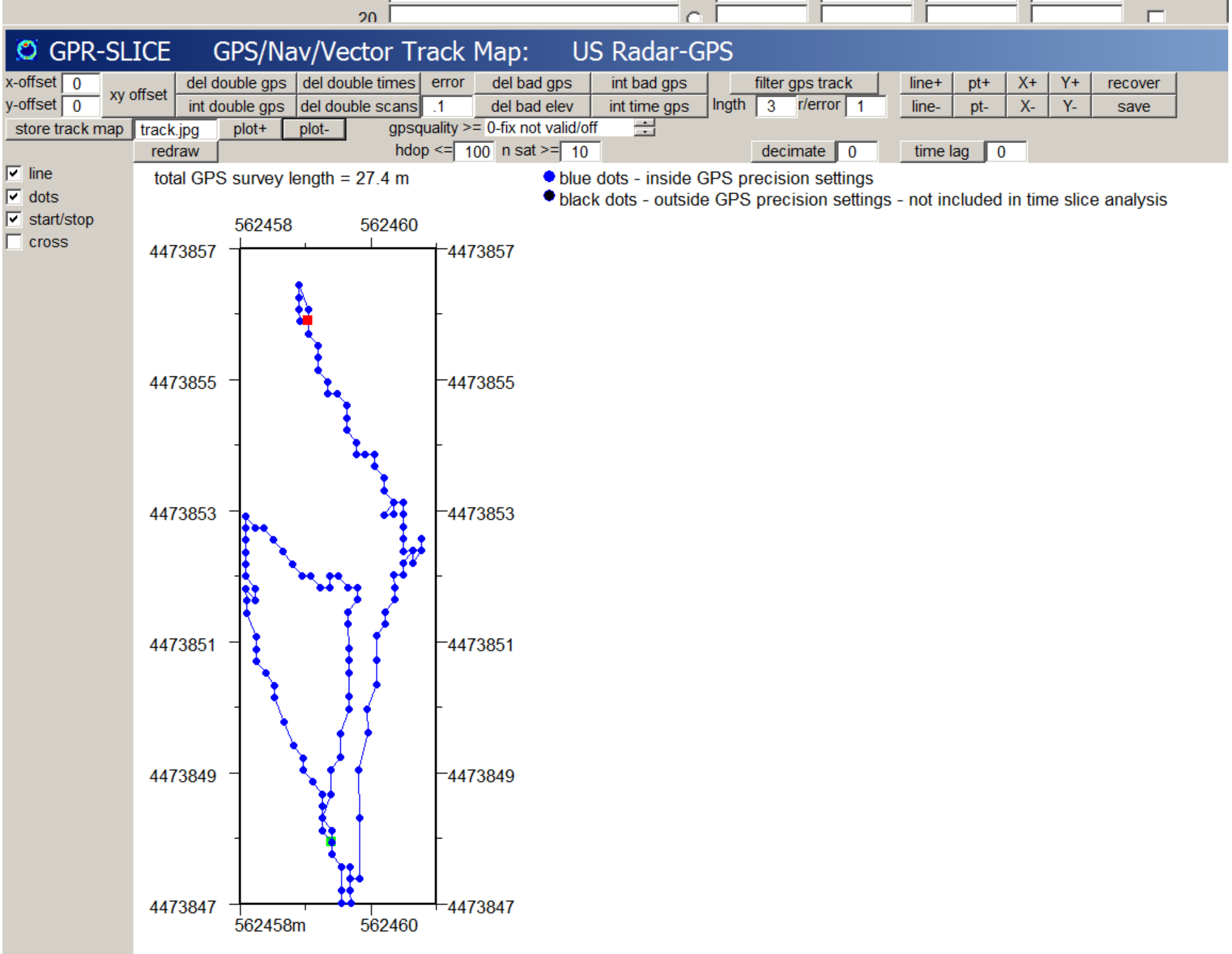



```
00000,00001,40.41291,-74.26383,40.2,0.9
00001,00037,40.41291,-74.26383,40,0.9
00002,00089,40.41291,-74.26383,39.8,0.9
00003,00137,40.4129116666667,-74.2638316666667,39.5,0.9
00004,00187,40.4129116666667,-74.2638316666667,39.4,0.9
00005,00234,40.4129116666667,-74.2638316666667,39.2,0.9
00006,00290,40.4129116666667,-74.2638316666667,39,0.9
00007,00333,40.4129133333333,-74.2638316666667,38.7,0.9
00008,00383,40.4129166666667,-74.26383,38.9,0.9
00009,00433,40.41292,-74.26383,39,0.9
00010,00483,40.4129216666667,-74.2638283333333,39.1,0.9
```

The log files have the reading #, the scan #, and the latitude and longitude, the elevation, and the HDOP listed. These data are converted to GPR-SLICE format using the US Radar to UTM button in the Edit Info File menu (shown in diagram on the next page). This button will do the UTM conversion for the latitude and longitude as well as place the scan # in this log file into the 5th column of the *.rad.gps files generated by GPR-SLICE. Because the 5th column has the scan # associated with the GPS reading, the user should use the GPS Vector/Trace# navigation option in the Navigation pulldown menu. (An example of a GPS track from this equipment is also shown in a following diagram on the next page).

Note: This manufacturer is still in the development of GPS integration and their log file may have changed at the time of this manual update.

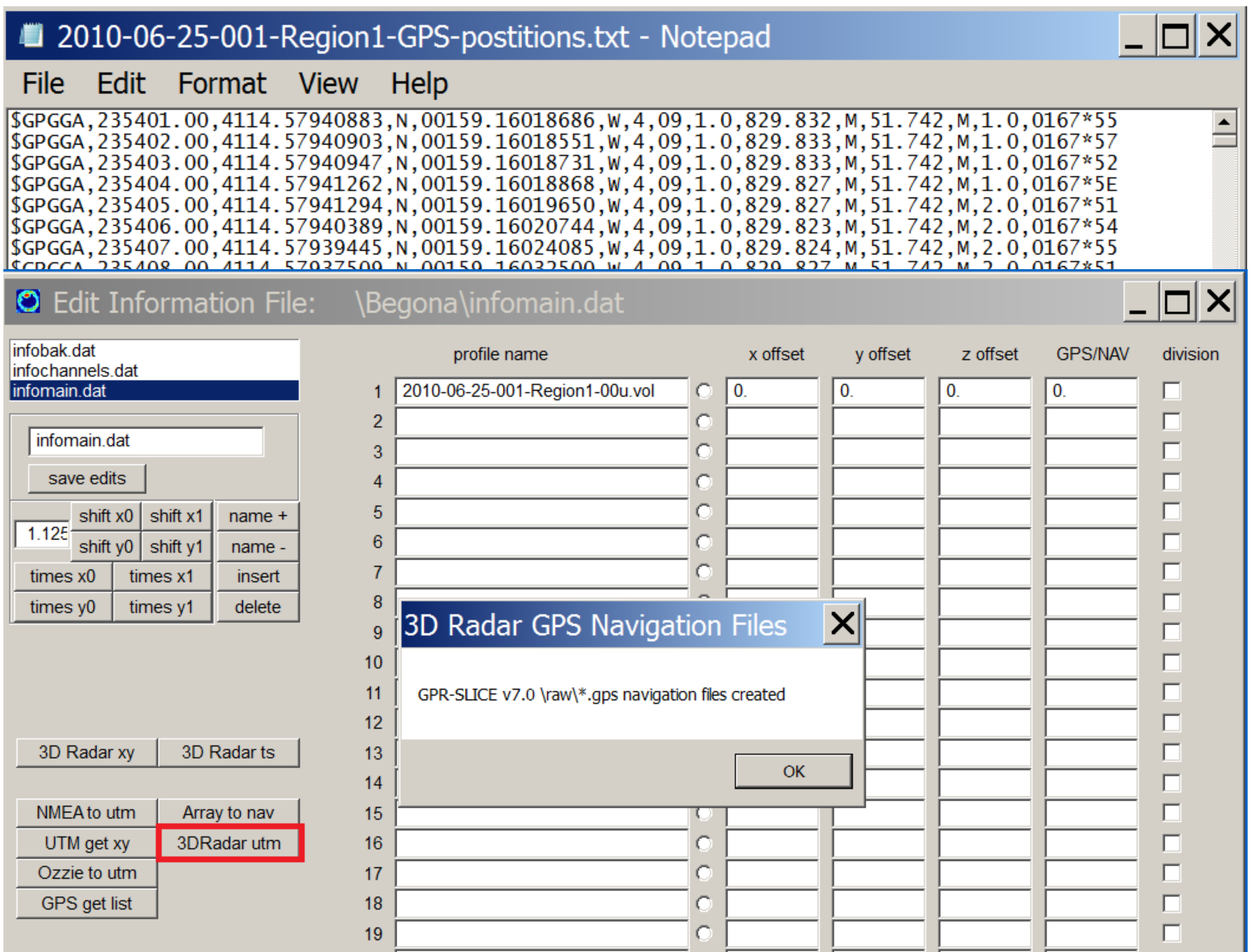

Edit Information File: \US Radar-GPS\info.dat
info.dat
infobak.dat
save edits
shift x0
shift x1
name +
shift y0
shift y1
name -
times x0
times x1
insert
times y0
times y1
delete
US Radar xy
US Radar ts
US Radar utm
NMEA to utm
UTM get xy
Ozzie to utm
GPS get list
profile name
x offset
y offset
z offset
GPS/NAV
division
SURVEY_0032.RAD
US Radar GPS files
GPR-SLICE v7.0 \raw*.rad.gps navigation files created
OK


GPR-SLICE GPS/Nav/Vector Track Map: US Radar-GPS
x-offset
y-offset
xy offset
del double gps
del double times
error
del bad gps
int bad gps
filter gps track
line+
pt+
X+
Y+
recover
int double gps
del double scans
del bad elev
int time gps
lngth
r/error
line-
pt-
X-
Y-
save
store track map
track.jpg
plot+
plot-
gpsquality >= 0-fix not valid/off
redraw
hdop <= 100
n sat >= 10
decimate
time lag
line
dots
start/stop
cross
total GPS survey length = 27.4 m
blue dots - inside GPS precision settings
black dots - outside GPS precision settings - not included in time slice analysis
562458
562460
4473857
4473855
4473853
4473851
4473849
4473847
562458m

3D Radar GPS Navigation

Purpose: To introduce how 3D Radar GPR/GPS surveys are integrated into GPR-SLICE v7.0 software.

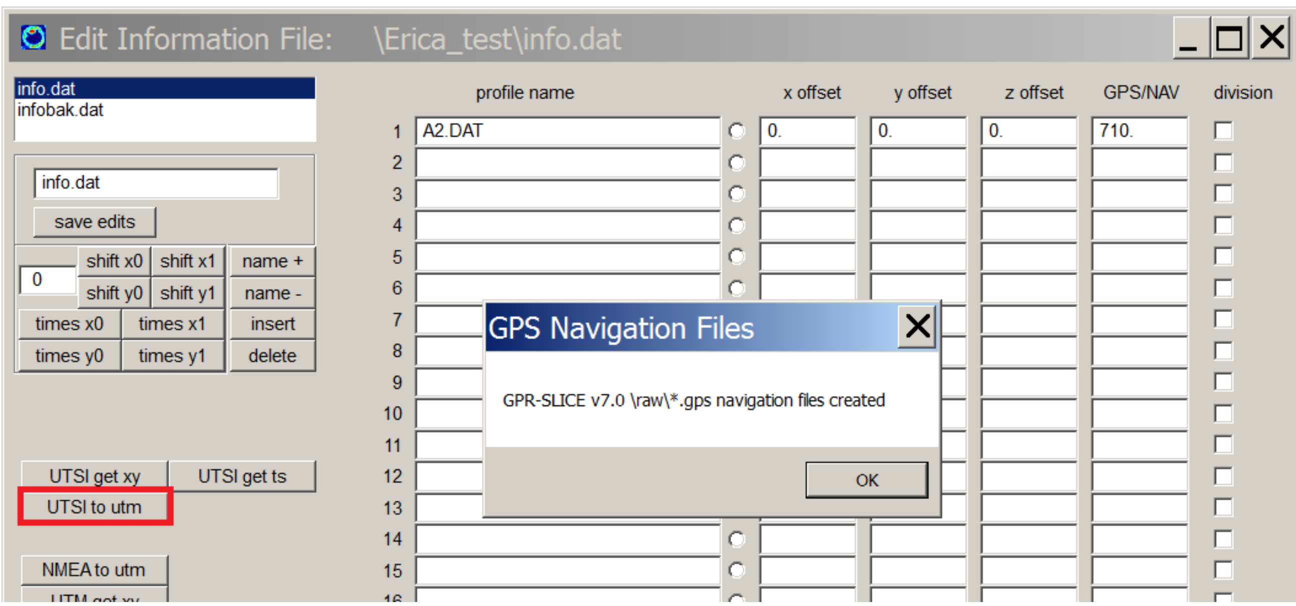
Basic Information: With every 3D Radar GPR/GPS survey, a positions.txt log files is created for every main track radargram. There is a button called 3D Radar UTM in the Edit Info File menu. Clicking this button will generate the *.vol.gps files for GPR-SLICE processing with all the UTM conversions, etc. (The details for this multichannel manufacturer are aloso available in an addendum manual for multichannel licenses).

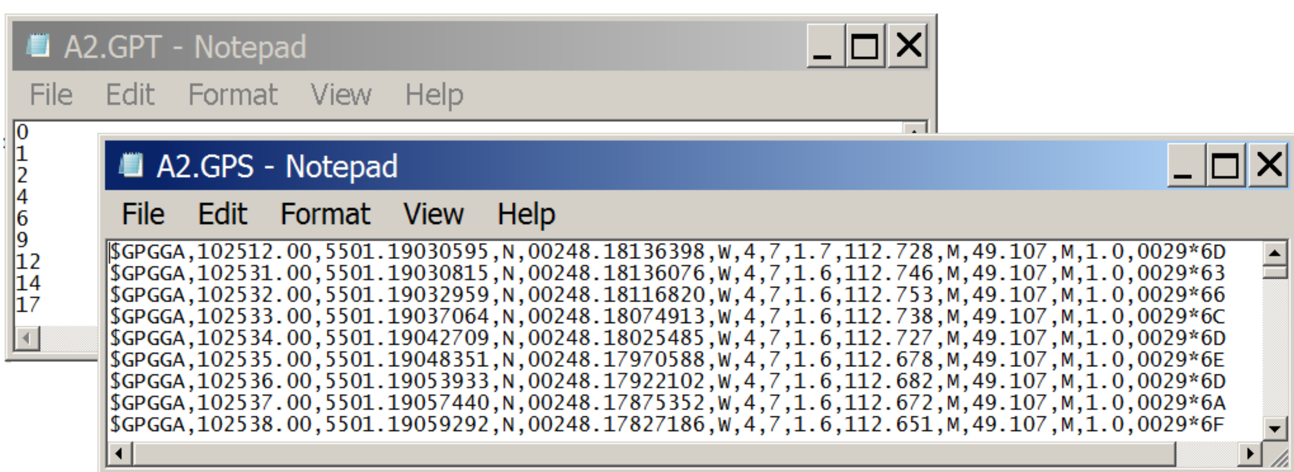


UTSI Electronics

Purpose: To introduce how UTSI Electronics equipment has GPR/GPS surveys integrated into GPR-SLICE v7.0 software.

Basic Information: UTSI Electronic GPR/GPS surveys creates a *.gpt log and a *.gps log file for every radargram. The *.gpt file contains the scan number where NMEA strings are recorded and correspond to the *.gps file that is recorded. There is a button called UTSI to UTM in the Edit Info File menu, clicking this button will generate the *.dat.gps where the UTM conversion are done, and the scan#'s from the *.gpt files are written to the 5th column of the navigation files. Users of this equipment will use the GPS Vector/Trace # option in the Navigation menu to assign the NMEA information to it appropriate scan number.

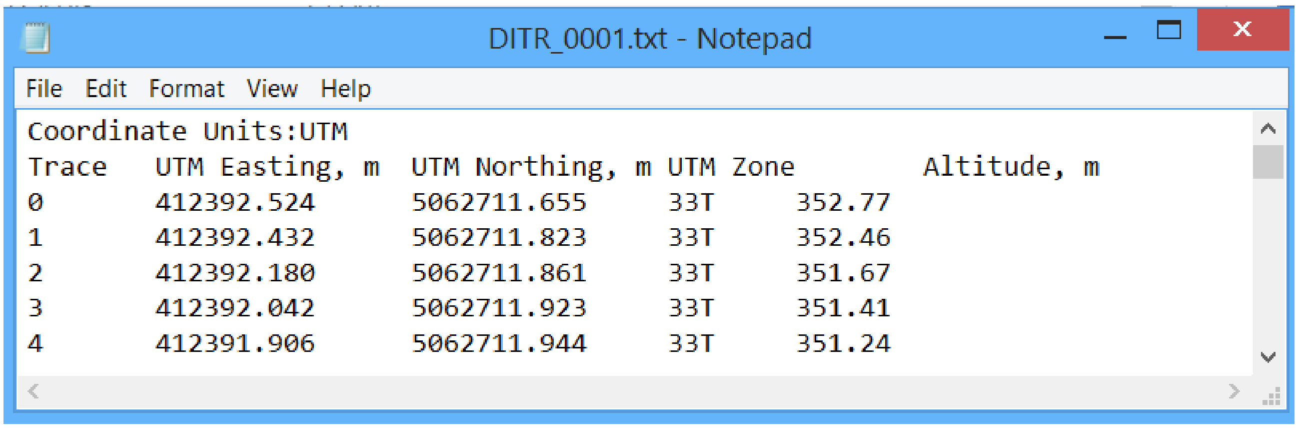




Radarteam

Purpose: To introduce how Radarteam GPR/GPS surveys is integrated into GPR-SLICE v7.0 software.

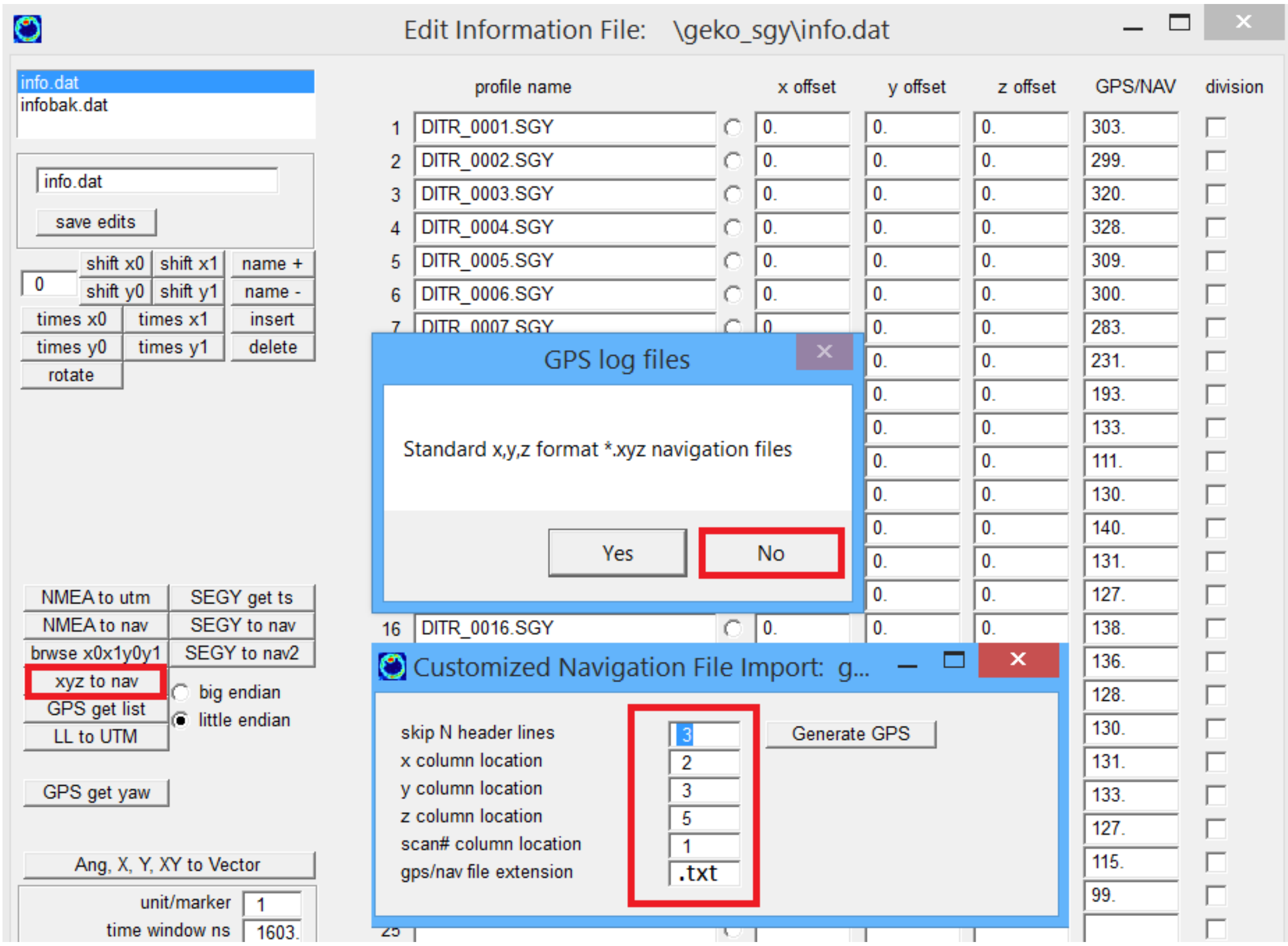
Basic Information: Radarteam has a *.txt files containing navigation information that is associated with each radargram. An example is shown below:

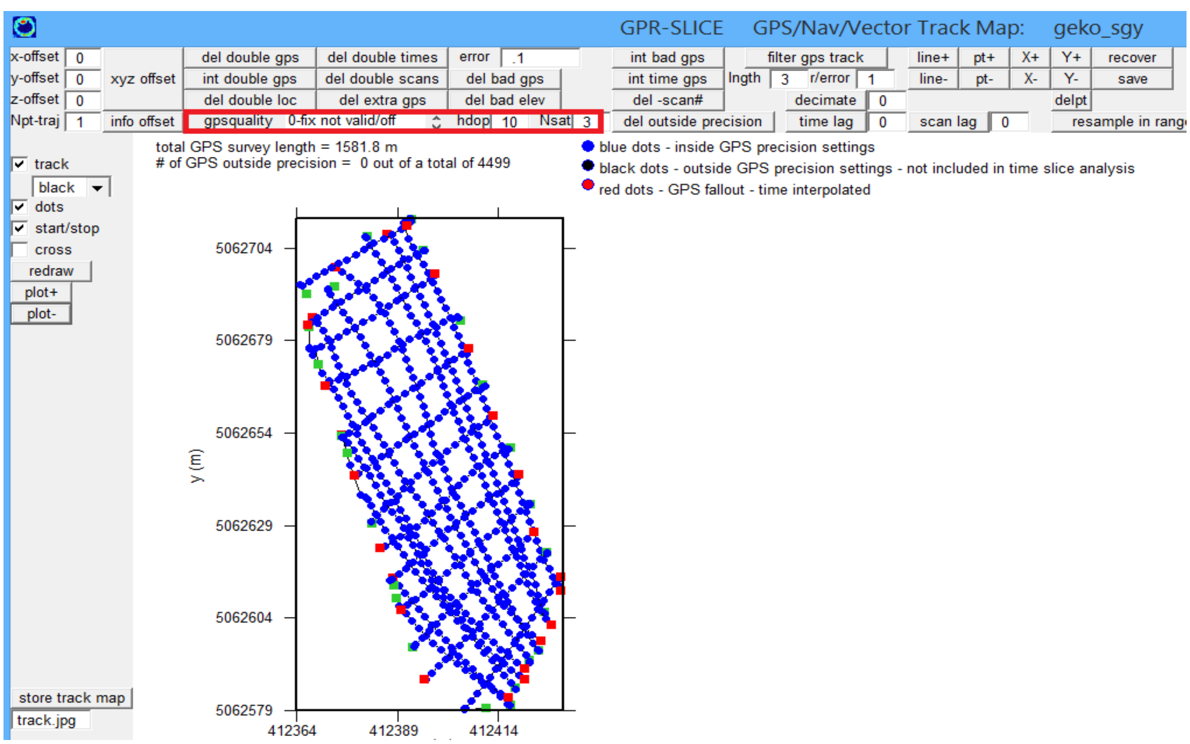



```
Coordinate Units:UTM
Trace    UTM Easting, m   UTM Northing, m  UTM Zone         Altitude, m
0        412392.524       5062711.655      33T      352.77
1        412392.432       5062711.823      33T      352.46
2        412392.180       5062711.861      33T      351.67
3        412392.042       5062711.923      33T      351.41
4        412391.906       5062711.944      33T      351.24
```

The *.txt navigation files do not have all the basic information contained in the raw NMEA string. Things such as the HDOP, number of satellites, gps quality are missing. To create the *.sgy.gps files associated with each radargram the button XYZ to Nav button is clicked on. A dialog will pop up and ask if this is a standard XYZ navigation file which the user will answer with “NO”. This will launch a customized read/import menu (see screen shot next page). The user will need to set the number of lines to skip in the header of the file as well as the columns for the X, Y, Z information and the file extension for the navigation - *.txt.

Note: Because the Radarteam is missing HDOP, number of satellites and the GPS quality, artificial values need to be inserted for these into the GPS Track menu (see screen shot) such that all the points appear as blue dots - and are not discarded when navigation precision is implemented in the time slice menus.

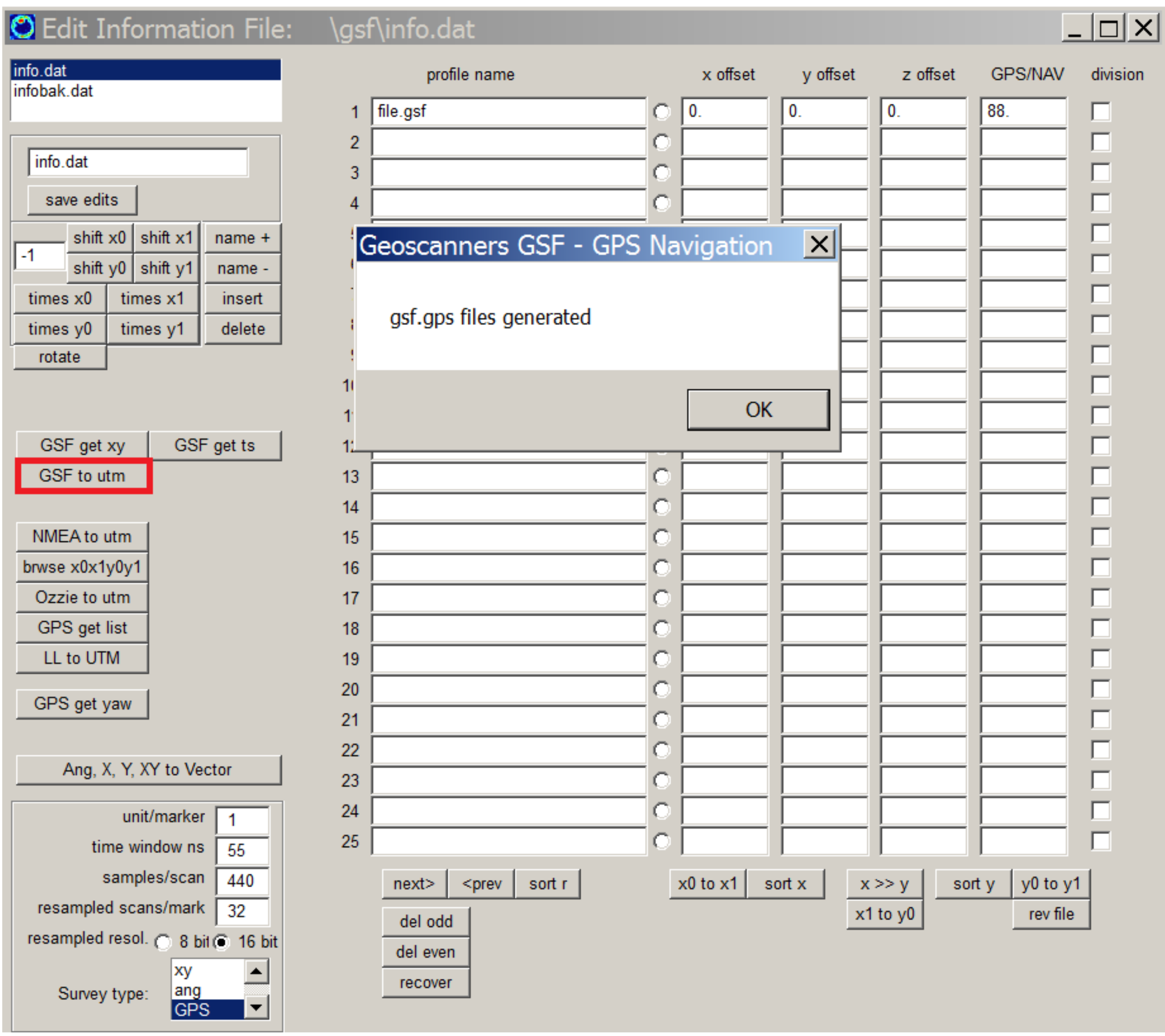

Edit Information File: \geko_sgy\info.dat
info.dat
infobak.dat
info.dat
save edits
shift x0
shift x1
name +
shift y0
shift y1
name -
times x0
times x1
insert
times y0
times y1
delete
rotate
profile name
x offset
y offset
z offset
GPS/NAV
division
DITR_0001.SGY
DITR_0002.SGY
DITR_0003.SGY
DITR_0004.SGY
DITR_0005.SGY
DITR_0006.SGY
DITR_0007.SGY
DITR_0016.SGY
GPS log files
Standard x,y,z format *.xyz navigation files
Yes
No
NMEA to utm
SEGY get ts
NMEA to nav
SEGY to nav
brwse x0x1y0y1
SEGY to nav2
xyz to nav
GPS get list
LL to UTM
big endian
little endian
GPS get yaw
Ang, X, Y, XY to Vector
unit/marker
time window ns
Customized Navigation File Import: g...
skip N header lines
x column location
y column location
z column location
scan# column location
gps/nav file extension
Generate GPS
.txt


GPR-SLICE GPS/Nav/Vector Track Map: geko_sgy
x-offset
y-offset
z-offset
Npt-traj
xyz offset
info offset
del double gps
int double gps
del double loc
del double times
del double scans
del extra gps
error
del bad gps
del bad elev
gpsquality 0-fix not valid/off
hdop
Nsat
int bad gps
int time gps
del -scan#
del outside precision
filter gps track
lngth
r/error
decimate
time lag
line+
line-
scan lag
pt+
pt-
X+
X-
Y+
Y-
delpt
recover
save
resample in rang
total GPS survey length = 1581.8 m
# of GPS outside precision = 0 out of a total of 4499
blue dots - inside GPS precision settings
black dots - outside GPS precision settings - not included in time slice analysis
red dots - GPS fallout - time interpolated
track
black
dots
start/stop
cross
redraw
plot+
plot-
store track map
track.jpg
y (m)
5062704
5062679
5062654
5062629
5062604
5062579
412364
412389
412414

GeoScanners

Purpose: To introduce how GeoScanners of Sweden GPR/GPS surveys is integrated into GPR-SLICE v7.0 software.

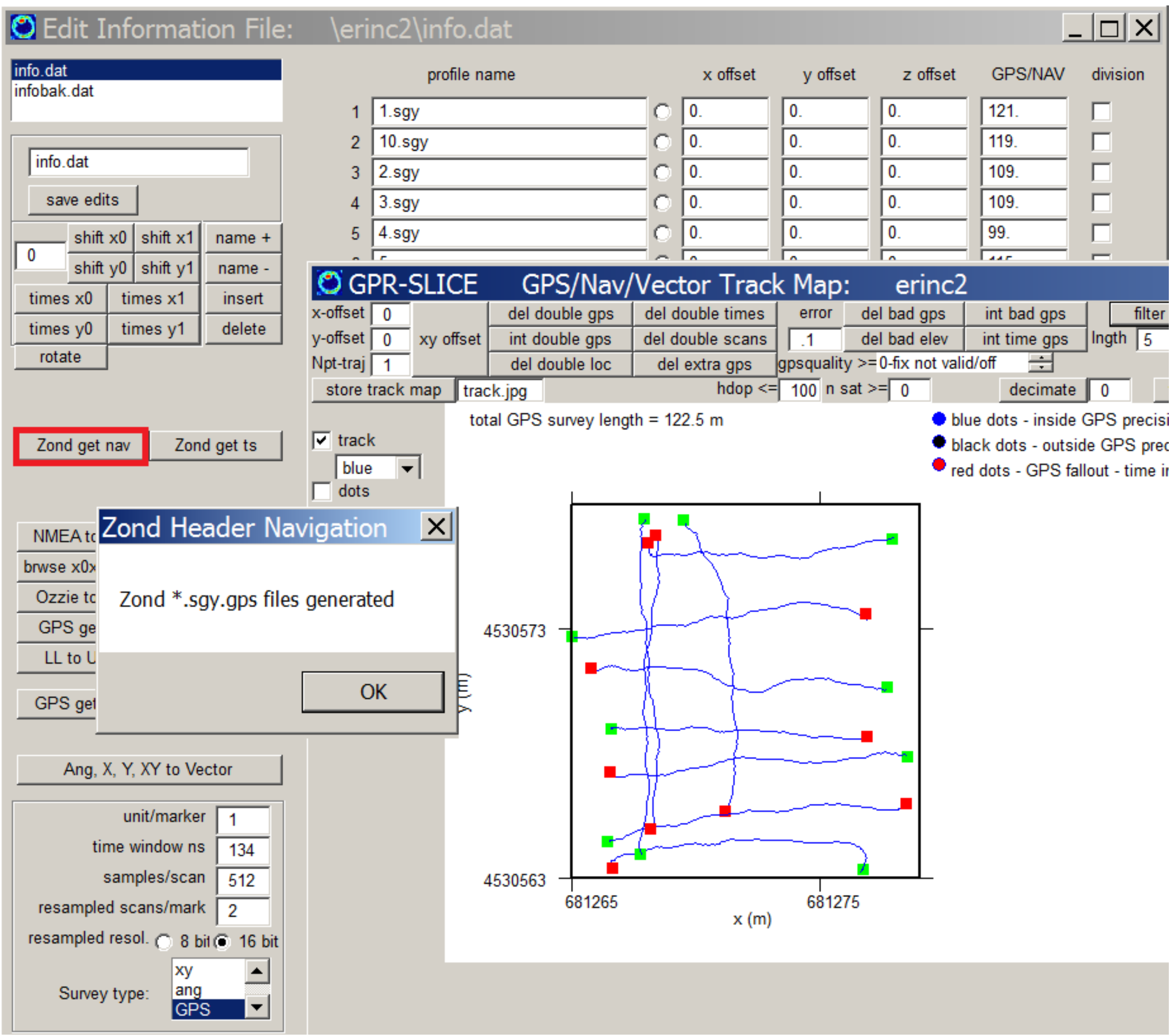
Basic Information: GeoScanners has scan trace headers where information describing the location of the scan on the ground is stored for each individual scan. There is a button called GSF to UTM in the Edit Info File menu, clicking this button will generate the *.gsf.gps where the direct translation to UTM is done. The corresponding scan#' are written to the 5th column of the navigation files. Users of this equipment will use the GPS Vector/Trace # option in the Navigation menu to assign the NMEA information to it appropriate scan number.



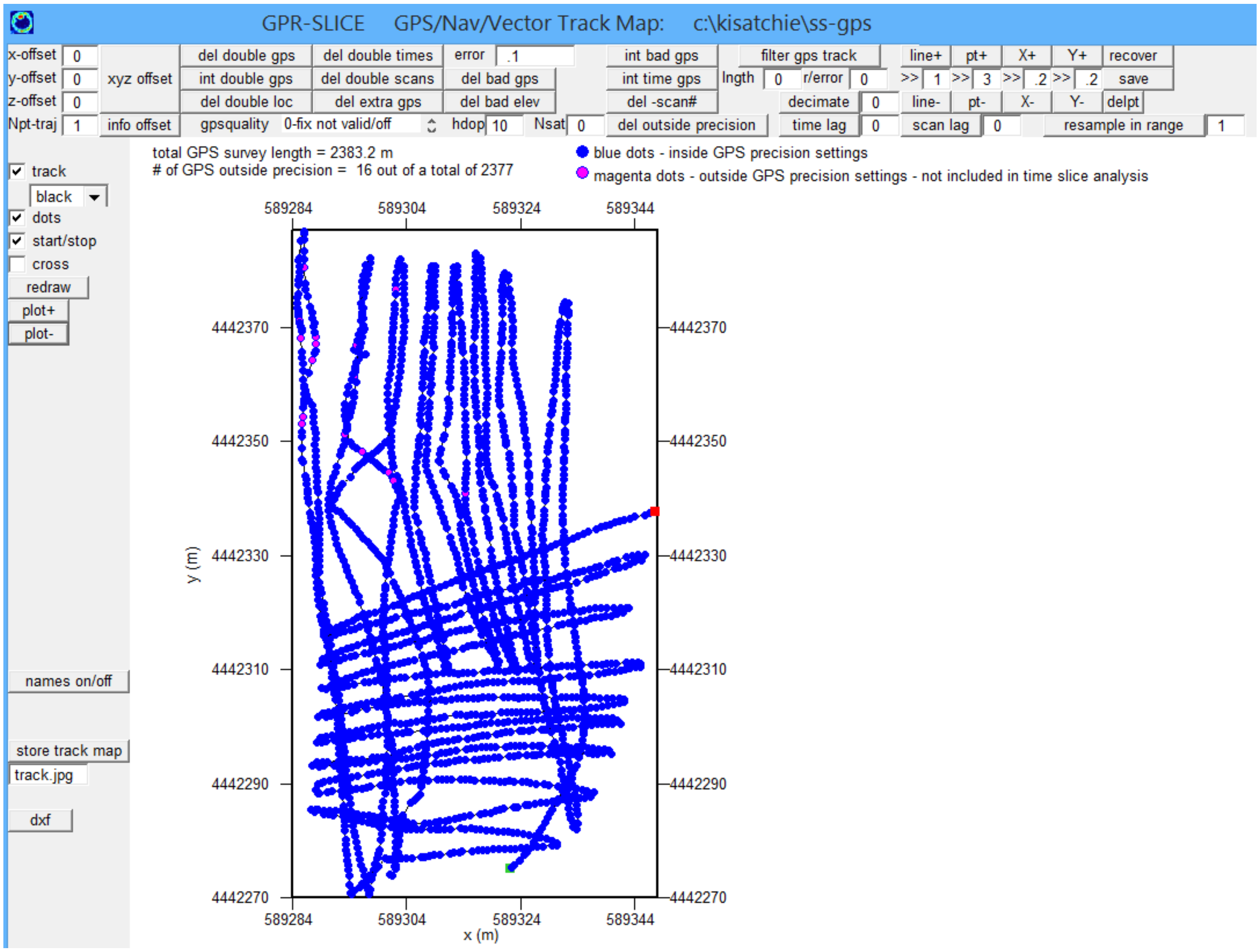
Zond, SEGY/2

Purpose: To introduce how Zond of Lativia GPR/GPS surveys are integrated into GPR-SLICE v7.0 software.

Basic Information: Zond (or SEGY/2) has scan trace headers where information describing the location of the scan on the ground is stored for each individual scan. There is a button called GSF to UTM in the Edit Info File menu, clicking this button will generate the *.sgy.gps where the direct translation to UTM is done. The corresponding scan#' are written to the 5th column of the navigation files. Users of this equipment will use the GPS Vector/Trace # option in the Navigation menu to assign the NMEA information to it appropriate scan number.



GPS Track Map Filtering



Various problems with typical GPR/GPS data collection can occur which can affect the quality of subsurface imaging made with this automated navigation. In the course of collecting GPS data, there can be data fallouts or multi-pathing which can cause GPS points to become erratic. Some GPS navigation systems may not be updating quick enough and duplicate GPS points can sometimes infiltrate GPS navigation.

When there is fallout between GPS points, it will be necessary in some situations to be able to estimate GPS navigation between these data areas. Also, erratic GPS points need to be filtered or removed from the GPS files. Various filtering options of GPS navigation files is currently available in the GPS Plot menu to correct some of these problems. The main options are:

- Delete Double GPS
- Delete Double Loc
- Delete Double Times
- Delete Double Scans
- Delete Extra GPS
- Delete Bad GPS
- Delete Bad Elevation
- Delete –scan#

- Interpolate Double GPS
- Interpolate Bad GPS
- Interpolate Time GPS

1) Delete Double GPS: This option when clicked in the Edit Info File Menu will delete all consecutive GPS points which are duplicated in the *.*.gps files. The reason for doing this is that often many GPR/GPS data collections are not able to provide quick enough unique GPS reading associated with the radar data. Often the GPS logger will insert the identical GPS reading between several adjacent readings. In one instance, a recent user of the software was able to extract GPS readings for every individual record radar scan. In this particular dataset, the GPS readings would not change for upwards of 20-30 scans. In order to provide better dead reckoning navigation between unique GPS readings, it is best remove duplicate GPS readings and allow the software to interpolate time slice data between points where unique GPS readings are available.

2) Delete Double Loc: Operation to remove GPS points that have exactly same GPS locations of eastings and northings on consecutive GPS points

3) Delete Double Times: Filtering operation to remove GPS points where the GPS time is duplicated usually in consecutive points in the navigation log file’

4) Delete Double GPS (Scan #’s) – Critical Option for GPS Fallout: Normal operations of the GPS with this equipment will have a log file of the Trace # followed by 1 line of the $GPGGA. There can be other NMEA strings, but usually only one $GPGGA line will follow the Trace #. However, in the instance with poor GPS and significant fallout, multiple $GPGGA lines can be written to the log file. It is critical that these points be removed from the converted *.*.gps navigation files generated in

GPR-SLICE. A warning that GPS readings with duplicated scan numbers will be launched in the Edit Info File menu when GPS log files from the manufacturers are converted to GPR-SLICE log files.

5) Delete Extra GPS: An operation to remove GPS readings in the log file with scan numbers listed that go beyond the number of scans in the recorded radargrams.

6) Delete Bad GPS: In this option all GPS points in the *.*.gps files which are further than the error (set in the GPS track menu) away from the average GPS reading will be deleted. The auto-detection in the algorithm will find these GPS points and delete them from the *.*.gps files. The process will automatically update the *.*.gps files.

7) Delete Bad Elev: Filtering of the GPS listings to remove elevations which are completely in error.

8) Delete – scan#: Operation to remove negative scan numbers from the GPS log files – which can happen on some equipment where the GPR cart is backed up during data collection.

0) Interpolate Double GPS: Often double GPS points or more can be found in some raw GPS logs do to a variety of reasons. Often the double GPS points are discovered however the timing information in the GPS log file is continuing to increment. Clicking this operation will cause GPR-SLICE to discover the number of double GPS points and to find where the first unique GPS point is discovered. GPR-SLICE will then linearly interpolate the double GPS points to create unique GPS readings.

10) Interpolate Bad GPS: This option should be run in place of the Delete Bad GPS operation. This function will search for all GPS points which are the set error distance away from the average GPS reading, and it will replace this point with an interpolated point found between the two closest valid GPS points surrounding the bad point. There is a possibility that many poor GPS readings are significant in a file. A reasonable value of for the error setting may have to be tried. Values can range from 1-.0000001 sometimes depending on the data quality.

11) Interpolate Time GPS: Interpolation of GPS fallouts can be accomplished in time. In this operation, GPR-SLICE will read the 4th column of the *.*.gps files and extract the time of the GPS reading. The GPS reading is converted to the total number of seconds. If any adjacent GPS reading is currently is more than 1 second away, GPS values will be interpolated in between to make estimated GPS reading

every second. In order to properly use this option, the user must make sure that the 4th column of their *.*.gps file contains time written as “hh:mm:ss” with quotes around the time (e.g. “06:55:32”). In later version of GPR-SLICE UTC time with decimals is now being written for the generated GPS files.

An error threshold setting was added to the GPS Track menu for removing GPS data. The error threshold is set to a fractional percent of the average UTM reading. For errors greater than the error threshold, the GPS point is automatically removed. This setting in the Track menu should not be used to try and remove points that are only a meter or so away from its estimated position. The setting is for fallout where the recorded readings are from corrupted navigation numbers that are incorrectly recorded or from loss of satellites. In these instances, the GPS fallout are usually numbers that far away from the average UTM numbers.

Note 1: After running any of the filtering operations, the information file will be automatically updated to reflect the edited number of GPS listings for each GPS radargram

Note 2: It is possible to run a combination of the GPS filtering operations in the Edit Info File menu. For instance, the user could run Delete Double GPS, then run Delete Bad GPS, followed by Interpolate Time GPS.

Note 3: The user cannot run Delete Bad GPS followed by Interpolate Bad GPS or vice versa. Delete Bad GPS will delete the bad GPS points. If one ran the Interpolate Bad GPS operation, the search algorithm would not find any bad GPS points to interpolate. However, running the Interpolate Bad GPS option will automatically find the bad GPS points and then interpolate them. These 2 buttons should never be run together in an operation.

Note 4: Remember that scan numbers must also be present in the 5th column of the *.*.gps files to use the interpolation filtering features.

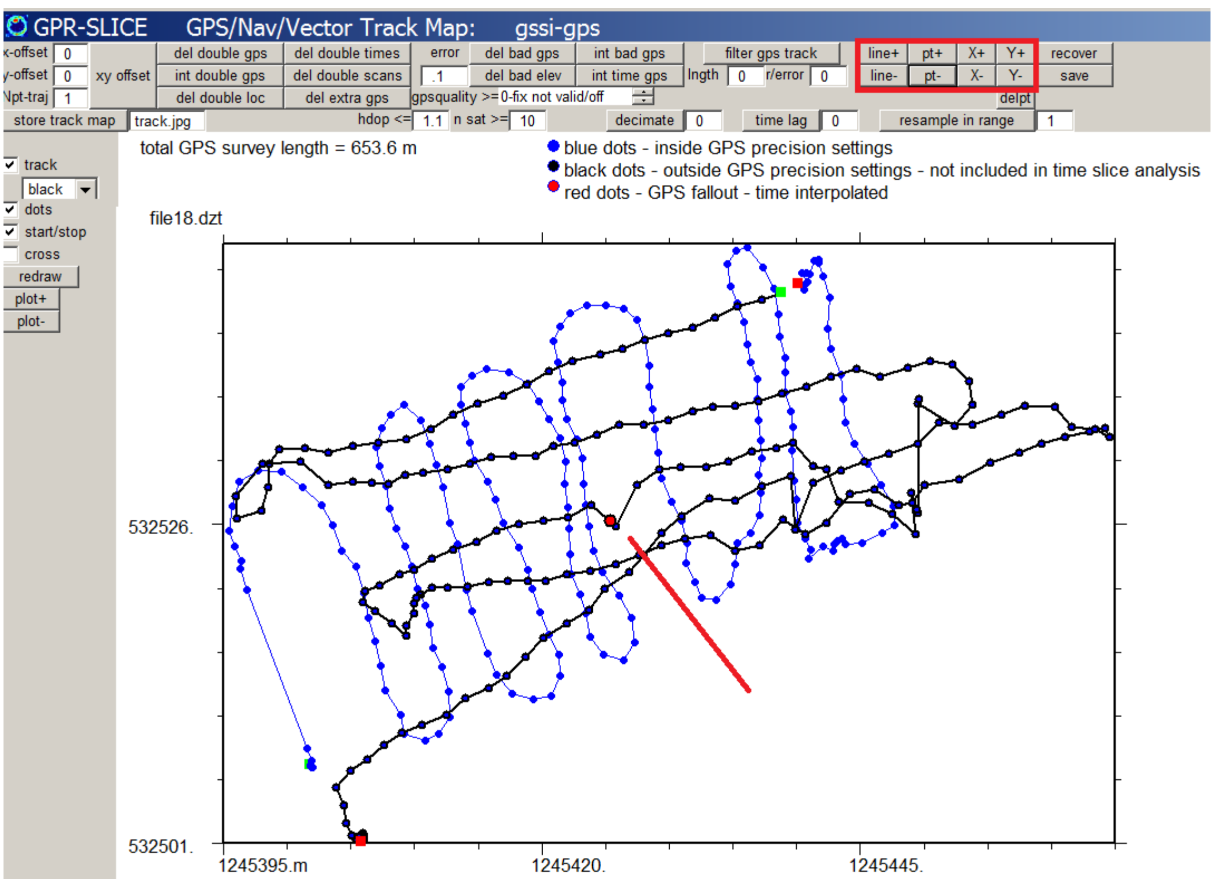
Note 5: During the implementation of Mala GPS options in the software, some *.cor files had scan numbers which were less than the previous scan numbers. This is of course an impossible occurrence and represents some fallout of information in the GPS logger. Testing for this condition is now made in the GPS Track menu. Clicking the Del/Bad GPS button, these errant points will also be removed. This test is now provided for all GPS generated from any GPR manufacturer’s system.

Correcting navigation points manually in the GPS Track Menu

In the GPS Plot menu there are buttons to manually change the location of any GPS point for any radargram (see following diagram). The buttons in the GPS Plot menu are:

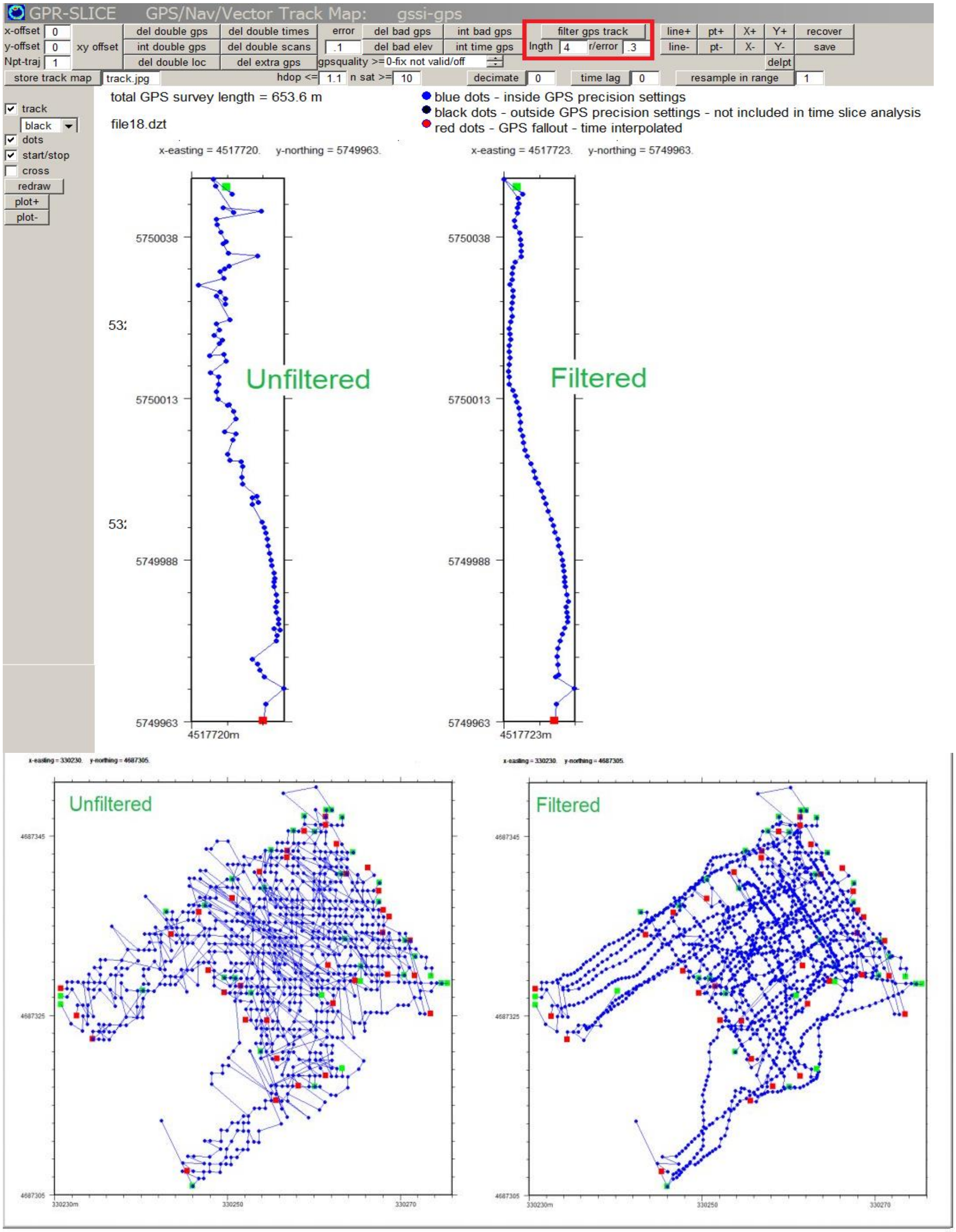
Line+/-:	increment between GPS radargrams
Point+/-:	identify a point along a GPS radargram
X+/-:	adjust the highlighted GPS point in the x direction
Y+/-:	adjust the highlighted GPS point in the y direction

In the example in the following diagram in which only 2 radargrams are in the information file, the Line+ button was clicked once to highlight the 2nd radargram, following by 24 clicks of the Point+ button to get the noisy GPS point highlighted. Then to adjust the point the user can click the X or Y buttons to move the point up/down or left/right. The Save button should be clicked after each GPS point is adjusted. The single GPS points can also be deleted from the track by clicking the del pt button as well.



Filtering/Smoothing of the Entire GPS Track

Filtering and smoothing and rewriting of the entire noisy GPS track can be accomplished in the GPS Track Menu. The GPS track filter has 2 settings: the filter ***length*** is the number of GPS points on each side of the local GPS point to take a moving average; the ***r/error*** setting is the maximum error distance acceptable from the difference between the averaged GPS reading and the local reading. If the threshold is breached, the averaged GPS reading over the filter length will replace the local reading. Several different levels of smoothing can be achieved depending upon the settings. The filter works for either one track or in batch for whatever number of GPS lines you have in the project information. Several examples of a single GPS track filtered, as well as a multi-track filter are shown in the next figures. The user should experiment with different filter lengths and r/error settings. Longer lengths and small r/error will provide larger smoothing - whereas reducing the length to a few gps points on each side of the desired point, along with a larger acceptable error will produce tracks with less smoothing.


GPR-SLICE GPS/Nav/Vector Track Map: gssi-gps
x-offset 0
y-offset 0
xy offset
Npt-traj 1
del double gps
del double times
int double gps
del double scans
del double loc
del extra gps
error .1
del bad gps
int bad gps
del bad elev
int time gps
filter gps track
lngth 4 r/error .3
line+ pt+ X+ Y+ recover
line- pt- X- Y- save
gpsquality >=0-fix not valid/off
delpt
store track map
track.jpg
hdop <= 1.1 n sat >= 10
decimate 0
time lag 0
resample in range 1
track
black
dots
start/stop
cross
redraw
plot+
plot-
total GPS survey length = 653.6 m
file18.dzt
blue dots - inside GPS precision settings
black dots - outside GPS precision settings - not included in time slice analysis
red dots - GPS fallout - time interpolated
x-easting = 4517720. y-northing = 5749963.
x-easting = 4517723. y-northing = 5749963.
5750038
5750013
5749988
5749963
4517720m
4517723m
Unfiltered
Filtered
Unfiltered
Filtered

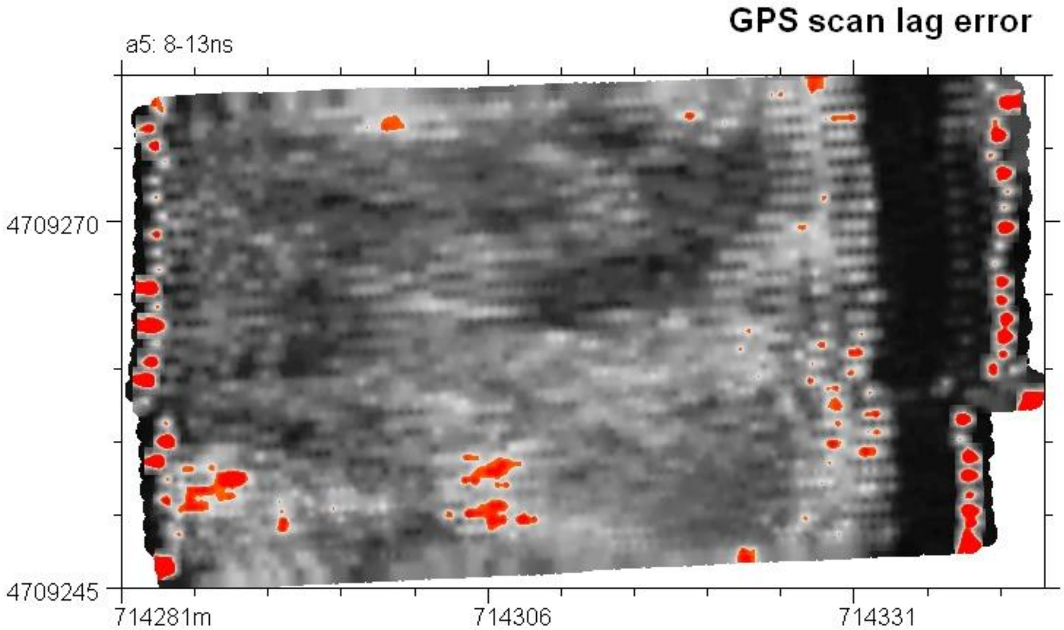
The filter was designed so that the first N points at the beginning or at the end of the GPS track are not filtered to preserve the original raw start and end locations, as well as to only implement the filter when it is completely over GPS data within the track. One can see that the filtered GPS track has some original noise (preserved) at the beginning and end. The current consensus is that it is good to preserve these first few points at the beginning and end. This may change at a later date.

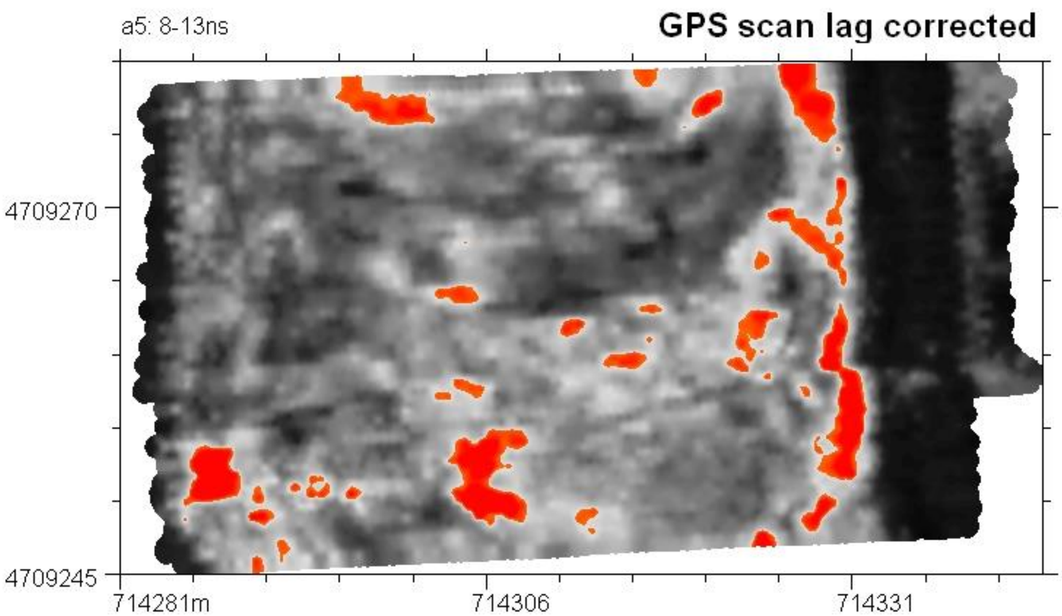
One can place a track jpg name in the menu and clicking the "Store Track Map" will write the name of the desired map jpg as well as write a single comprehensive GPS track file for all the radargrams in the project with the extension ".txt" in the \raw\ folder. The main project folder still contains the map.jpg of the track in case you do not want a customized name. Along with the options to move points around individually which we detailed in a newsletter last year, the GPS/GPR users now have global track filtering options available.

Note: Before leaving the GPS Track menu the user can recover all filtering done to the GPS track files by clicking the "Recover" button. The software will automatically update the GPS tracks to the filtered tracks once you exit the GPS Track menu.

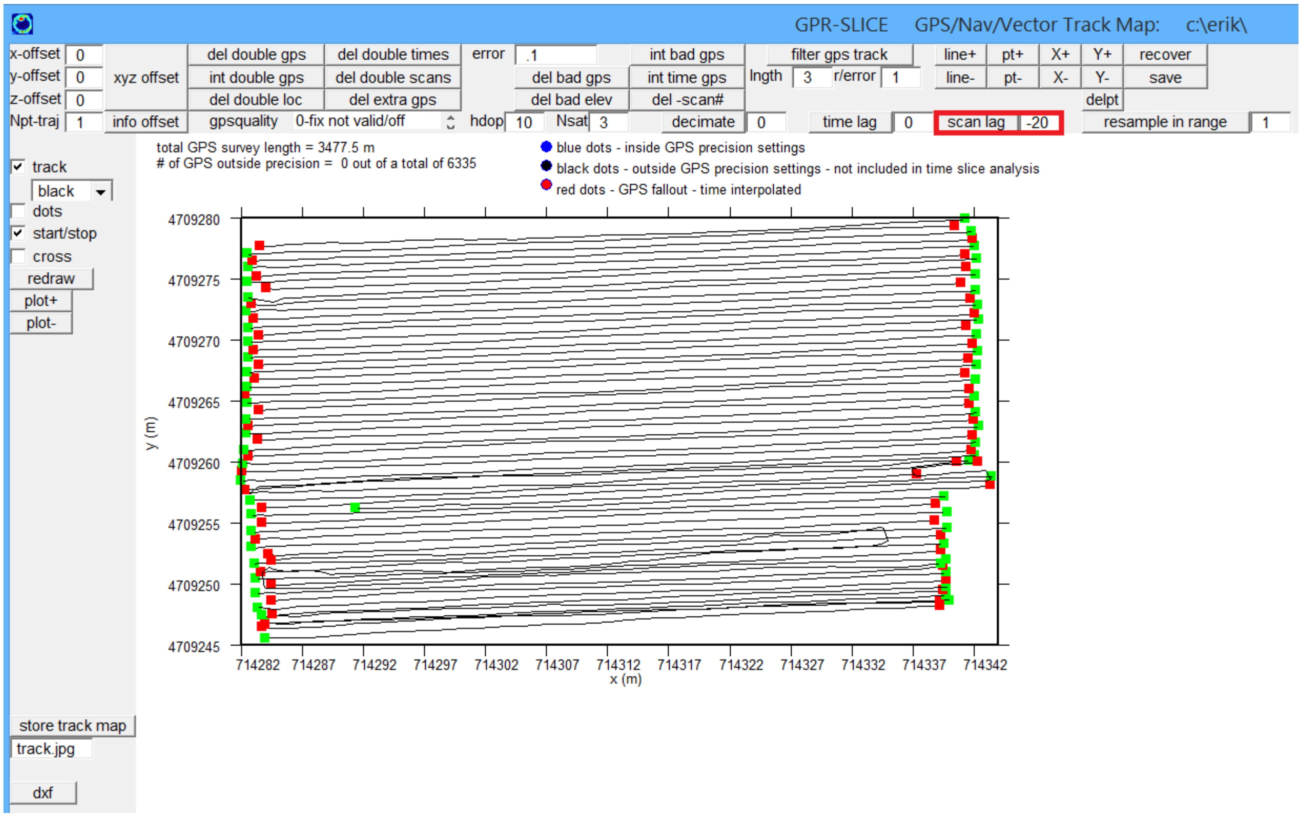
GPS Scan Lag Correction

In data collection with a GPS unit, there is the possibility of recording delays between the GPS and GPR. The manifestation of this is that the radar scan number associated with a GPS reading may be off by a constant number of scans from its real location. For a survey that is collected with a lot of forward and reverse GPS radargrams, the effect of this scan lag can be very dramatic just as it is in regularly navigated dataset. The effect of such a GPS scan lag or latency is shown in the following diagram (courtesy of 3DGeophysics.com):





The top diagram shows anomalies that look like they are hatched and broken. In the bottom diagram is a corrected time slice. To correct for the GPS scan lag, the user must use a setting in the Navigation menu called Scan Lag. The correction for this problem, assuming the staggering is caused by a constant shift between the GPS reading and its corresponding scan number, is to add/subtract a constant number of scans to each associated GPS scan or trace #. The following example a scan lag of -20 scans is applied to the GPS traces which corrects the staggered image:

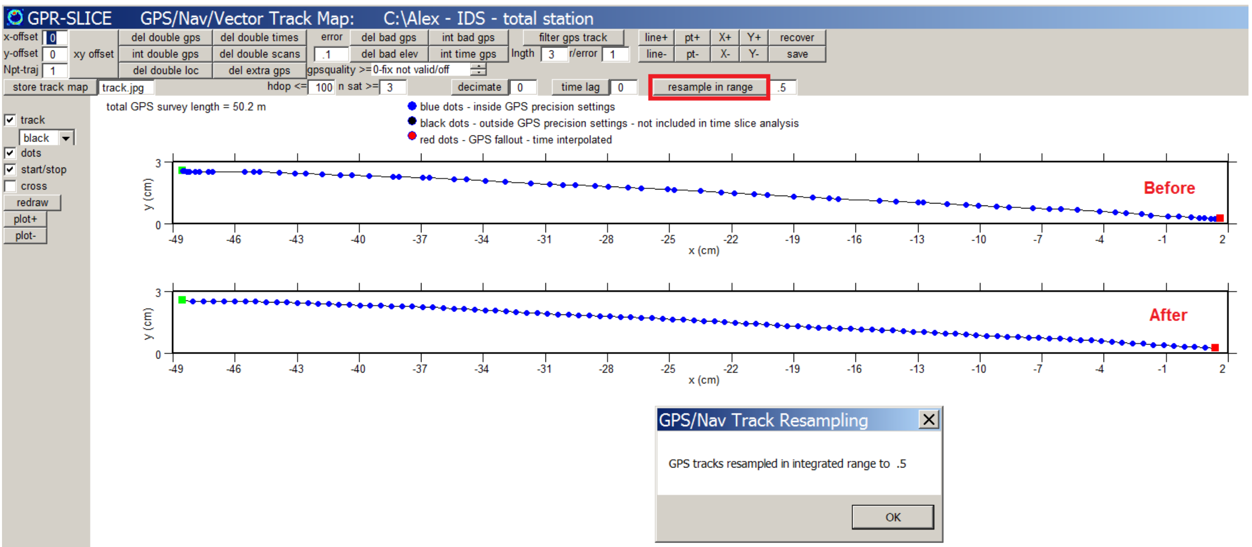


Decimating the GPR/GPS track

An option to decimate the number of recorded GPS readings for any given survey is available. There may be various reasons that decimating the GPS record will provide better navigation. Some GPS systems currently can output GPS for every scan. However, in some cases the GPS loggers are not really updating the position as quickly as it might be outputting the log information. The net effect can be GPS readings that are clustered in locations or are in identical locations. In addition, having GPS readings on every scan, although this can be completely processed in the software, can lead to overly large ASCII time slice that need to be gridded. The reason is that if every scan has a navigation marker, then every scan will also be included in the Slice/Resample operations where the Cuts-per-Mark setting will require generating a time slice value on every scan. Having 100 scans per meter or more would generate very "thick" ASCII dataset which will require more time for gridding. A value of 10 decimation can often be used with out loss of resolution for most GPR/GPS surveys when the GPS data exists on every scan. Of course the decimation should also be chosen based on the scan/GPS reading density.

Note: For GPS readings collected on every scan, if it desired to process these time slices just as they are, the bins per mark should be set to 1 – one can not set it to any higher value since there is one time slice value per scan

Resample in Range for total station or GPS fallout with survey wheel engaged



A special button to resample a GPS track or a total station track when fallout is present can be implemented. The Resample in Range button reads the track and then will mathematically integrate the length along the track to reset positions at the desired length. In the example in Figure 1 the total station track was resampled at 0.5m. The requirement of the operation is that the data was also collected equidistantly along the ground (e.g. with a survey wheel). When fallout occurs with total station (or GPS) multiple points can be recorded in the previous locations until valid measurements are taken. The delete double GPS point option should first be engaged so that the general track movement can be mathematically integrated to give the most accurate resampling of the track that is synced with scans. This button became necessary for a recent dataset collected with a multi-channel equipment in a city street in Spain where buildings and obstructions caused the total station readings not to be properly updated.

Filtering of GPR time slices via GPS quality, NSat, HDOP

The 20 column GPS format now is used in all GPR/GPS operations in GPR-SLICE v7.0 is useful for filtering of GPR time slices based on the navigation precision. Three new additions to the GPS files over GPR-SLICE v5.0 include: the GPS quality, N Satellites, and the HDOP. The first 8 columns of the GPS navigation files used in GPR-SLICE v7.0 are:

eastings, northings, elev(m),"time", scan #, **GPSquality, Nsatellite, HDOP**

This format became necessary in order to accommodate the use of GPS quality, the number of satellites and the HDOP in filtering operations.
The GPS quality has 6 levels and these are

0 – no fix
1 – aGPS (autonomous)
2 – dGPS (differential)
3 – not defined
4 – RTK-fixed
5 – RTK-float

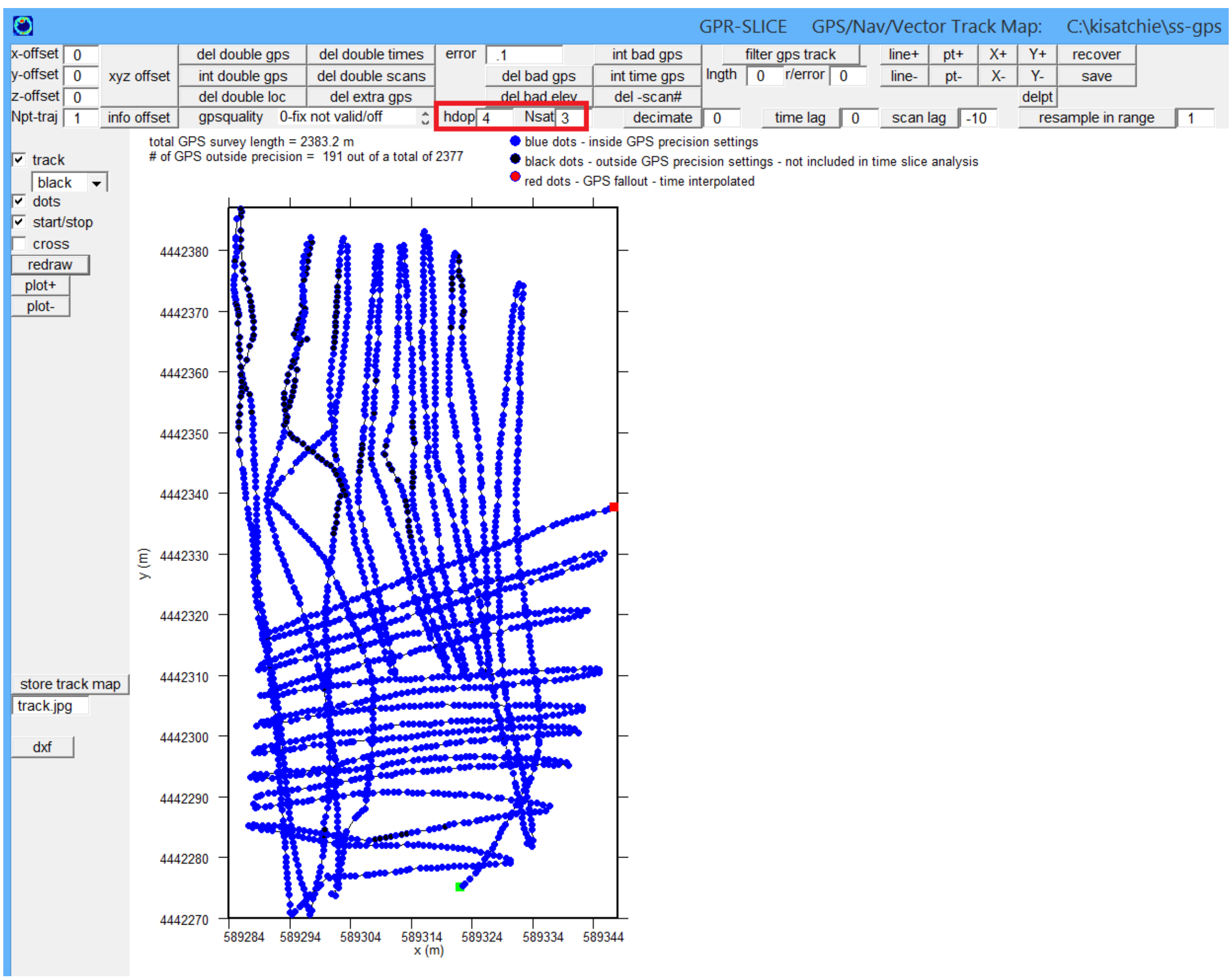
The GPS quality can change during recording based on changes to the system being used. In GPS lingo, RTK fixed is actually a better quality GPS fix then RTK float, however, the numbering system in the NMEA string has RTK float as a larger number. During reads of the file, GPR-SLICE will re-weight the levels to make RTK-fixed the best possible GPS quality.

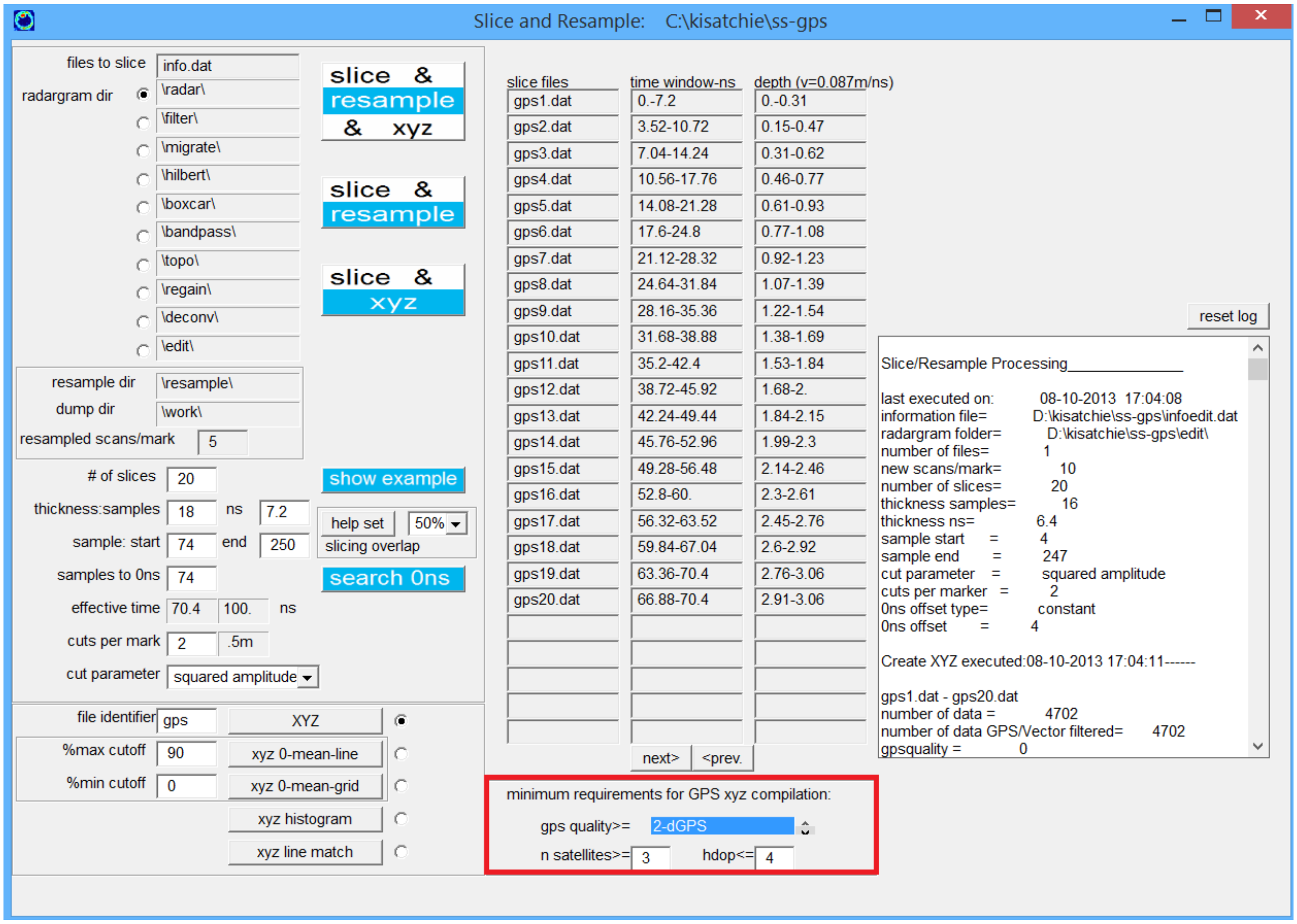
The number of satellites in the fix is also recorded in the NMEA string. The fewer number of satellites can also be correlated with the precision of the GPS navigation. The HDOP, called the horizontal dilution of precision gives a measure of the fix resolution. Fractional values between 1-3 are common for the HDOP, but values can be higher. The larger the HDOP, the poorer the GPS fix is. All GPS NMEA strings contain this information in the raw GPS logs for most manufacturers.

GPR/GPS track portions that do not meet a user defined setting for GPS quality, N satellites, or HDOP be automatically removed from time slice images. Such operations are common with other 2D geophysical tools that are being used in surveying. These options will help to make the GPS track operations in the software more robust and provide the user more controls and quality assurance in navigation and imaging.

These options can be visualized in the GPS Track menu as well as in the Slice/Resample operations. Shown in the following figure is an example GPS track map with portions shown in black. In this dataset, courtesy of the Indiana Geological Survey, we have the GPS quality set to dGPS, N satellites to 4, and the HDOP to <= 3.2. If the user wants to see just HDOP changes, then they can set the GPS quality to the lowest setting (0-no fix) and also set N satellites to 0. Clicking the Redraw button will refresh the GPS track map with the new settings.

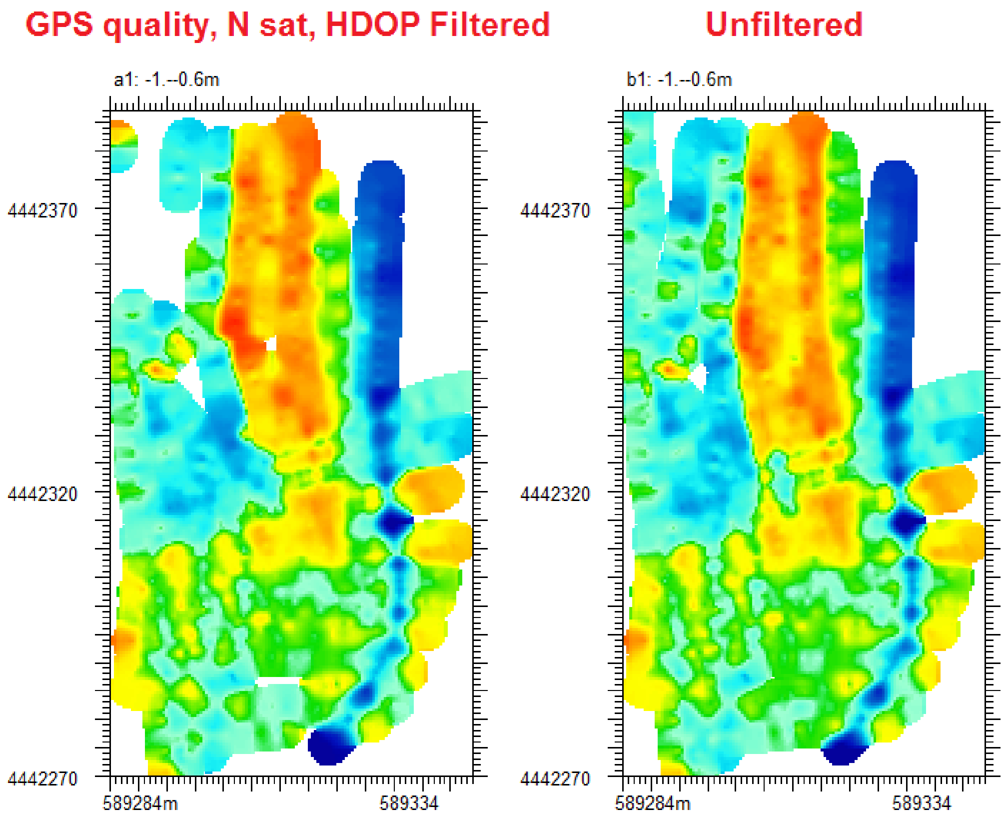
In the following figure, the GPS track map showing portions of the track in black are lower in GPS quality, N satellites, and HDOP. At this point in GPR-SLICE operations, the GPS settings are only used to visualize portions of the GPS track that meet the desired precision. During Slice/Resample operations, the entire GPS track is processed, however, at the creation of the XYZ ASCII time slices these settings are used to filter and remove those portions of the GPS track that do not meet the desired criteria





The GPS quality, N satellites and the HDOP settings will only show in the Slice/Resample menu for GPS projects and will remain hidden for non-GPS projects.

An example of a filtered time slice based on the GPS quality, N satellites and HDOP is shown in comparison with an unfiltered time slice:

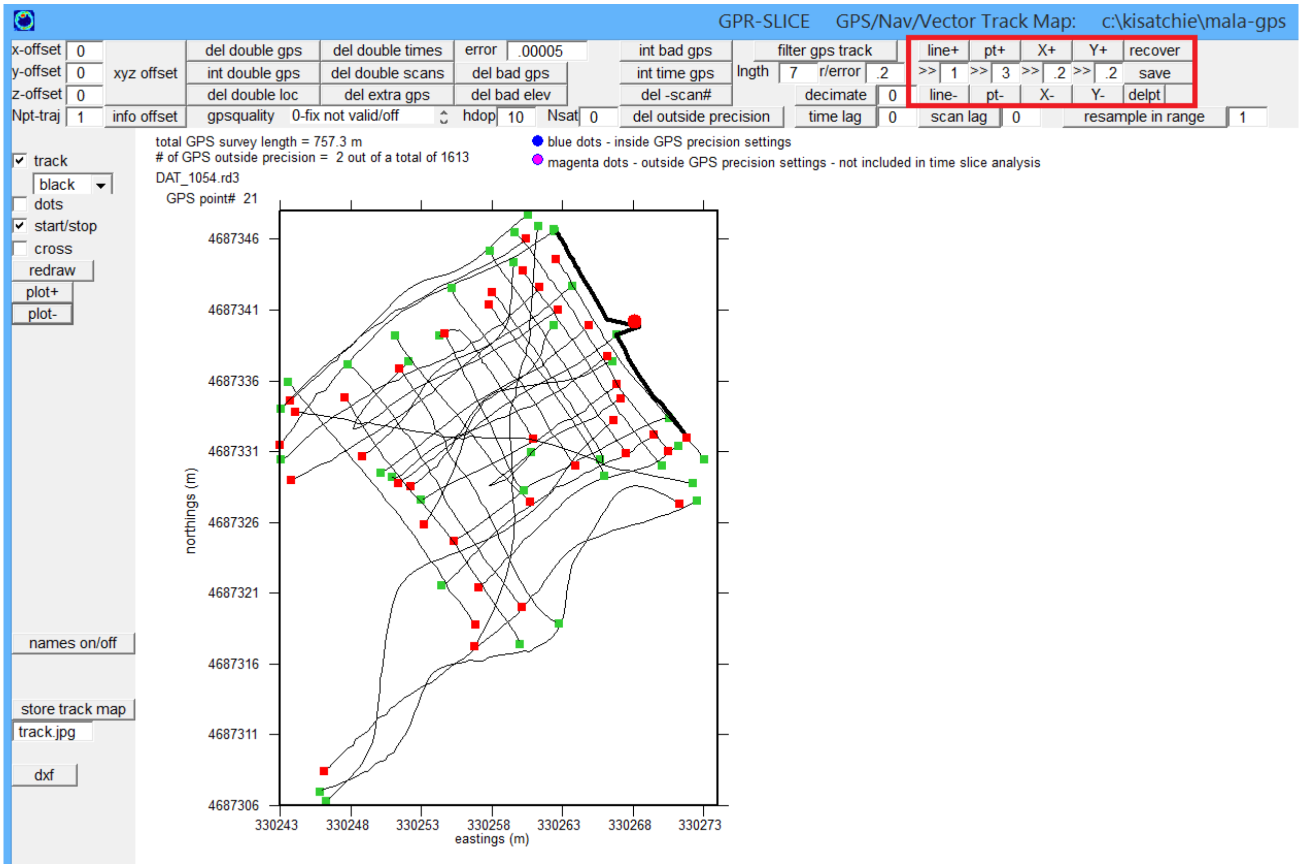


In this example of a GPS quality, N satellite and an HDOP filtered and unfiltered times slice are compared.

Note: Some manufacturer's GPS formats have removed information in the NMEA string such as the number of satellites or the HDOP, etc. The user may need to place artificial values in the for these in the GPS track menu to insure that all the points are included in time slice analysis if precision information is not available.

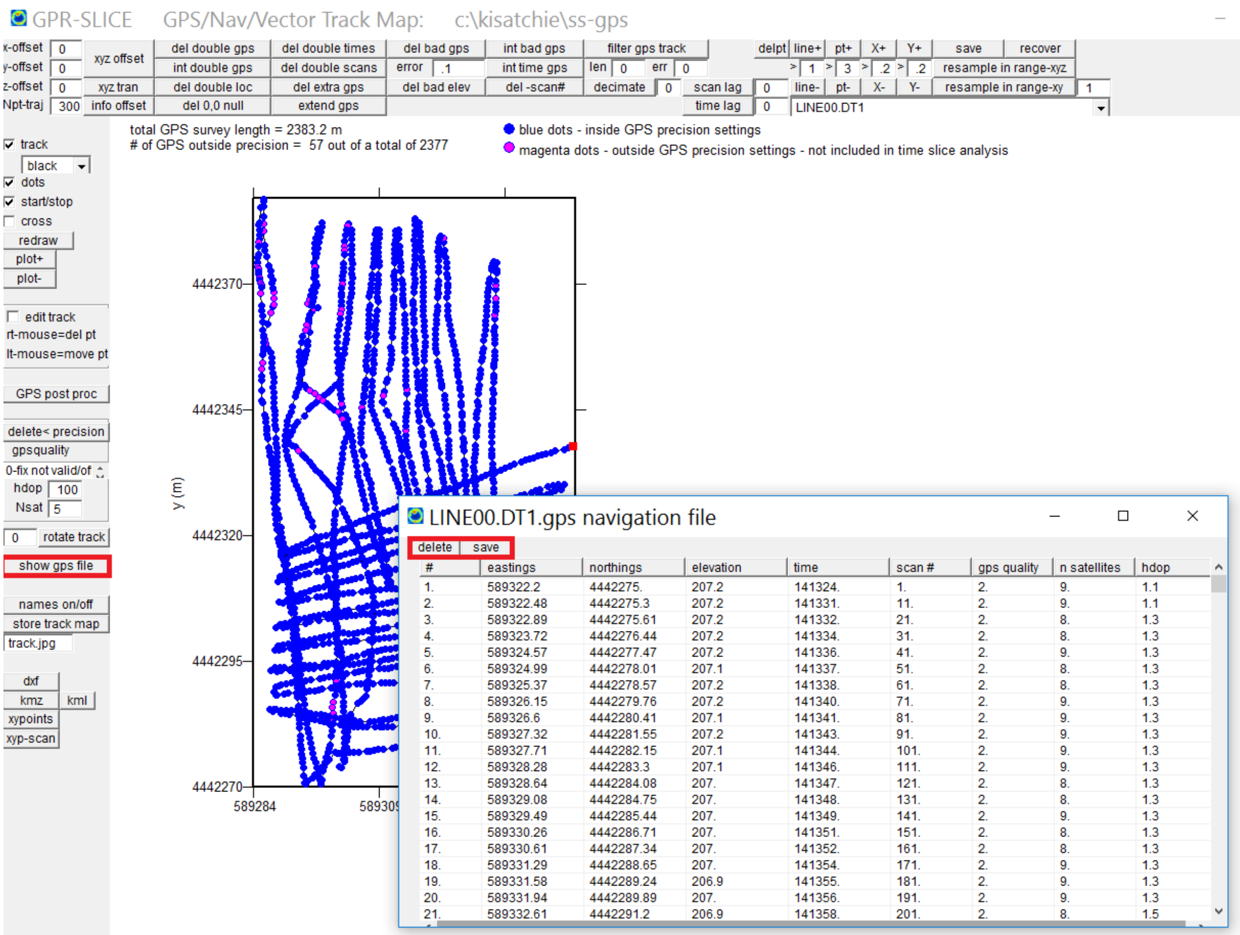
Manual Filtering of GPS Track

A set of buttons and settings to manually adjust any point along a GPS track are available. With line+/- and the XY -+ buttons the user can quickly scroll to any GPS profile and then move along any individual track to get to a desired GPS point to adjust the location by making repeated clicks on the X or Y +- buttons. The amount to move the GPS point can be differentially set for forward and backward movements. An example is shown in the following screen shot of the GPS Track menu:



GPS Listings Spreadsheet

GPS navigation files that are made for each radargram in the information file can be easily accessed using the Show GPS File buttons in both the GPS track menu and in the Edit Info File menu. The GPS data will be presented in a spreadsheet available for additional editing if needed and can be used to quickly identify problem GPS points in the file. The 8 columns shown are the eastings, northings, elevation, time, scan#, gps quality, # of satellites and the HDOP. (GPS navigation files are 20 columns long with columns 9,10, 11 which are reserved for vector scan definitions, and 9 columns leftover for future growth)



GPR/GPS Total Station Navigation

Purpose: To introduce how total station surveys are integrated into GPR-SLICE software and to show all the steps from using raw total station tracks to creating time slice datasets.

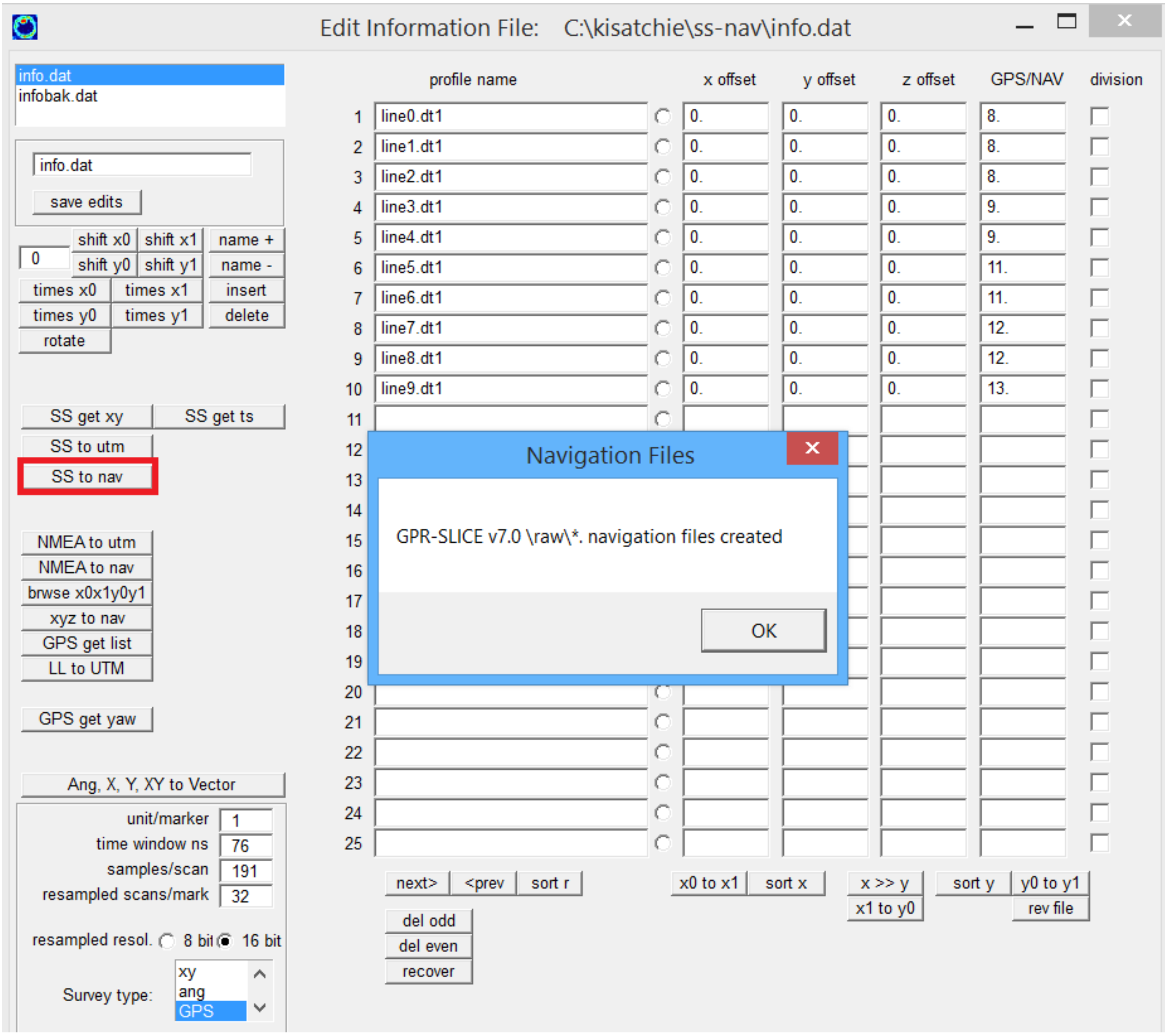
Basic Information: Total station navigated GPR surveys are possible with GPR-SLICE v7.0. Currently only equipment from Sensors and Software, Mala Geoscience, and IDS of Italy provide a standard format for the total station log, which is identical to the GPS NMEA string form or a customized form which is read in the Edit Info File menu. Total station surveys are identified in the Create Info File menu with the "GPS" identity. For example, for every Sensors and Software total station GPR survey, a GPS log file with the extension *.gps is created for every radargram. This *.gps file looks identical to the *.gps files generated for real GPS navigation – only that the local x and y coordinates of the survey replace the latitude and longitude locations in the NMEA string:

LINE0 - Notepad

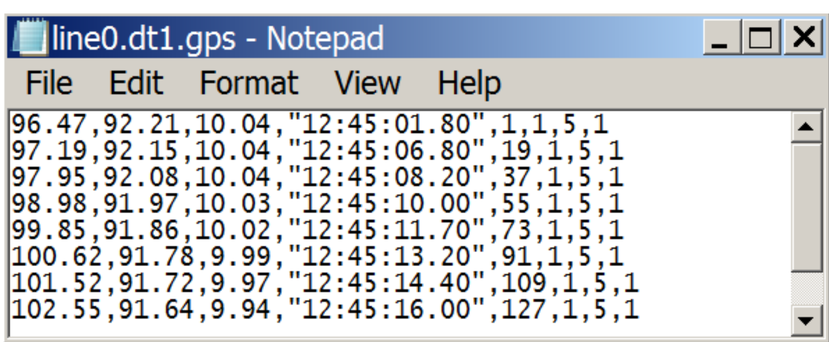
File Edit Format View Help

```
Trace #1 at position 0.000000
$GPGGA,124501.80,92.21,N,96.47,E,1,05,1.0,10.04,M,0.0,M,0.0,0001*99
Trace #19 at position 2.880000
$GPGGA,124506.80,92.15,N,97.19,E,1,05,1.0,10.04,M,0.0,M,0.0,0001*99
Trace #37 at position 5.760000
$GPGGA,124508.20,92.08,N,97.95,E,1,05,1.0,10.04,M,0.0,M,0.0,0001*99
Trace #55 at position 8.640000
$GPGGA,124510.00,91.97,N,98.98,E,1,05,1.0,10.03,M,0.0,M,0.0,0001*99
Trace #73 at position 11.520000
$GPGGA,124511.70,91.86,N,99.85,E,1,05,1.0,10.02,M,0.0,M,0.0,0001*99
Trace #91 at position 14.400001
$GPGGA,124513.20,91.78,N,100.62,E,1,05,1.0,9.99,M,0.0,M,0.0,0001*99
Trace #109 at position 17.280001
$GPGGA,124514.40,91.72,N,101.52,E,1,05,1.0,9.97,M,0.0,M,0.0,0001*99
Trace #127 at position 20.160000
$GPGGA,124516.00,91.64,N,102.55,E,1,05,1.0,9.94,M,0.0,M,0.0,0001*99
```

Clicking the SS to Nav button in the Edit Info File menu:



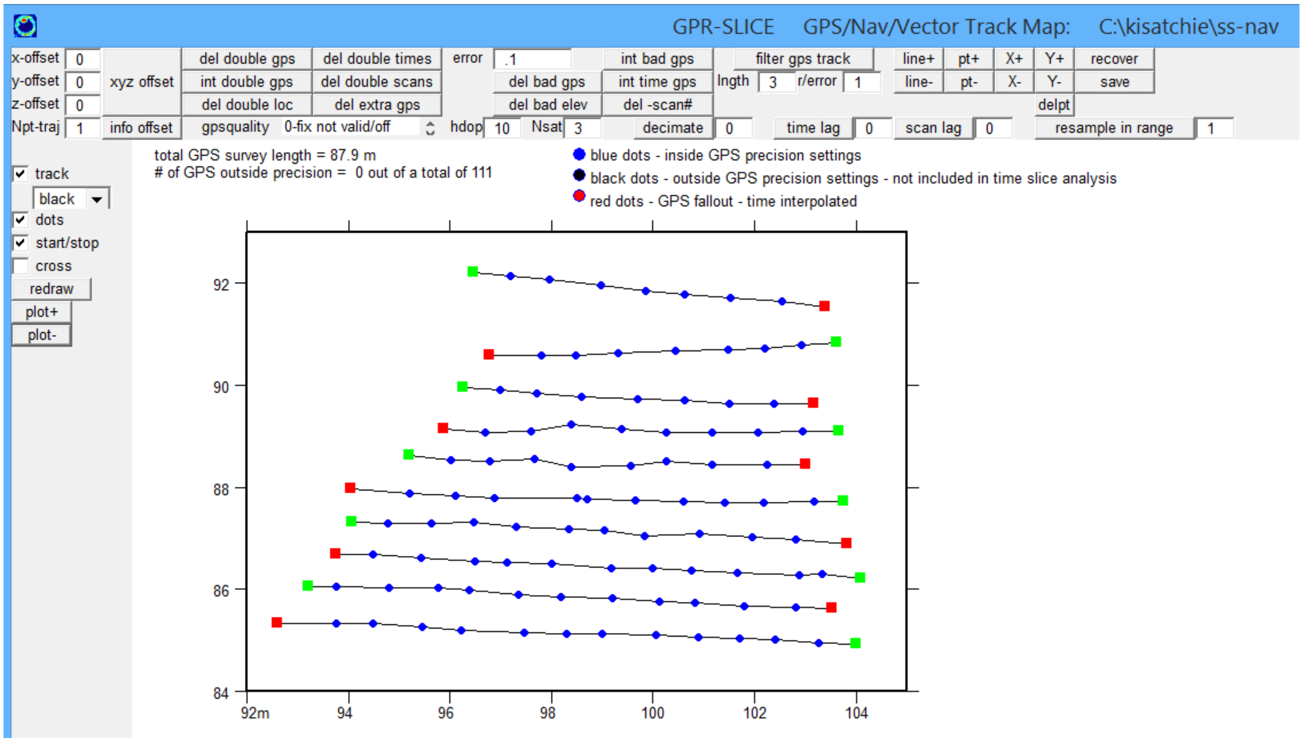
will generate the same 5 column standard GPR-SLICE *.dt1.gps file: total station x, total station y, total station elevation, “time”, scan #:


line0.dt1.gps - Notepad

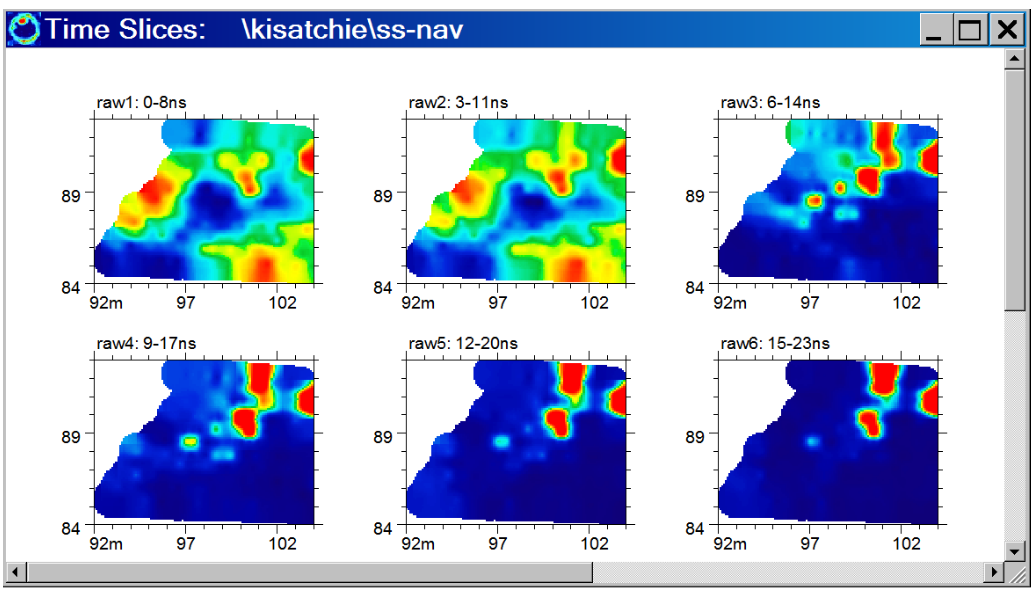
File Edit Format View Help

```
96.47,92.21,10.04,"12:45:01.80",1,1,5,1
97.19,92.15,10.04,"12:45:06.80",19,1,5,1
97.95,92.08,10.04,"12:45:08.20",37,1,5,1
98.98,91.97,10.03,"12:45:10.00",55,1,5,1
99.85,91.86,10.02,"12:45:11.70",73,1,5,1
100.62,91.78,9.99,"12:45:13.20",91,1,5,1
101.52,91.72,9.97,"12:45:14.40",109,1,5,1
102.55,91.64,9.94,"12:45:16.00",127,1,5,1
```

The total station GPR tracks for this project are shown:

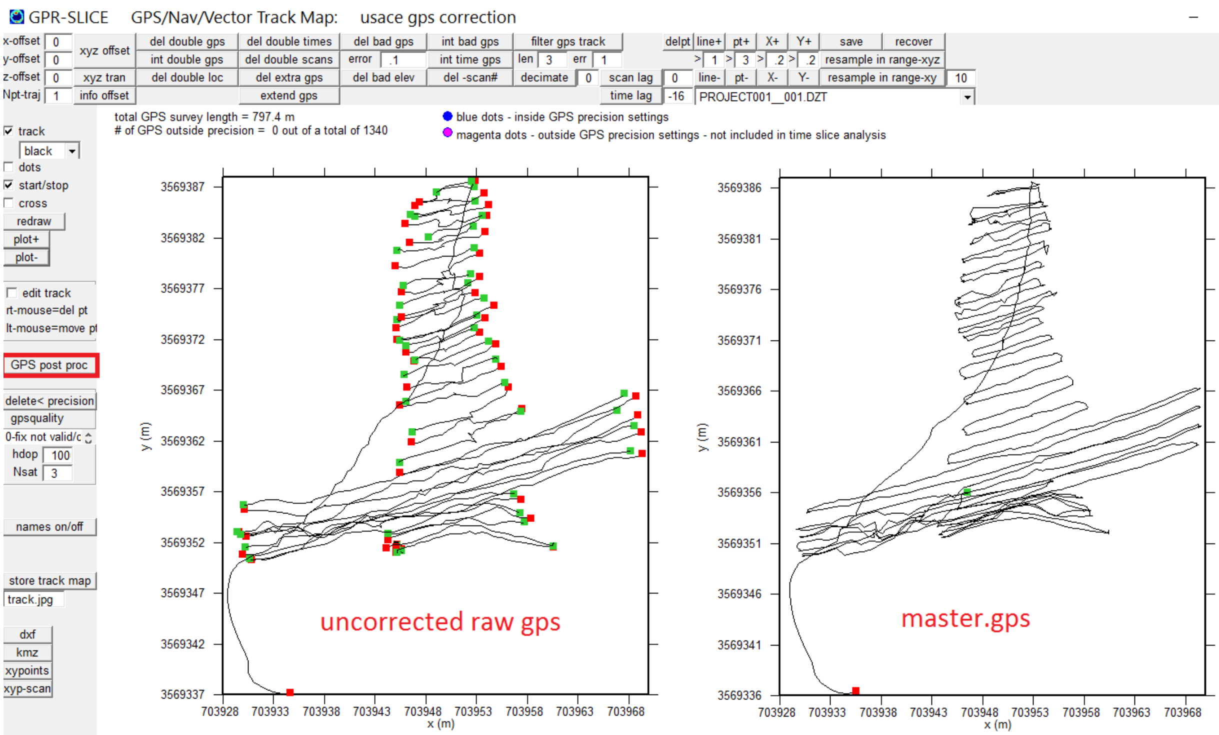


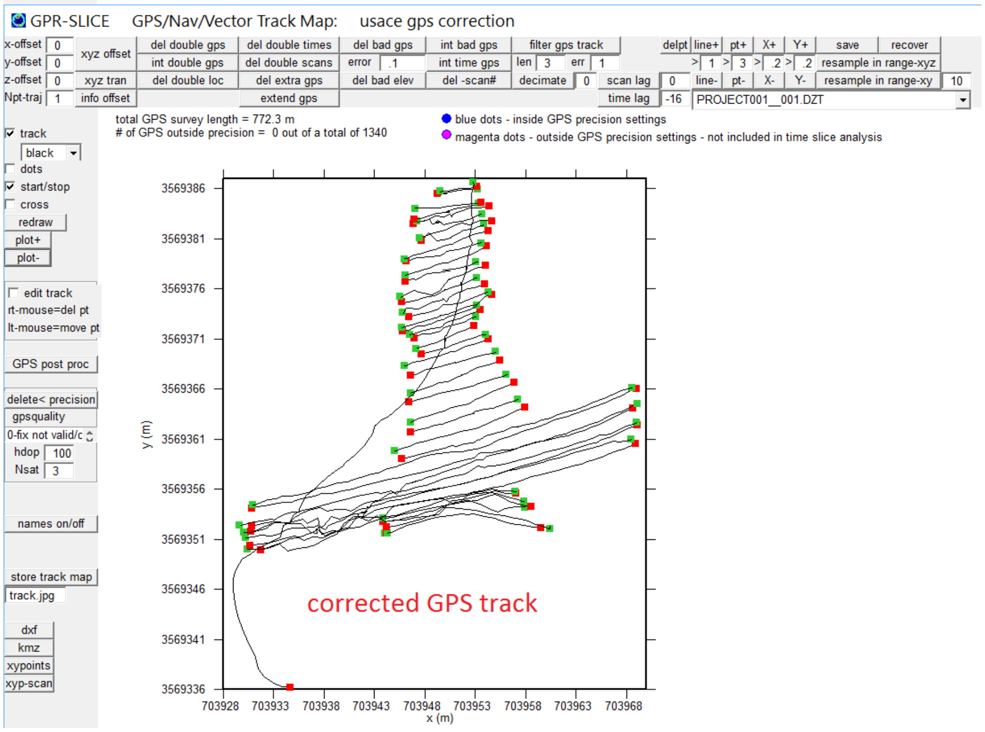
The time slices for this total station GPR/GPS project are show below:



Notes: The * to Nav buttons are also provided in the software but are currently not activated for some manufacturers since they have yet to integrate total station surveys. Once these companies provide the format of their total station navigation files then these buttons will be turned on. Most likely these formats will emulate the NMEA string format in replacing just the latitude and longitude with local station coordinates.

GPS post processing from a Master.gps file



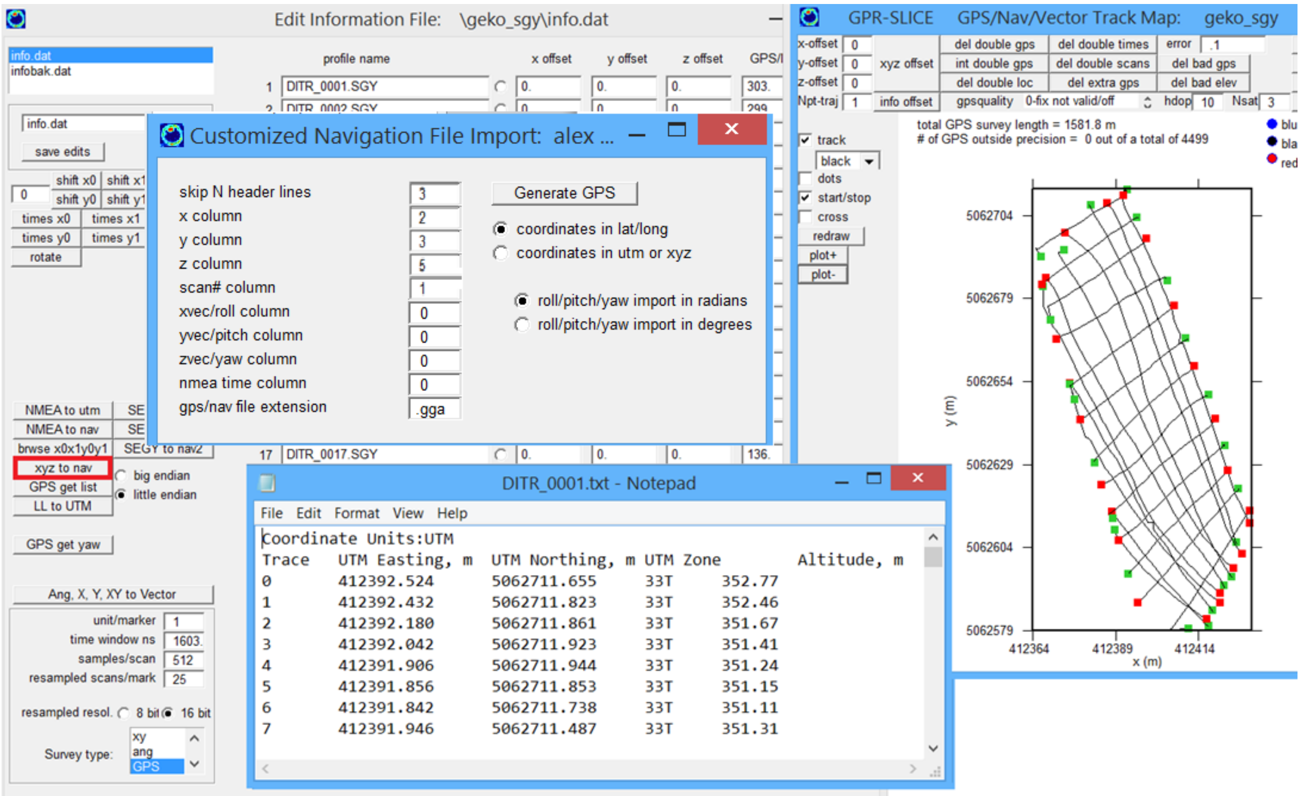


The GPS Track menu has specialized options to post process raw uncorrected GPS tracks from a master gps track. This GPS survey will be made from a single master GPS log file that is recorded simultaneously and which is later post processed to yield a corrected GPS track. GPR-SLICE can merge the corrected master.gps track with the raw uncorrected GPS tracks for each of the files in the project. The master.gps file should encompass the entire time that comprises the individual GPS files. The button called GPS Post Proc (shown in the GPS track screen shot) will read the uncorrected GPS track for each radargram and will extract the corresponding location in the master.gps processed track to extract the exact location. Linear interpolation is made between the 2 bordering times in the master.gps to yield the best possible corrected track. The master.gps track will usually have been post processed in alternate third party software such as Pathfinder before being use to merge and correct with the individual profile tracks in GPR-SLICE

Note: The master.gps is a single recorded GPS over the entire survey time and is 4 columns with time, eastings, northings and elevation – comma delimited, and should reside in the \raw\ folder of the project.

Flexible GPS/total station navigation file input read

Some users are developing their own GPS and total station navigation formats which are not linked to the GPR manufacturer that they are using. For this reason, a flexible navigation file input read was developed for the Edit Info File menu. Using the XYZ to Nav button will launch another menu where the user can set the number of lines to skip in the header, file extension names, the columns for the x, y, and z of the data as well as the scan number if it exists. An example of a RadarTeam Cobra *.txt navigation file format, and how the flexible read can be used to import this to the *.*.gps files for this manufacturer is shown in Figure 8. This flexible read can be applied to any kind of navigation, GPS, total station or any user defined navigation. The only requirement is that the navigation file for a radargram must have the exact same name other than the defined file extension.



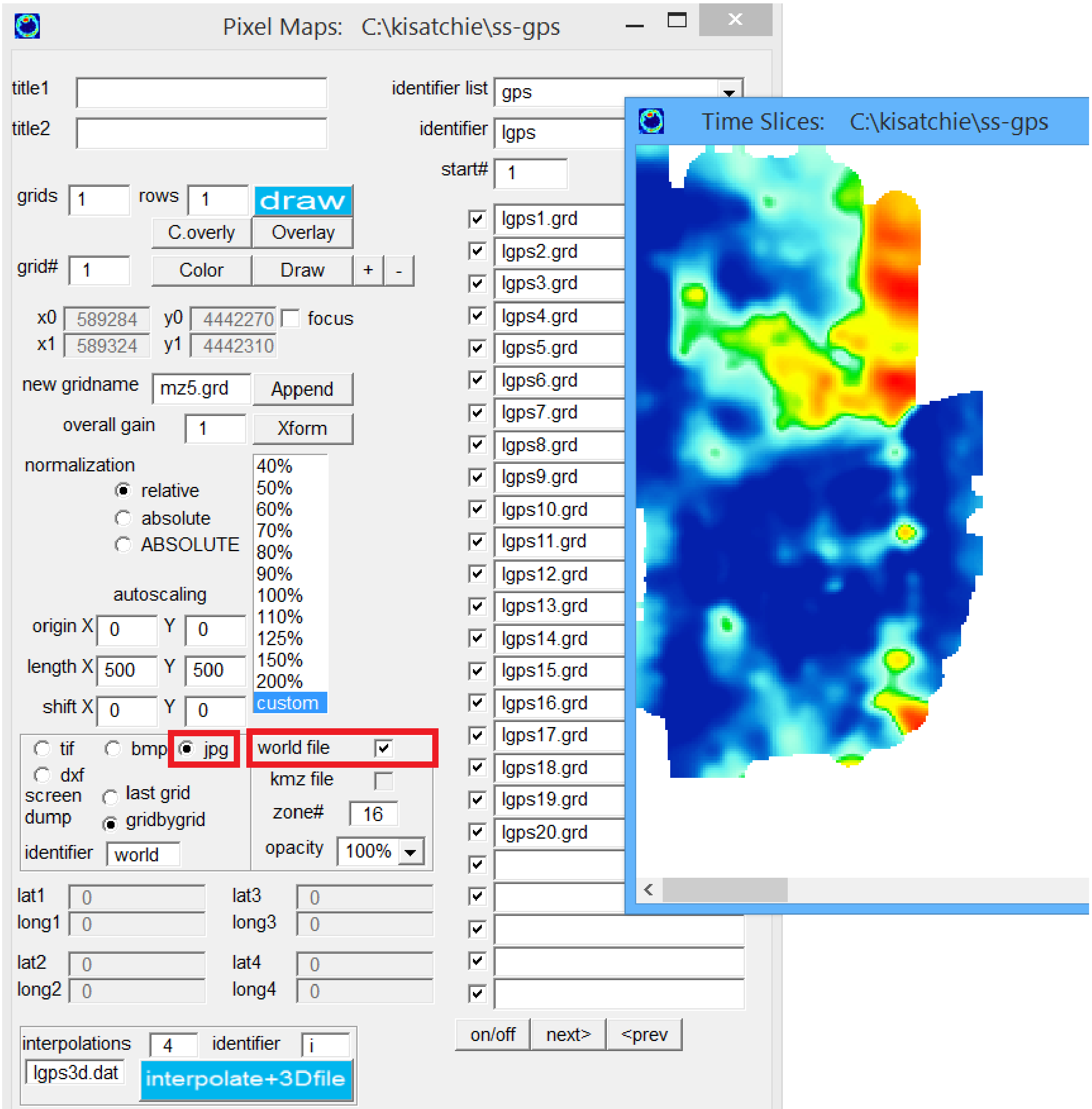
GIS Options: Creating World Files (*.jgw)

GIS Software like Arc-Info or Arc-View requires a corresponding world file for jpeg images to be viewed in their corresponding UTM coordinates. As more and more GIS referenced surveys are required, we have made the options to generate World Files easier for jpeg and bitmaps outputs in GPR-SLICE. When the corresponding world file for a jpeg is available, the user has many options available to them to overlay or view other databases where they collected their grids. World files can be created in GPR-SLICE when a jpeg or bitmap is being outputted. The 6 requirements to have a world file written when an image is being outputted are:

1. Axes displays for both x-y axes and the time axis are turned off in the Options Menu.
2. Custom display size is being used in the Pixel Menu.
3. x origin and y origin of the pixel maps are set to 0.
4. x shift and y shift of the pixel maps are set to 0.
5. The grid-by-grid screen dump option is clicked on.

6. The JPG screen dump option is clicked on.

When the World File checkbox is checked on in the Pixel Map menu, all these settings are automatically instituted to generate the image and to write the corresponding world file. The world file that is automatically written has an extension *.jgw for jpg or *.bgw for bitmaps. The world file has several pieces of information describing the meters per pixel as well as the starting Eastings and the highest Northings value in the image. An example of a GPR-SLICE image displayed in GIS software (HGIS-PRO Spatial Analysis Lab Version) from a dataset made from a (Sensors and Software) GPR-GPS survey is shown below (image courtesy of 3D Geophysics):



Note: When the World File option is shut off is the user will have to go back into the Options menu and turn back on the axis displays to get the screen to put back on the desired axis labeling. In addition, the user may need to re-insert customized plotting sizes and plot shifting settings after using the World File option.

Google Earth Images: Creating *.kmz Files

Since the Spring 2010 GPR-SLICE was enhanced to provide Google Earth *.kmz files from any geo-referenced time slice dataset. Google Earth maps are archived files containing a *.kml file and a geo-referenced image file:

wm10.kml - Notepad

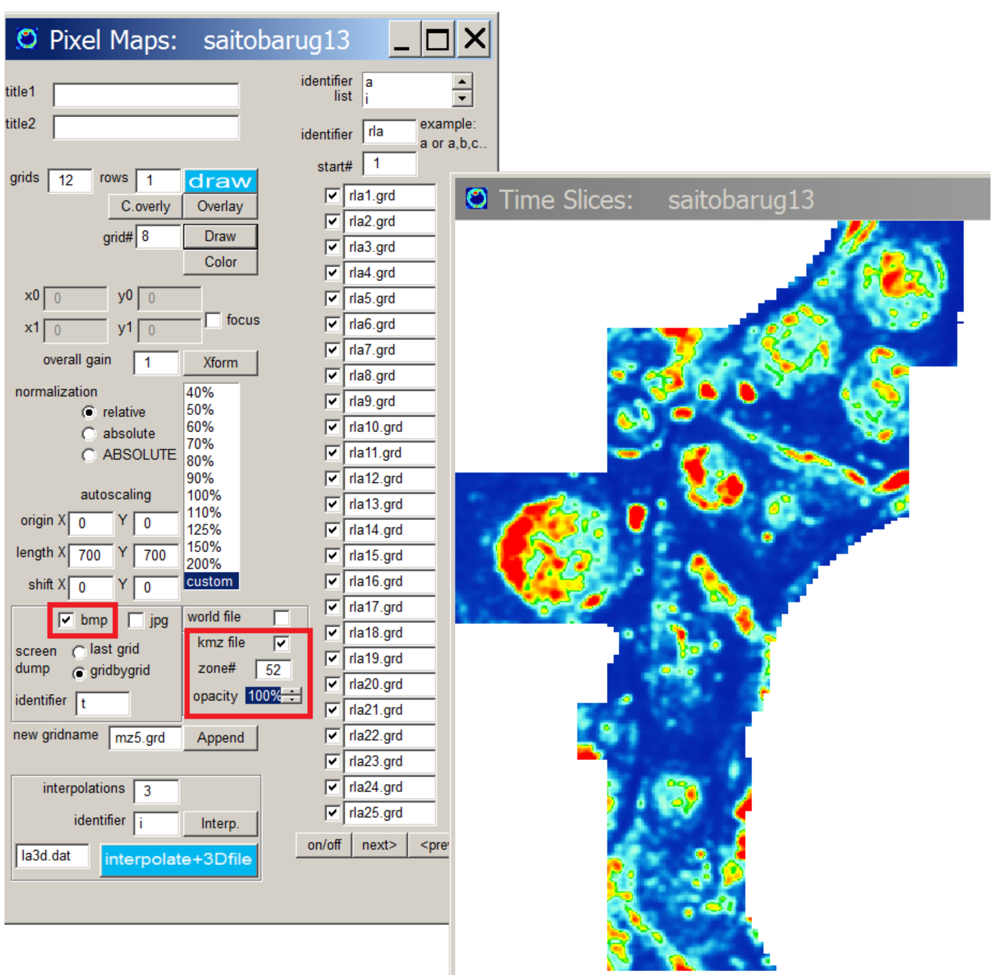
File Edit Format View Help


```xml
<?xml version="1.0" encoding="UTF-8"?>
<kml xmlns="http://www.opengis.net/kml/2.2" xmlns:gx="http://www.google.com/kml/ext/2.2">
<GroundOverlay>
<name>wm10.kml</name>
<color>ffffffff</color>
<drawOrder>1</drawOrder>
<Icon>
<href>wm10.png</href>
<refreshMode>onInterval</refreshMode>
<refreshInterval>86400</refreshInterval>
<viewBoundScale>0.75</viewBoundScale>
</Icon>
<gx:LatLonQuad>
<coordinates>
-71.0600882460361,42.3194902356668
-71.0596880298961,42.3194974279586
-71.059701244383,42.3199024429772
-71.0601014630862,42.319895250584
</coordinates>
<rotation>0</rotation>
</gx:LatLonQuad>
</GroundOverlay>
</kml>
```

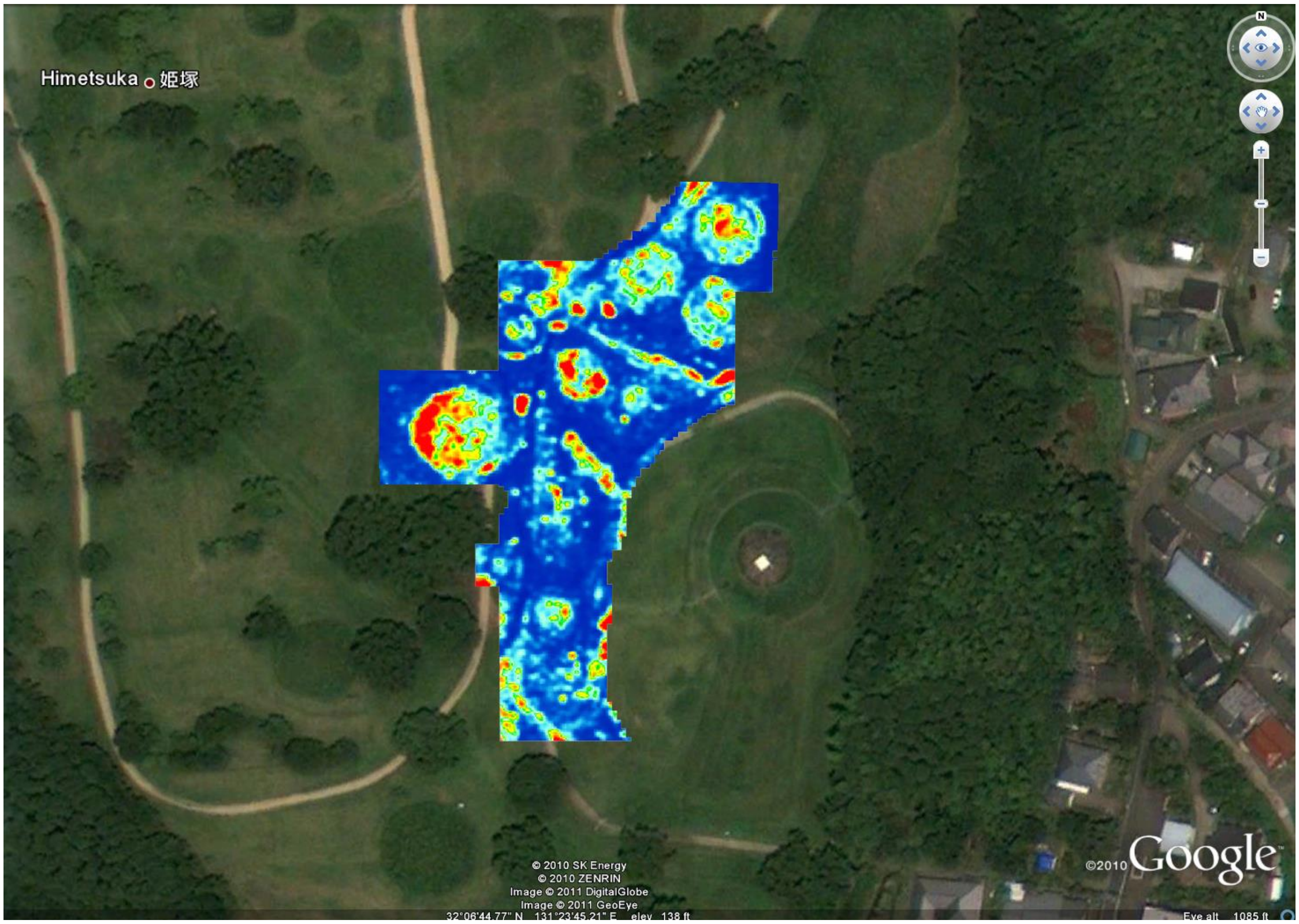

The kml file contains the longitudes and latitudes of the image corners along with other information on the image generation (see the internet for more details). In the kml file is a link to a subfolder called \georef-images\ where the georeferenced image is stored. The kmz file contains both the *.kml and the subfolder \georef-images\ with the image in it. The *.kmz file is an archived file with these 2 files in it. The dll Litezip.dll is used in GPR-SLICE to make the kmz and archived file. So, a single file contains all the necessary information to place the image in its exact location on the earth. (This is more convenient then World files where 2 separate files on disk need to be read).

To generate the kmz files from a single or complete time slice dataset, the user sets the zone number (if not already automatically set from a native gpr/gps survey – rotated/translated local grids into geo-referenced grids will require the user to set this), clicks on the bmp checkbox, followed by checking on the kmz checkbox in the Pixel Map menu. Bmp files are used since the complete color resolution without degradation to jpg is needed. Drawing the screen, bmp files as well as png images files will be written to the \jpg\ folder in the project. The png files are necessary since this image format is more advanced than bmp allows for alpha channels – bytes which describe the transparent nature of a certain color. When the screen is drawn with the bmp and kmz checked on, a shelled executable call convert.exe which resides in the \slice\v7.0\ folder is run. This software, from Image Majik is free to the public for commercial or non-commercial applications. Convert.exe will convert the *.bmp files to *.png files, with information on the transparent or null areas. For GPS surveys, the blank area not gridded or surveyed will remain as transparent regions when the image is flow into Google Earth. The run time operation will also make of copy of the geo-referenced image in a subfolder called \georef-image\ with the *.png files in it. The archived kmz file contains this subfolder with the *.png file in it.

An example of where the settings are made to generate the kmz files in the Pixel map is shown in the following menu screen shot:



A Google Earth overlay for this *.kmz file found in the \jpg\ folder of the project after generation is shown:

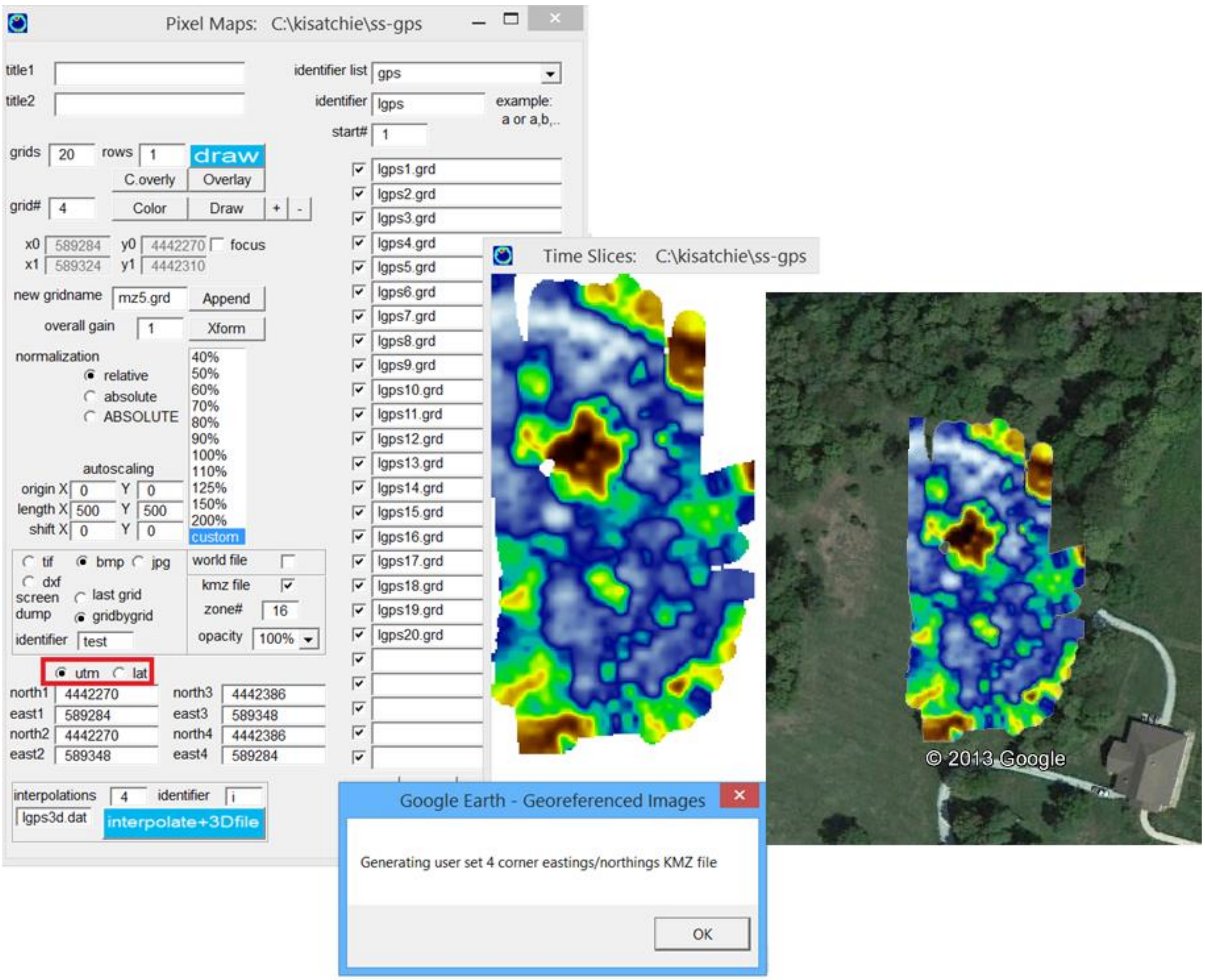


(Data courtesy of the Saitobaru Archaeological Museum and collected in conjunction with the Geophysical Archaeometry Laboratory Saito Division in Miyazaki prefecture Japan.) This site has large earthen burials from the Kofun period 300-700 AD, many of which are still intact. GPR has been effective in helping to discover subterranean chambers on intact as well as destroyed burial mounds.

4 Corner Lat/Long/UTM Settings for Georeferencing Local Grids

Another option to place local grids into a georeferenced grid by setting the lat/long or the utm of each corner of the time slice is available in the Pixel Map menu (Figure 7). The user must set in order the southwest, southeast, northeast and northwest corners in decimal lat/long or easting/northing. To generate Google Earth time slices the

BMP and KMZ checkbox are clicked on. The 4 corner georeferenced time slices can also be generated in batch for all the time slices displayed to the dialog. (Georeferencing is also available with the rotate/translate option in the Grid menu; 4 corner designations are also available in the Pixel 2D menu for large survey areas for multichannel license).

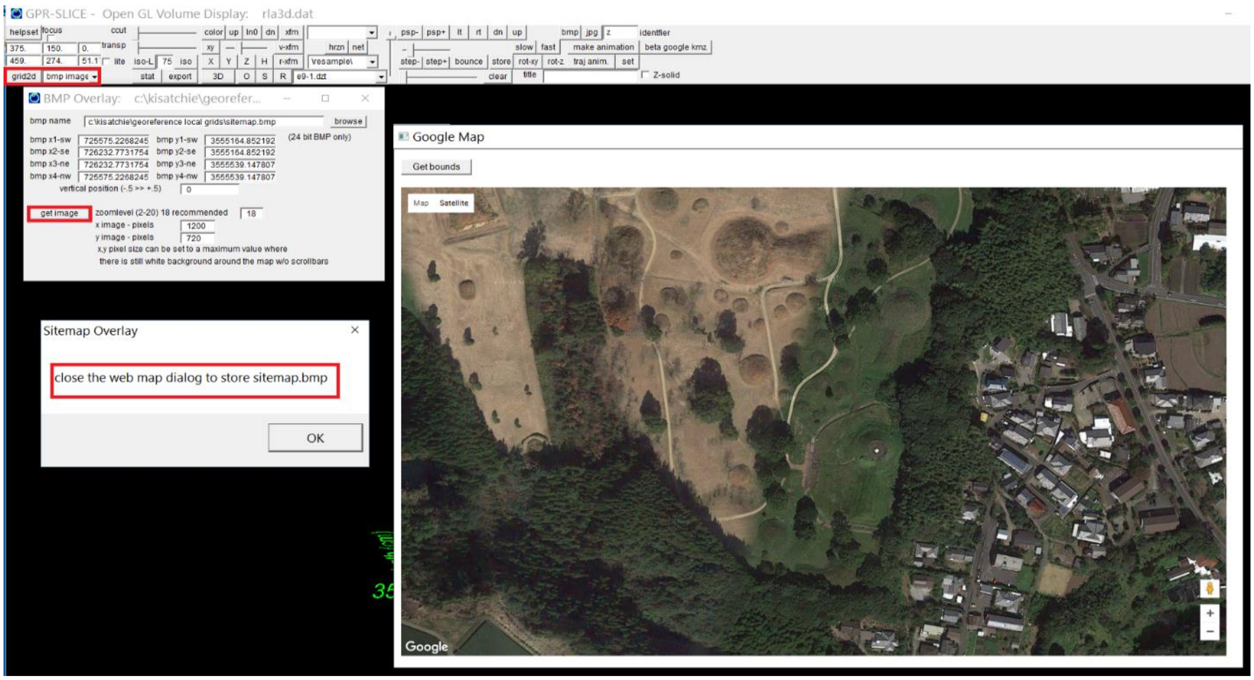


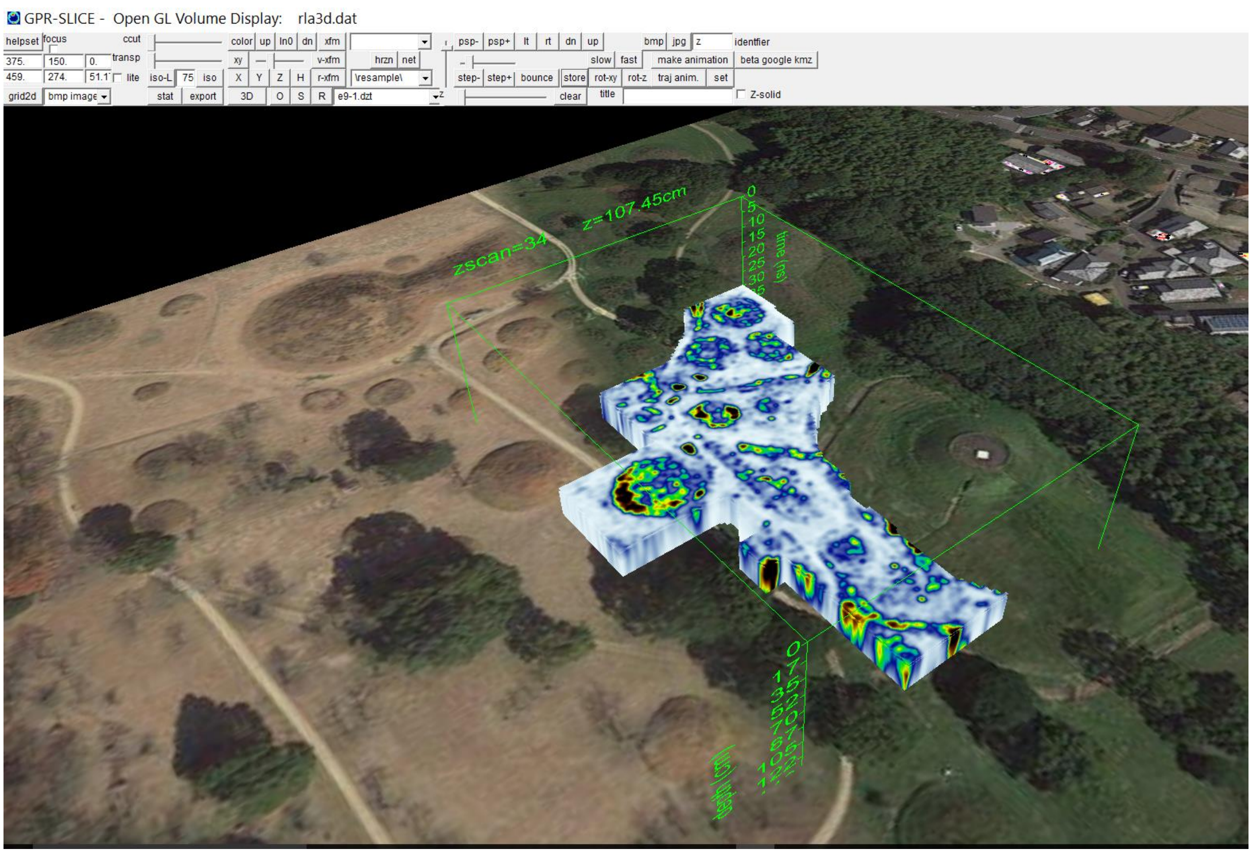
OpenGL Volume Overlay of Geo-Referenced Images, Site Plan Bitmaps or Google Earth Maps

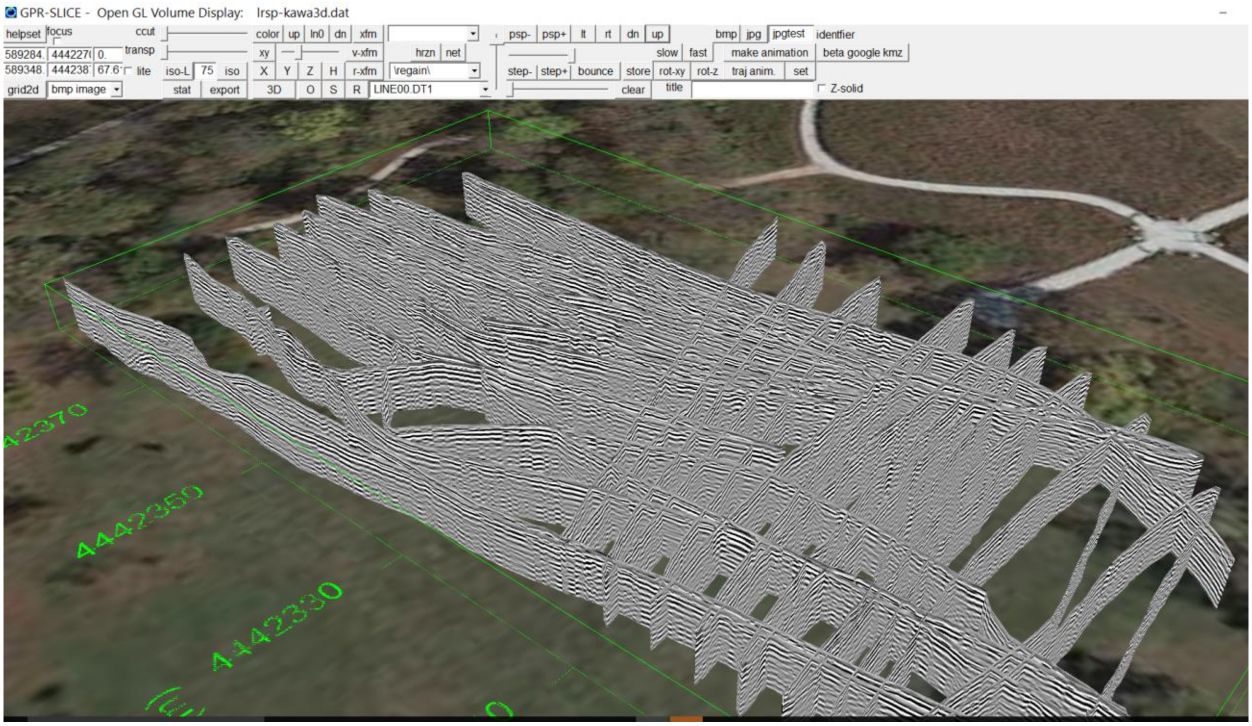
GPR-SLICE can now automatically retrieve a Google map for GPS datasets. A new executable which is shelled out to call googmap.exe, will read the 3D volume and center a Google map on the grid. The zoom level of can be set before storing the map (shown in the following figure). A value of 18 for instance will give a typical distance of around 450 meters over the image which defaults to 1000x700 pixels. The pixel size can be increased to values just slightly less than the full native screen resolution of the display. If higher resolution is needed choose a zoom level of 19-20 or use a denser display monitor. A zoom level of 10-17 can be used to make a bitmap overlay that shows more of the surrounding area at the site. To generate the sitemap.bmp, simply close the Google Map dialog to store the bitmap to the main project folder. Animations on top of the image or various other displays are all possible. Several examples of what can be accomplished with the new map oeveraly are shown for the Saitobaru National Burial Mound in Miyazaki, Japan. A GPS radargram from the Strawtown Archaeological Site in Indiana is also given in the following figures.

In the BMP Overlay menu, the depth of the sitemap.bmp can be adjusted on import. The depth is currently set as a graphical input from -0.5 to +0.5 where 0 is half way between the 3D volume depth. Time slices below the image depth will be masked as will displayed radargrams. The transparency slider bar can be used to look through the sitemap.bmp. In this example UTM coordinates are used, but bitmaps of site plans with local grid coordinates can also be used or any localized bmp – it does not have to be a map! The Z scan time slice can be animated on top of the geo-referenced bitmaps. To do this it is best to set a small transparency on the slider bar and then to look directly down on the Z plane using the 2D – Z, X, Y (off) button in menu.

Note: For retrieving a Google map does require an internet connection, so it is best to download your desired images before going to a remote field site. The Google map dialog should not be maximized and the default dialog size should be left stationary. Zoom levels should be set before launching Google maps.


GPR-SLICE - Open GL Volume Display: rla3d.dat
BMP Overlay: c:\kisatchie\georefer...
Google Map
Get bounds
Map Satellite
Sitemap Overlay
close the web map dialog to store sitemap.bmp
OK
Google

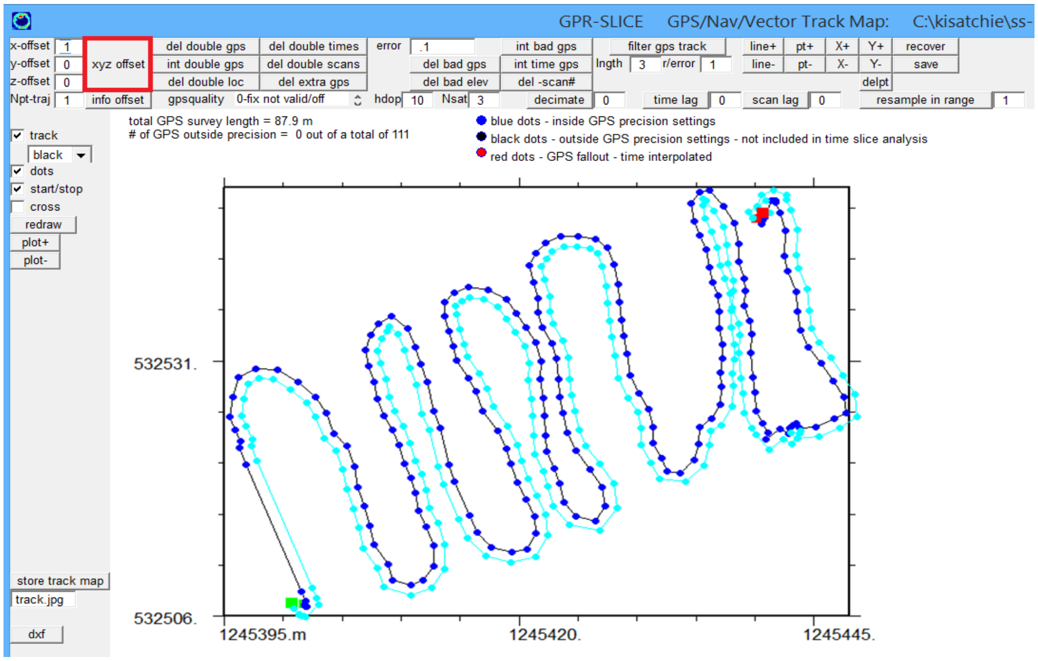

GPR-SLICE - Open GL Volume Display: rla3d.dat
z=107.45cm
zscan=34
time (ns)



Adjusting for GPS Antenna and GPR Antenna Offsets

In the GPS Plot menu the navigation files can be adjusted to account for the X and/or Y offset between the GPS antenna and the GPR antenna. The offset correction is dependent on the direction of the antenna. The direction is estimated by looking at the two nearest surrounding points and then using this to determine the angle and direction of the GPR antenna with respect to the GPS antenna. The projections of the known-fixed offset of the GPS antenna and the GPR antenna into eastings and northings values are then adjusted to the *.*.GPS Files. Clicking the XY Offset button will apply the offset correction and display the corrected GPS track (in a cyan color – the original track is shown in dark blue). To store these changes the user should click the Save button. If the user wants to recover any change from the beginning of a session, there is a convenient Recover button located in the GPS Track Menu.

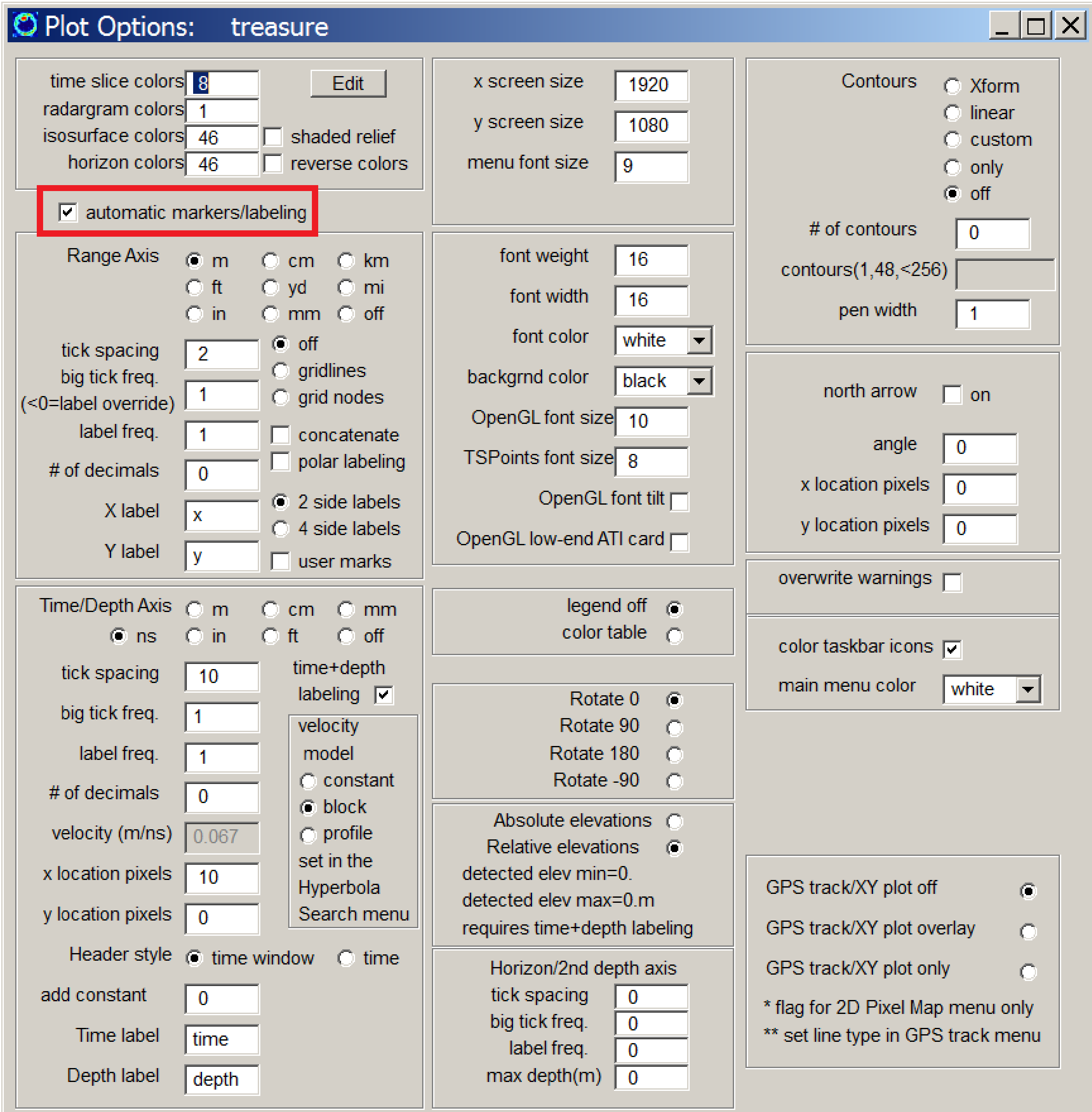
There is also an Info Offset button which will read the specific set offsets in the information file for each radargrams and apply to the GPS track. The offsets can be set different for every line collected on the site!



Note: For XY offset calculations the trend of the GPS track needs to be calculated. The setting Npts Traj in the GPS track menu tells how many GPS points on each side of the track will be used from the point on the track to determing the trend of the GPS unit. Usually a setting of 1 - meanin 1 point on each side of the local point is used to determine the GPS orientation wrt to the GPR antenna. Using a larger Npts Traj value can help to smooth out small pertubations in the GPS unit trend and better position the antenna when the offset (coordinate rotation is being made).

Note: For all operation - the Del Double GPS, Del Bad GPS, Intp Bad GPS, Intp Double GPS, and the Intp Time GPS operations will automatically update the *.*.GPS files. If however, the Recover button is clicked the original *.*.GPS files will be imported back. **XY Offsets need to have the user click the SAVE button to update the new updated track.**

IX. Plot Options Overview



The Plot Options menu is available on the GPR-SLICE taskbar and is used to conveniently control all graphic displays of time slices, 3D volumes and radargrams. In this submenu the user can either set output for automatic labeling or they can manually adjust all labeling on graphic displays, as well as assign color tables, font sizes etc. In the Plot Options menus controls are available for:

- setting GPS tracks overlay displays on or off on 2D time slices
- contour line controls for 2D time slices
- font sizes/colors/background colours for all 2D graphic menus as well as Open GL menus
- absolute or relative elevation labeling displays when topographic corrected or topography warped displays are engaged
- depth + time axis labeling for radargrams and Open GL menus and
- reads velocity profiles and assigns corresponding variable depth labeling on radargrams and Open GL display
- polar labeling options for tunnels and cylindrically adjusted radargrams
- assigning color tables for time slices, 3D volumes, isosurfaces and horizon surfaces
- setting 2 sided or 4 sided labeling of time slices
- shutting on/off user inserted markers display on survey wheel or alternately navigated radargrams
- sets a 2nd depth label for horizon detection displays in the Static menu

GPR-SLICE presently has 50 different color tables which are preliminary color tables – the user is encouraged to create their own color tables which will best fit their needs as well as for matching their particular default printer. The color tables can be viewed by clicking on the Edit button in the Options Menu. GPR-SLICE uses a color palette, which is composed of 256 different colors. The color tables can be edited and stored to new color table numbers. The Edit Menu works by the user first clicking on a color, and then inserting that color into the palette graph. After several locations are filled in, the user can then click the "interpolate'" button which will create a continuous color table between the inserted colors. The interpolation is a simple linear interpolation between the hue, whiteness and saturation between each color chosen.

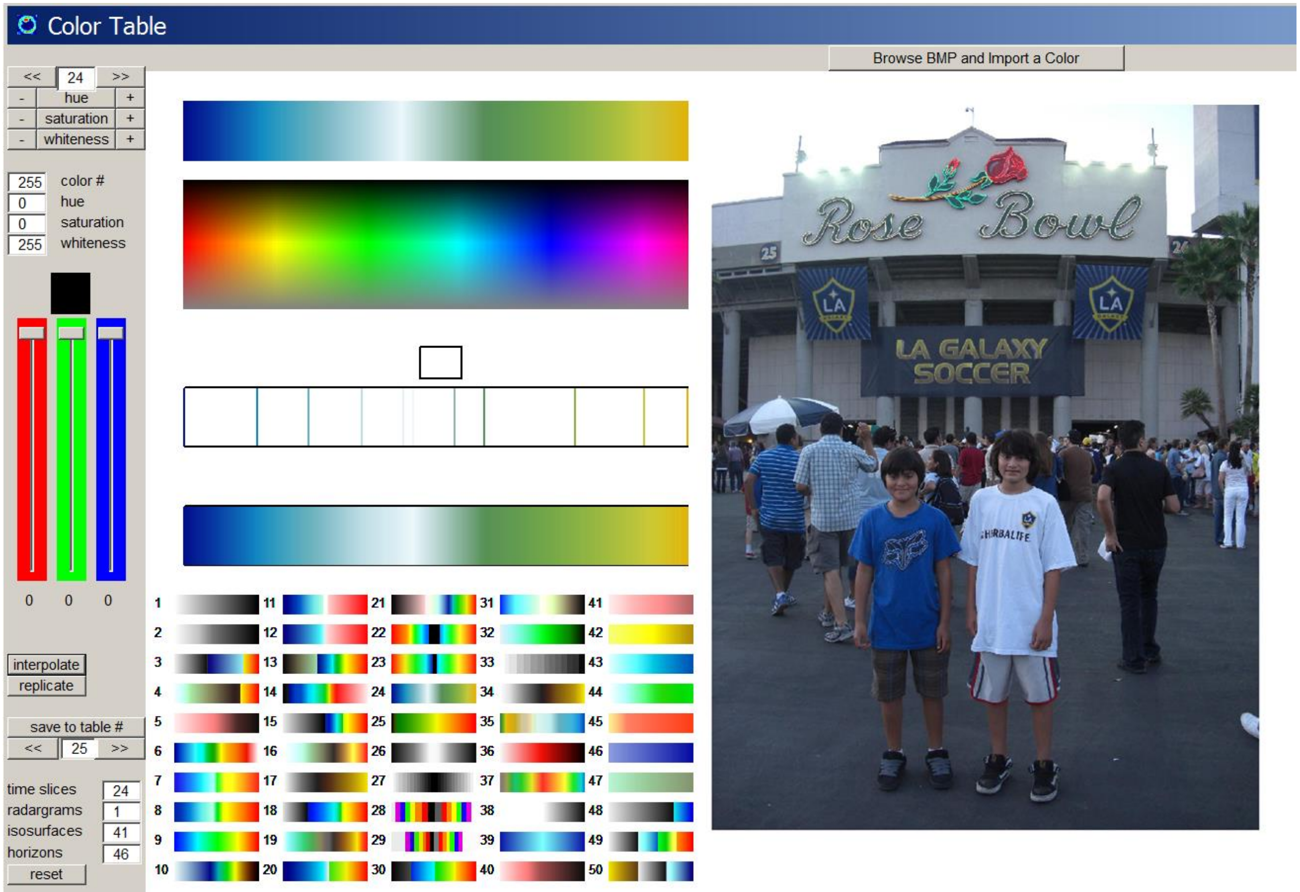
Shown in the example on the next page is the color table. The user has clicked on several colors and placed them in the palette locations, which are shown as thin narrow lines. Clicking the "interpolate" button then made a continuous gradation of colors between the inserted colors. By clicking the "save table #", the user can stored a color table, in this case to table #21. By clicking the "replicate" button, a step-wise color table, with color values being identical till the next inserted color is found will be generated. This option is useful if the user wants to use say only 16 colors across the possible 256 color table.

The user can import a palette from the 50 different color tables by clicking through the import + or import – switches provided in the menu.

The imported palette will appear on the top palette location. The user can also change the hue, saturation and whiteness for any of the palette imported or for the master palette. The actual values for the hue, saturation or whiteness in the range of 0-255 can be inputted in the menu by the user. Slider bars allow the user to generate any conceivable RGB color combination. Once a color is generated, clicking on the color box with the box will store that color which can then be dropped onto the color palette graph.

A new feature also in GPR-SLICE v7.0 is the ability to import any bitmap and chose colors from ones imported pictures/palettes and insert into the palette development bar for complete color table interpolation (as shown in the next menu screen shot).

Note: The user should make sure to place a color at the beginning and end location within the palette to interpolate or replicate. The user can remove a chosen color within the working palette by hitting the right mouse button over the chosen color. In this case when the user wants to create a replicated or stepped color palette, the last color chosen should also be placed at the color position 255 and also at some lesser location e.g. 240, and then the replicate switch should be clicked. This will cause the last color chosen to be replicated from position 240 to 255.



Render Colors

The color table to be used to display 3D volumetric renders. Currently a convenient color located at color table #41 is provided. The shading of this color table may or may not be sufficient for some computers and may greatly differ even more after output to a printer is done. The user should create their own 'shadow' color table which will best show light reflecting off the 3D slope renders that they will be creating.

Note: An option to reverse the displayed color tables is available in the Options Menu. **The user should be careful about this switch and not forget to turn it off** after they have created their output maps. Inherently forgetting about this switch could cause the user to reverse their subsurface interpretations as well since weak reflectors would show strong colors and strong reflectors would show weak colors.

Plot Labeling

Complete automatic labels for all graphic output are available. The user can display the range information using either: cm, m, km, in, ft, yd, mi. Tick marks, big tick marks, and the frequency of axis labels can be set in the Options Menu. A checkbox for overlaying a square grid lines over the maps can be turned on. The frequency of the grid lines follows the big tick mark frequency for 2D time slices. Gridlines option will also turn on a background for 3D isosurface displays.

For multi-plot time slice screens, the user may want to turn off all the labeling and just have it on the very last pixel map to make the screen 'less busy' looking. In this case the user can set the label frequency to -1 to accomplish writing range labels only on the last plot. The number of decimals to display for range and time/depth labels can also be adjusted. A north arrow can also be plotted on the screen for time slices.

Contour Overlays

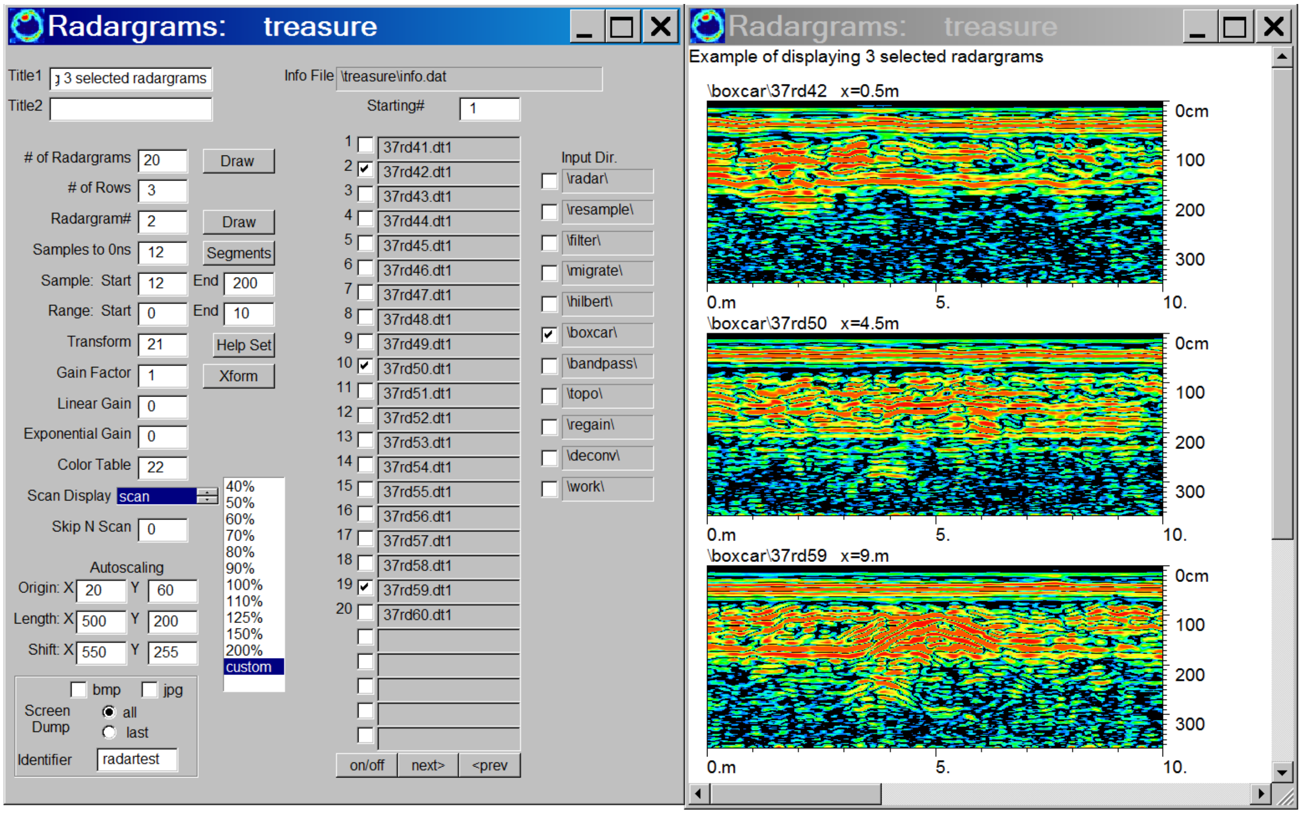
Several options for display of contour line overlays are available: transform, linear, custom, only, off. For pixel overlays, a basic contour map is overdrawn on top of the color pixel map. For a transform setting engaged for contour overlays, the contours lines will follow the unique data/color transform being used to display the individual time slice. For a linear setting, the contours separation will follow constant offsets between contour lines. Custom is for the user explicitly setting the contours to be shown. Contours are normalized between 256. For no contours, the "off" setting is clicked on. The number of contours to draw can be set in the menu.

Rotate 0, Rotate 90, Rotate 180, Rotate -90

The user can rotate the time slice maps, clockwise by 90, or 180 or counterclockwise by -90 degrees. The original axis labels and origin are preserved so that rotated display will show descending labeling of the axes. Rotation at other angles requires the use of the rotate/translate function in the Grid Menu, where a different gridset will need to be made.

Note: If rotated displays are active, split screen functions of showing corresponding anomalies between time slices and radargrams will not work properly. The rotation angle should be set back to "0" before these operations are launched in the software.

Radargram Menus: Overview



2D Radargrams

In the 2D Radargram menu, which can be launched at the Radar icon on the main menu, the user can

- create multi-radargram displays with any number or combinations of radargrams drawn to the screen and that will appear in a single dialog and from different processed folder combinations
- launch the XYpoints dialog to choose anomalies across any radargrams drawn to the screen
- create 2d animations

To show the most customizable options in the 2D radargram menu, an example screen shot in which the user is displaying radargrams #2, 10 and 19 from the information file is shown. These radargrams are checked on while all the other radargrams are checked off. There is an easy on/off button to check on all or check off all of the radargrams. Using the customizable size option, the exact length and width of the radargram plots in pixels is set (to 500 and 200 respectively). The radargrams plots that are drawn to the screen will be shifted 550 pixels in x and 255 pixels in y between adjacent radargrams. For this example, the user sets the total number of radargram to 20 and the number of rows to 3, which when drawn will show 3 radargrams drawn in column. In this example because 3 radargrams are clicked on and 3 rows are set, there is no opportunity for any x shifting of the radargrams. If in this example 2 rows were set, the 3rd radargram would be drawn to the right of the top radargram, 550 pixels from the first radargrams origin.

In the radargram menu, some regaining of radargrams for graphic display can be done several ways. An overall gain factor, linear gain with depth, and an exponential gain with depth, can be applied to the display of the radargrams. The total gain, to a radargram scan is

total gain = (gain)*(1+irange*rlgain)+exp(irange*expgain)

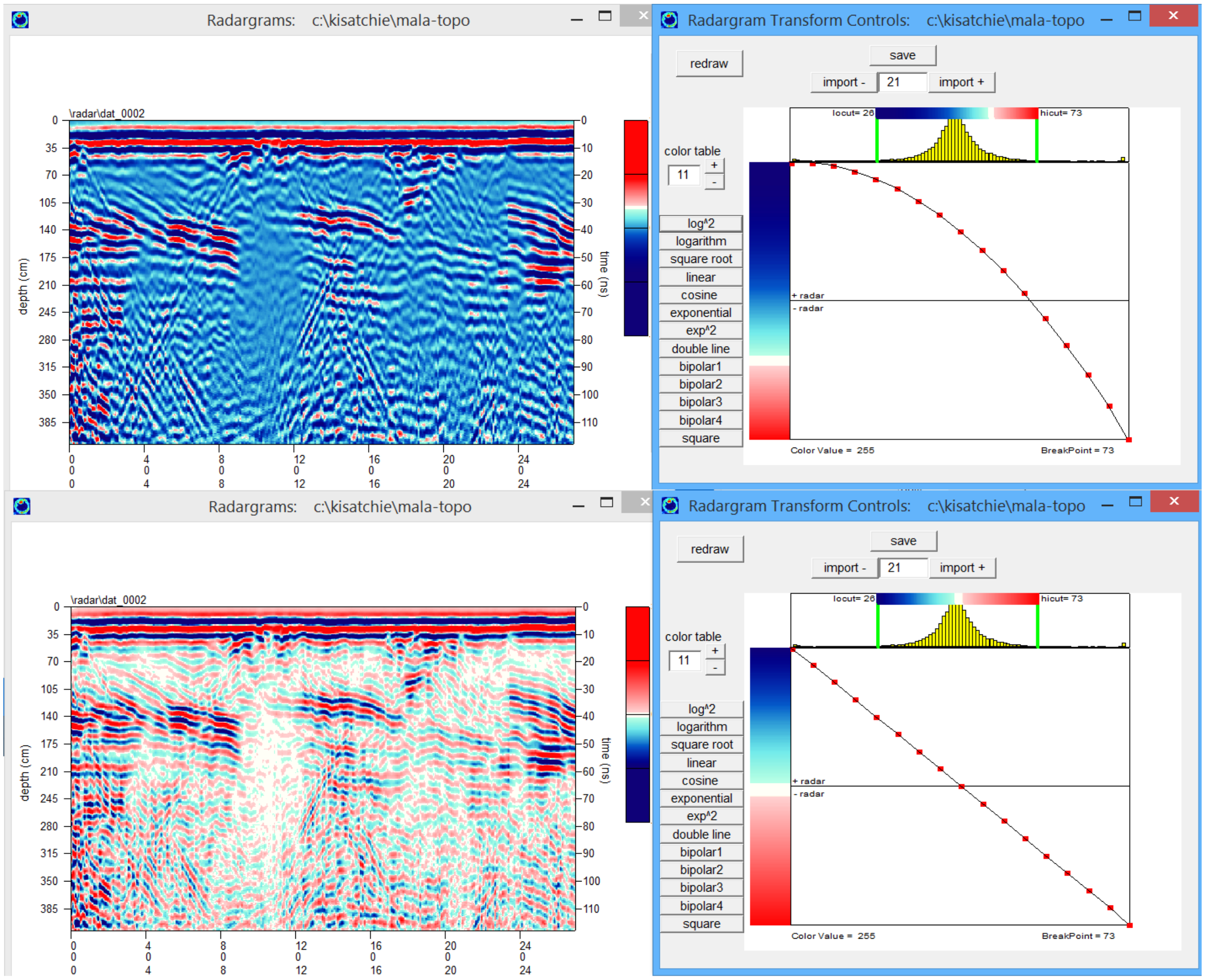
where	gain	= overall gain factor
	rlgain	= linear gain factor
	expgain	= exponential gain factor
	irange	= (i-1)/(n-1), i=1 to n
	n	= number of samples/scan

By setting the linear gain factor to 0, essentially shuts off linear gaining across scan depth of the radargram. Setting the exponential factor will exponentially increase/decrease the gain with time/depth in a radargrams. (See 7.12 for the equation controlling gain with time/depth). For example, setting the exponential gain to 2 will increase the relative gain progressively with the value of bottom reflector gained by e^2 (where e is the natural logarithm, 2.7818) compared to the top reflector. Normally, if the user has converted their radargrams with gain, they will not apply a regaining factor here, and will just keep the gain set to 1 and the other linear and exponential gain set to 0.

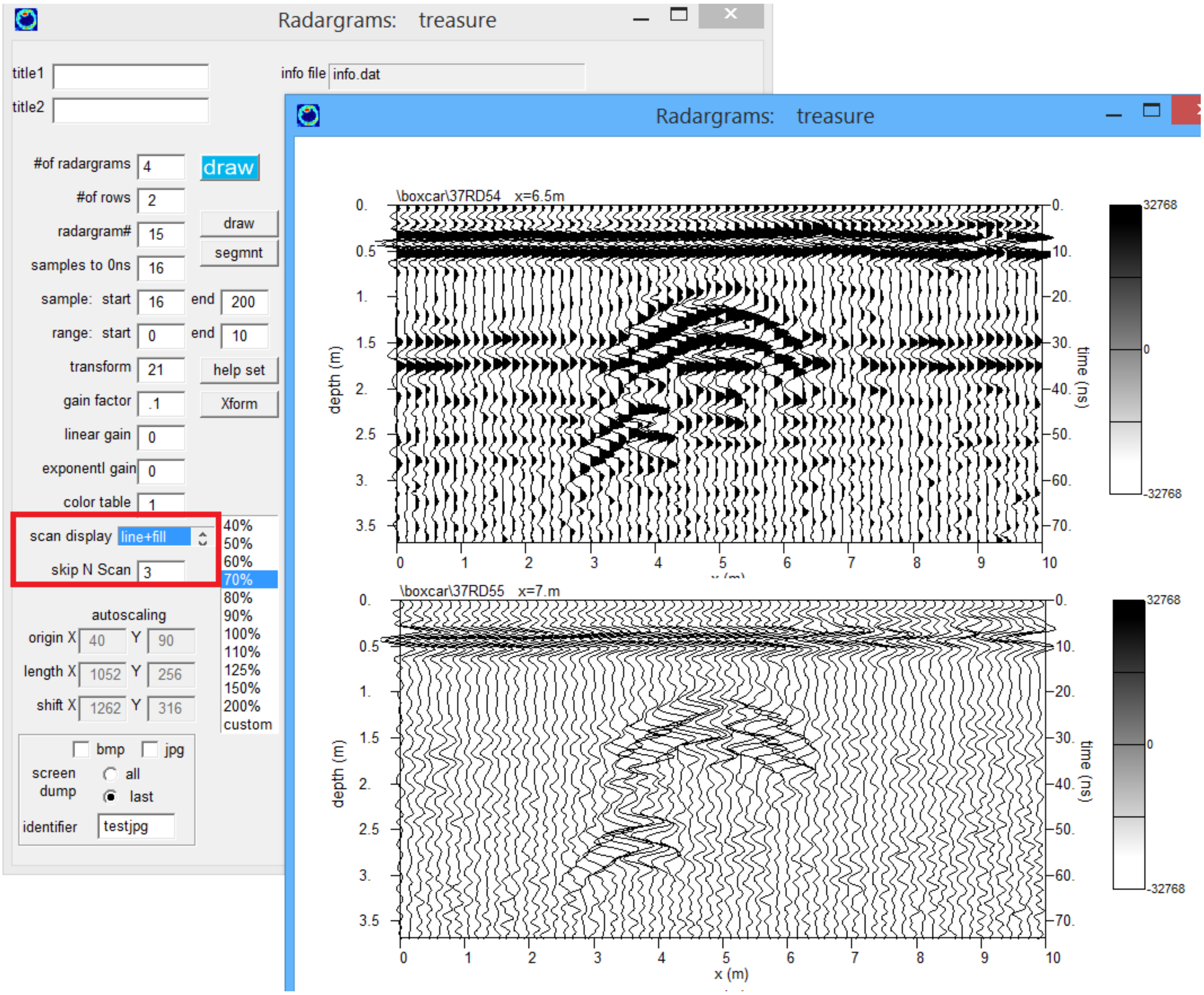
Radargram Transform Control Menu

Adjusting transforms on 2D radargram displays has been improved and follows similar operations available in the Pixel Map menu. After a 2D radargram display is drawn, the user can click on the graphic and the Radargram Transform Controls menu will launch. The user can set lo-cut and hi-cut threshold bars which are always active. An example of the same radargram using different transform curves is shown in Figure 9.

Should a different set of radargrams be inserted, the transform controls will normally need to be adjusted as this information is not stored in the radargrams but is a separate generic file containing the transform and colorization information.



Radargrams can be displayed in either color scan, line, line with negative pulse filled, line with positive pulses filled, line with +/- pulses filled, or a color line mode The user can adjust the amplitude of the wiggle traces by changing the overall gain factor in the menu. Usually a low gain factor value like .1 or .05 is necessary to get the pulses to scale properly. Wiggle trace displays normally require skipping N number of scans to see individual traces more clearly, as shown in the following screen shot:



GPR-SLICE will automatically compute optimal plot size lengths to show multiple radargrams on one computer screen. Custom settings can also be made the will draw radargrams beyond the computer screen. Scroll bars will appear for these displays.

Two settings for controlling the screen outputs are available: Last or All. Checking the Last switch will cause a screen dump to be written only after the last radargram is outputted to the screen. The file will have the filename prefix given by the Screen Dump identifier setting.

Concatenating 2 or More Broken Radargrams

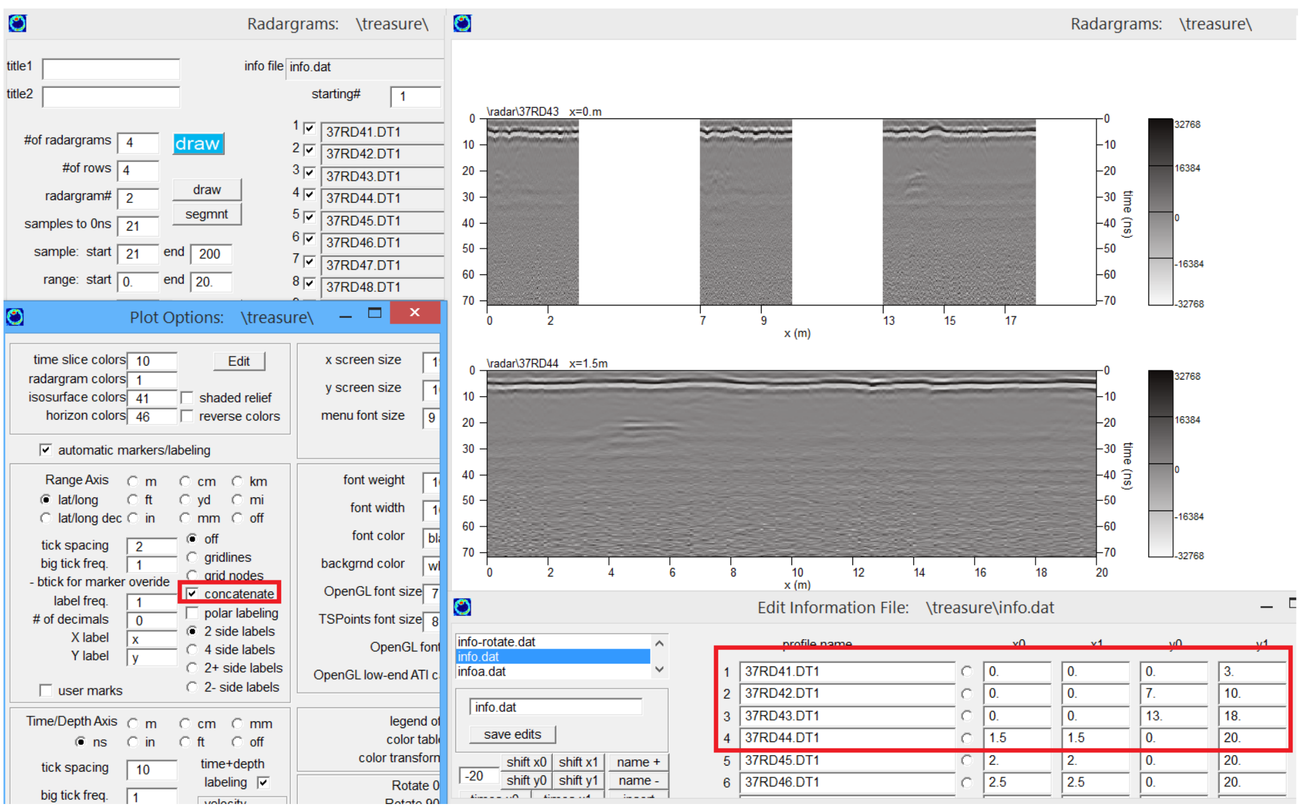
The Radar menu is capable of showing 2 more radargrams collected along the same transect with different starting and stopping locations, in the same radargram display. Often in GPR surveys obstructions along a line may require several broken line segments to be recorded. These line segments can all be shown in the same graphic screen if the following are done:

1) Use the Sort X or Sort Y buttons provided in the Edit Info File menu to insure that the broken files are consecutively placed in the information file.

2) Check on the Concatenate checkbox in the Options menu to tell the Radar display to show broken consecutive files on the same graphic display.

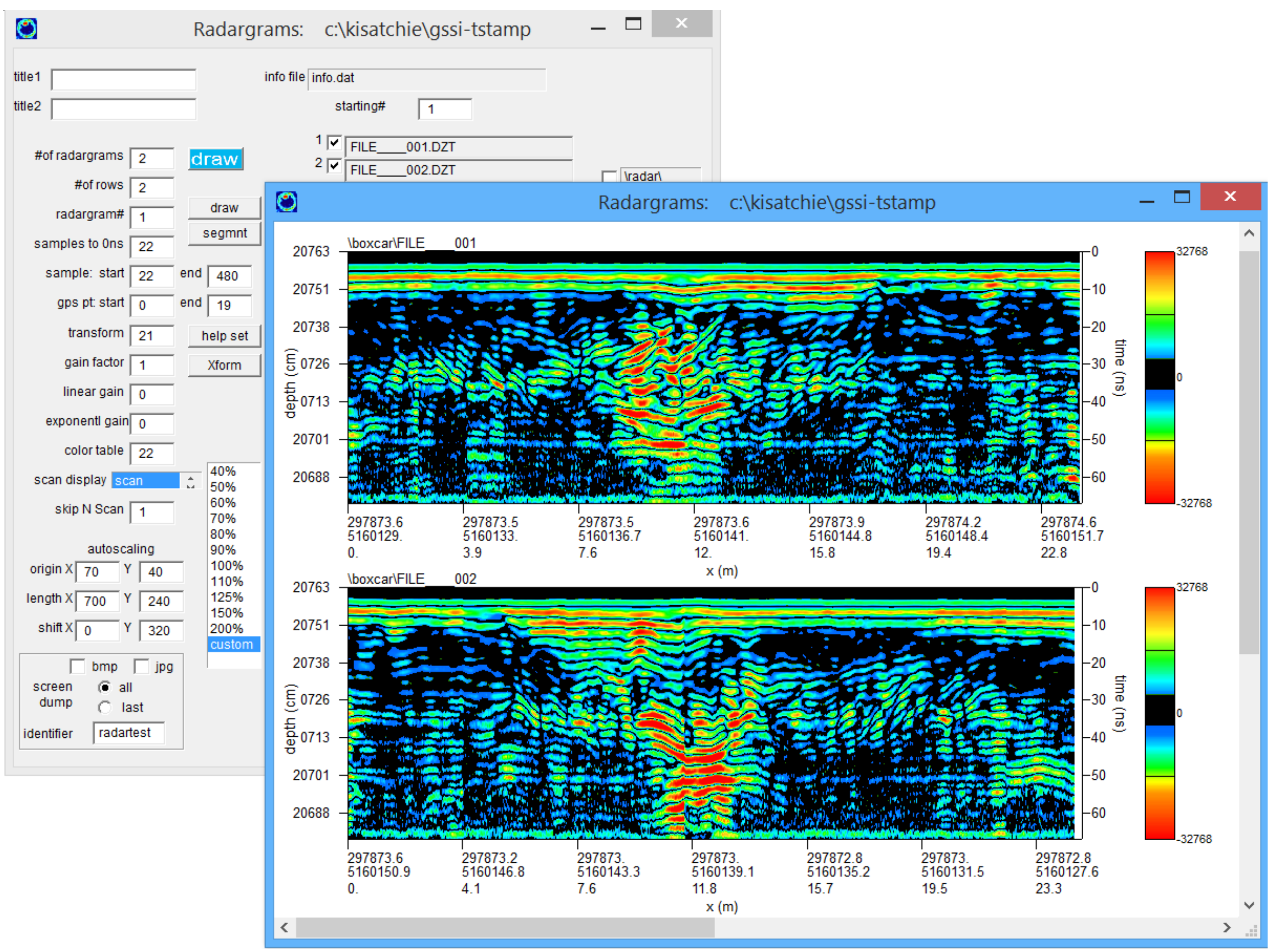
3) In the Radar menu, set the Range Start/End values to be inclusive of the entire start and end ranges.

An example of 3 broken files along the same line are concatenated and shown with a single complete radargram:

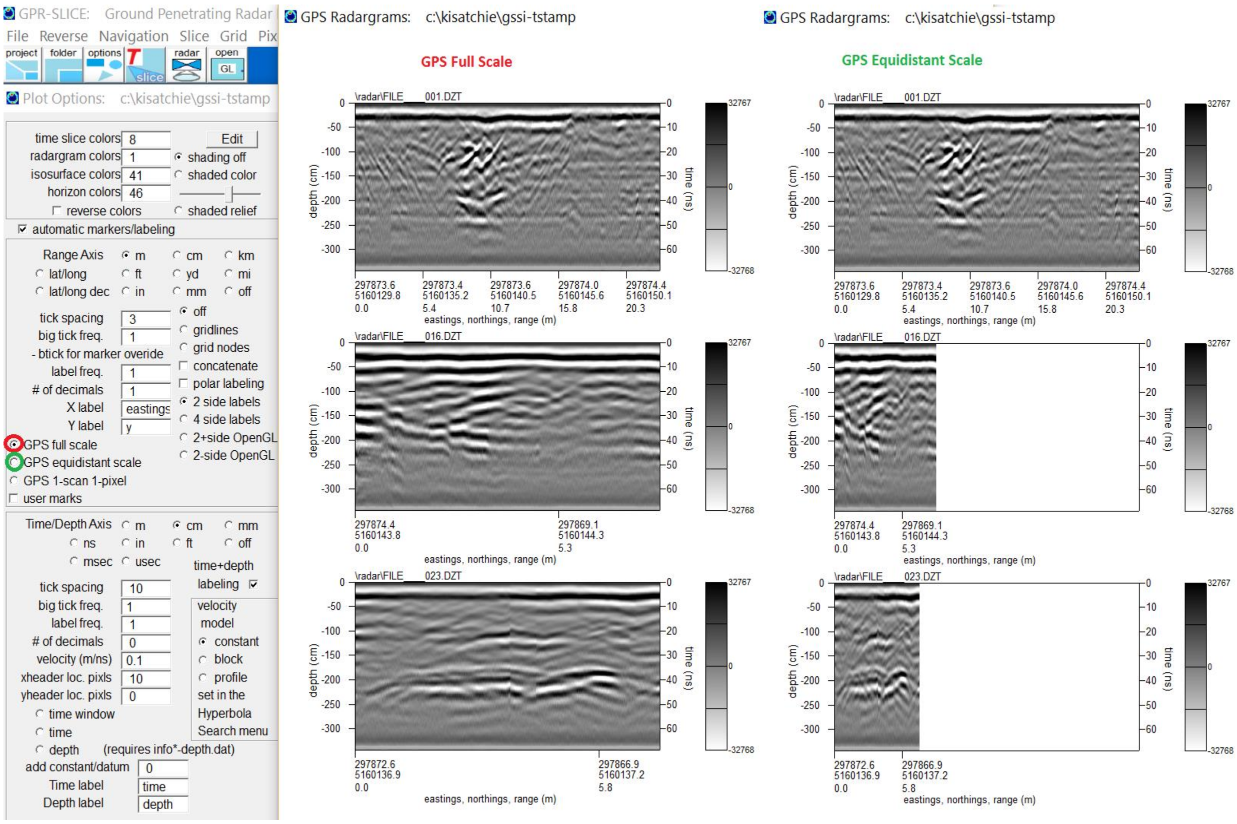


2D GPS Radargram

GPS radargrams can be displayed in the 2D Radargram menu (see the following figure). The user does **not** explicitly set the x and y starting and ending values in terms of eastings and northings. In this menu the user sets the number of GPS listings given in the information file. For example, let's say a GPS radargram has 200 listings (or 200 seconds) of data. The user can then say set the range start to 0 and the range end to 19. The 2D GPR radargram will display from the beginning up to the 19th GPS reading. The way GPR-SLICE works here is that every radar scan that has an associated GPS reading is tagged (in the 2nd sample of the scan – as is any kind of radargram is GPS or otherwise in GPR-SLICE). The 2D GPS radargram will display the radargram up to number of GPS readings desired as set by the range start and range end values in the menu (see the following diagram). The eastings and northings values are conveniently written as labels on the displays of 2D GPS radargrams.



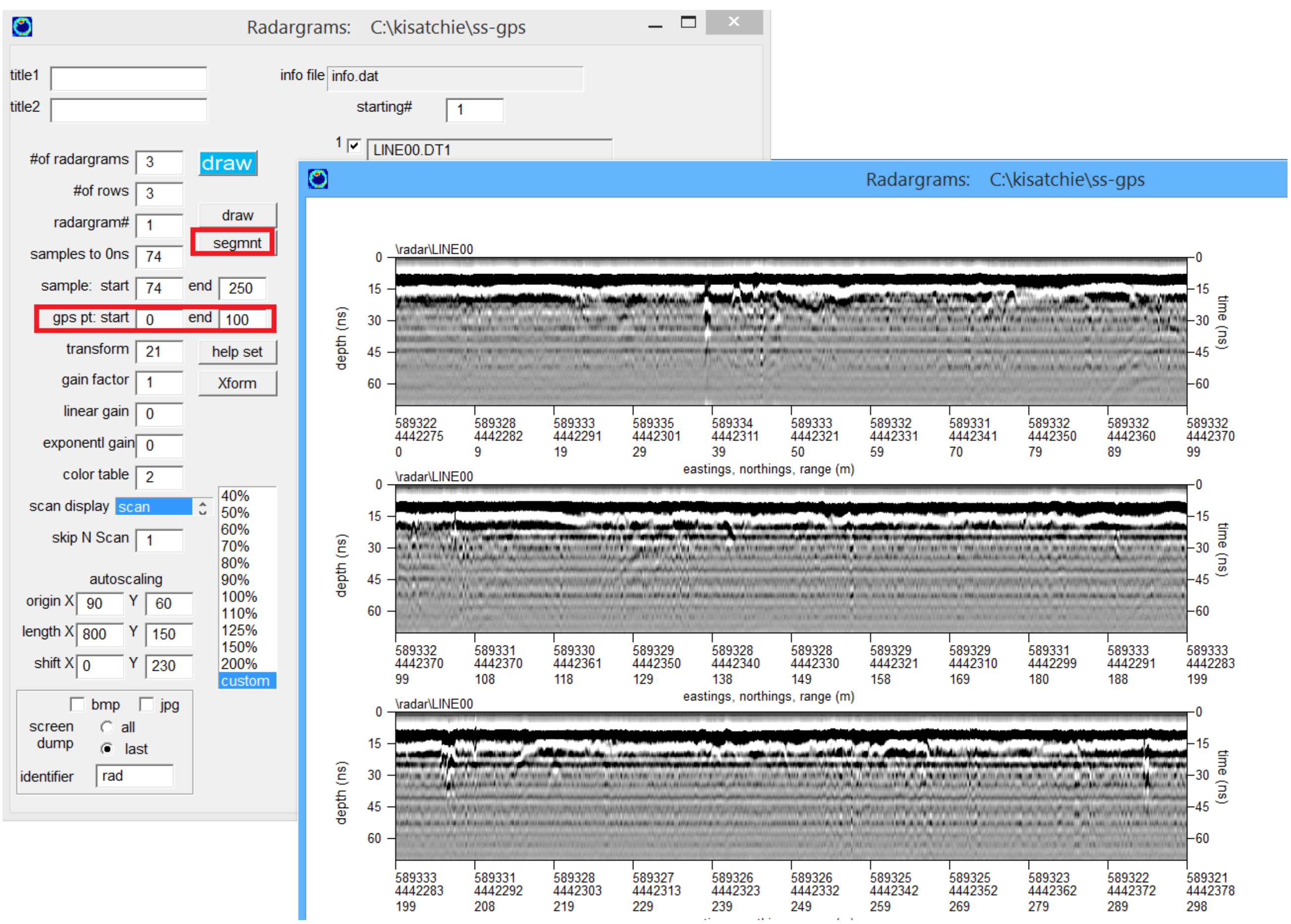
GPS Full Scale, Equidistant Scale, and 1scan-1pixel Scale



GPR-SLICE now has new options for multi- GPS radargram displays. There are 3 choices called GPS full scale, GPS equidistant scale, and GPS 1-scan 1-pixel scale. GPR full scale will show GPS radargams completely across the desired width of the graphic pixel length chosen. If some radargrams have very few GPS readings or more scans, regardless of the differences, each radargram plot will be shown with the same horizontal graphic scale. If GPS equidistant scale is chosen, the radargram will be scaled by how many GPS readings there are for each radargram and the GPS start and GPS end settings on the Radar 2D menu. This display will help to better show the relative sizes of features with the same number of GPS points per horizontal length. The option GPS 1-scan 1-pixel scale will show one scan per pixel. This display is equivalent to the GPS equidistant scale option but will display whatever number of scans there on each radargram horizontally. For some graphic cards, there could be a limit and probably radargrams with more than 50k scans should not be used. If radargram with more than this, the GPS 1-scan 1-pixel option can be used alternatively with the Segment option to show vertical columns of the same radargrams made in segments.

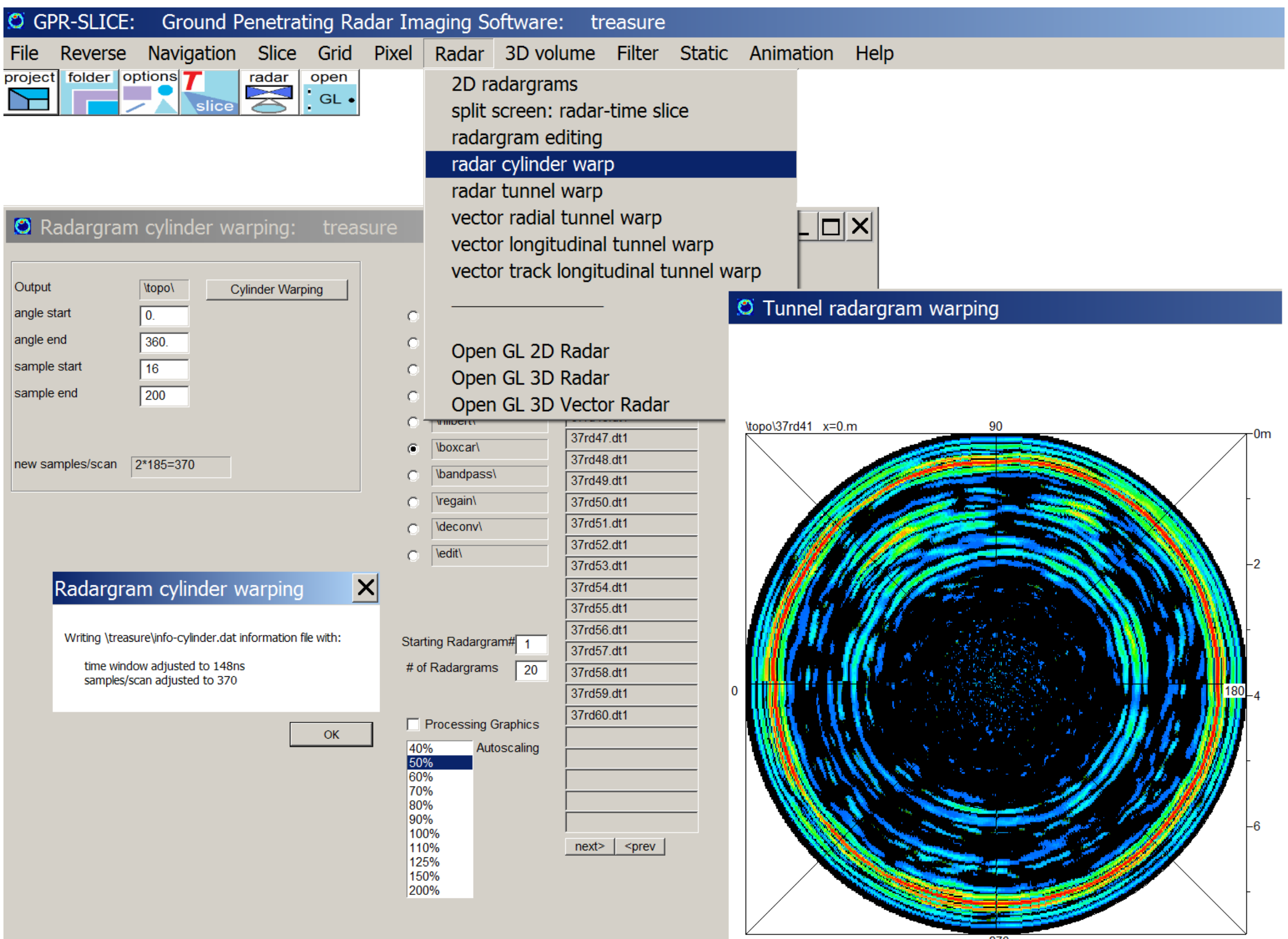
Segment Option to Show Consecutive Portions - Long Radargrams Displays

It is possible in GPR-SLICE to automatically show consecutive segments of a long radargram on a multi-radargram display. Using the Segment button as seen in the following figure for example, 6 consecutive segments of a GPS radargram are displayed to screen. This is very a effective display options for showing long radargrams or portions of a radargram on a single screen. Although the example shown is for a GPS radargram, this option is also available for regular surveys as well. For GPS radargrams, the range start and range end values correspond to total number of GPS readings to include in each separately display radargram segment that is drawn to the screen.



Radargram Cylinder Warp (Binary Corrected - Non-Vector Method)

Cylinder warping of radargrams can be done to have radargrams emulate profiles collected over cylindrical objects. One method describes how to do this by actually creating a new binary radargrams that is warped and written into it cylindrical shape. (Another menu for tackling the same problem but graphically – without actually writing a new radargram – is discussed in the Vector Imaging section of this manual). The angle start and end values (see the following figure) are will wrap the radargrams over and angle across the cylinder. Once the process is completed, the cylindrical warped radargrams will be written to the \topo\ folder in the project. Automatically a message box will appear at the end of the warping process which will indicate that a new information file appended with the name "cylinder" was written



Cylindrically warped radargrams will have a new samples/scan that is twice the original radargram. Thus in the example, the new scan length of the warped radargrams is 2*(number of samples/scan – 0 ns offset). In the example shown, the new samples/scan of 370 is written into an information file called info-cylinder.dat. To display the warped radargram, the user must first make this information file active in the Edit Info File menu. The next step is then to go to the 2D Radargram menu and display radargrams in the \topo\ folder.

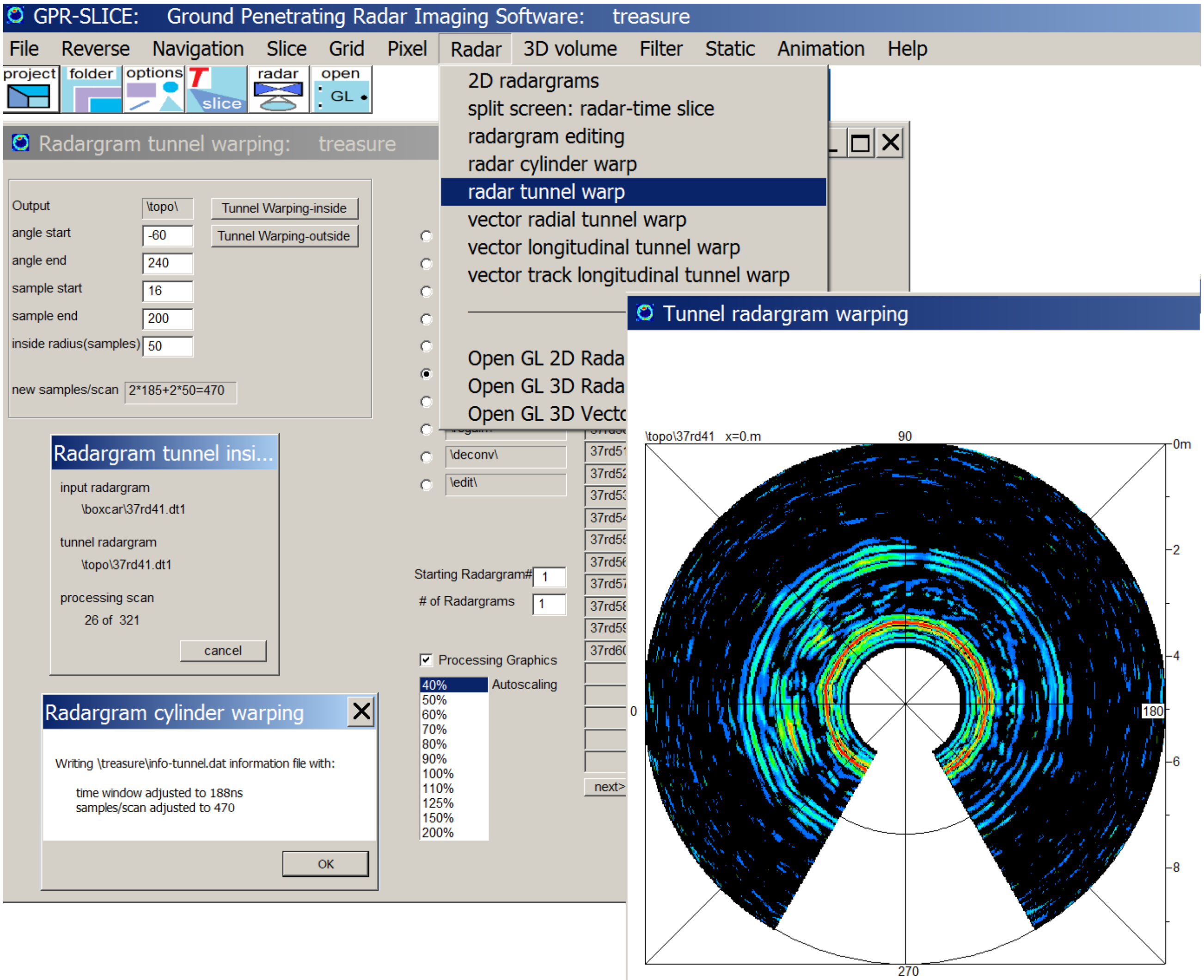
Radargram Tunnel Warping

Tunnel warping from a survey made on the inside or from the outside of the tunnel can be implemented. The user can also set the starting and ending sample values within the radargram to warp. A separate menu called radargram cylinder warping is also available from the main pull down menu. This menu is similar to the tunnel warping when the inside radius of the tunnel is set to 0.

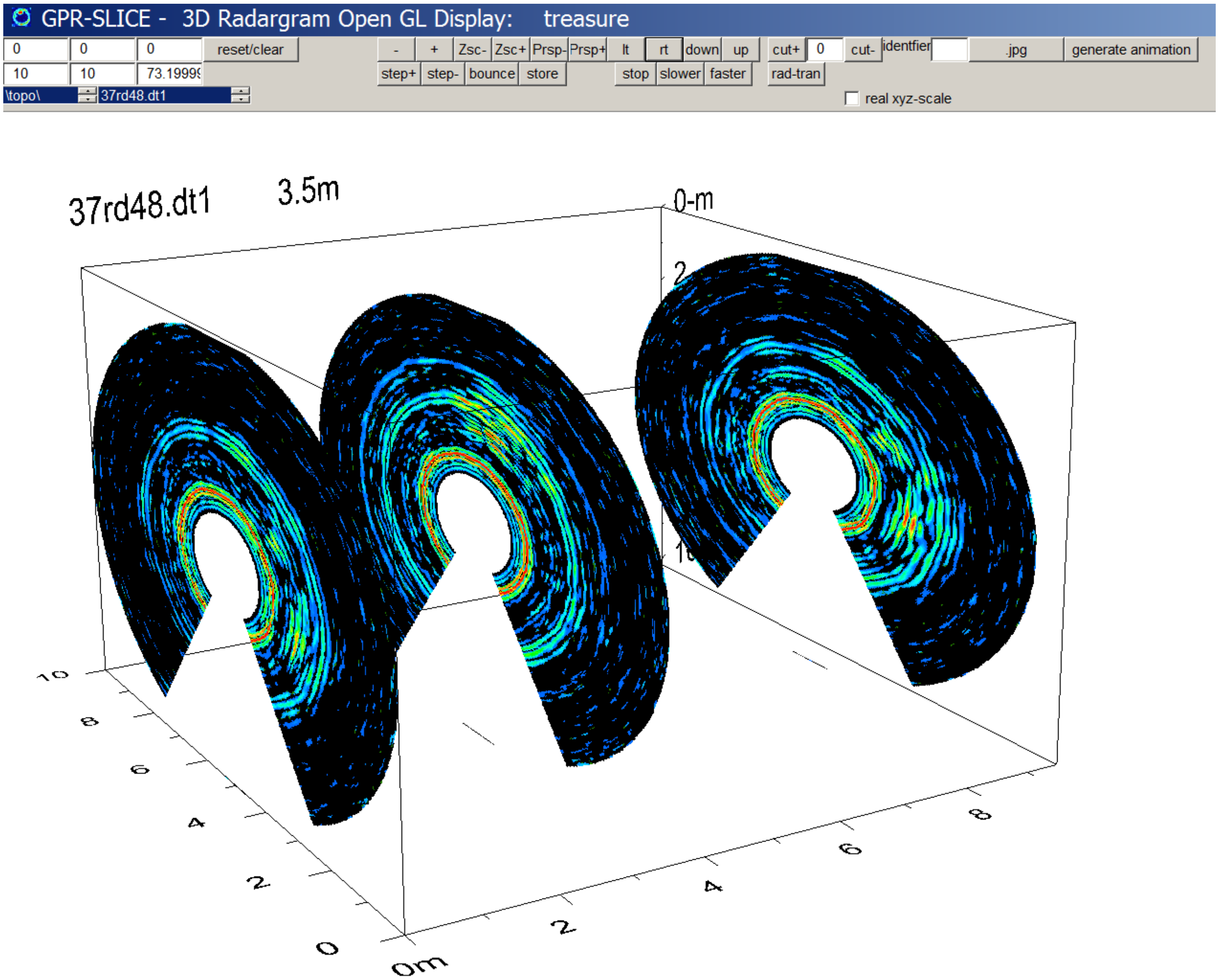
When the warping process is complete a message box will appear that will indicate the name of an automatically created information file to describe the warped radargrams. Tunnel warped radargrams will have an information file appended with the word "tunnel". Warped radargrams have a new scan length associated with the radargram. The new tunnel scan length for the radargrams is 2*(sample end - sample start + inside radius in samples). This is written to a new information appended with the word "tunnel". The warped radargrams are written to the \topo\ folder. One will need to make the tunnel info file active in order to properly display the tunnel warped radargrams.

In the example shown the tunnel warping was implemented from the inside. Thus the ground surface reflection can be identified as the strong reflection on the inside of the tunnel. If the tunnel warping – outside button were pressed, the radargram warping will be generated assuming the antenna is on the outside of the tunnel.

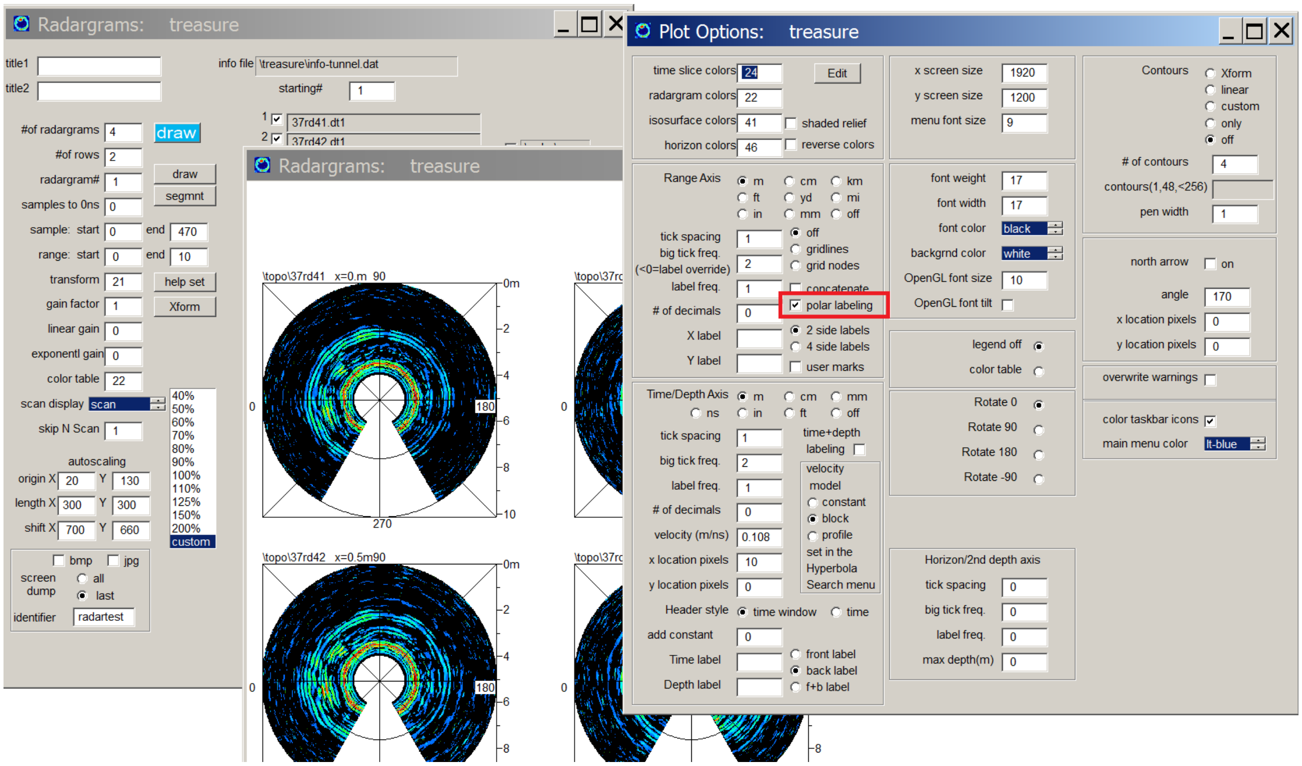
Shown in the next menu screenshot is the menu for radial tunnel warping of radargrams where the survey was made from the inside of the tunnel. A button for project the radargrams from the top of the tunnel can also be generated using the Tunnel Warping Outside button. The tunnel was surveyed from angle -60 to 240 as an example. The radial warped radargrams are written to the \topo\ folder and can be displayed from the \topo\ folder using the newly generated info-tunnel.dat file containing the new samples/scan for the warped radargram.



Tunnel warped radargrams can be displayed in the Open GL 3D Radar menu as shown in the next menu screenshot:

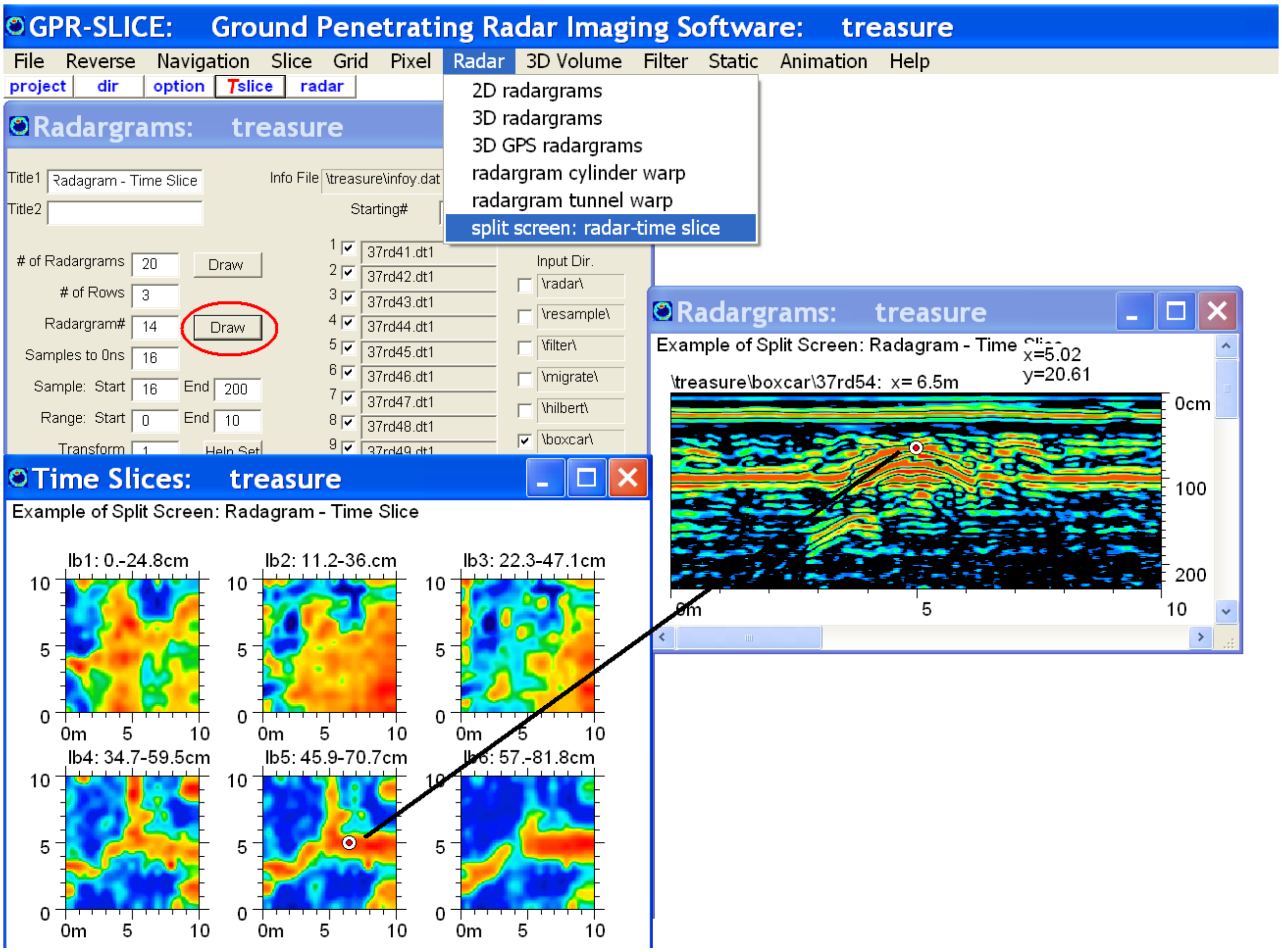


For re-display of the binary corrected - tunnel warped radargrams, there is an option to set a flag in the option menu to generate polar labeling for the 2D Radar menu. An example of a multi-radargram display using the Radar menu is shown in the following screenshot:



Split Screen: Radargram-Time Slice

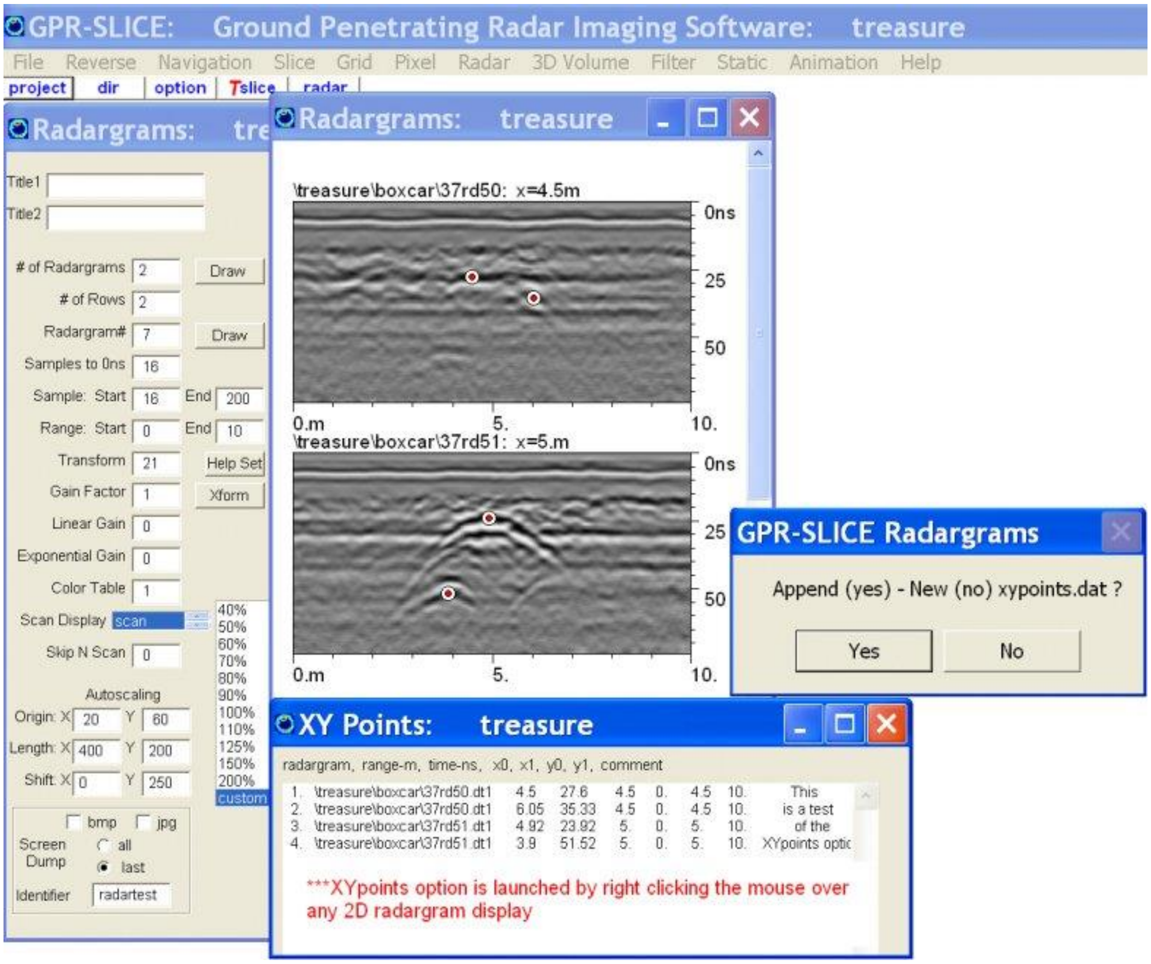
A very useful feature that is similar to the split screen option in the Pixel map menu is the radar to time slice split screen feature. In this operation, the users will normally first set the desired display of a single radargram as well set the display of a series of time slices in the 2D Pixel menu. Then, entering the Split Screen: radargram-time slice pulldown menu option (see the following figure), the user can click on any radargram anomaly and have the corresponding feature be identified within a series time slice map. The time slice maps will appear automatically once the radargram is clicked on with the bulls-eye. The split screen option will read the appropriate time window on the radargram and discover which single time slice in a series of time slice drawn to the screen contains the corresponding reflection time of the chosen anomaly. If the user has not drawn the full series of the time slices to the screen, the bulls-eye may not appear since the search algorithm will be unable to find a time slice with a corresponding depth.



Storing Anomaly Locations on Radargrams – XYPoints Option

An option to choose anomalies on the radargrams with the mouse and store the locations of these anomalies is available. To launch the option the user simply right clicks the mouse over any radargram or multi-radargram display. Then, using the left mouse button the user can store anomaly points which are also written to a real time dialog to the screen. A comment can be inserted in the on-line dialog which is also written into a file called XYPOINTS.dat file on exiting the menu. On launching the XYPOINTS option again, the user has the option to either append to the current XYPOINTS.dat file or to start a new file. The process also tracks multiple radargrams written to the screen so the user can click on any radargram and store points in any sequence. All the anomaly information is written to the XYPOINTS.dat file which is located in the main project folder.

An example of XYPOINTS option for storing mouse clicks over a multi-radargram display is shown in the following screenshot:

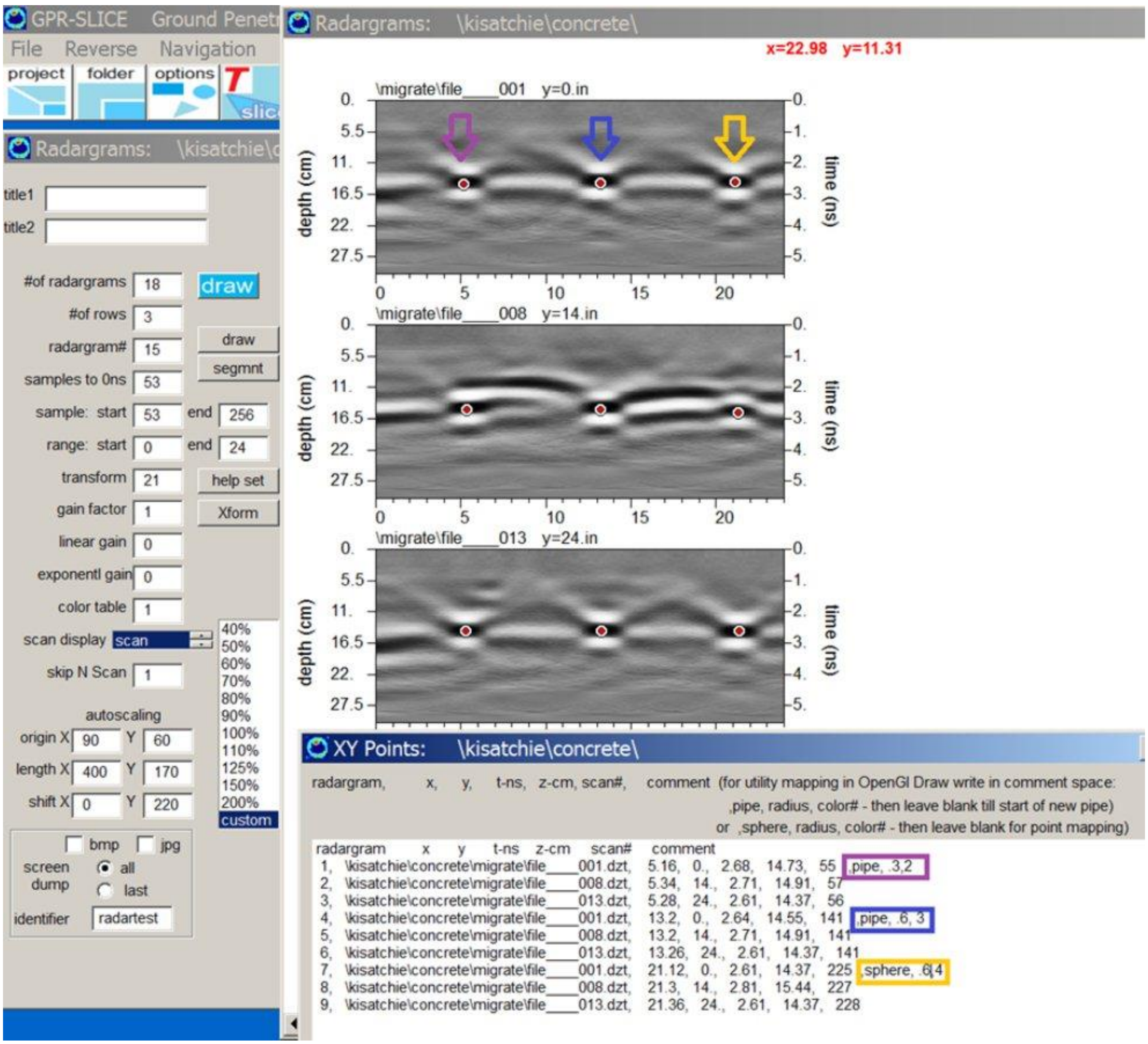


XYPoints in 2D Radar Menu for OpenGL Volume import

XYPoints operations have been in GPR-SLICE for quite some time. These operations have now been extended to allow the user to pick pipes on the 2D radargrams and have these imported to 3D pipes displays in OpenGL Volume Draw. The operations to export are:

1) Enter the Radar 2D menu and display the desired radargrams (Figure 1)
2) Right click the mouse on the graphic to start the XYPoints anomaly menu
3) Left click the mouse on the first detected pipe across the various radargrams, picking in incremental spatial order

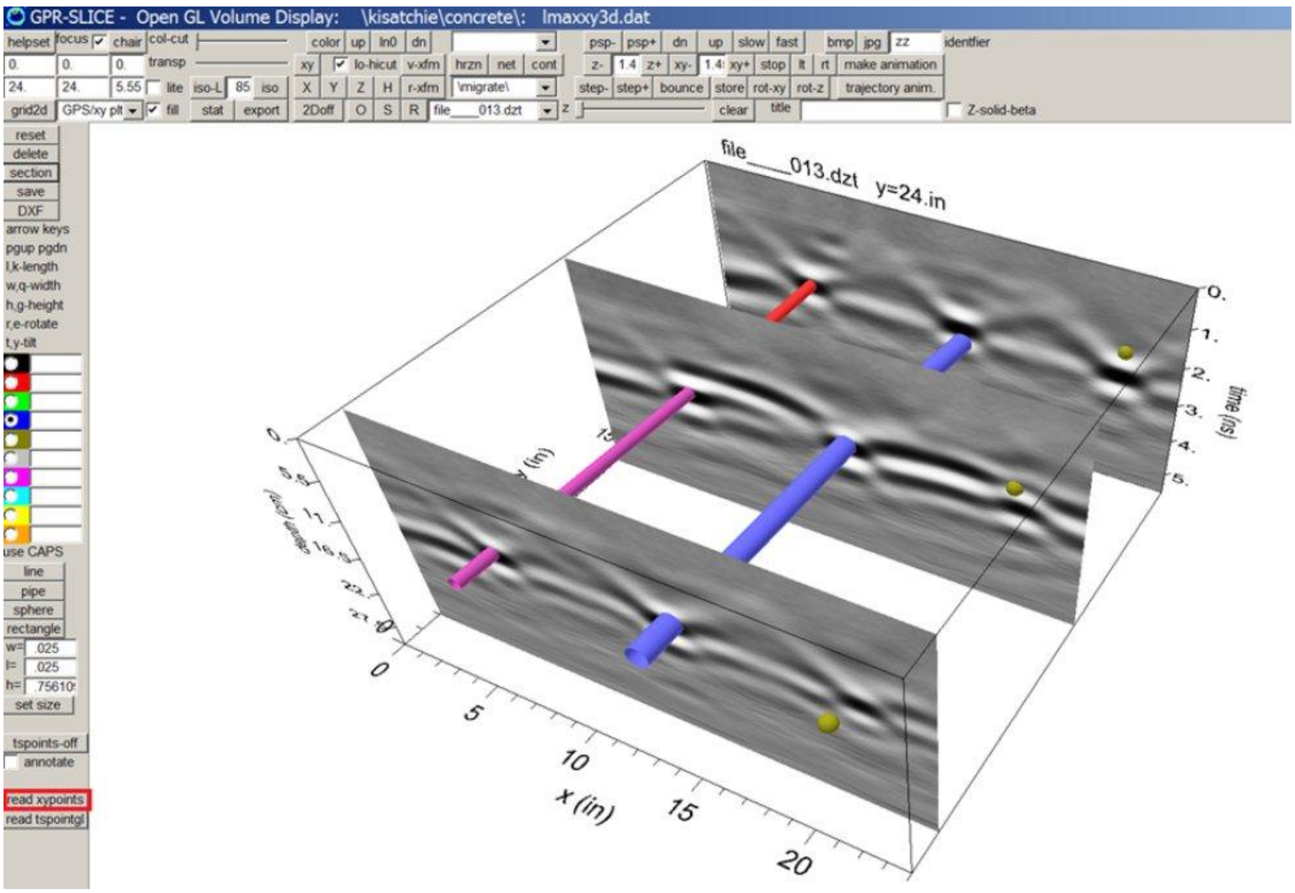
4) In the comment section of the XYPoints dialog type: **pipe, radius, color #** - everything must be comma delimited. For drawing points that will get imported into OpenGL Volume Draw rather than pipes, the comment section should be assigned as: **sphere, radius, color #** (Figure 1).
5) Enter the OpenGL Volume Draw menu and click **XYPoints** button (Figure 2)



After step 5 the drawn points will be transformed into 3D pipes or point sections. If any editing is desired the user can either re-enter the Radar

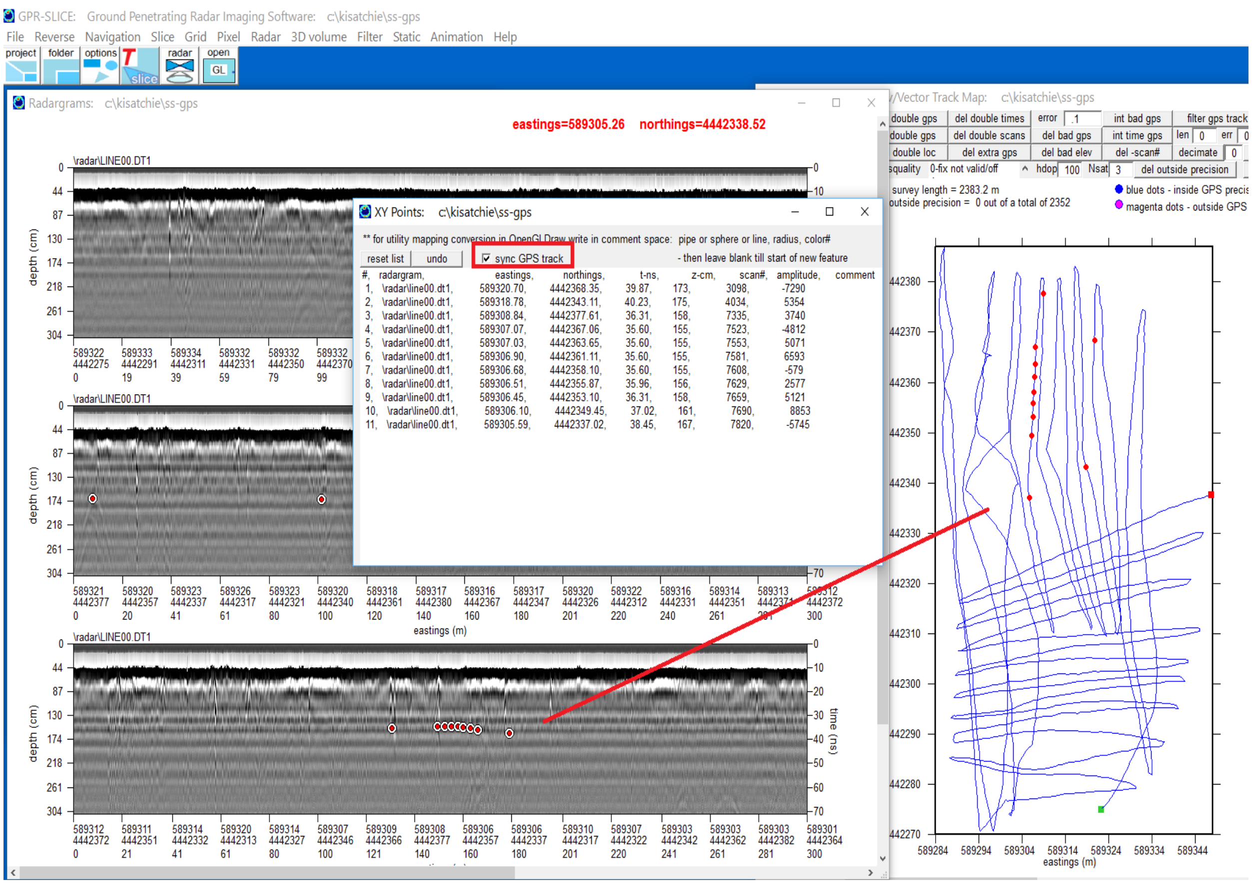
2D menu for appending and adjusting the XYPoints file. Drawn sections can also be removed in OpenGL by using the ***section*** and ***delete*** buttons.

Currently, the XYPoints option can also accept 3D points which can be imported into OpenGL Volume Draw. For this operation the user types in **sphere, radius, color#** into the comment space. This only needs to be typed in one time at the start of the first feature and then all other clicked points can be left blank in the comment section.

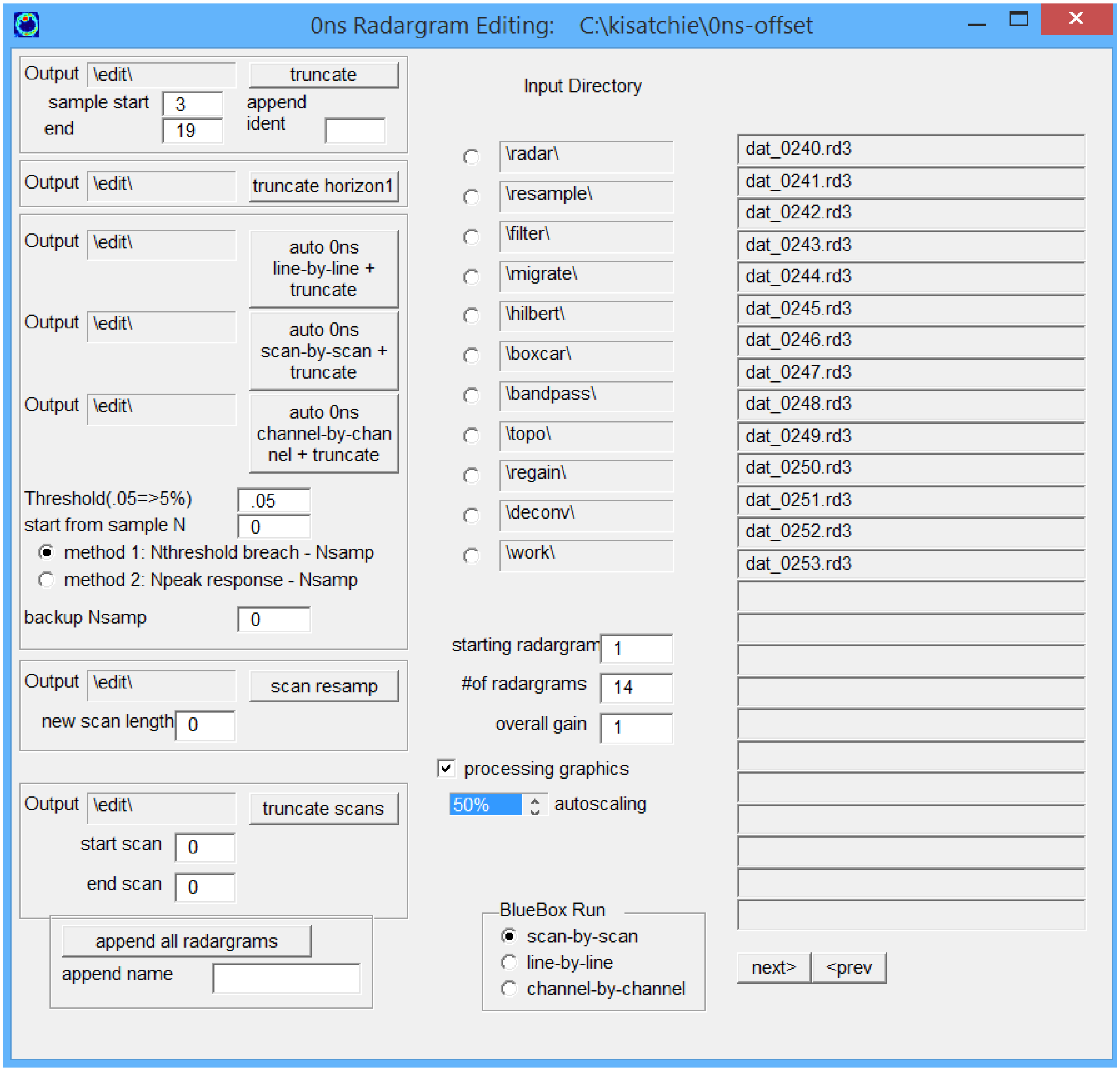


GPS track sync with XY points operations

For XY points operations for GPS surveys, an option to sync the chosen points on the radargrams with the GPS track location can be launched. To launch this capability, one simply right clicks the mouse on the radargram 2D display and the software will bring up the XYPoints dialog. Clicking on the “sync GPS plot” checkbox will open the GPS track menu in its own dialog. Choosing any anomaly on any radargram in the Radar 2D display will show the corresponding location of that anomaly on the GPS track. The example shown below was generated from a single GPS track survey and using the Segment option in the Radar 2D menu to show portions of a single radargram in consecutive column displays.



Radargram Editing



Radargram Editing has essential functions to:

- detect time 0ns on radargrams and to automatically correct them
  - scan-by-scan
  - line-by-line
  - channel-by-channel (for multichannel equipment)
- crop the radargram following a defined start and end samples on the digitization of the pulse
- crop the radargram from a defined start scan and end scan

- resample the digitization on the radargram pulse
- truncate to the first horizon defined in the Horizon Detection and Mapping menu

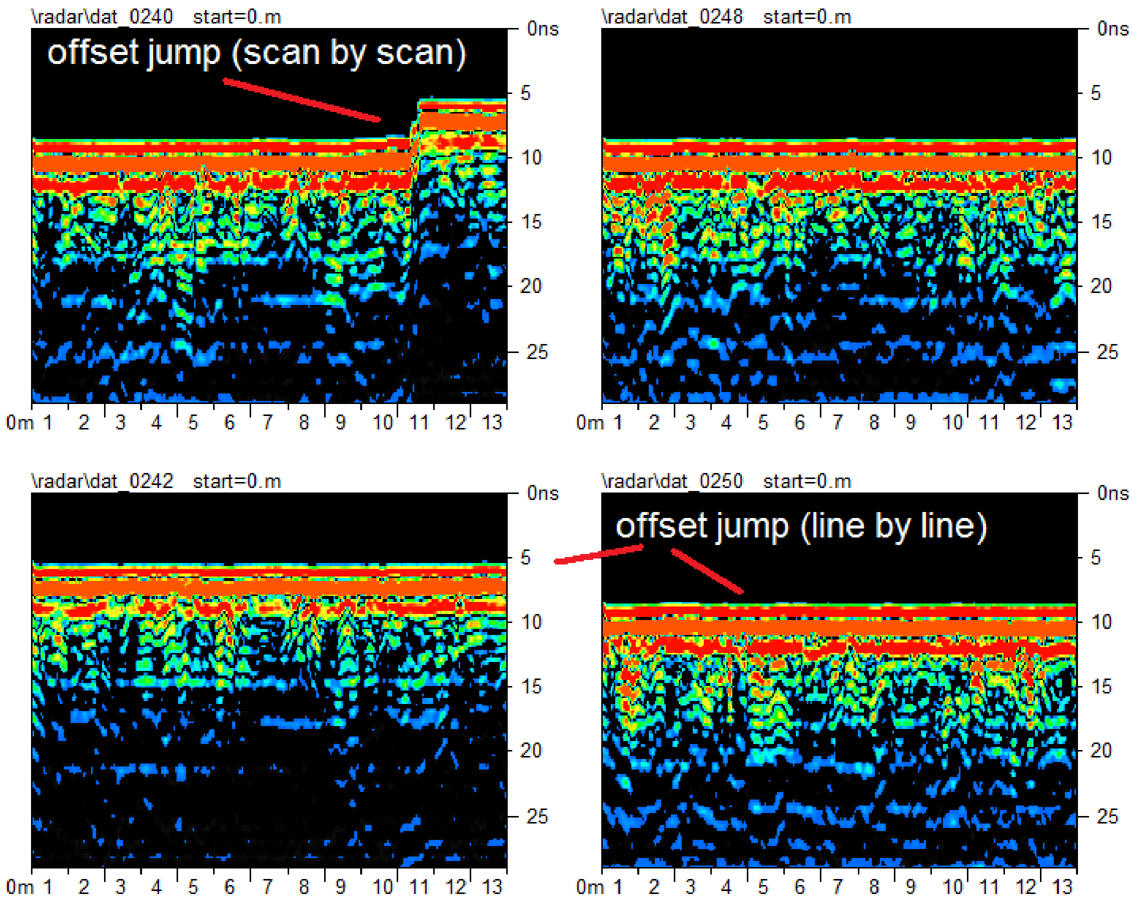
At the end of processing all the radargrams a new information file called infoedit.dat will be automatically created which contains the new samples/scan for the edited radargrams. The time window will also be automatically adjusted in the infoedit.dat file. The edited radargrams are written to the project \edit\ folder.

Complete descriptions of all the radargram editing operations are discussed.

Time 0ns Auto-detection and Radargram Truncation

An option to detect the sample number for each individual scan where the time 0 ns is located is available in the Radargram Editing menu. With this process in GPR-SLICE, the user can automatically detect the 0 ns scan-by-scan across each pulse or define time 0ns by the average detection using the line-by-line operation across the entire radargram. The software will truncate the radargram and generate a new radargram with the variable 0ns offset truncated across the entire radargram. This operation will run in batch.

One might ask why one would want to detect the 0ns scan-by-scan as opposed to just finding the average time 0ns. Well, there are some datasets, where the 0ns drift occurs dramatically within the radargram profile. This situation can occur with any equipment that undergoes some kind of electronic drift/noise. An example dataset where the time 0ns is variable is shown in the following:

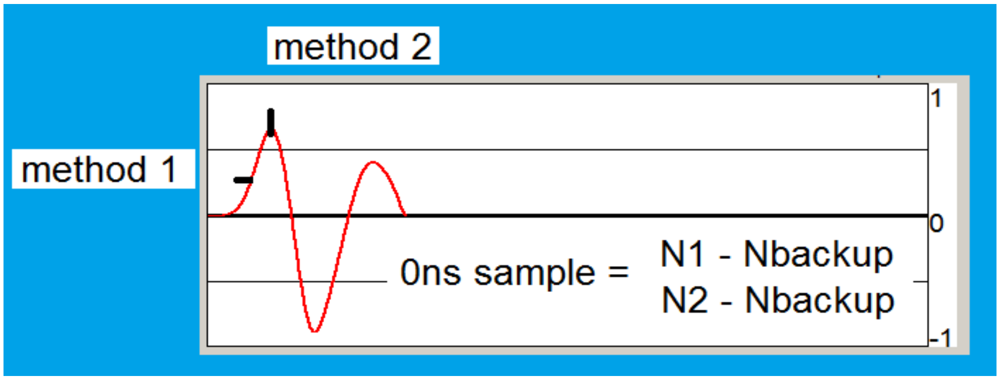


The 0ns offset in the top left radargram shifts by about 3ns suddenly near the 10 meter range. The other radargrams also shows significant changes in the 0ns offset between different lines. Making time slices of 0ns offset uncorrected radargrams will produce inconsistent and noisy time slices which will appear to have apparent mosaic, striping and other problems, in addition to not showing reflections at equal depth across the site.

Clicking the button 0ns Scan-by-Scan+Truncate will start the process to detect the variable time 0ns location and correct for it. The process works by looking at a threshold change on the signal prior to the pulse rising. Several options for detecting the 0ns position have been added to the Radargram Editing menu. The user can choose between 2 methods for defining the ground surface reflection:

1. Breach of a defined threshold on the initial pulse minus N samples to backup the detection.

2. Detection of the peak response of the initial pulse minus N samples to backup the detection.



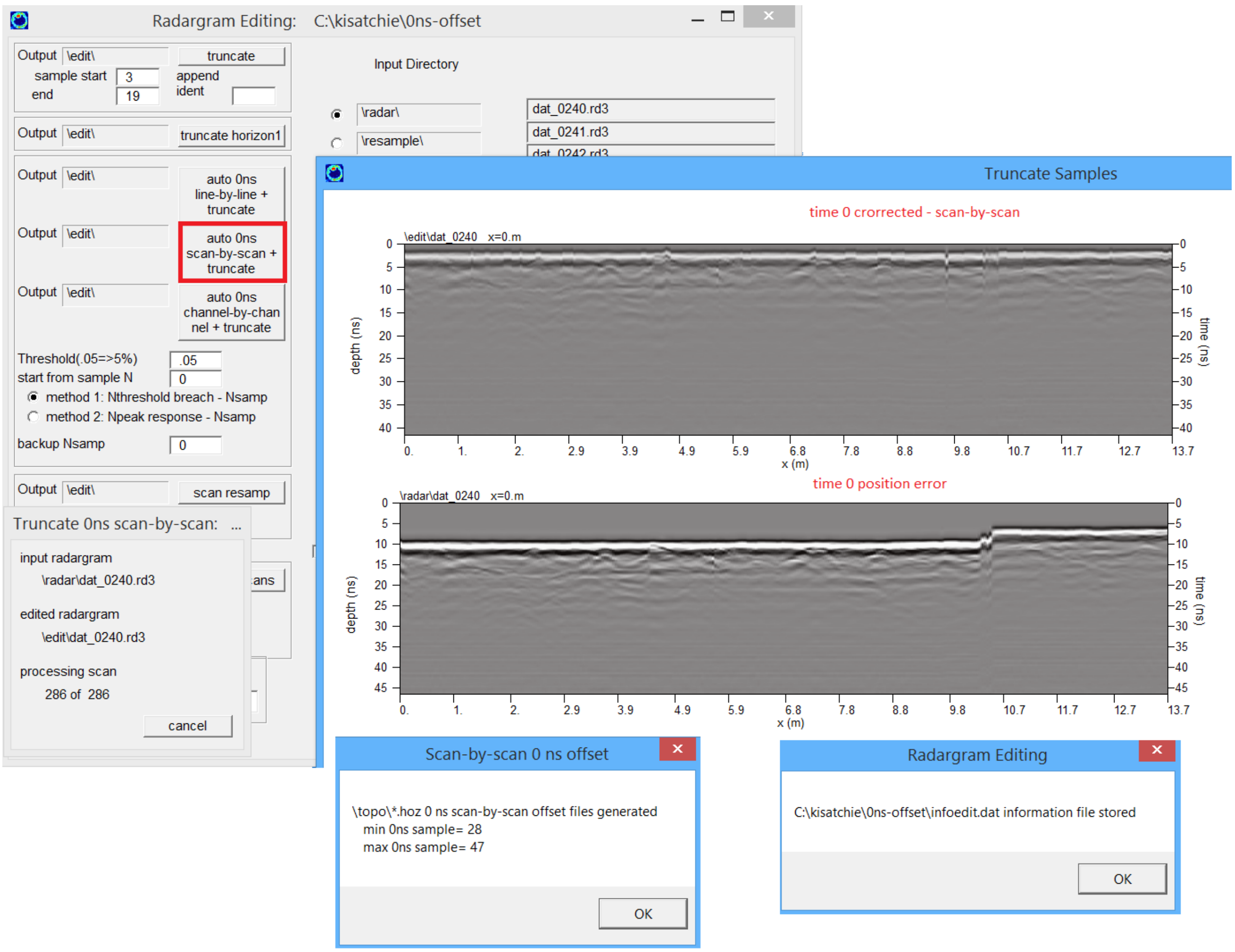
For both methods, the user can set a number of samples from the threshold breach or the peak detection level to back up the 0ns setting. For instance, a setting of 0.2 for the threshold and 4 for the backup Nsamp item will find the first sample where 20% maximum of the peak of the pulse is breached and then will back up the 0ns setting to 4 samples earlier than this. When the peak response of the initial response in method 2 is desired, the user may need to back up a different number of samples to get the desired 0ns detection. Usually the backup will be slightly more when the peak response in method 2 is used.

After the operation, a message box will relay the smallest and the largest 0ns offset across the entire set of radargrams first. This information is needed prior to adjusting and truncating a new set of radargrams with a new sample length. For instance, in this dataset, the minimum and maximum sample positions detected are the 26th and 44th sample. When the process of radargram editing/truncation is finished, a new set of radargrams will be written to the \work\ folder containing radargrams which have the 0ns adjustment for each scan, and total scan length of (N sample – 44). A new information file called infoedit.dat will be written. To continue the data processing, the infoedit.dat file should be highlighted in the Edit Info File menu to make it the active information file.

The radargram editing for 0ns offset, requires several important data processing step in order to properly generate time slices. These steps are:

1) Convert the \raw\ data using **Batch Gain** (not Batch Gain – Wobble) and with **NO** gain curve- e.g. all the gain points set to 1.

2) After reversing the files if necessary, continue to the Radargram Editing menu and run the scan-by-scan or the line-by-line process to adjust for the 0ns offset and to write a set of 0ns corrected radargrams in the \radar\ folder to the \work\.



(At runtime operations, only the corrected radargrams is actually displayed)

3) highlight the infoedit.dat file in the Edit Info File menu for the new set of radargrams in the \edit\ folder that have been adjusted.

4) Return to the Filter menu and run the Regain menu on the \edit\ folder to make gained radargrams in the \regain\ folder.

5) From here the user can proceed do to other RSP if desired.

Step 1 is necessary since applying gain prior to correcting for the 0ns offset would result in unequal gaining after truncation. The gaining of the radargram must be done **after** the 0ns adjustment is made.

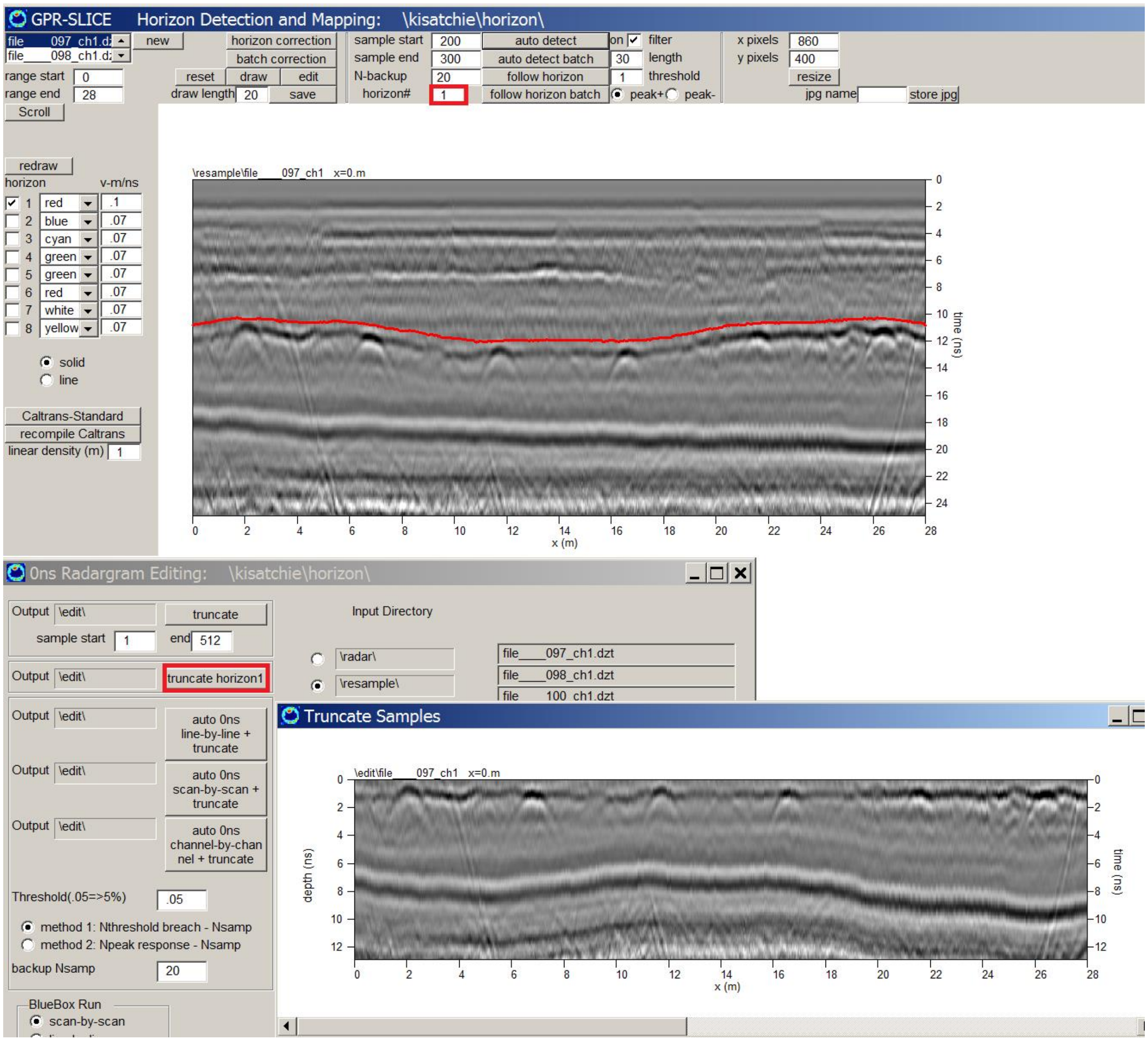
Similar operations are done for line-by-line 0ns detection. In this operation, the average 0ns offset across each individual line is first calculated and this is used to make the adjustment.

Note 1: Line-by-line operations for time 0ns radargram editing should normally be used over scan-by-scan operations in the case when the time 0ns offsets are not changing across the individual radargrams. Line-by-line will compute the average time 0ns correction and insure that small vertical perturbations from pulse truncation on noisy radargrams before the ground wave do not infiltrate the edited radargrams.

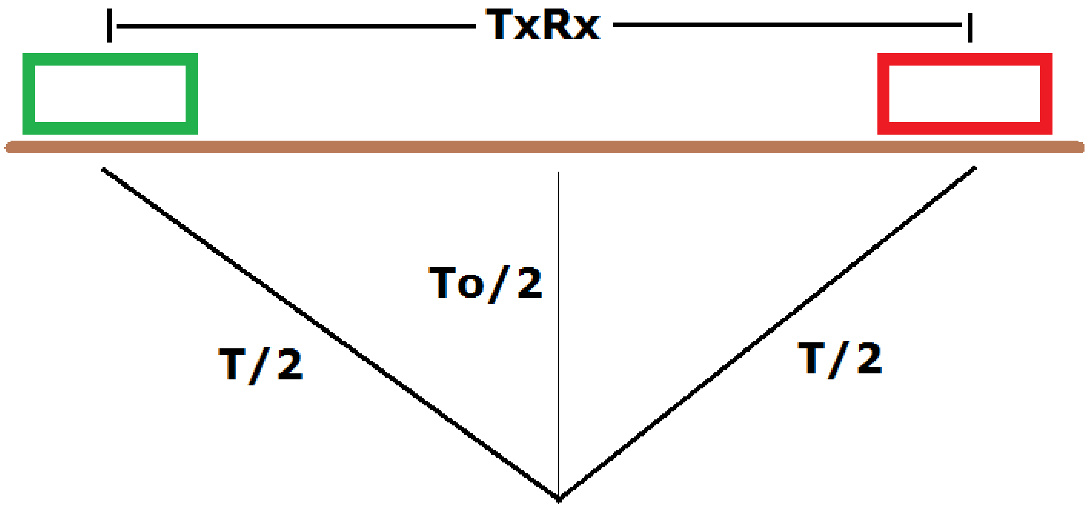
Truncate Horizon#1 from Horizon Detection and Mapping Menu - Imported to Radargram Editing Menu for Vartiable Time Ons

The button, truncate horizon1, allows the user to truncate the radargram to the first horizon defined in the Horizon Detection and Mapping menu. The first horizon in this menu can be automatically detected as well as edited or manually drawn by the user with the mouse to define time 0ns across the radargrams. The horizons are written as *.hz1 files for each radargram in the project. The operation Truncate Horizon1 will read these time 0ns profile written for each scan and will truncate the radargrams to these sample numbers.

Removing the ground surface reflection that has a varying position per scan has been available in the Radar Editing menu. The scan-by-scan truncate option is usually applied for this operation. The scan-by-scan operation looks at a threshold on the scan and will trigger a detection. Sometimes, this simplified methodology does not work very well on very noisy datasets and a more advanced methodology is needed to define the time 0 location. For this reason, the options available in the Horizon Detection and Mapping menu are now available for importing the defined horizon #1 for truncating the radargrams. This menu allows detection of the peak+ or peak- of the pulse as well as having options to engage a filter on the detection. For radargrams where the time 0 is quite variable and not easily defined, the user can also manual adjust the detected horizon#1 with mouse drawing options. Once the horizon#1 is defined or auto detected in the menu, this horizon is then available for truncating in the Radar Editing menu. An example of the location and settings for this new operation for time 0 or truncation to any desired horizon is shown:



Normal Moveout Correction

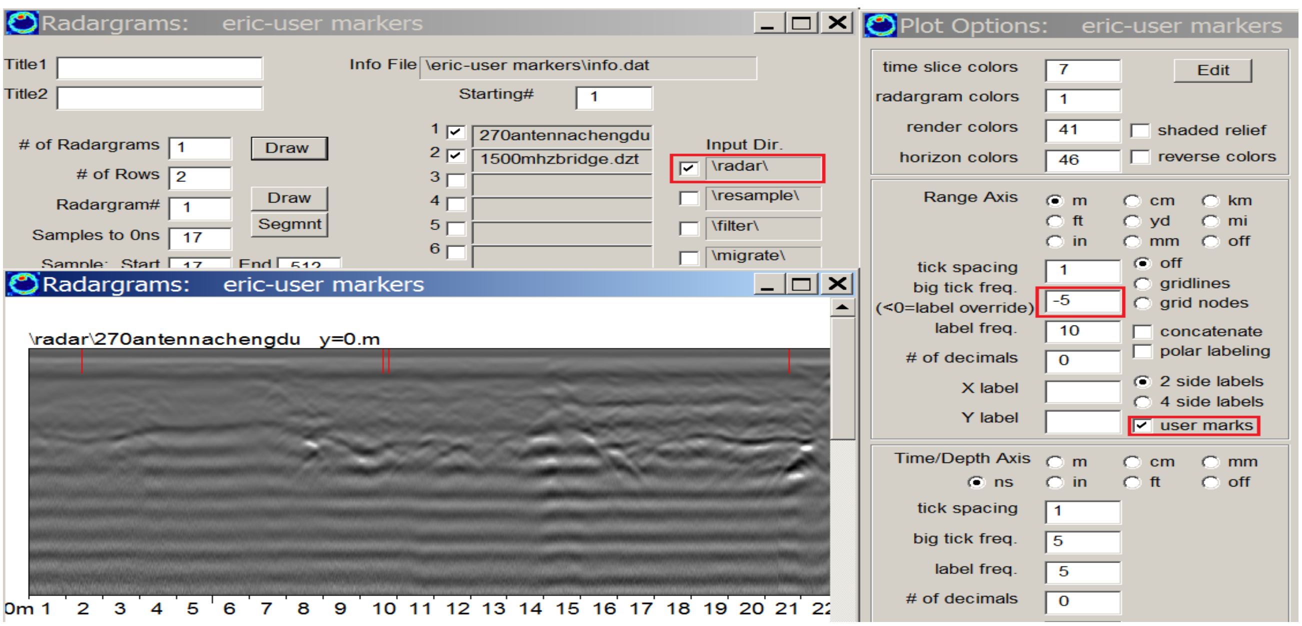


Normal Moveout Correction: $To^2 = T^2 - (TxRx)^2/v^2$

Almost all commercial antenna have an offset between the transmitter and receiving antenna. For most antenna, if we consider the distance between the antenna to be small or 0, the travel time of the radar waves can be considered to be a simple two-way up and down – straight vertical path. However, for bistatic antenna, the transmitter and receiver are far apart. The effective depth for a wave traveling from bistatic antennas, is given by the travel time at 0 offset between the transmitter/receiver – To. To has an effective depth less than a monostatic antenna where the transmitter/receiver are at the same location. The samples collected from a bistatic antenna can be adjusted with the "normal moveout correction – NMO" which will place recorded radar pulse samples in their correct vertical position. The corrections in GPR-SLICE currently assumes a constant velocity across the site. The NMO correction is available in the Radar Edit menu. Before NMO is applied, the radar profiles should have time 0ns edited out, and the information file should generally be an info**edit.dat file indicating that time 0 was removed. The user needs to set the velocity and the distance between the transmitter and receiving antennas TxRx. Clicking the normal moveout button will start the process. The input directory will automatically be set internally and is the \edit\ folder – the output folder containing the normal moveout corrected radargrams will be the \nmo\ folder. After the process, a new information file called info**nmo.dat which has the adjusted time window and that corresponds with the normal moveout corrected radargrams will be written.

Displaying User Inserted Marks on Survey Wheel Radargrams

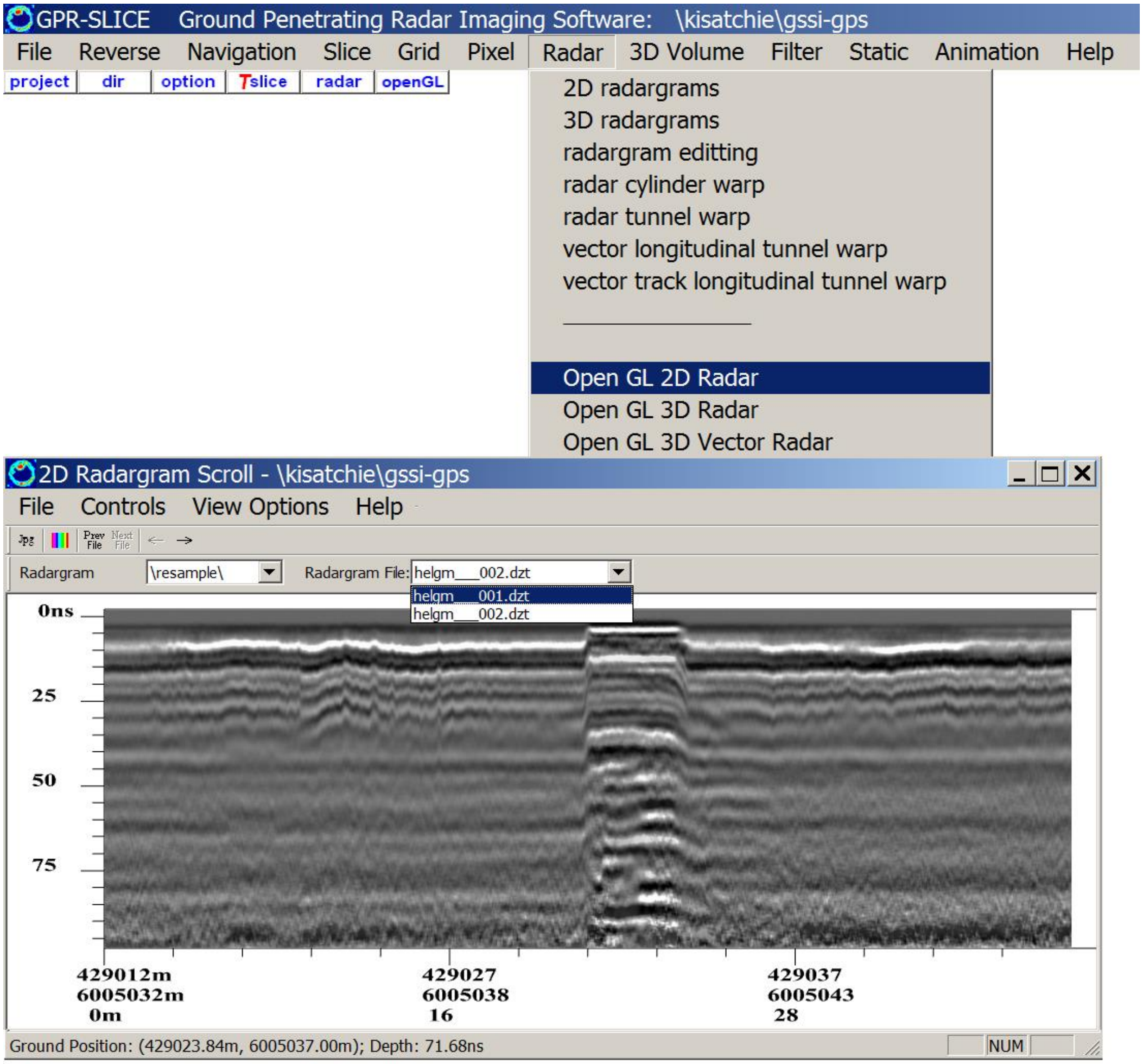
Often in GPR survey collected with a survey wheel, the user may want to mark locations on the radargram with additional user-inserted marks. GPR-SLICE is able to display these additional marks. The settings necessary to get the Radargram menu to display these are marks are 1) negative big tick frequency in the Option menu, 2) User Marks checked on in the Option menu, and 3) choosing the \radar\ folder for display.



Open GL 2D Radargrams

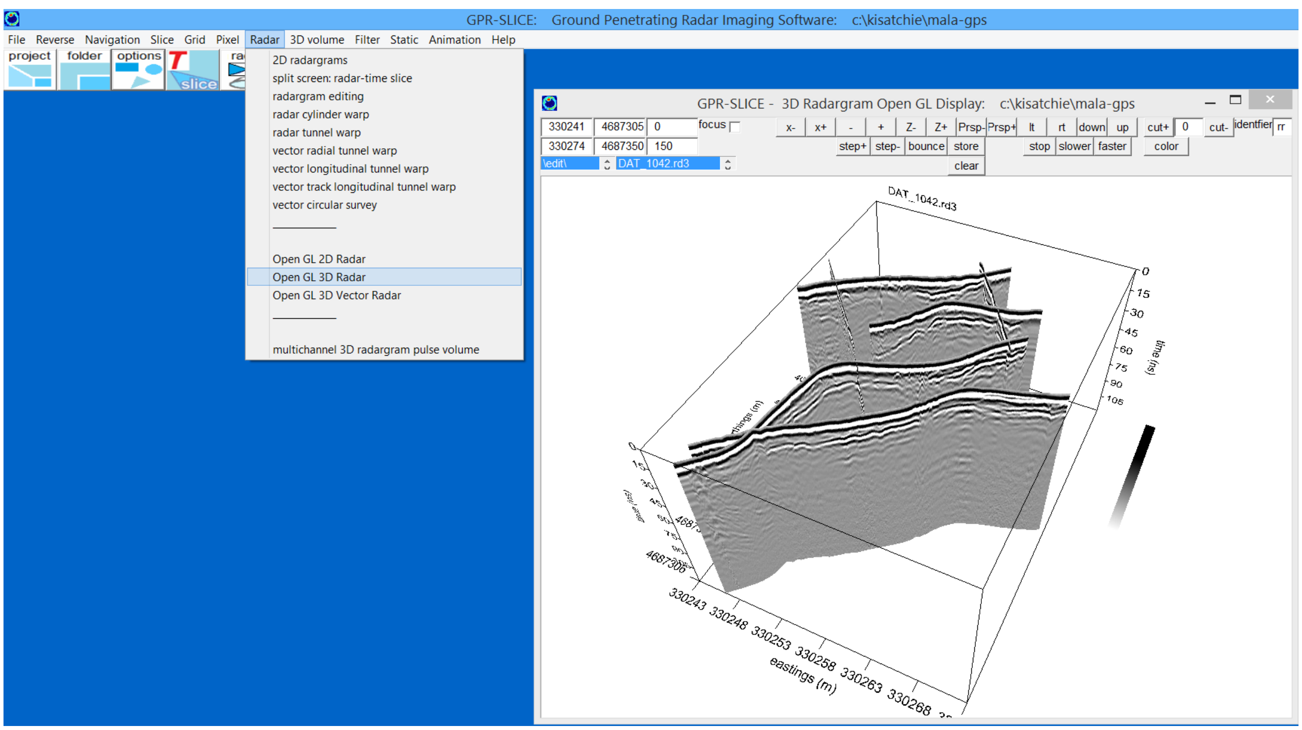
An Open GL Radargram for displaying radargrams in 2D is available. This menu allows the user to display very long radargrams and to instantly scroll across these radargrams. Radargrams several hundred megabytes long or longer can be shown in this 2D radargram scroller module. This menu is a separate module and is shelled out to in GPR-SLICE v7.0. The module is run synchronously – requiring users to exit this module first before other functions can be run in GPR-SLICE. The 2D radargram scroller module has options to show regular surveys and

GPS radargrams. The position of the mouse in xyz space for any kind of survey is shown in the menu.



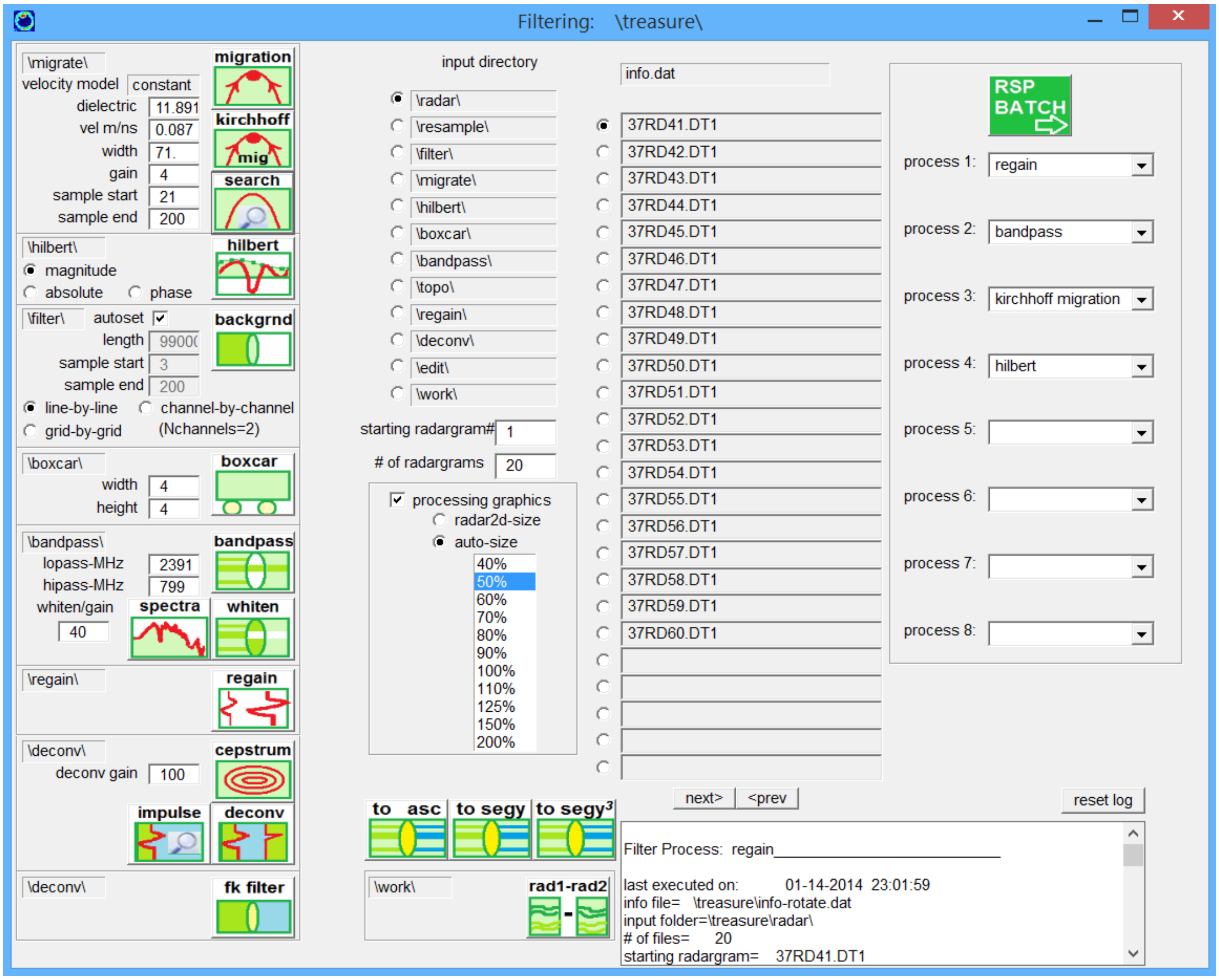
Open GL 3D Radargrams and GPS Radargrams

A standalone Open GL Radargram menu for displaying just radargrams in 3D is available. An example of GPS radargrams displays are shown in the following screen shot. In the OpenGL Radar menu the user can display a radargram from any folder or combinations of folders. To do this there is a "Store" button which will preserve the radargram with the current folder. In addition a standalone OpenGL Vector Radargram menu is also available just to display vector radargram displays



Note: This menu and the OpenGL Vector Radar menus are now completely encompassed in the OpenGL Volume menu where 3D volume elements and 3D radargrams and 3D vector radargrams can now be displayed. These menu may be removed in later versions of the software.

FILTERING Menu: Overview



Radargram processing prior to slicing analysis can be done within this menu. GPR-SLICE version 7.0 currently provides for the following radargram signal process:

- background removal
- Kirchoff migration and hyperbolic summation migration with variable velocity
- Hilbert transform
- boxcar smoothing

- regain
- bandpass filtering
- spectral whitening
- cepstrum deconvolution
- spectral deconvolution
- fk filtering

Background Removal

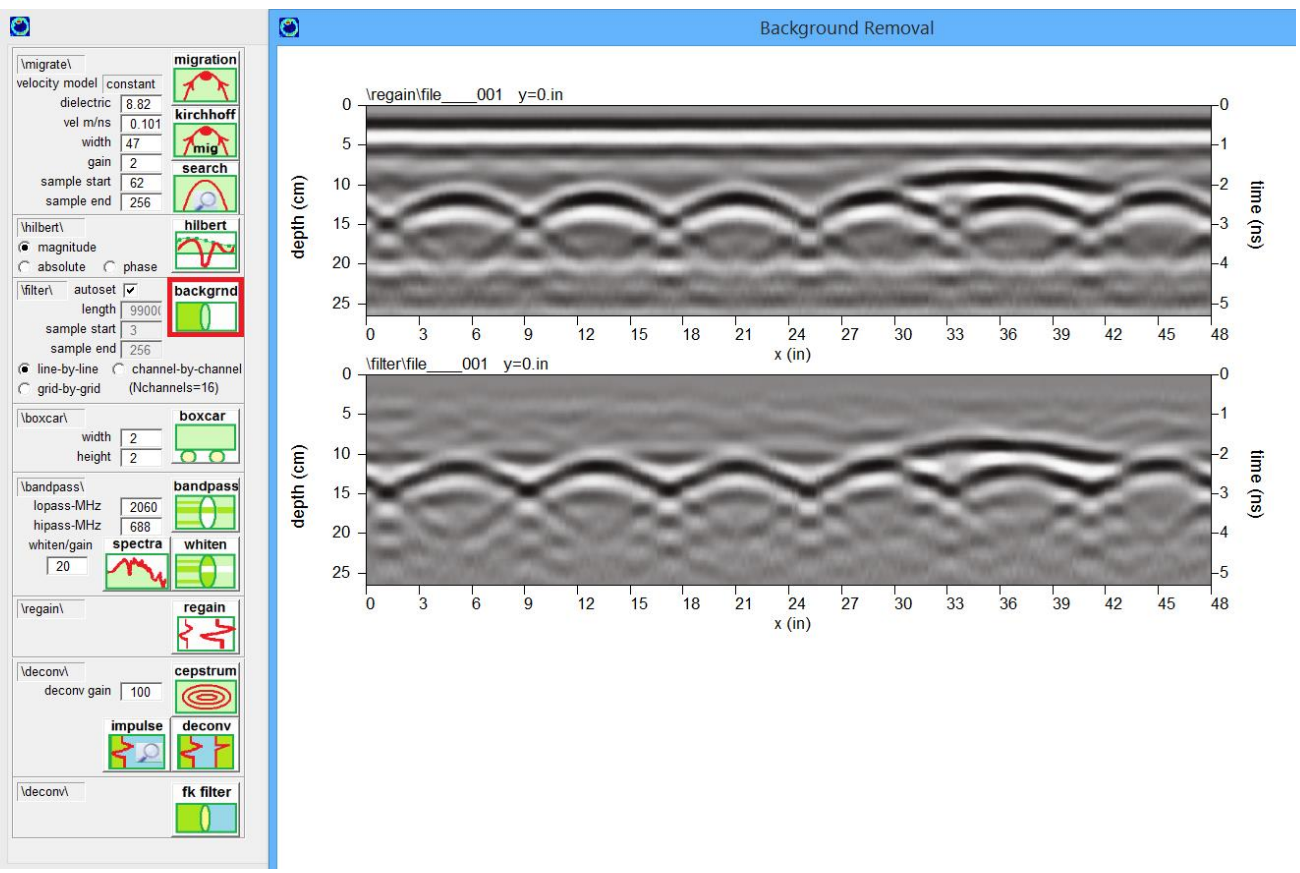
Probably the most commonly used filter on GPR data is the background removal filter. The background removal filter is essentially a process where the average scan across a radargram is subtracted from each individual trace within the radargram. The background filter is used to remove banding noises that are seen across the radargrams. Shown in the diagram on the next page is an example of a raw radargram with the background removed. In the background filtering the user has the option to apply the operation over a sample start and sample end. Three kinds of background filtering can be implemented:

1. line-by-line - the average scan on each individual radargrams is computed over the filter lengths and subtracted from the center of the filter
2. grid-by-grid - the average scan over the entire grid and inclusive of all the radargrams in the project is computed and subtracted from each radargram
3. channel-by-channel - the average scan over each individual channel for a multi-channel system is calculated over the entire grid and subtracted from the individual track radargrams for each channel

The user can set the length that the filter operates over for line-by-line background filtering. Normally, the filter length should be set to a number much larger than the total number of scans in the radargram. One can simply place an artificially large number, e.g. 20000 in the filter length menu slot. This will insure that the same average scan across the radargram is subtracted from every scan. Using a value less than the total number of scan in the radargram will apply a background filter that subtracts a local average. There could be situations where a filter length less than the total number of scans in the radargram may be useful in simple 2D mapping of structures, by removing local averages along the radargram. Background filtering has an automatic option to set the filter length to an artificially high value, e.g. 99000 prior to running the filter. With the auto set checkbox engaged, the background filter will automatically compute the average scan across the whole radargram.

For customized filter lengths, the auto set checkbox can be unclicked and edited as desired. In the past, some users neglected to adjust the default filter length on new projects and this new auto set option will negate the need to manually place in a large filter length for computing the average scan.

Note 1: Background filters are applied too often automatically without much thought being given to its effect on data. The background removal filter will take out the banding noises but it can also take out what appears to be banding noises, but are actually strong linear reflection that are parallel to the radargrams track. If a buried pipe were parallel to the antenna track over the ground, background removal would eliminate this overall strong reflection recorded from the pipe. Background filters remove banding noise and real reflections that are along the profile track.



Note 2: It is best to always compute time slices from raw radargrams in addition to using processed radargrams. Time slicing is in itself a natural background removal filter because only reflections above or below the average reflection are being compared and visualized. Background removal should normally only be used to help see reflections in the

radargram profiles themselves, or to help remove extraneous line noises which can sometimes infiltrate the time slice maps.

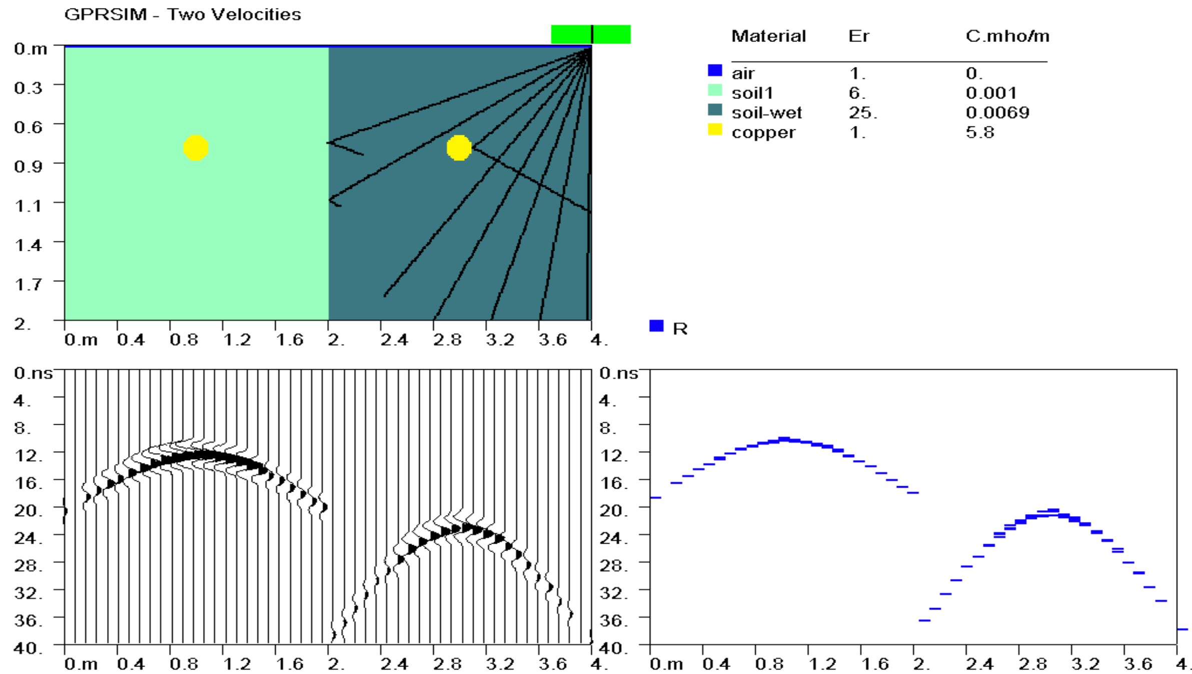
Migration

For those not familiar with the effect of surveying with GPR antennas, cylindrical or round objects buried in the ground create hyperbolic reflections patterns. Because GPR antenna have a broad directional response function and send radar waves out of the antenna in many directions, objects off to the side of the antenna can reflect energy back and be recorded. When the object is directly below the antenna the two-way travel time is small, but when it is off to the side of the antenna, the two-way travel is longer – the net effect – creating a hyperbolic pattern.

The shape of the hyperbola is uniquely determined by the microwave velocity of the ground. Slower velocities will cause the hyperbolas to be narrow, and faster velocities will cause the hyperbolas to be broader. Shown in the following figure is GPRSIM Ground Penetrating Radar Simulation (see www.GPR-SURVEY.com) for 2 circular objects buried in the ground at the same depth, but in 2 different materials. Soil1, the light green material, has a dielectric of 6, and the dark green has a dielectric of 25. The microwave velocity is given by

$$V= C/(Er)^{.5}$$

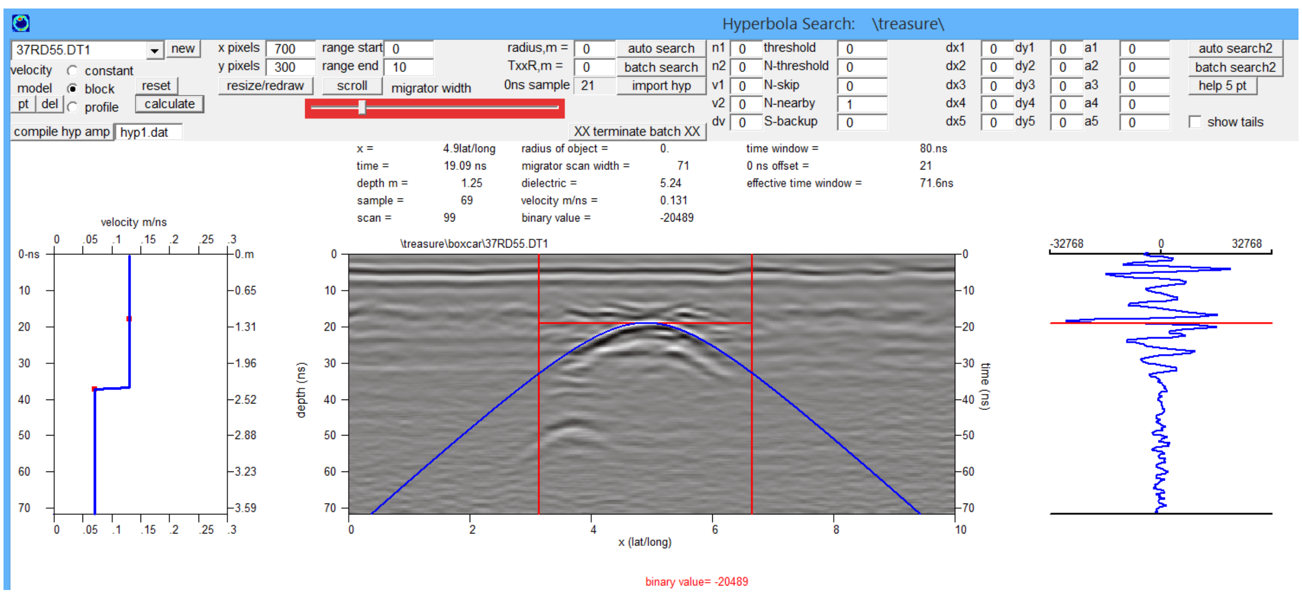
where c =speed of light 3*10^8
Er=relative dielectric permittivity



The velocity of the 2 soils are 12.2 cm/ns (for the light green soil) and 6.0 cm/ns (the dark green soil) respectively. The shapes of the hyperbola are thus quite different. I like to liken the shapes of the hyperbola as the "DNA of the ground", which allows us to determine an important physical property of the ground - the dielectric permittivity.

Migration is a geophysical signal processing filter which will remove hyperbolas in the data. The process works by first fitting a hyperbola to match the hyperbolas found on the raw radargrams. The hyperbola is then "applied" throughout the radargram and all the waves that fall along the hyperbola are added up and the resultant wave is placed at the vertex of the hyperbola. This is done for every point collected in the radargram. When the hyperbolas on the field data lines up with the hyperbola generated by the migration filter in the process, the resultant pulse by adding up all the in-phase components along the hyperbola will be very strong. When the computer generated hyperbola is slightly shifted and not aligned exactly with the hyperbola located on the radargram, the out-of-phase components when added up will tend to 0. The net effect of applying the hyperbola filter will collapse the hyperbolic reflections to point reflections. This of course only happens in the perfect world. Variable velocities and small errors in navigation can create pseudo reflections.

There is a dedicated menu for searching the hyperbola in Filter Menu (see next menu screenshot). The user can use left and right mouse buttons to change the narrowness of the hyperbola to match a hyperbola seen in the field data. Each click of the left mouse button will reverse the direction of the fitted hyperbola. It is normally best to choose narrow hyperbolic features, as these will be closer to point source reflectors and give more accurate measurements. This enhanced menu also has options to adjust the size of the drawn radargram in terms of x pixel and y pixel to help best to show the hyperbolas. The user can also set the start/end ranges to focus in on a particular location in the radargram to better show just the desired area where hyperbolas are observed. The Search Hyperbola Menu will show the dielectric and calculated velocities and depths to the object real time.



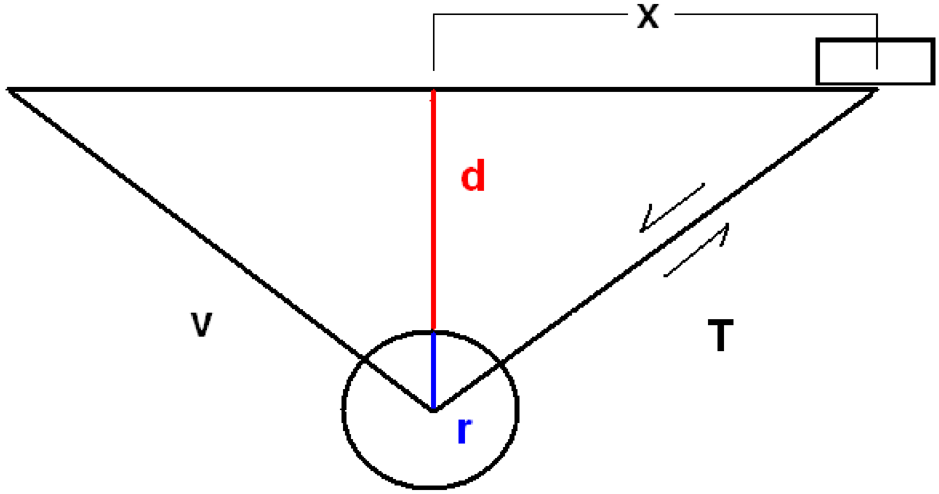
For migration, the user must also set the migrator scan width. In the above example, the migrator scan width is 70 scans and is represented by the two red vertical lines. The migration filter will be operated over just this length. The user can expand this or decrease the width by using the migrator red slider bar in the menu.

Two kinds of migration are available: Kirchoff migration and hyperbolic summation migration. Hyperbolic summation – also known as diffraction stack migration – is a migration process where all the amplitudes over hyperbola are added up and placed at the apex. Kirchoff migration makes is a variation on hyperbolic summation where the wave obliquity and spherical spreading corrections are included for each of the summed amplitudes over the hyperbolic aperture.

Migration processes will run in batch until the last radargram is processed. The user can click on the “processing graphics” switch to see real time graphic results of the radargrams before and after migration. Migrated radargrams are usually a bit weaker in gain overall. The user has the option to apply an overall gain in the Filter Menu to the migrated radargrams before they are written into the \migration\ folder. This is usually needed for migrated radargrams as currently the data are not renormalized after migration. An overall gain factor of 1-4 is usually necessary to regain the migrated radargrams during batch operations. The user will have to investigate manually what a good gain value will be needed for process.

Hyperbola Search for Large Cylindrical Objects

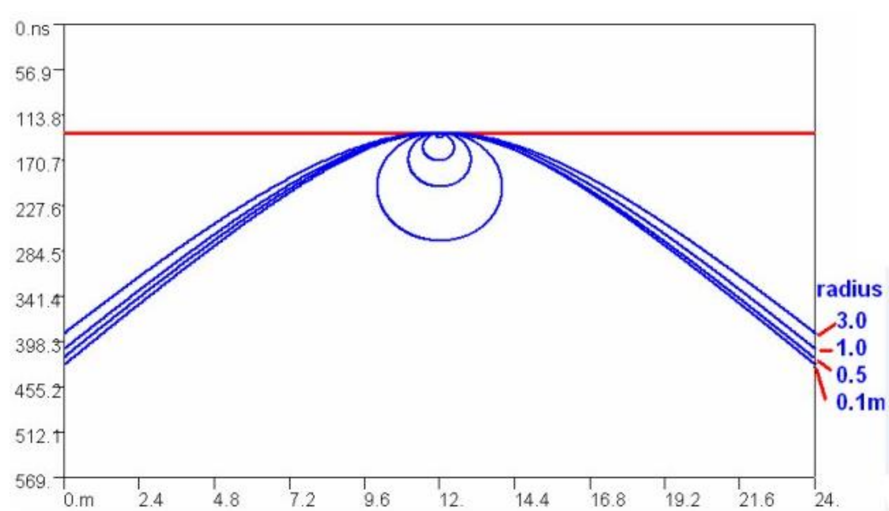
Migration discussed so far is for point sources. If large cylindrical objects are in the ground, the effects of its size change the shape of the hyperbola. The two-way travel time to a cylindrical object with a radius r is given by:



The two-way travel time T to a cylindrical object is:

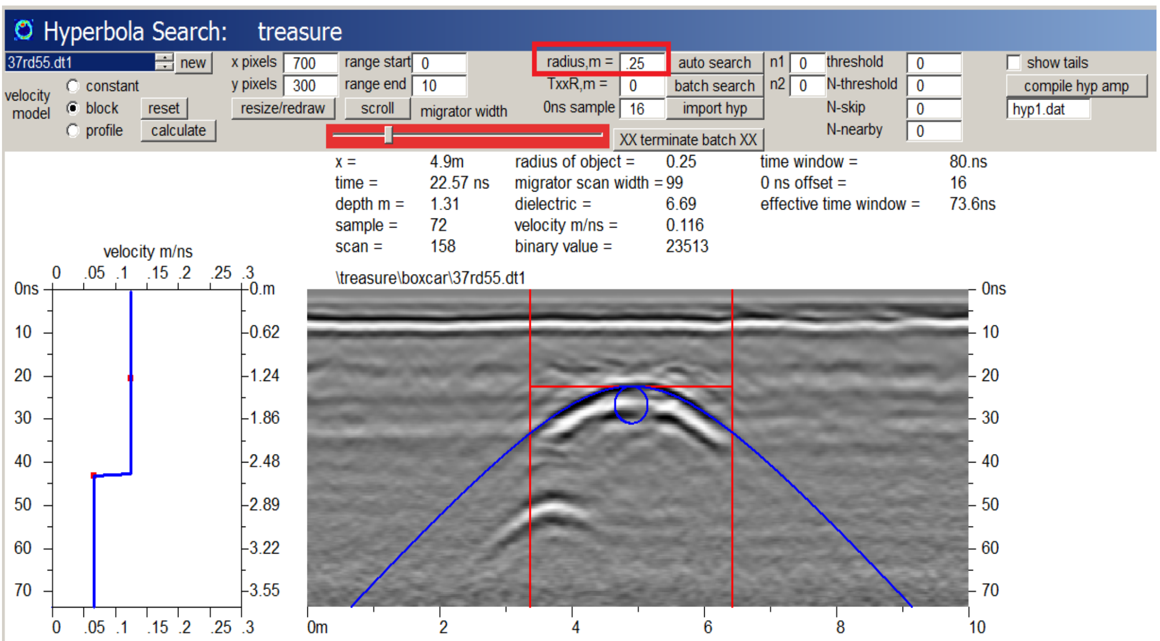
T = 2/v (-r + sqr(x*x +(d+r)*(d+r)))

where v =microwave velocity
r =radius of the object
x =horizontal distance
d =depth to the object



The hyperbola formula reduces to the familiar point source formula of T vs X when r is set to 0. A series of hyperbola shapes for different size radius is shown in the above diagram.

If the velocity is known for a site than an estimate of the size of a cylindrical object can be made. Likewise, if the velocity is not known, but the size of the cylindrical object is, the velocity can be determined by fitting the hyperbola to the observed hyperbola on the radargram. The radius in the Hyperbola Search menu is set on the top of the dialog:



If the radius is something other than 0, then the equivalent size of the object will be shown overlaid on the radargram. Note, that the drawn cylinder may appear with vertical exaggeration because the y axis of the circle is converted to time in nanoseconds. The user will click the left or right mouse buttons to set the hyperbola velocity if this is known. (Normally, a very discrete point source hyperbola should be identified rather than large broad hyperbola, to obtain an estimate to the microwave ground velocity – since often the sizes of cylindrical objects or utilities may not be known at the site). Once the velocity is set, then the user can manually adjust the radius until a good fit is made between observed and calculated hyperbolas for cylindrical objects with large radius.

Kirchhoff Migration for Fixed Transmitter-Receiver Offsets.

Many antennas have separate receiving and transmitting antenna that are separated by a fixed distance. Although we normally refer to many antennas as mono-static antenna, in fact, most antenna are bi-static antenna with a fixed-constant offset. The constant offset for some of the antennas from different manufactures is shown in the following table.

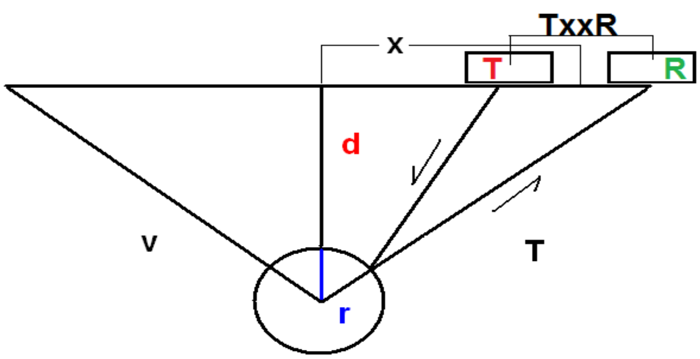
Table of Transmitter-Receiver Separation

Manufacturer	Model#	Freq (MHz)	TX-XR separation (m)
IDS		600	.15
		400	.2
		200	.25
Mala		2300	
		1600	
		1200	
		800	.14
		500	.18
		250	.36
		100	
Sensors& Software		1000	.0762
		500	.1524
		250	.2794
		100	
		50	
GSSI	52600	2600	.04
	5100	1500	.058
	5101	1000	.11
	3100	1000	.0762
	3101	900	.1524
	5103	400	.16
	3105	300	.3556
	5104	275	.24
	5106	200	.332
	33200mlf	100	customized
US Radar		2000	.54
		1000	.11

500	.22
250	.39
100	.637
100 bistatic	1.444

(We are still waiting to be able to fill in some of the commonly used antenna systems into this table. Please look in the future for this newsletter on-line to see any updates available to this information and for more manufacturers' that are integrated with GPR-SLICE).

The constant separation between transmitting and receiving antenna can be used in generating a hyperbola to measure the velocity of a material accurately. In addition, the separation can be used to get a more accurate migration. For hyperbola searching, the travel time for an antenna with transmitting and receiving antennas separated by the distance TxxR, is given in the following diagram:



The two-way travel time T to a cylindrical object with transmitter-receiver antenna separation TxxR is:

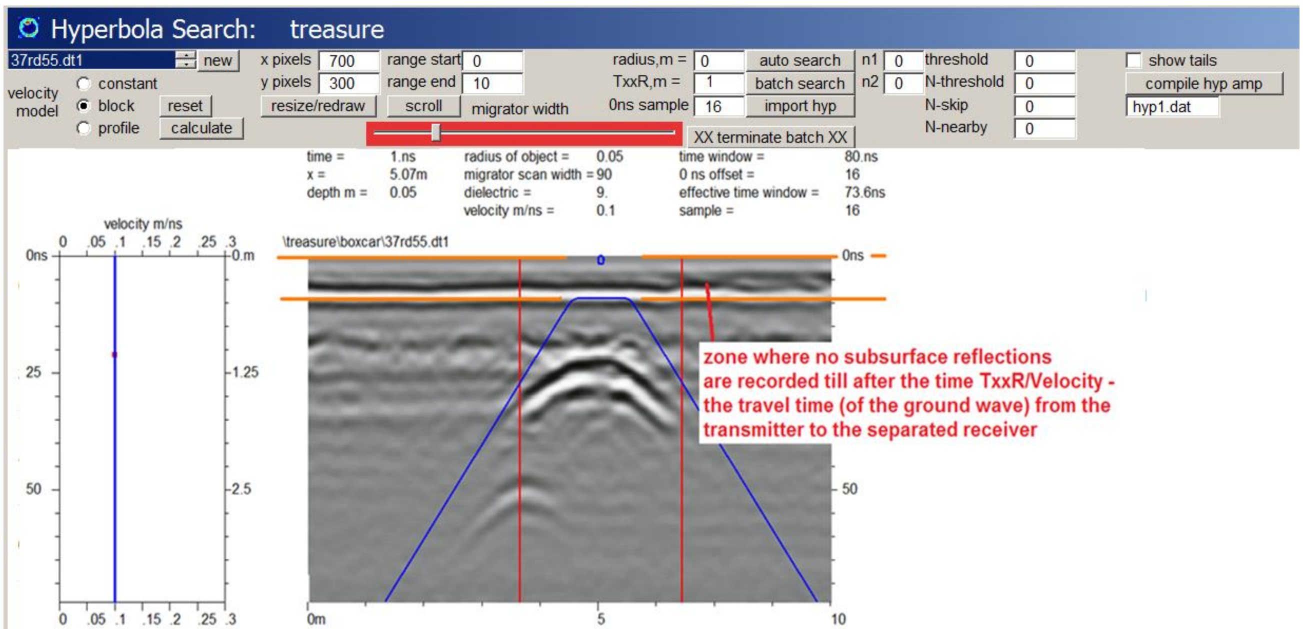
$$T= \left(-2r + \mathrm{sqr}\left((x+TxxR/2)^2 + (d+r)^2\right) + \mathrm{sqr}\left((x-TxxR/2)^2 + (d+r)^2\right)\right)/v$$

where v =microwave velocity
r =radius of the object
x =horizontal distance
d =depth to the object
TxxR=transmitter-receiver separation

Plotting T versus X will give a description of the hyperbola for the most general case of transmitter and receiver separation, and for a radius of the subsurface object.

In migration operations with separation between transmitting and receiving antenna, the radius of the object is not included in the calculation - although the bi-static antenna separation is included in the process. The radius is only used to assist in getting better description of velocity if it is known. In general, the radius of subsurface objects is not known, and the point source target is often assumed (e.g. r=0).

An interesting effect of having a separated transmitter-receiver is that there are no subsurface reflections that can be recorded prior to the ground wave time between the transmitter-receiver, e.g. no reflections from the ground can be recorded before the time TxxR/velocity. In a graphical description of this in the software, we have the hyperbola going flat at this cutoff time as shown in the following diagram:

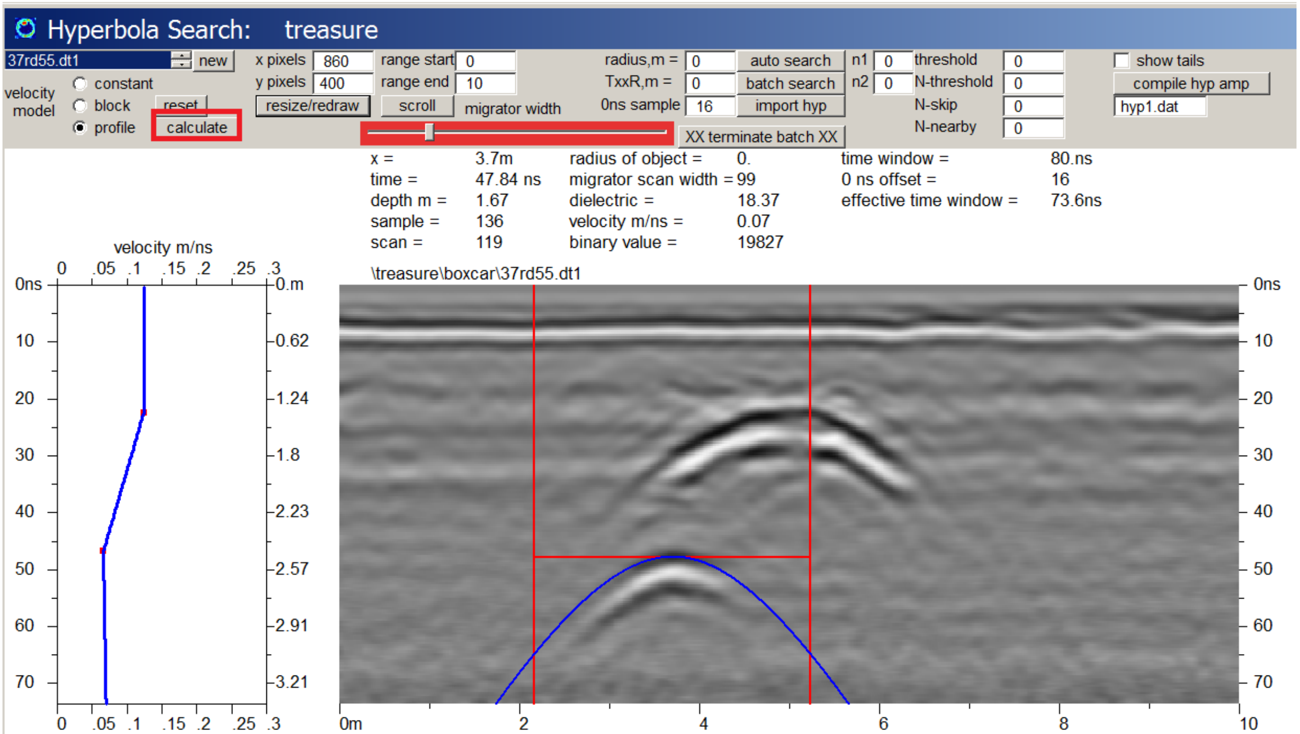


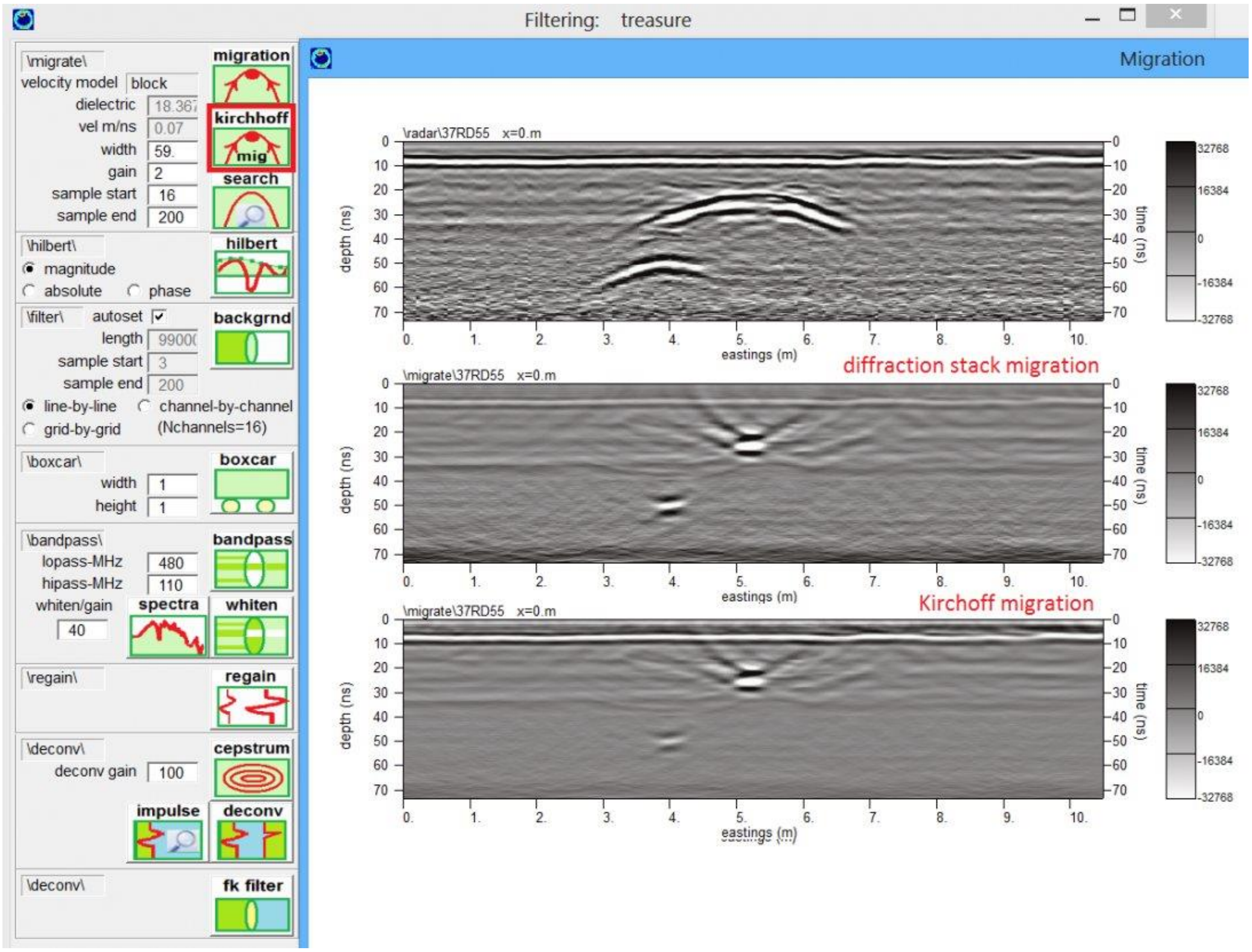
In this example, the TxxR separation is set to 1 meter for illustrative purposes, and the velocity is set to 0.1m/ns. In this case the time for the ground wave to arrive from the transmitter to the receiver is 10ns. We can see that in the example the hyperbola has gone flat at this travel time. In essence, no reflections can be recorded above this time (if we believe Einstein is correct and velocities in the ground are less than the speed of light!). These new options have also been inserted in **GPRSIM v3.0** software for those users of this application.

Variable Velocity Migration

Migration can be done in GPR-SLICE v7 using a continuously varying velocity profile with depth. In the Hyperbola search menu, the user first finds recorded hyperbolas in the radargrams. The hyperbolas are chosen by left clicking the mouse and holding it down to match the hyperbola. After a match is made, the right mouse is then clicked to save the discovered point. The velocity of the discovered point will appear on the location in the radargram chosen as well as on the velocity profile plot.

Three kinds of possible velocity models can be calculated from the chosen points: constant, block or profile. The Constant model will compute an average calculation of all the chosen points. (For constant settings, the average velocity and dielectric will appear in the Filter menu items for migration). The Block model will generate constant velocity regions from the chosen point - till the scan depth where another velocity point is encountered. Profile, generates a linearly interpolated velocity profile between the chosen points. For Profile velocity models, the user should make sure to choose and set a hyperbola on the bottom of the radargram to get a complete profile. A depth range axis also appears on the velocity plot. This depth range is an integrated depth range which corresponds to the velocity profile. Thus the depth interval between tick labels can vary and is not constant when the velocity profile is variable. An Example of a profile velocity model and its diffraction stack migration and a comparison with Kirchoff migration is shown in the following diagrams:


Hyperbola Search: treasure
37rd55.dt1
new
velocity model
constant
block
profile
reset
calculate
x pixels 860
y pixels 400
resize/redraw
range start 0
range end 10
scroll
migrator width
radius,m = 0
TxxR,m = 0
0ns sample 16
auto search
batch search
import hyp
XX terminate batch XX
n1 0
n2 0
threshold 0
N-threshold 0
N-skip 0
N-nearby 0
show tails
compile hyp amp
hyp1.dat
x = 3.7m
time = 47.84 ns
depth m = 1.67
sample = 136
scan = 119
radius of object = 0.
migrator scan width = 99
dielectric = 18.37
velocity m/ns = 0.07
binary value = 19827
time window = 80.ns
0 ns offset = 16
effective time window = 73.6ns
velocity m/ns
\treasure\boxcar\37rd55.dt1

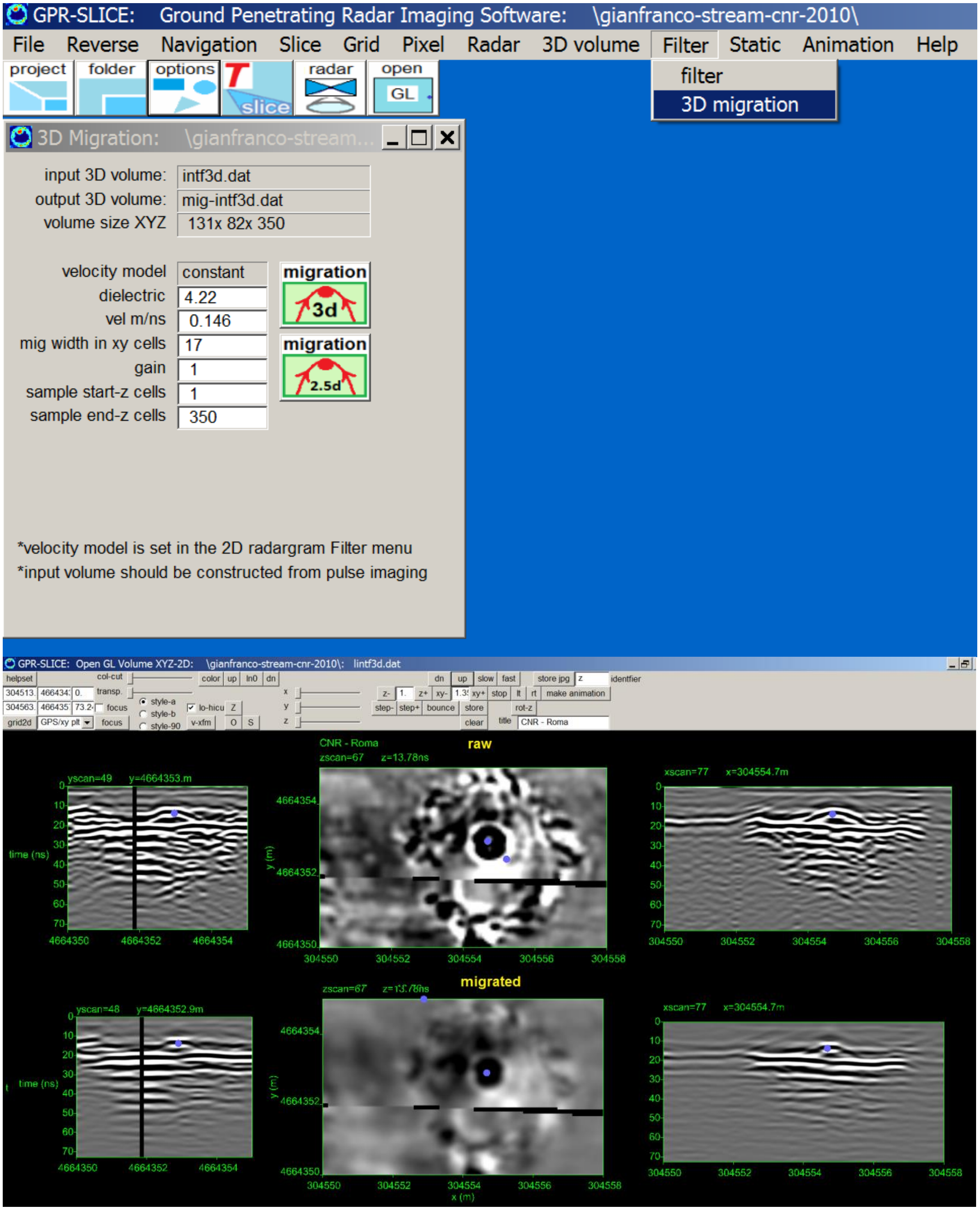


3D/2.5D Volume migration

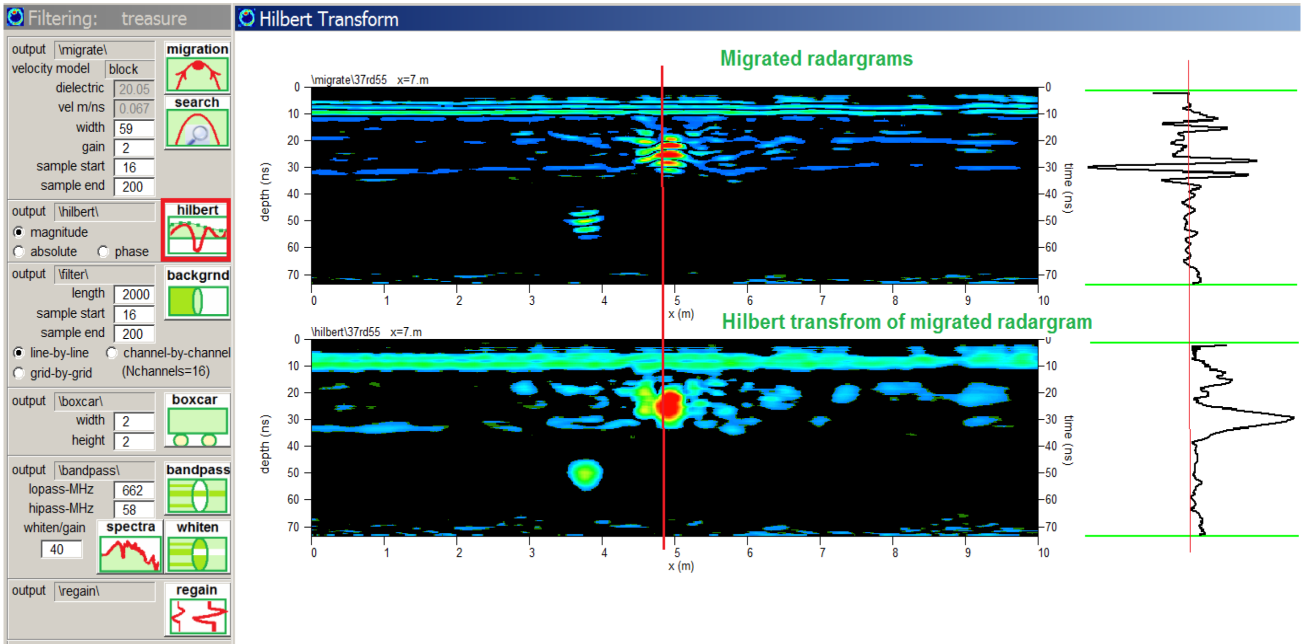
3D and 2.5D volume migration is available from the Filter pulldown menu. 3D migration requires a 3D volume to have been constructed from the radar pulse. 3D migration also requires tight spacing between the radar antenna on the ground in order to be close to a ¼ wavelength of the transmit pulse. For most operations, only multichannel users can really take advantage of 3D migration since high density - area coverage of a site is available with these systems. Multichannel systems are usually processed to create 3D pulse volumes. Single channel users, should they take extremely tight radar profiles over a site, they can then also create a 3D pulse volume and use the new migration routine. In general, 3D migration also requires extremely good accuracy in the navigation. 3D Kirchoff migration works by summing all the radar pulse samples found along the surface of a 3d hyperboloid. Because the pulse is being summed over this surface, any small errors in navigation of the location of the radar pulses in the volume can cause noise and lack of good collapse of radar diffractions. Multichannel systems have the advantage of fixed antenna elements and thus have much better navigation in the volume then usually can be achieved from a single channel system survey over a typical site. 3D migration for all filtering operations should be used in on appropriate sites when navigation confidence is very high. If navigation is poor, 3D migration will degrade the diffraction collapse and lead to more destructive – rather than constructive - interference in summing the raw pulses over diffractions.

2.5D migration is also provided. In this operation, the full 360 degrees around the hyperboloid is not used– only the x and y planes that are 90 degrees apart are summed in the migration process. Some researchers believe 2.5D migration is better to apply then full 3D migration, in part since the full beam response function of the antenna are not properly known. The migration operation requires the user to set the velocity model in the Search menu in the 2D Filter menu. Constant, block, or profile velocity models are available for 3D migration. The migrator width is set as the number of xy cells. If a volume is made and a migrator width is initially defined in the 2D menu from a radargram, then if 3d migration is desired, the migrator width should be adjusted to the equivalent length should the full resolution volume not match that of the radargram scan density.

An example of 3D migration taken from a test site at Consiglio Nacionale delle Ricerche with an IDS Stream multichannel system is shown in Figure 3. The system had 15 channels at 12cm separation. A metal sphere buried at 50 cm depth is clearly imaged in the unmigrated and 3D migrated images.


GPR-SLICE: Ground Penetrating Radar Imaging Software: \gianfranco-stream-cnr-2010\
File Reverse Navigation Slice Grid Pixel Radar 3D volume Filter Static Animation Help
project folder options slice radar open GL
filter
3D migration
3D Migration: \gianfranco-stream...
input 3D volume: intf3d.dat
output 3D volume: mig-intf3d.dat
volume size XYZ 131x 82x 350
velocity model constant
dielectric 4.22
vel m/ns 0.146
mig width in xy cells 17
gain 1
sample start-z cells 1
sample end-z cells 350
migration 3d
migration 2.5d
*velocity model is set in the 2D radargram Filter menu
*input volume should be constructed from pulse imaging
GPR-SLICE: Open GL Volume XYZ-2D: \gianfranco-stream-cnr-2010\: intf3d.dat
CNR - Roma
raw
migrated
time (ns)
y (m)
x (m)

Hilbert Transform

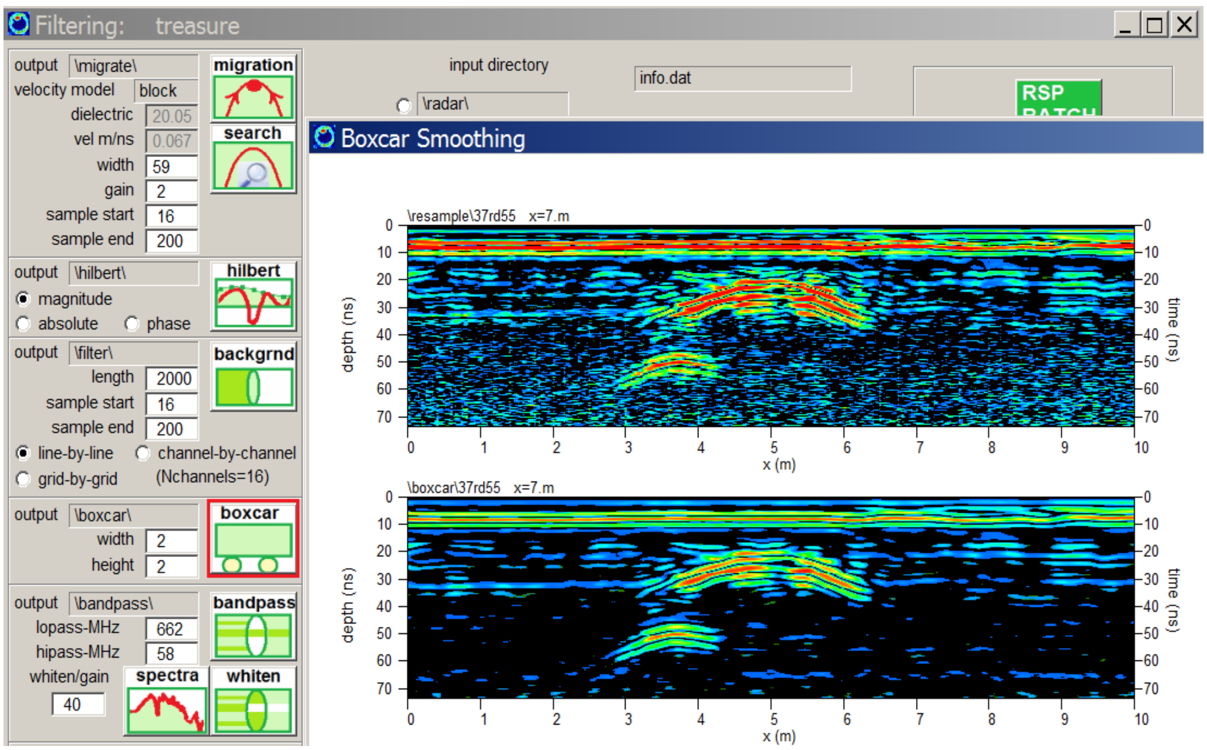


Hilbert Transforms will convert radargram pulses to pulse envelopes. The sinusoidal pulses are converted to positive domain envelopes. (The mathematics to do this is beyond the scope of the presentation for the manual, however, it basically involves taking the Fourier transform to convert the radargrams to the frequency domain first, then shifting imaginary frequencies by 90 degrees, and then doing the inverse Fourier transform).

Hilbert Transforms are all rectified signals in the positive. Thus slicing a Hilbert Transform signal is similar to slicing of the squared amplitude signal which is also a rectified signal. Hilbert Transforms are particularly useful in the case when the user might like to perform very thin slices less than the size of antenna wavelet. Creating time slices from raw radargram pulses where the time slice window is shorter than a wavelet, can yield noisy looking slices which may not be useful for some applications. This is because the slicing window may be located over the phase of the pulse where it is near 0. Hilbert Transforms of a raw pulse signal near 0 phase would show a strong reflection, close to the signal peak, since the envelope of the signal is being used.

Note: In our time slice method discussed in the Quickstart section, when we do not use the Hilbert Transform, we normally use the square amplitude but with a time window which is several pulse widths long. In this instance the phase of the signals are not critical because the slicing thickness is larger than the wavelength of the recorded reflections. Time slices of radargrams made with or without the Hilbert Transform are very similar when the slicing window thickness in time is larger than the antenna wavelet.

Boxcar Smoothing

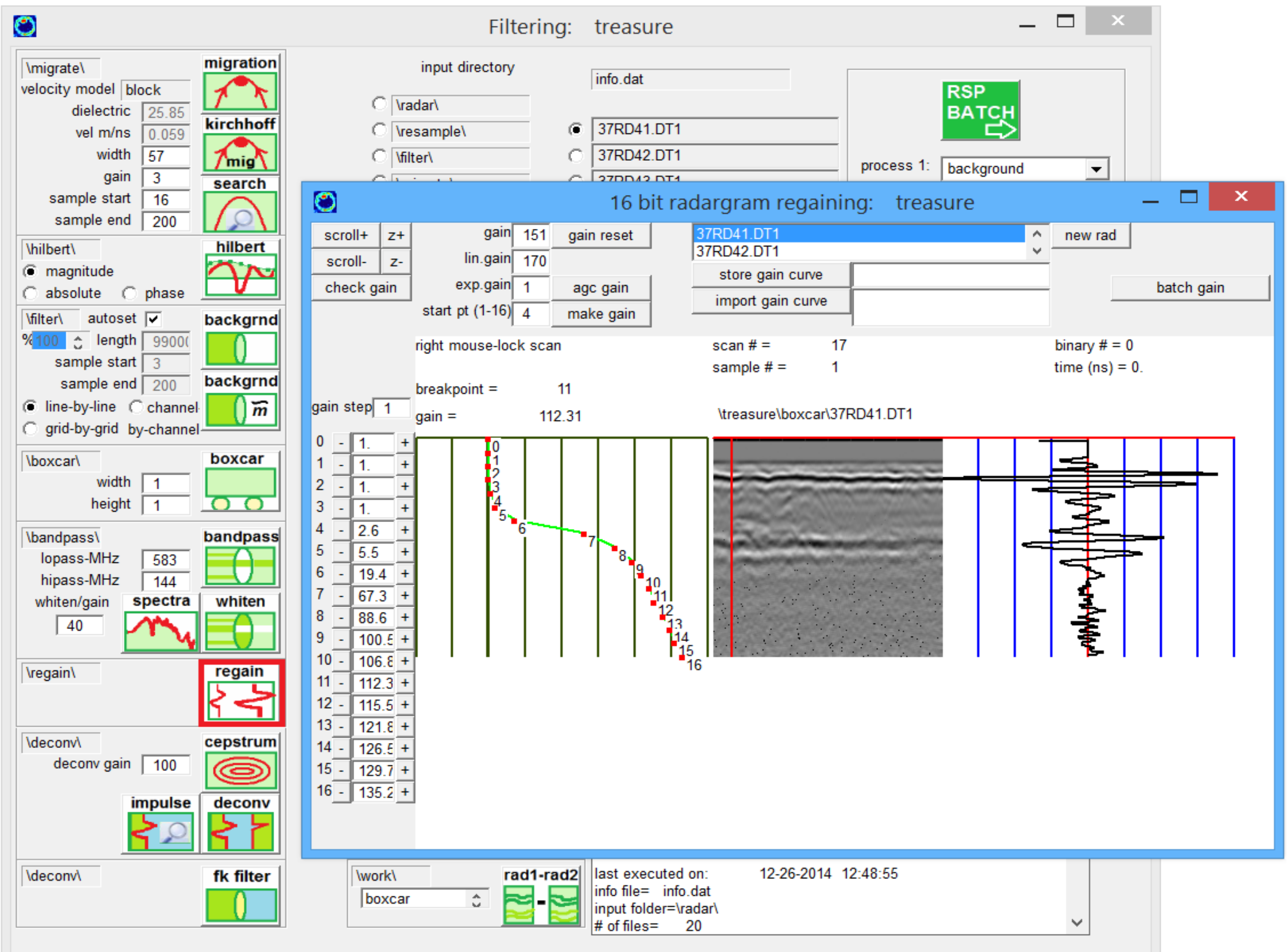


To smooth GPR radargrams which have hi-frequency random noise, a boxcar filter is available in the Filter Menu. The boxcar filter asks for the user to insert the width and height of the boxcar in samples. The filter lengths are lengths of the samples on each side of the radar scan value to be smoothed. Thus if one enters 3 for the width and height of the filter, the actual length of the filter looks 3 scans to the left and 3 scans to the right, plus the scan to be examined, or a total of 7 scans, e.g. 2*3+1. The boxcar filter simply averages the values which are equally weighted and then writes a new radargram to the \boxcar\ folder. An example of a boxcar smoothed radargram is shown in the following diagram. In this example a boxcar filter is applied that is 2 by 2 (which is effectively 5 scans of averaging.

Note: Radar scan stacking can be achieved in the Boxcar filter by setting Height to 0 and then the Width to any number of scans to stack.

Regain

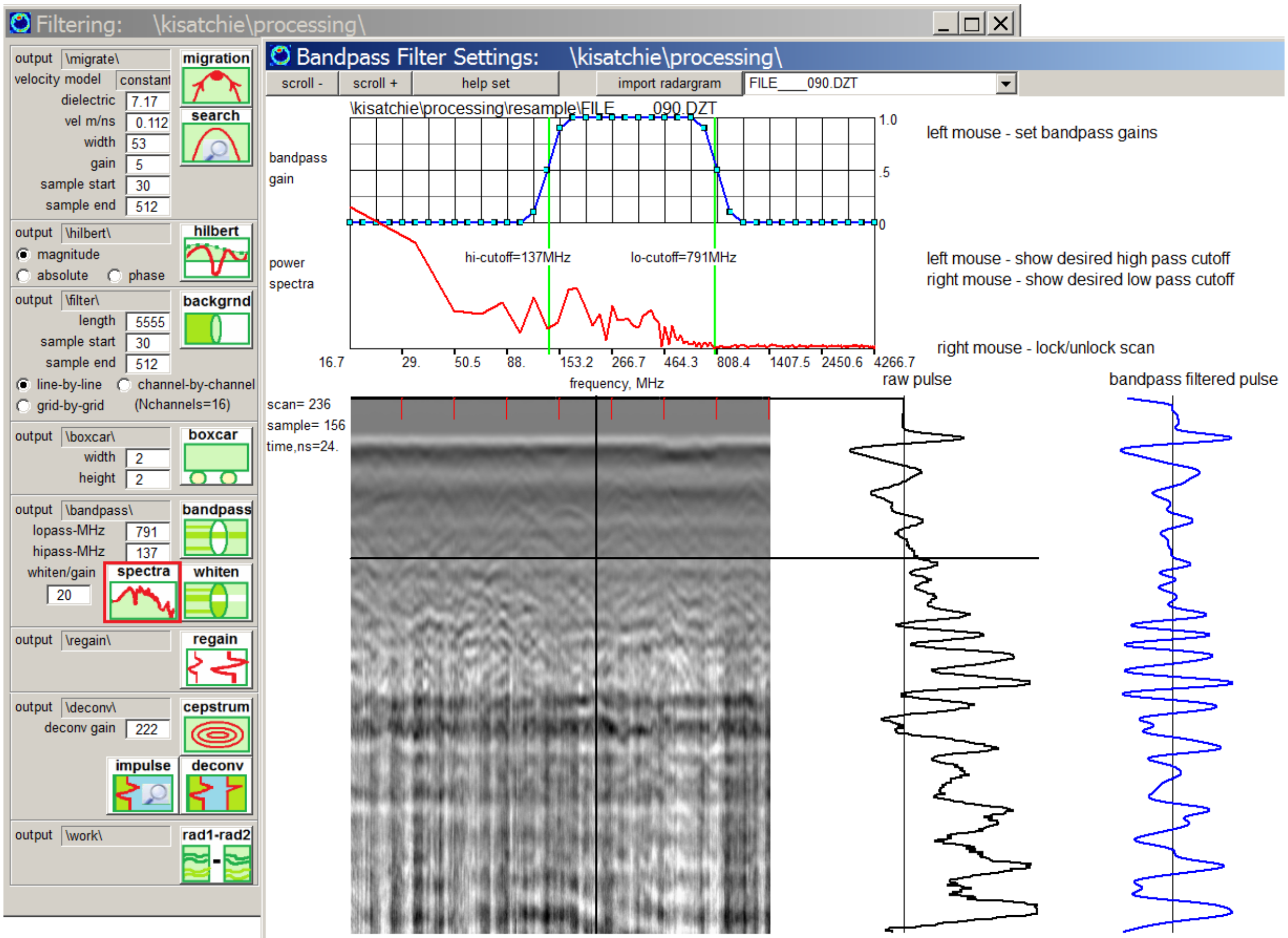
A "regaining" of radargrams using a user defined gain curve versus scan depth can be implemented in the Filter menu. This menu is similar to the operations available in the Convert Data menus. The only difference here is that the wobble removal options are not required here. In the submenu the user can choose to regain a single radargram or regain an entire dataset and write the results to a separate folder called \regain\. The menu operations allow for customized gain curves to be saved as well imported into the menu.



Regaining a radargram is often necessary when raw radargrams with no bandpass filtering are recorded in the field and 0ns offset positions errors exist in the data. In these instances, radargrams should be:

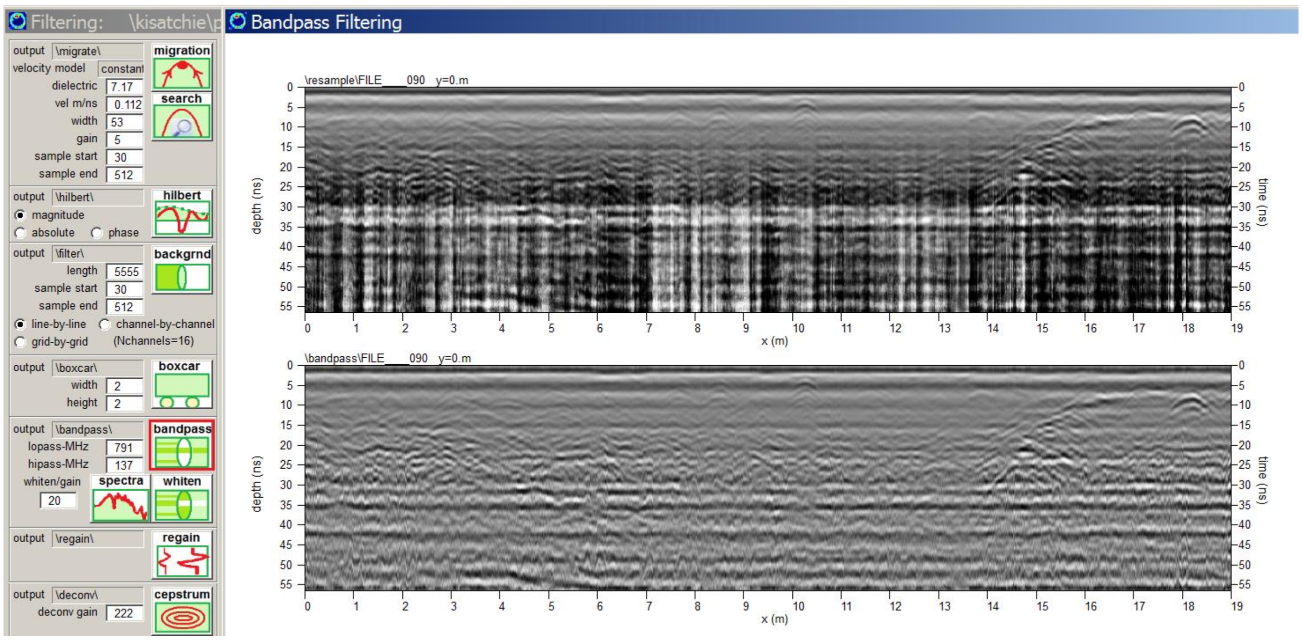
1. converted with Batch Gain - Wobble to remove the DC drift
2. radargram edited for 0ns
3. regained in the Filter menu.

Bandpass Filtering – Spectra menu



Radargrams can be filtered to reduce noise from oscillating components that have a regular frequency. Bandpass filters can be implemented to remove unwanted frequencies in the radar pluses. Before this filtering can be implemented, the frequency ranges over which to remove frequencies as well as the spectral curve to apply to Fourier transformed pulses needs to be set with the Spectra menu. Shown in the Spectra menu, are the raw pulse and shown along with the bandpass filtered pulse in the graphic dialog. One can move the mouse over any scan in the radargram (up to the first 400 scans) and show the pulse and the bandpass filtered pulse real time. The raw pulse shows DC Drift/wobble noise - the bandpass filtered pulse shows this noise removed. This can be seen since the pulse oscillates around the 0 line for the bandpass filtered pulse. The lo-pass and hi-pass frequencies are set with the left and right mouse clicks made over the spectra plot (shown as green bars). Clicking the Help Set button will automatically generate the bandpass spectral curve based on the lo-pass and hi-pass frequencies set.

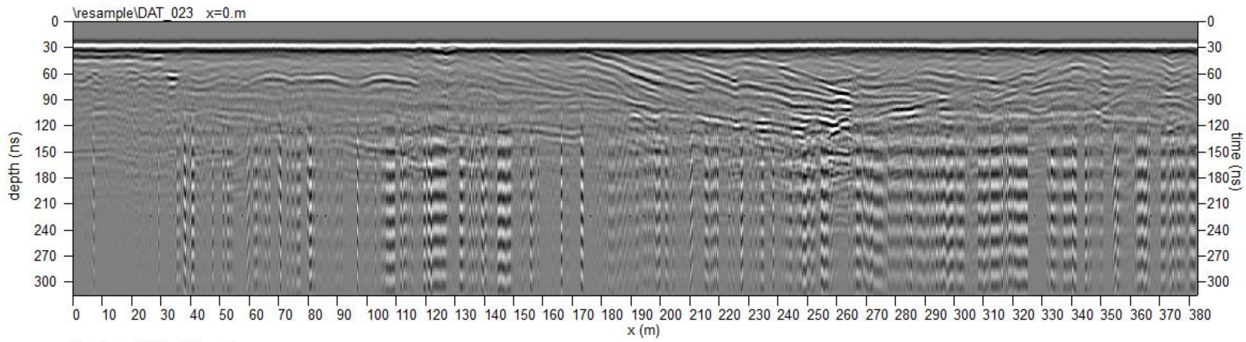
In the example radargram spectral components in the low frequency range are seen to be significant and dominate the power spectra plot. The low frequency noise causes DC-drift in the signal, resulting in the raw pulse floating away from the 0 line. Using bandpass filtering, one can remove these DC components in the GPR signal which is necessary before useful time slices can be generated

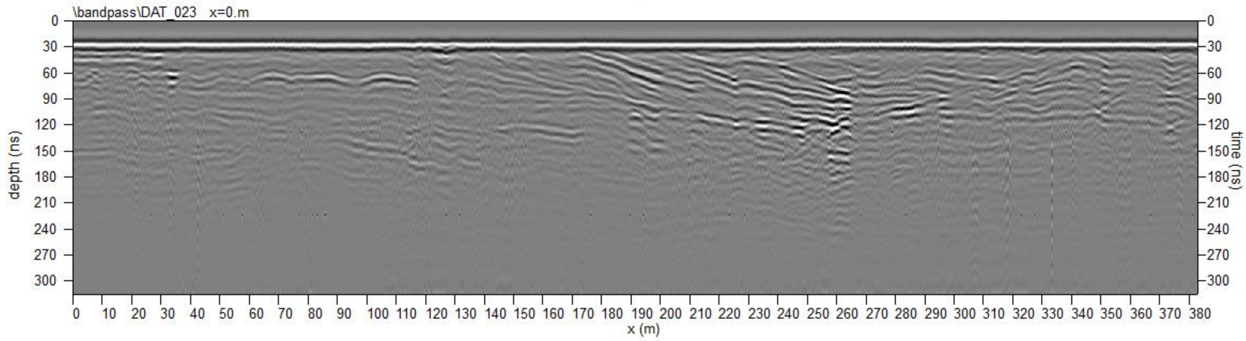


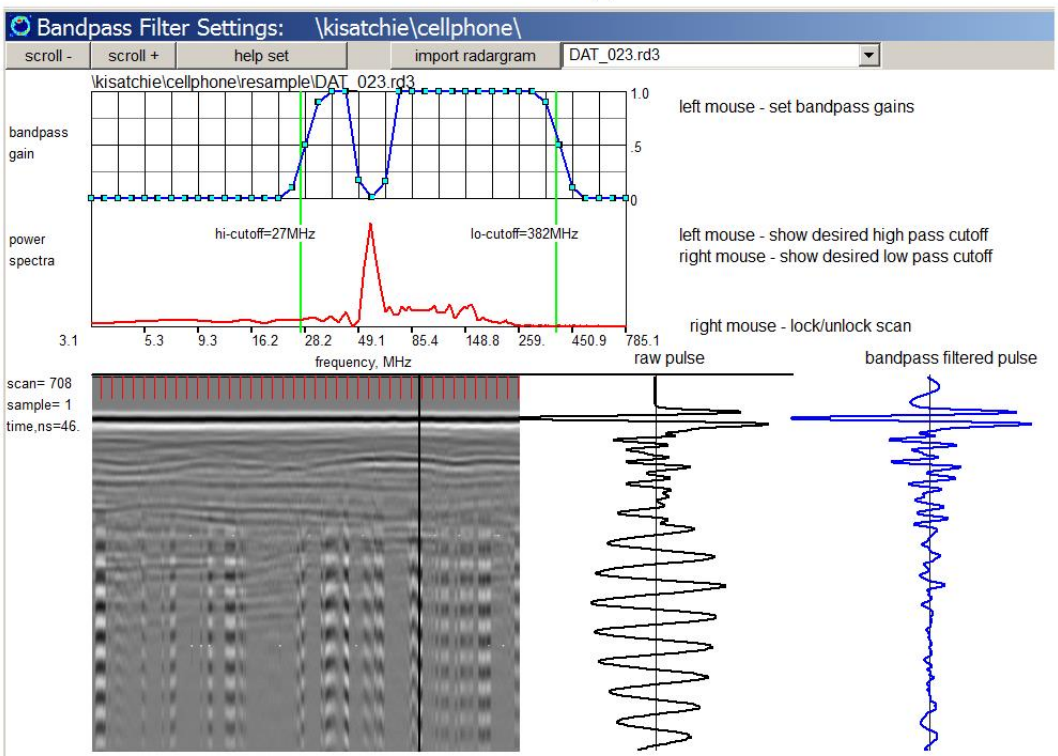
Notch Filters

The bandpass spectral gain curve can also be drawn with the mouse to generate a notch filter. An example of a radargram with severe and isolated transmission noises is shown in the next figure. The transmission noises are concentrated near 50Hz. Drawing a spectral curve to remove all the frequencies around this gives a notch filter. Running the bandpass filter with this customized notch filter design effectively removes the transmissions noises infiltrating the raw radargram.

Note: For bandpass filtering for digitized scan lengths of non-base 2 (e.g. scan lengths other than 128, 256, 512, 1024…etc.), scan lengths are zero-padded to the nearest base 2 binary length before filtering is done.





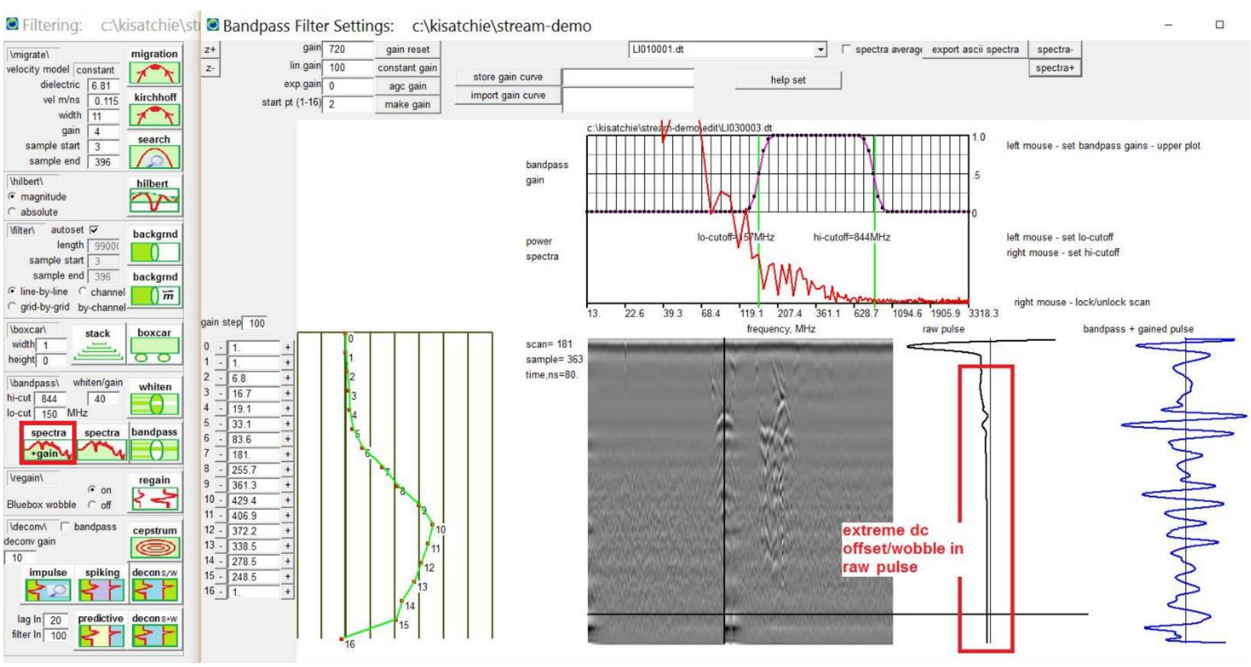


Bandpass filtered radargrams are written to the project in the \bandpass\ folder.

Spectra + Gain menu

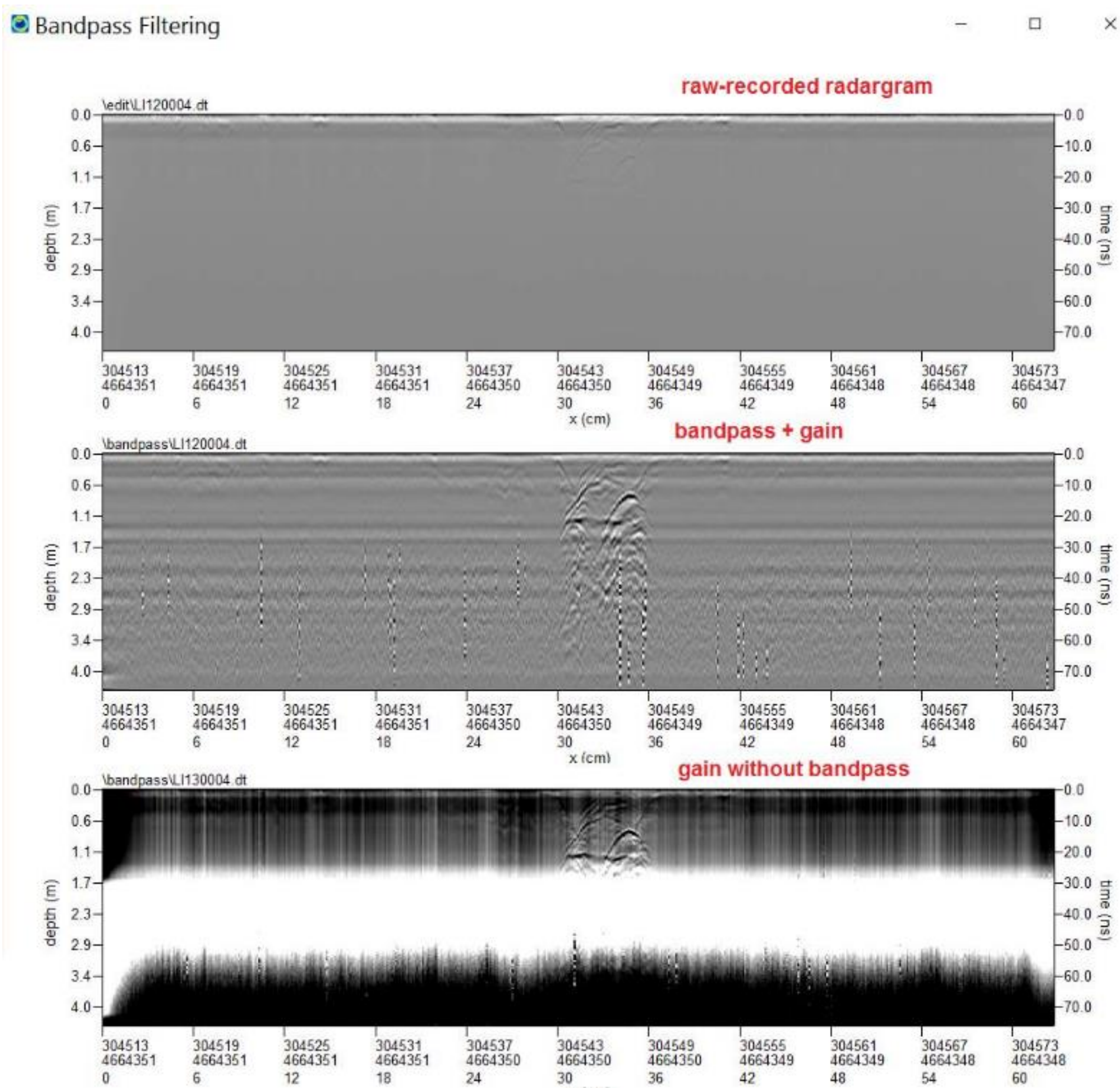
A nmenu called Spectra+Gain is available in the Filter pulldown menu. This menu allows the user to apply range gain on the radargram pulses real-time with the bandpass filter engaged. The radargram that is displayed will be the instantaneous radargram with the gaining and bandpass applied. The menu can be used as an alternative/addition to removing wobble or the dc offset on the raw radargrams.

For GPR equipment that already have bandpass filtering applied to the raw recorded data, this new menu may not have such a large impact on your processing steps and your final imagery. However, for those surveys where bandpass is not engaged in the GPR control unit and is not recorded into the raw radargrams, this range gain feature set in the Spectra menu, can provide an alternative and perhaps superior method to condition the raw pulses than simple wobble removal. An example of a dataset which appears to be quite noisy – with an extreme dc offset - and was recorded without bandpass filters in the raw data is shown in Figure 5. The raw-ungained pulse (s) show a small offset that when gained without bandpass are completely out of the binary resolution and are clipped. The bandpass application with simultaneous gaining will insure that the raw filtered pulses are within range and the wobble/dc offset removed.



Note: 1) recommendations are to use this new menu with time 0 edited radargams to avoid FFT (Fast Fourier Transform) wrap around effects that can cause noises above the 0 sample if not removed. This can potentially lead to false definitions of time 0 on processed radargrams.

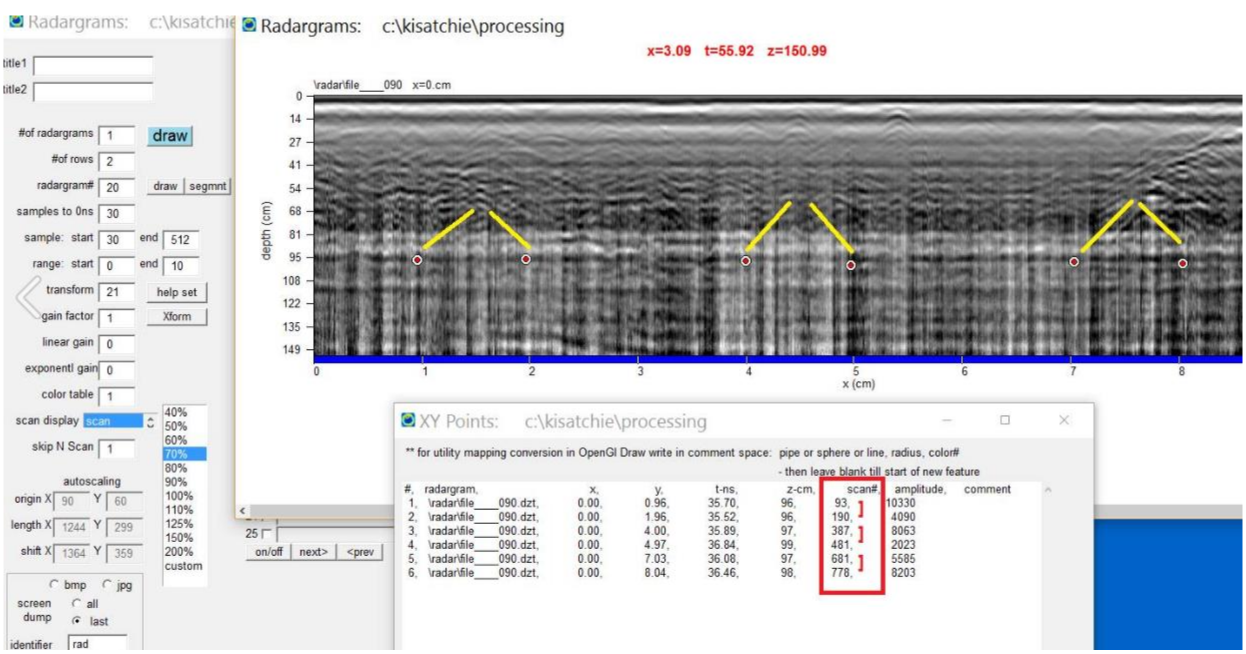
Note 2) batch gain rather than batch gain - wobble in the convert menus will typically be used without any range gain engaged if the new Spectra + Gain menu will be implemented



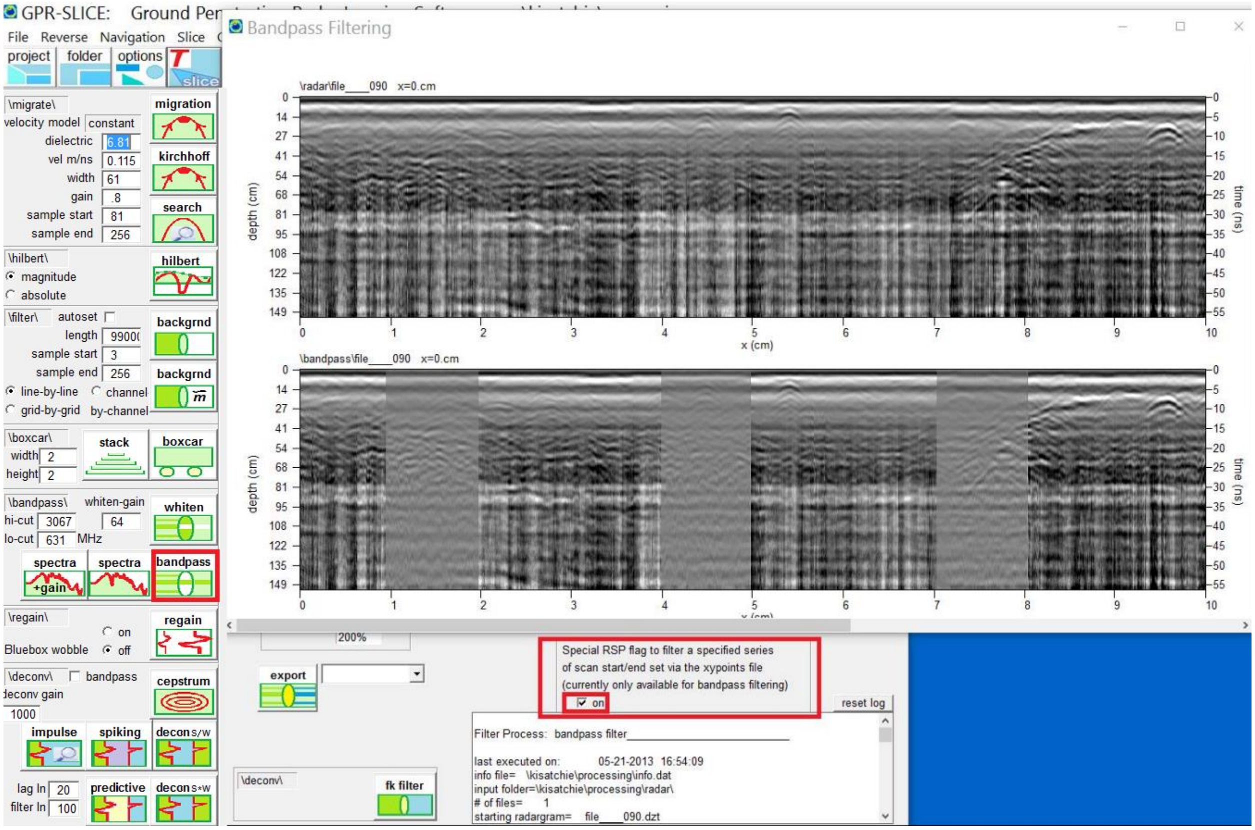
Customizable scan start/end for application of bandpass filters

A new option to apply bandpass filtering just to a set of selective scans in a dataset in which there are severe noise issues, without having to apply the filter across the entire radargram was added to the Filter menu. To implement this request a new flag option - set in the Filter menu will read the XYpoints file to discover those scan sections to apply the customized processing on (see following screen shots). The scan start/end values are set via the XYpoints operation, and should be made consecutively across the radargram. (XYpoints record among other things, the scan # of the chosen anomaly points, which makes this features convenient for providing this specialized feature.

Note: This new option currently requires working with an info.dat file with just the single radargram name for the differential bandpass filtering to be applied to.



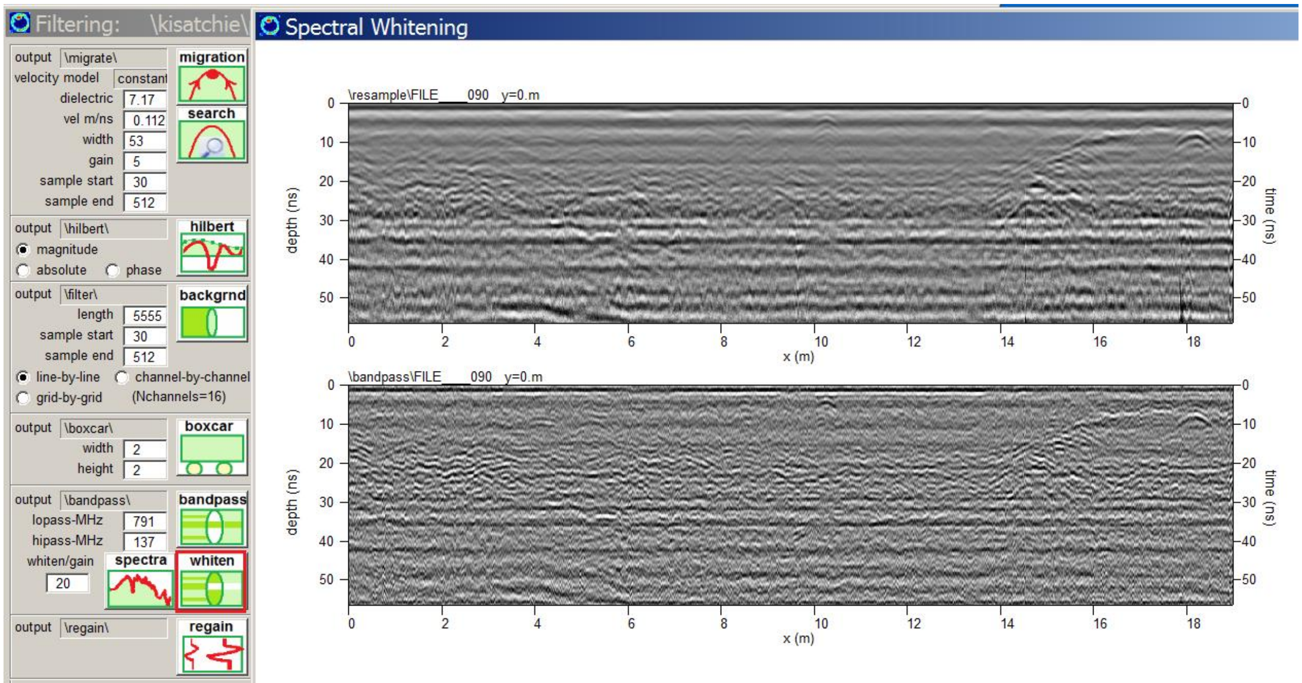
Shown in the following image are the results of applying differential bandpass filtering to the user set scan locations across a radargram:



Spectral Whitening

Spectral whitening is a filter process to equally weight all the spectral components with the same magnitude. The filter is implemented operationally by taking a Fourier Transform, adjusting all the +/- frequencies to have a magnitude of one, while preserving the spectral phase of each frequency. An inverse Fourier Transform is then executed to give a spectrally whitened pulse where the energy at all the frequencies is equal.

Operationally, spectral whitening also has bandpass components, however, the spectral gaining curve is NOT used – only the lo-cut and hi-cut frequency settings. All the frequencies within the bandpass are set to a magnitude of 1 – and all the other frequencies outside the bandpass are globally to 0. Spectral whitening is implemented with a sharp notched filter. In the following example, the lo pass and high pass are set to 1032 MHz and 140 MHz respectively.



Spectral whitening can amplify the entire range within the radargram and illuminate depth regions which may have not been optimally gained. At the same time, it can amplify areas which may or may not have any strong reflection contrasts in the raw radargrams. The example shows removal of low frequency noise and at the same time the ability of the spectrally whitened radargram to have more detail/gain in regions where lower amplitudes exist in the raw radargrams. Spectral whitening process requires manual setting of a gain factor to divide the spectrally whitened pulses. Values in the range of 10-100 can be used and it is common to try several values to see how the subsequent filtered radargram appears.

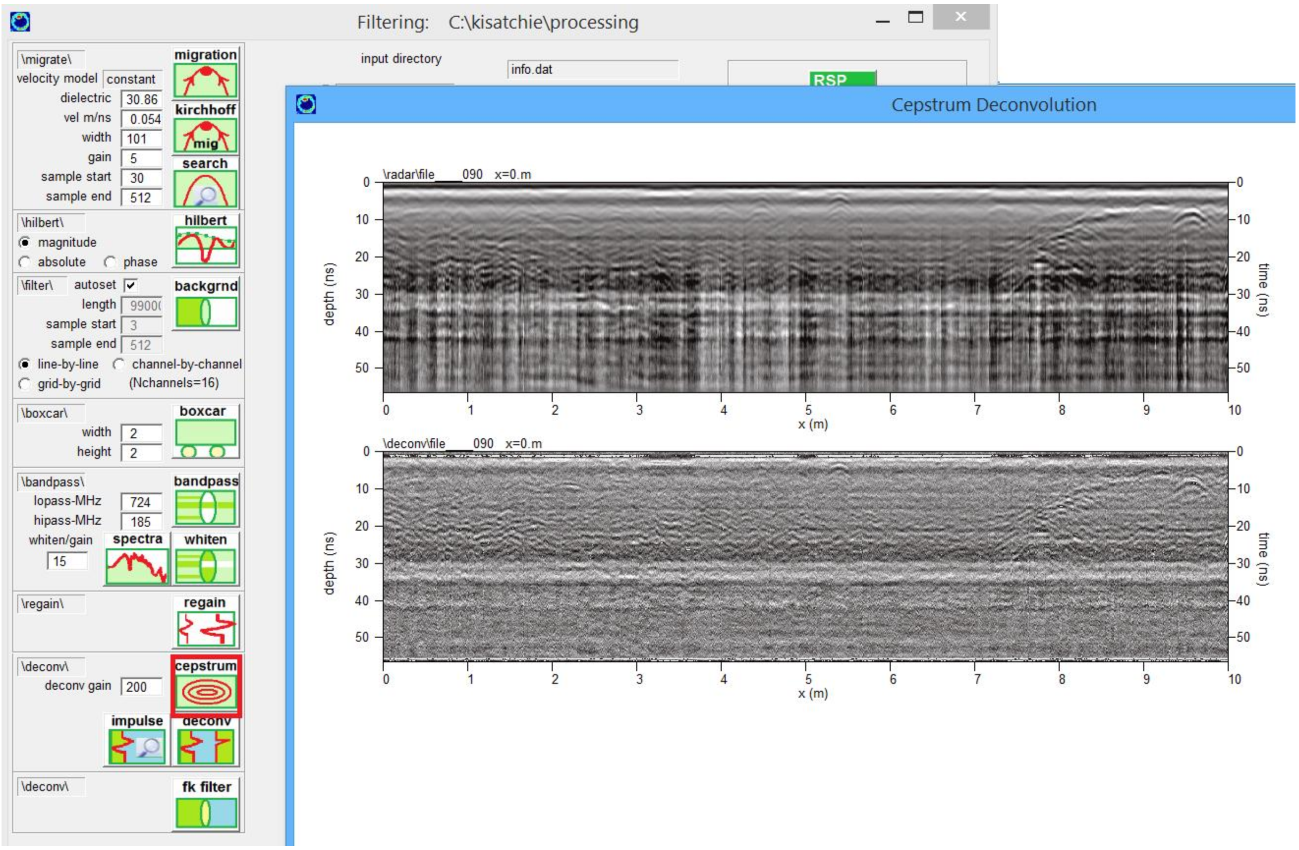
Note: to set the low-cut and hi-cut bandpass, the right and left mouse clicks are set in the graphic region where the power spectra is drawn. (These settings are only used to assist in drawing the spectral curve and are not used specifically in the bandpass filter. These settings however are used directly for the spectral whitening filter where only frequencies within these settings have magnitudes set equal to 1 – preserving the spectral phases. Magnitudes outside these bandpass settings are set to 0.)

Note: Spectral whitening can be a useful filter for multi-channel array data since antenna pair matching can be achieved by implementing this filter.

Cepstrum Deconvolution

Deconvolution is a signal process which can be valuable in removing multiples or echoes in GPR return pulses. Often, GPR pulses contain many reflections which are simply multiple reflections of radar waves from the same reflector. One example of a multiple reflection is a wave that travel downs to a reflector, back up to the ground surface to be reflected by the air-ground interface, and then back down into the ground only to bounce off the same reflector again. One method for reducing the energy from multiples is the cepstrum deconvolution process. In this signal process, the GPR pulses are converted to the spectral domain using Fast Fourier Transforms, the logarithm of the spectral components is computed, and then the inverse Fourier Transforms is made to convert back to the time domain - deconvoluted pulse. Taking the logarithm of the spectral components has the effect to smooth out amplitude undulations in spectral frequencies, and reduce the influence of multiple reflections. Cepstrum deconvolution requires the user to discover a gain factor to bump up the filtered radargrams to recordable thresholds.

Cepstrum deconvolution is available in the FILTER menu as shown in the following example. In this example, the raw radargram was converted without the wobble – low DC drift noise be removed, to see some effects of the filter. Cepstrum deconvoluted radargrams are written to their own unique folder called \deconv\.



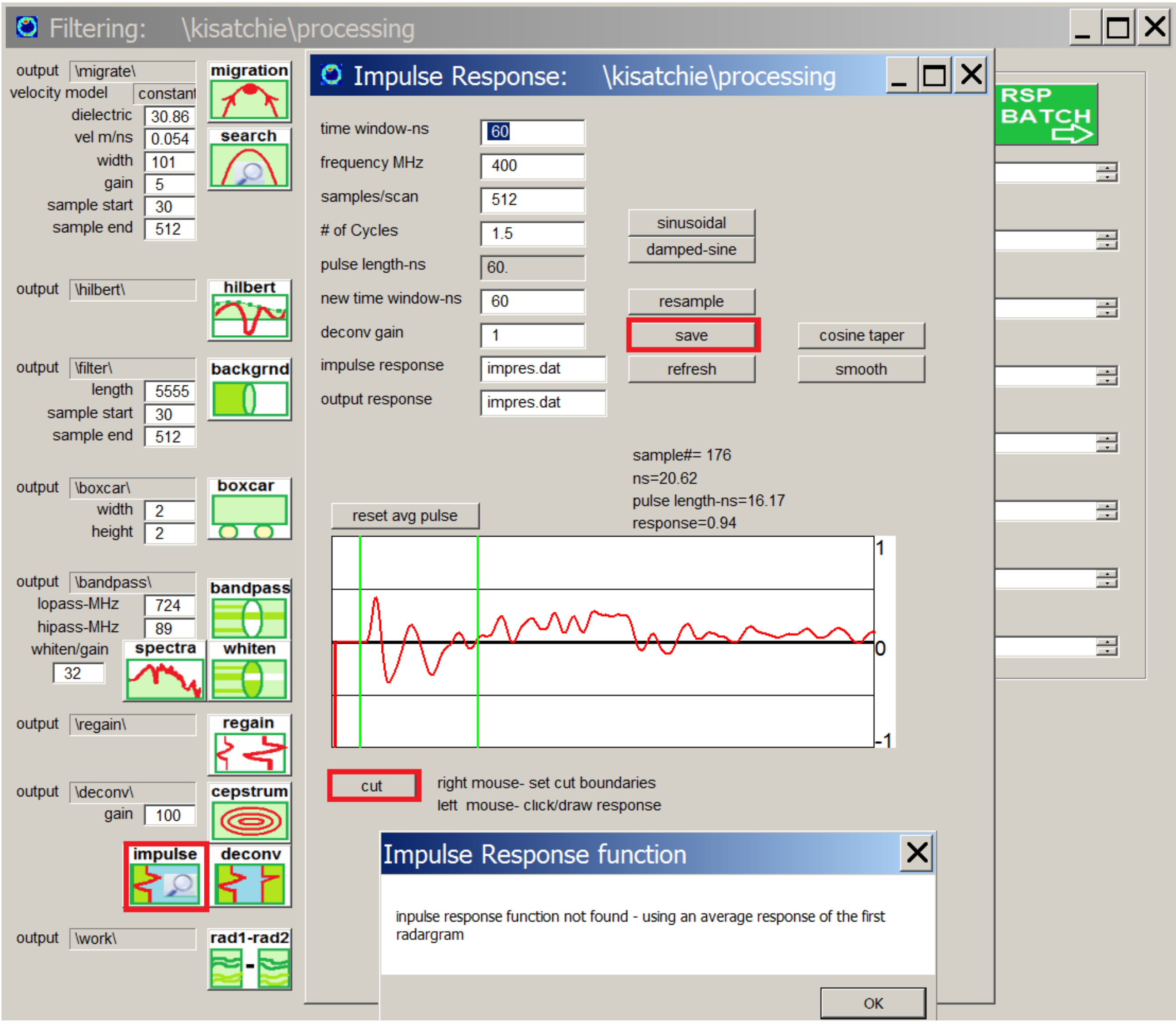
Spectral Deconvolution

Another deconvolution signal process is spectral deconvolution. In this method, the impulse response function of the transmitting antenna, call I(w) as a function of frequency, is divided out from the spectral frequencies of the pulse, called it P(w). The deconvolved signal in the frequency domain D(w) is:

$$D(w) = P(w)/I(w)$$

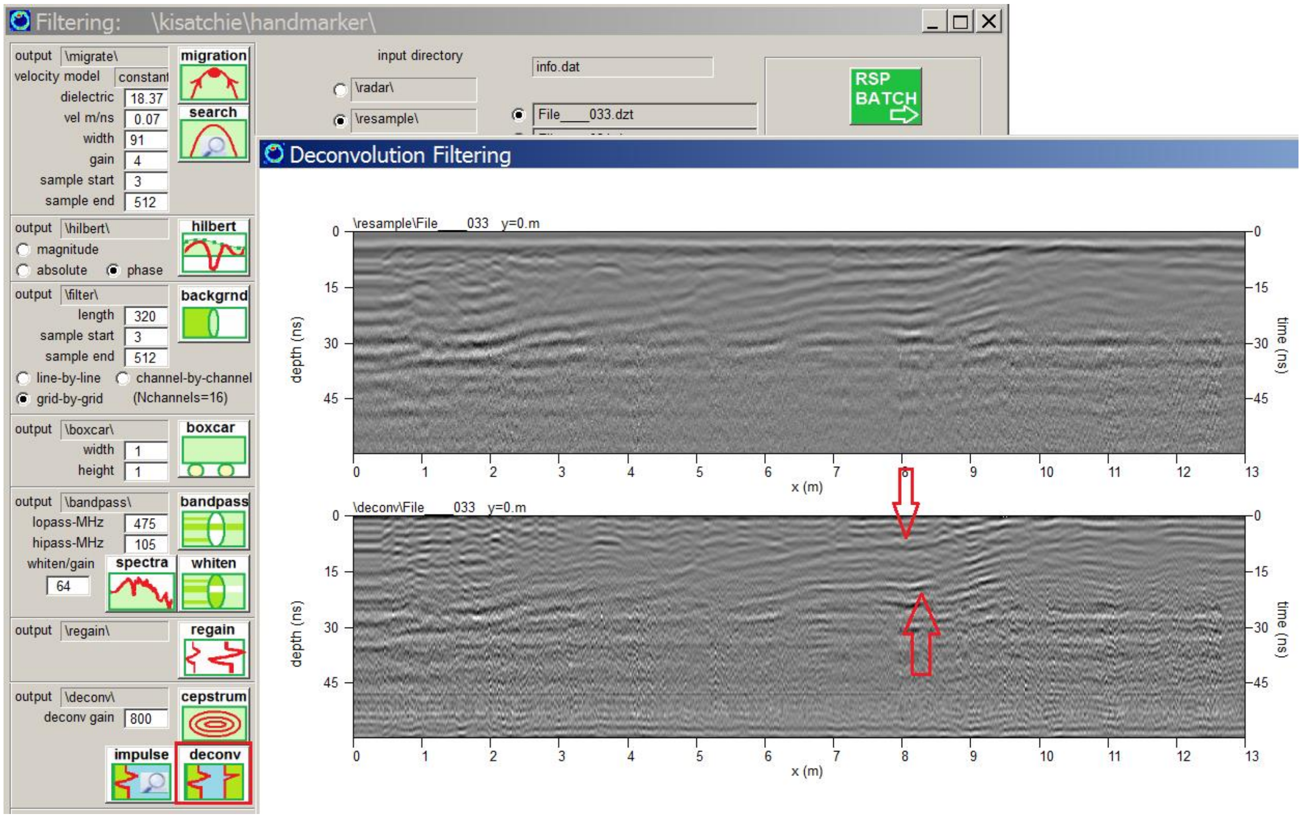
The beauty of working in the frequency domain is that what is normally a convolution in the time domain, is a simple division in the frequency domain!

GPR-SLICE has a menu to accomplish spectral deconvolution. One menu called Impulse will help the user to set the impulse response function by either generating a synthetic response, or by cutting a "probable" response from the top regions near the ground surface of a real radargram:



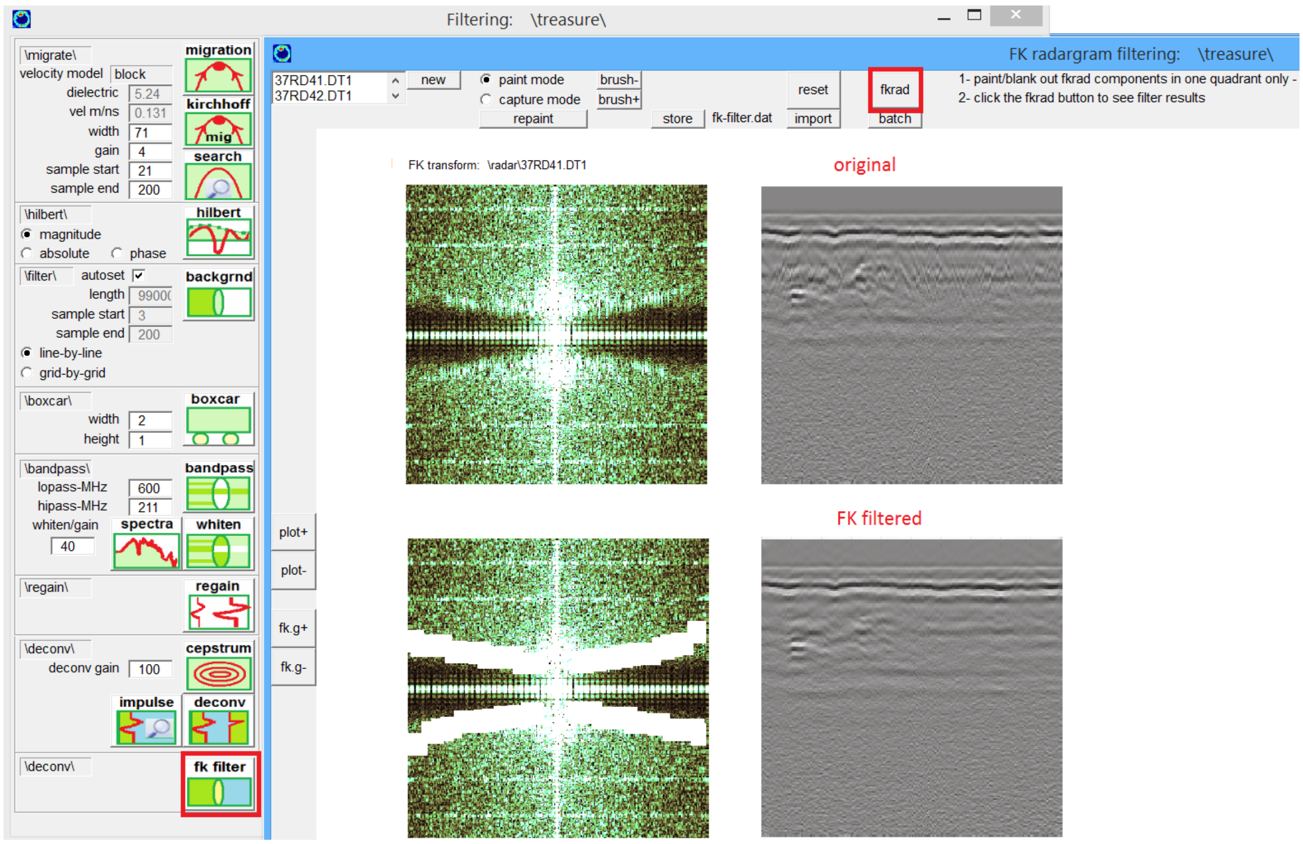
In the Impulse Response menu, the user can import any single radargram and use the right mouse to set locations on the pulse to cut the ground wave response. Clicking the Cut button will cut the response between the set boundaries on the pulse, after which the Save button is clicked. (Note: this is an approximation, and may not represent a good description of the real – transmitted response from the antenna).

Once the impulse response function is set the spectral deconvolution operation can be run. An example of spectral deconvolution is shown in the next figure:



If the proper impulse response function or a reasonable candidate for the response function is not set, very wild results in the impulse deconvolved radargram can result. There are many other kinds of deconvolution algorithms, however, none of them are a perfect medicine for removing multiples. Future updates may provide for additional deconvolution algorithm.

FK Filtering

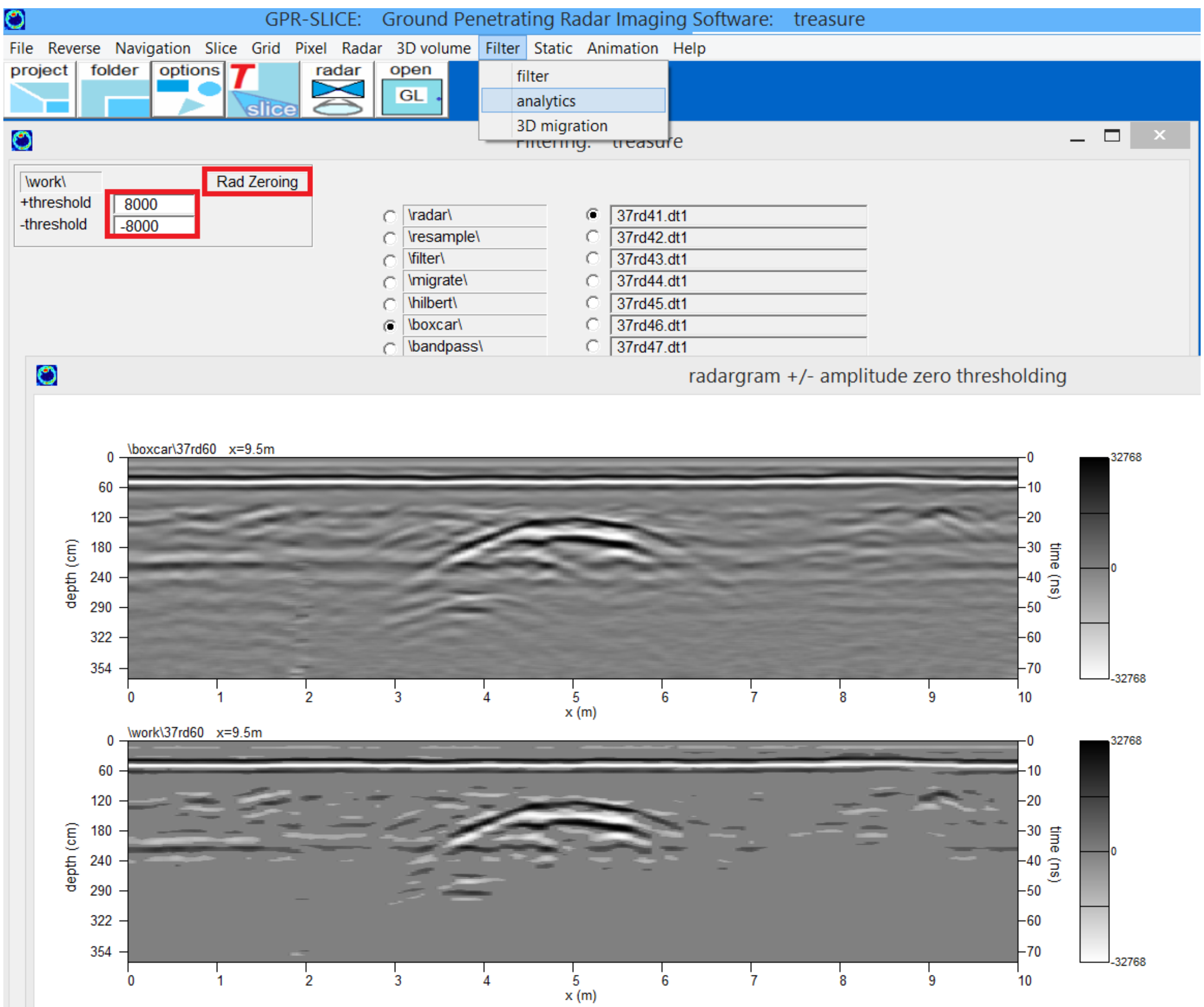


FK filtering is implemented by transforming the radargrams into 2D spatial frequency space and then allowing specific frequencies to be blanked out before transformation back to the time domain is made. Removal of specific spatial frequencies – much like discussed with 2D FFT filtering of time slices in the Grid Filtering section – can enhance features or reduce observed noises. An example of FK filtering is shown in the above screen shot. Using either a paint mode with a user set brush size or capturing the FK components, the users can blank out the desired frequencies. Sloping or diffraction components in the radargrams are suppressed by choosing frequencies components in the FK transform which are normal to the observed features time domain. FK filtering would be useful for also removing some kind of observed directional noise that might be observed in the radargrams. Batch processing can be implemented as well as options to store customized FK filters that are designed. (Beta designation is applied to the FK filter since it is currently limited to radargrams with limited scan density under a few thousand).

Radargram Threshold

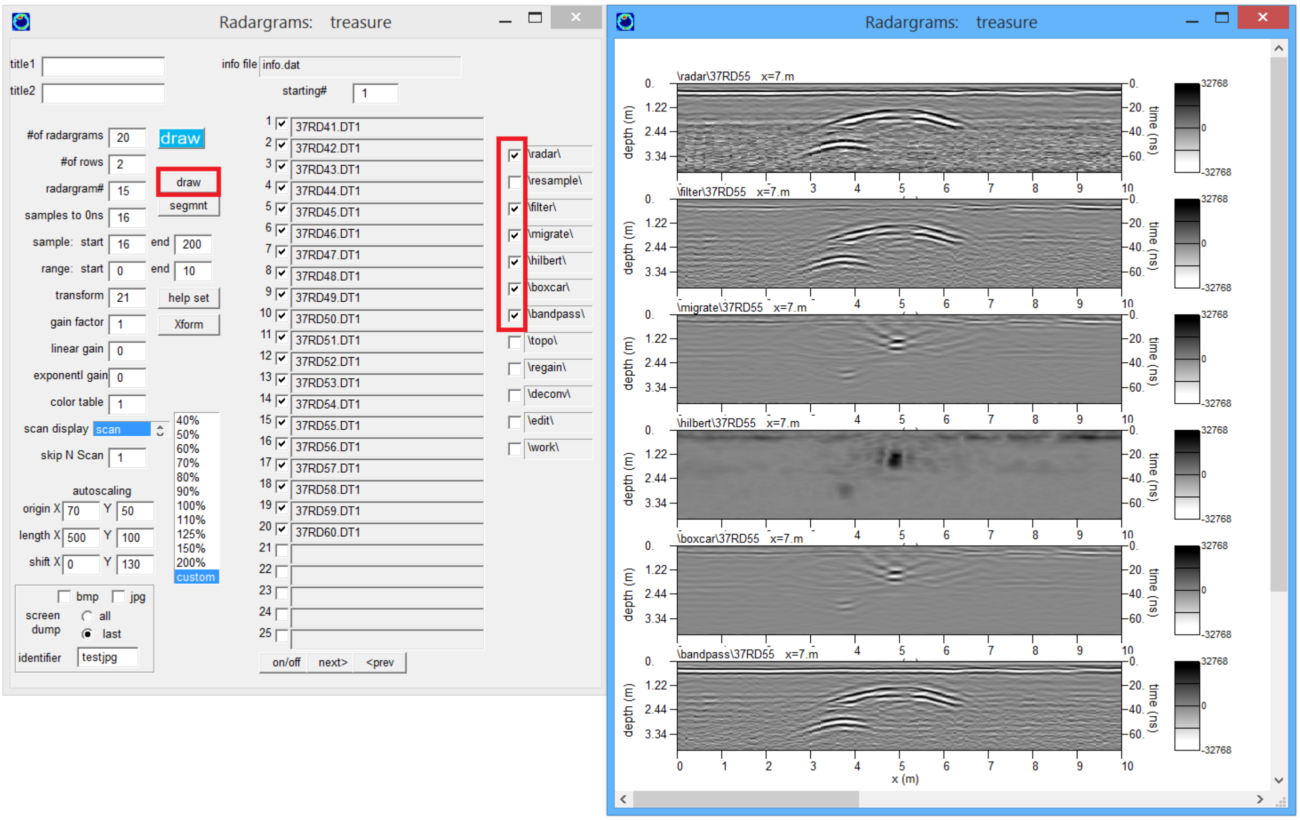
A new menu called Analytics was added under the Filter draw down menu (screen shot). The first operation added to this new menu is a Rad Zeroing button. Often on a radargram display one might only want to show data above and below certain amplitudes on the pulse. Trying to set this with just the color transform can be accomplished visually, however the displayed data are only colorized and not actually changed in the radargram. With this new threshold option, the user can independently set the negative and positive threshold below which all recorded radar values will be shown as zero. The operation will also write the radargram with threshold applied to the \work\ folder. The filtering operation will set all pulse values less than the set min/max values to binary 0.

Note: For the Hilbert folder the negative threshold is idle as no negative values exist from this filtered radargram.



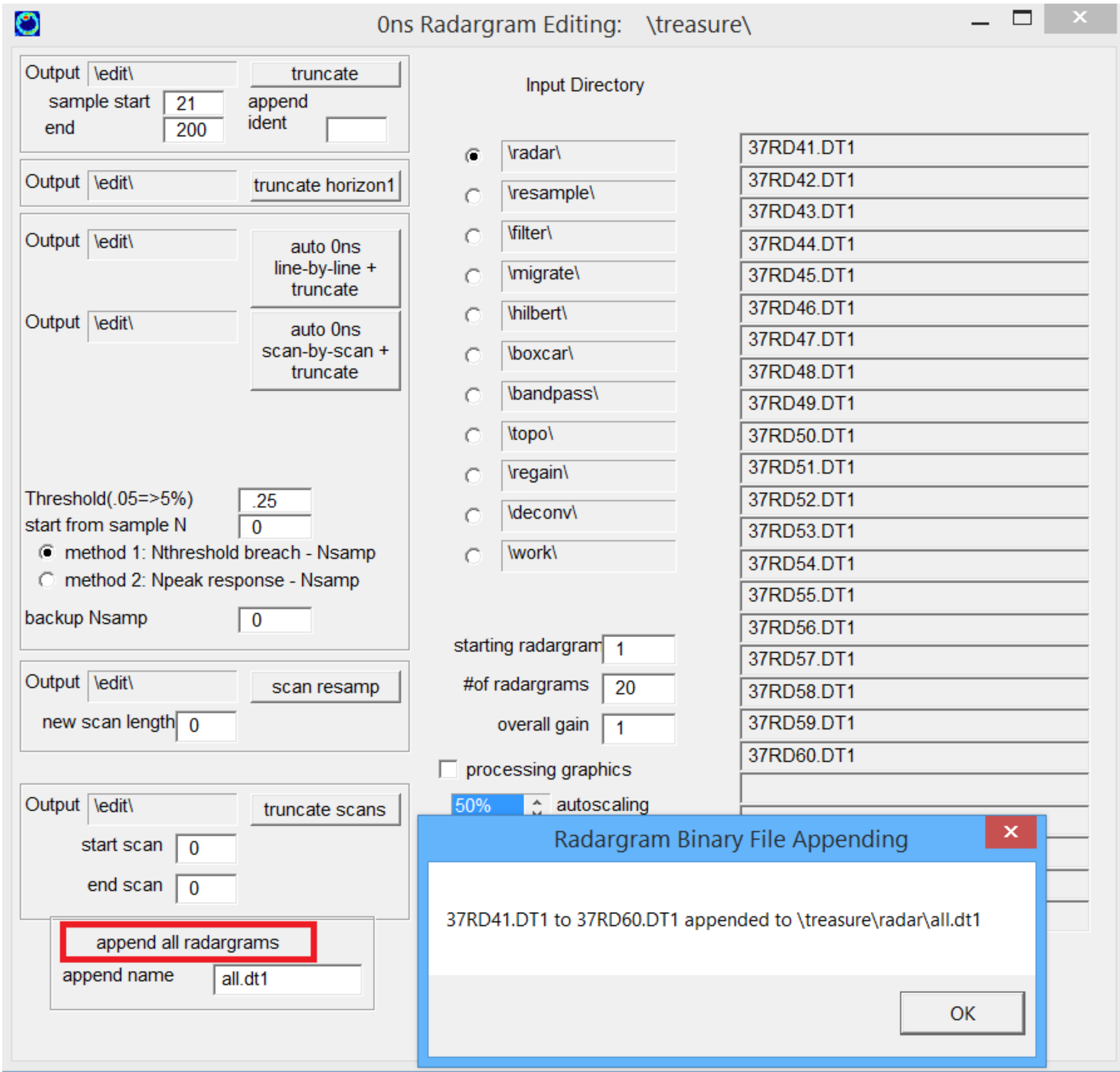
Multi-Folder Radar Display

Showing multiple processed folders for radargram displays can be done in the 2D Radargram Menu by clicking on the desired radar folders:



Radargram Appending

All the radargrams written into an information file can be appended to a single radargram file using the new ***Append All Radargrams*** button in the Radargram Edit menu. The option is provided in the menu traditionally used for just time 0 editing. After the appending option is completed, the user will need to create a customized information file to display the appended radargram name.



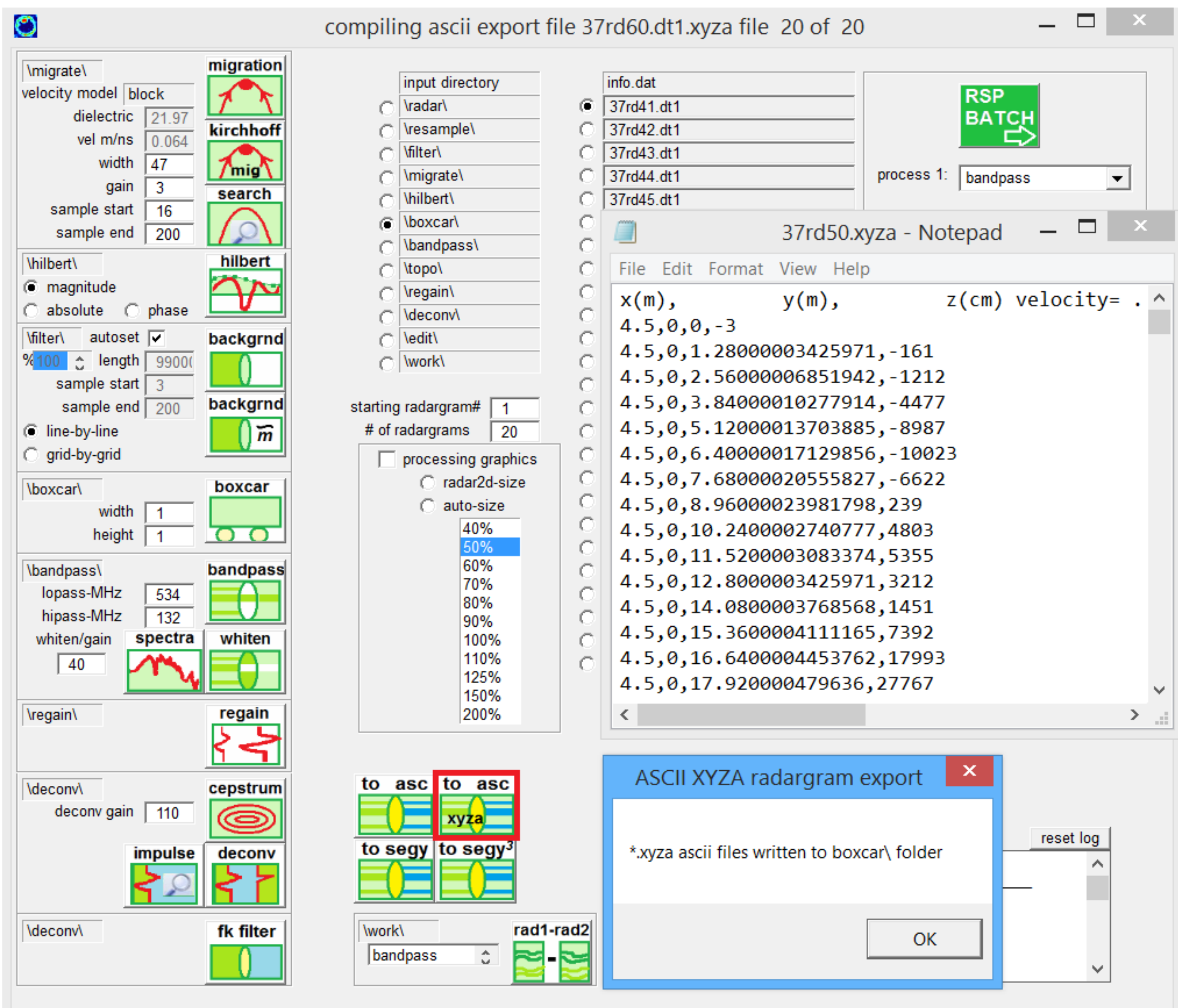
ASCII to *.xyz *.xyza, segy and segy3 radargram export

Several buttons in the Filter menu were added which will allow the user to export any processed radargram into several requested formats:

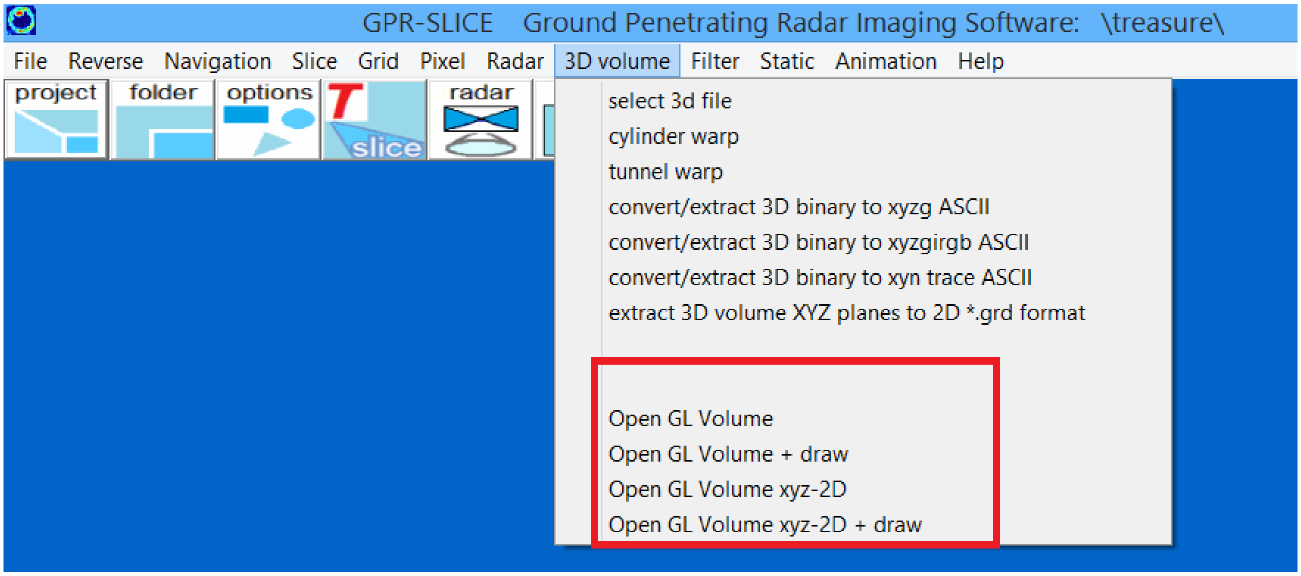
- .XYZ is a simple asci file written one pulse after another
- .XYZA is a 4 column file (see screen shot) with each radar pulse written as x,y,z and the amplitude
- SEGY is the standard seismic format
- SEGY3 is the standard 3d seismic format

X and Y are the horizontal position of each sample value recorded in the radar pulse; the Z value is the depth of pulse sample based on the time/depth axis chosen in the Options menu. If nanoseconds is chosen Z will be in nanoseconds – if a depth unit is set then Z will be converted to that depth unit using the active velocity.

Once the operation is run, the processed folder that was set will have ASCII files with the extension *.xyz, *.xyza or segy written. Note: The size of ASCII files are significantly larger than the binary format used for radargrams so don't be surprised to see the converted radargram in *.xyza format being 5-10 times larger on disk.



3D OpenGL Volume Menu Overview



In this 3D volume presentation menu the user has a host of possible display options including:

- X, Y, Z plane displays
- 3D radargrams
- Isosurface rendering
- Horizon surfaces
- Netplots
- Transparency displays

The requirements of the user to access the 3D Volume menu is to have created a 3D binary file within the Grid menu. If the user has not created the 3D binary file from the desired 2D grid dataset or from direct radargram insertion into a 3D volume with multichannel options, a message box will appear that the 3D binary header file (with the *.hed extension) was not found. Open GL is the primary visualization tool for examining 3D volumes of GPR data.

There are 3D and 2D Open GL menus for display of time slices and volume elements. To access the 3D displays, there are currently several Open GL menus to choose from listed on the 3D Volume pulldown:

- Open GL Volume – is the main Open GL visualization display. Opacity/transparency options are not included. XYZ fence displays are drawn as vertex quads in the volume.

- Open GL Volume + Draw – is the main Open GL Volume display with the added option toolbar for placing pipes, 3D rectangular shapes, or spherical/ellipsoidal objects into the volume.

- Open GL Volume XYZ-2D - is a 2D viewer of the 3D volume showing X, Y and Z cuts of the volume with controls on choosing Z anomaly locations for instantaneous showing on separate X and Y plane displays.

- Open GL Volume XYZ-2D + draw - is the same 2D Viewer but will also launch the drawing tools menu.

Open GL Volume Visualization

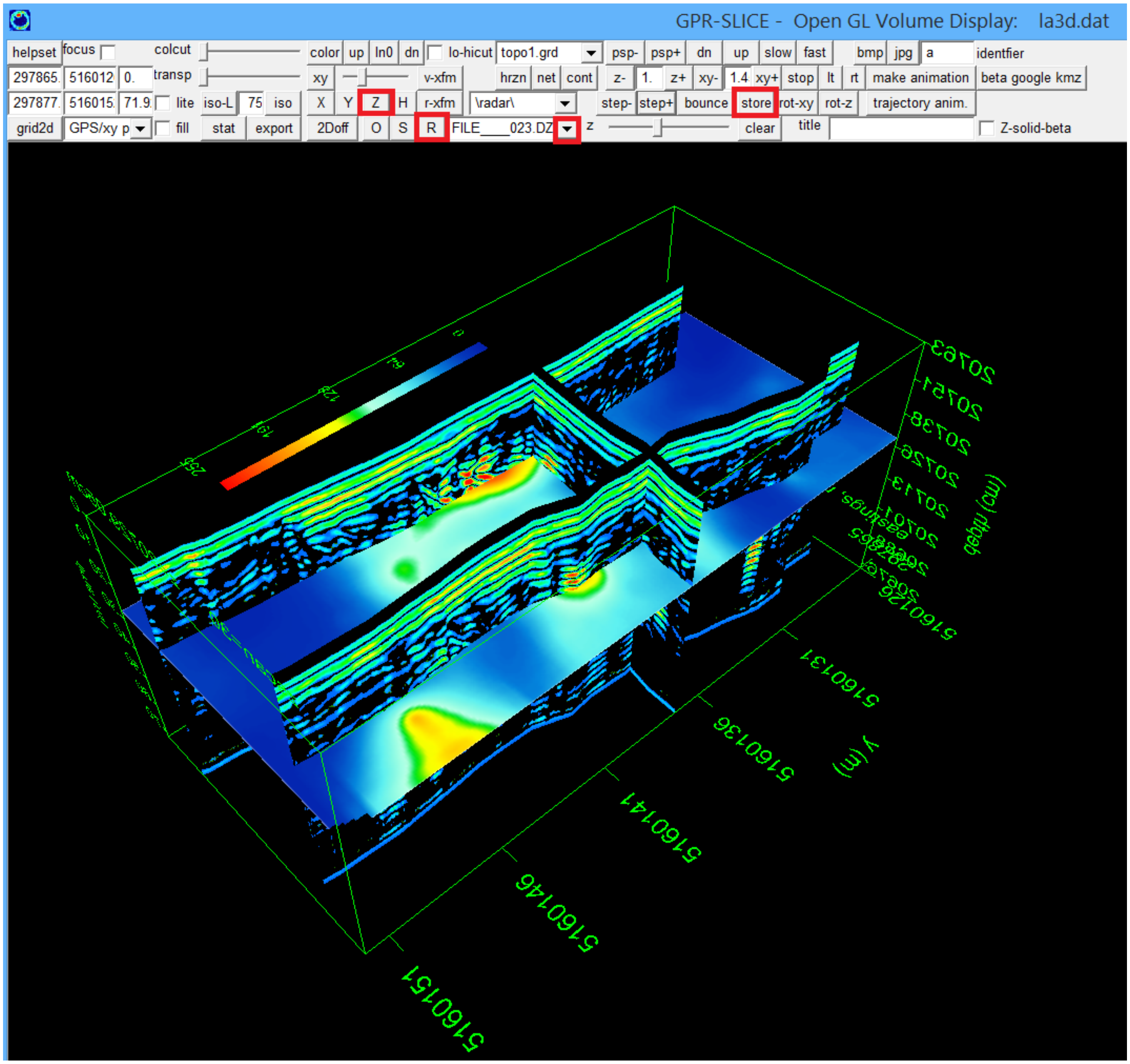
OpenGL (**Open G**raphics **L**ibrary) is a standard specification defining a cross-language and cross-platform API for writing computer graphics applications. The Open GL consists of over 250 different function calls which can be used to draw complex three-dimensional scenes. OpenGL was developed by Silicon Graphics is widely used in CAD, virtual reality software, video gaming software, scientific visualization, information visualization, and a host of other industries. OpenGL is managed by the non-profit technology consortium, the Khronos Group, Inc. Open GL for Power Basic which is the language that GPR-SLICE v7 is written in is also supported in Open GL.

In order to effectively run Open GL one will need to have a computer with a separate graphics card with at least 512 MB – but the more the merrier. Any computer with just an integrated graphics card will not be able to interact with GPR volume in a very instantaneous real-time experience. We recommend NVDIA graphics cards providing the best performance for Open GL applications in GPR-SLICE v7.

OpenGL Volume has been developed and built-in directly to GPR-SLICE V7 which allows mixing and matching of the following elements in the same graphic dialog and volume:

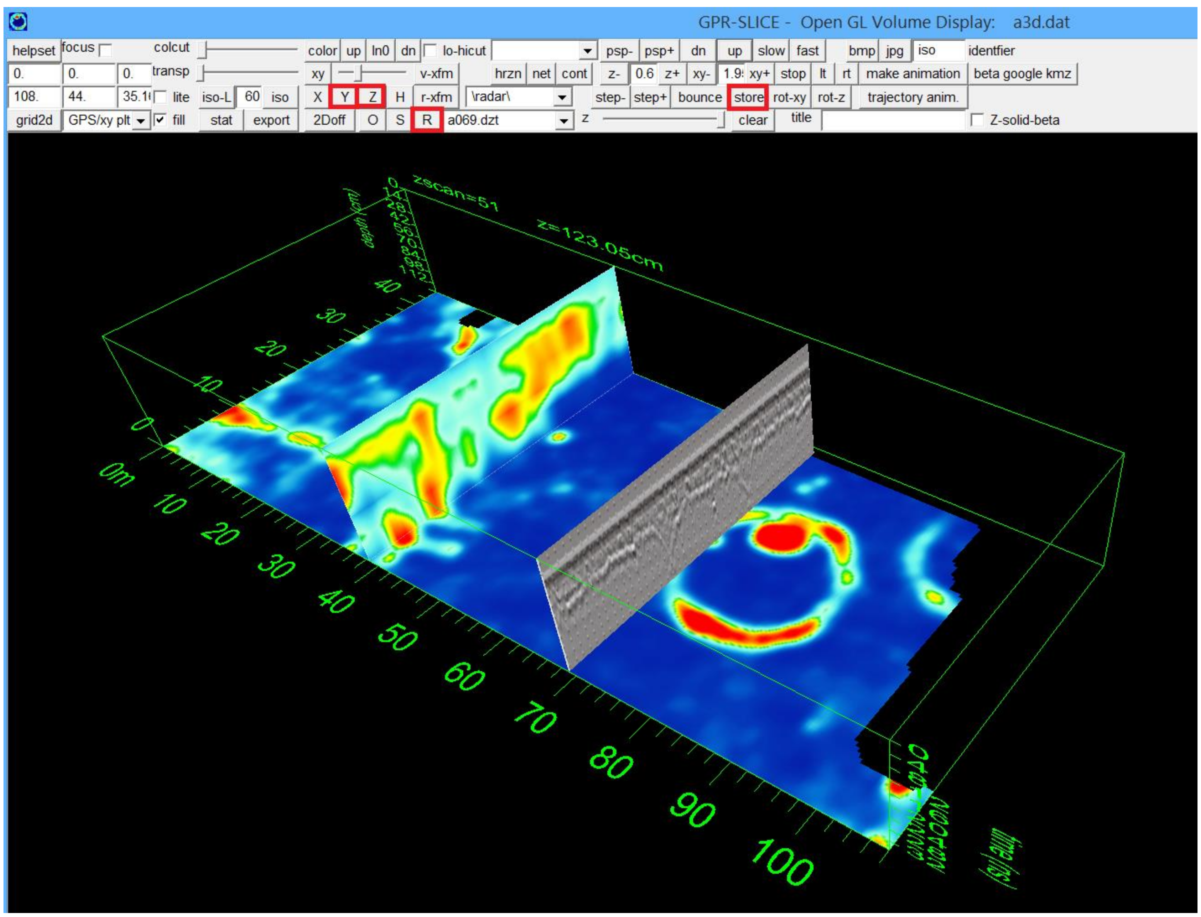
3D volume slices	topography
3D radargrams	isosurfaces renders
horizon surfaces	chair cutaways

Shown in following diagrams are examples of various displays that can be accomplished in Open GL Volume. The user can store any element to the screen using the "Store" button and then toggle through to other desired displays by clicking the appropriate buttons – **R**adar, X Y or Z, or **H**orizon. In the following pages there are some examples of the kinds of visualizations that can be achieved with Open GL:

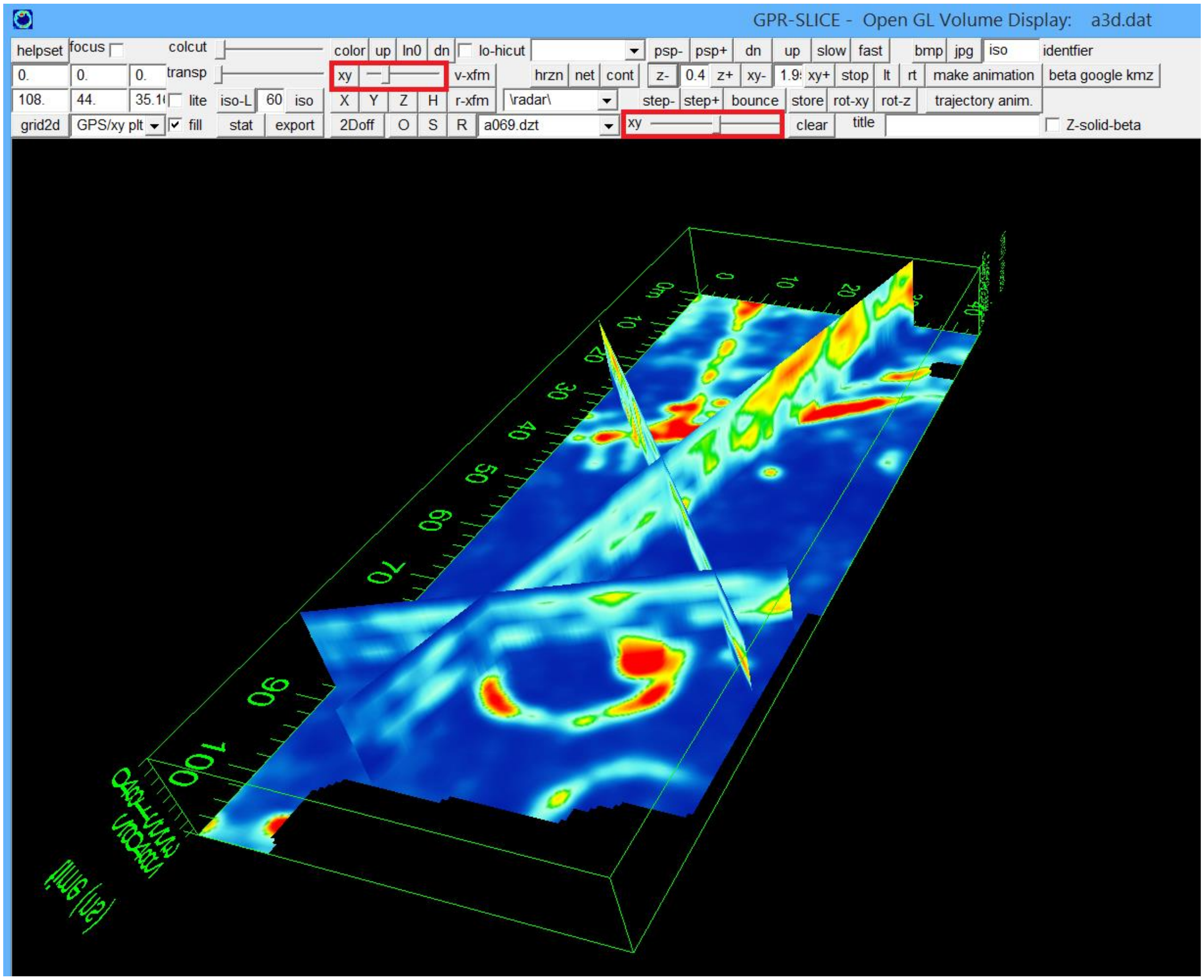


In this example several GPS radargrams along with a single z slice are shown simultaneously. First the radargram folder was set, followed by clicking the R button, then the store button to save the desired radargrams to the screen. After that, the z button was clicked and the slider bar adjusted to scroll to a desired z plane.

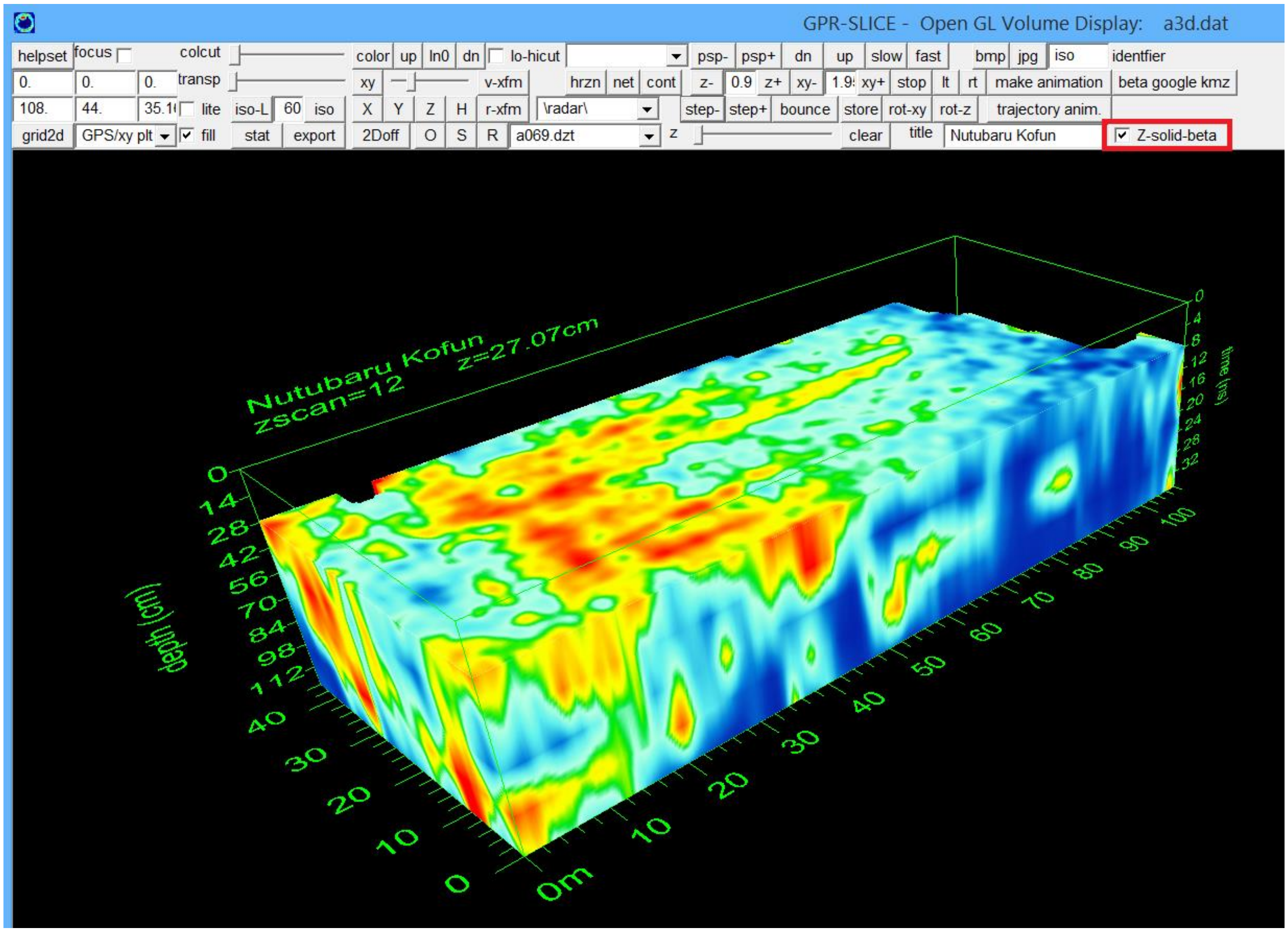
An interesting view for the OpenGL Volume display is to see the radargram side-by-side with a fence diagram in the exact location (as seen in the following diagram). One can visualize the GPR-SLICE volume image with the raw radargram to see how reflections are imaged/transformed by the slice operations. One will be able to discover that some anomalies, in which no coherent reflections are seen in the radargrams, are clearly illuminated in the 3D amplitude volume, when the volume is generated from normalized and interpolated time slices.



OpenGL Volume also has angled cuts through the volume. Clicking on the XY button the user can control the angle of the cut with the XY slider bar, and also advance the cut through the volume with the 2nd XY client slider bar as shown in the next screen shot:



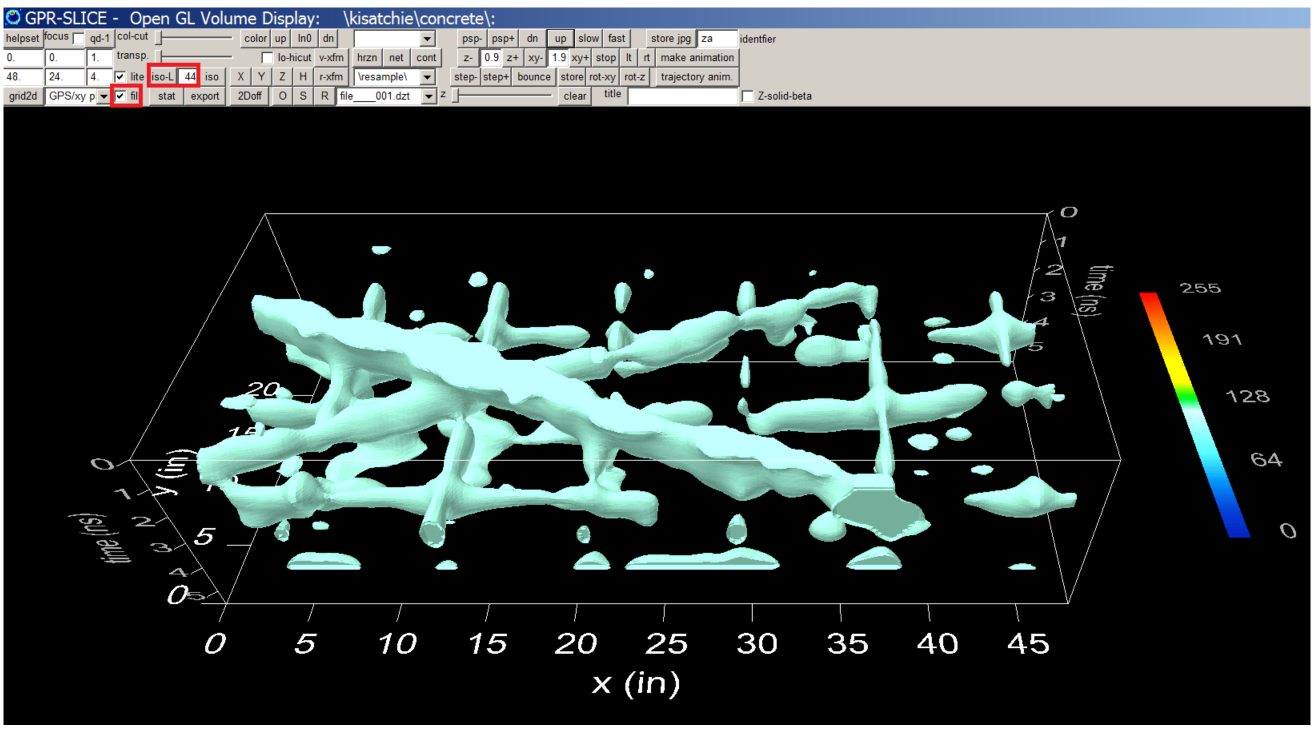
A solid 3D cube volume can also be obtained in OpenGL Volume by clicking on the Z solid (beta). This is given the designation of beta since real 3D voxels are not be shown – the software detects the outside edges of the level slices and renders the sides only. This saves on memory. An example of a solid look of the display volume is shown in the next screen shot:



Isosurface Rendering

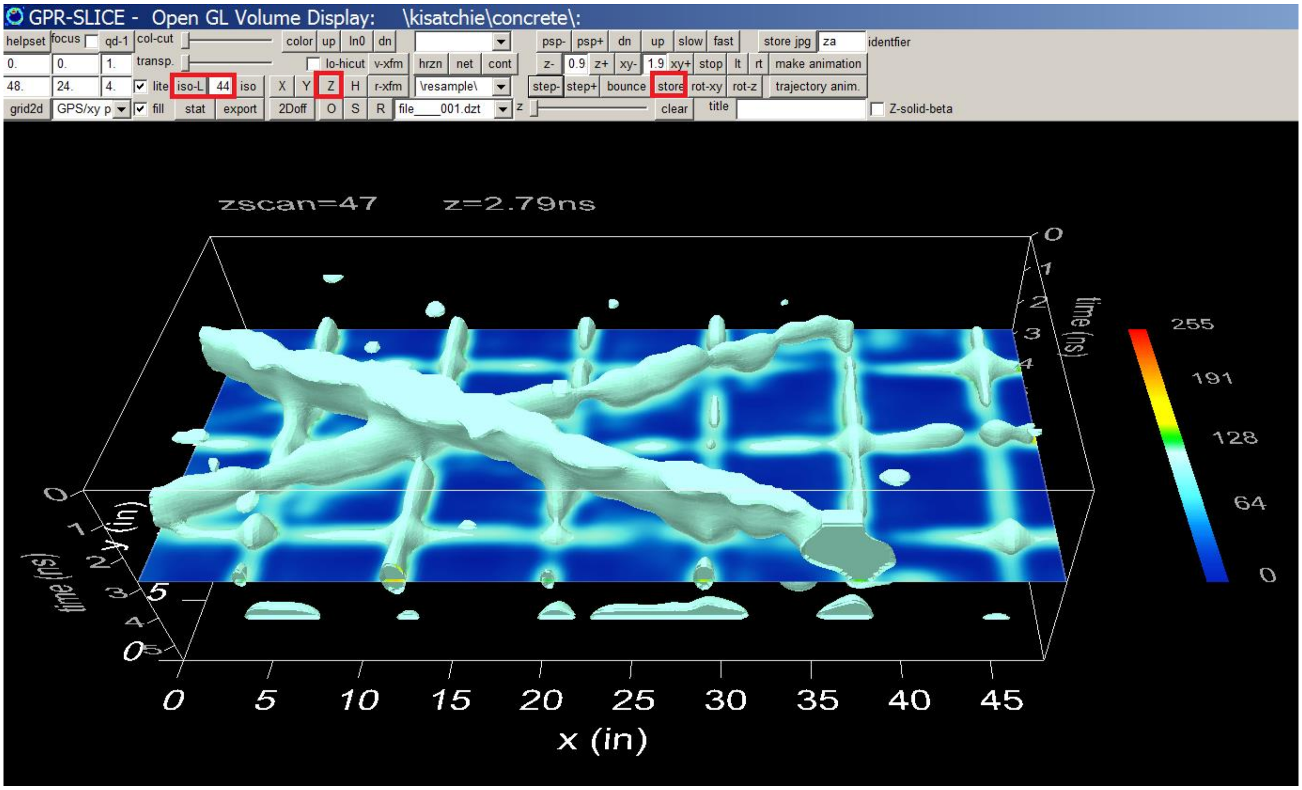
Isosurface renders are displays of surfaces of equal amplitude in the 3D volume. Shading is used to illuminate the surfaces to give an appearance of a real 3D image in the ground. The Marching cube algorithms with lookup tables were implemented in GPR-SLICE since June, 2010. Marching cube algorithm provides unique drawing orders for illuminating the triangular vertex planes that intersect a voxel. The result of implementing marching cubes is significant increased speed for display of isosurfaces.

GPR-SLICE v7 rendering calculates possible surfaces within the 3D volume and will display any surface the user sets between 0 and 100% of the maximum amplitudes in the volume. The 100% surface represents the strongest surface in the volume and 0% isosurface represents the weakest reflector. If for instance 0 were inserted in the isosurface setting in the Open GL Volume menu, then the entire 3D volume would be illuminated and nothing would be seen within the volume. Likewise, setting the surface to 100 would only show a single spec in the volume which would correspond to the maximum reflecting surface recorded. Using transitional values such as 50 would illuminate a surface which is 50% of the maximum value in the volume. Most projects will default to an initial value of 75% for the isosurface. A static isosurface option called ISO in the Open GL Volume menu has a predefined "shaded" color table which is set in the Color menu in the Options menu. The colors or shading do not change with rotation of the 3D volume with the ISO display. Here is an example of the isosurface threshold set to 42% for a concrete structure:



Open GL lighting of isosurfaces

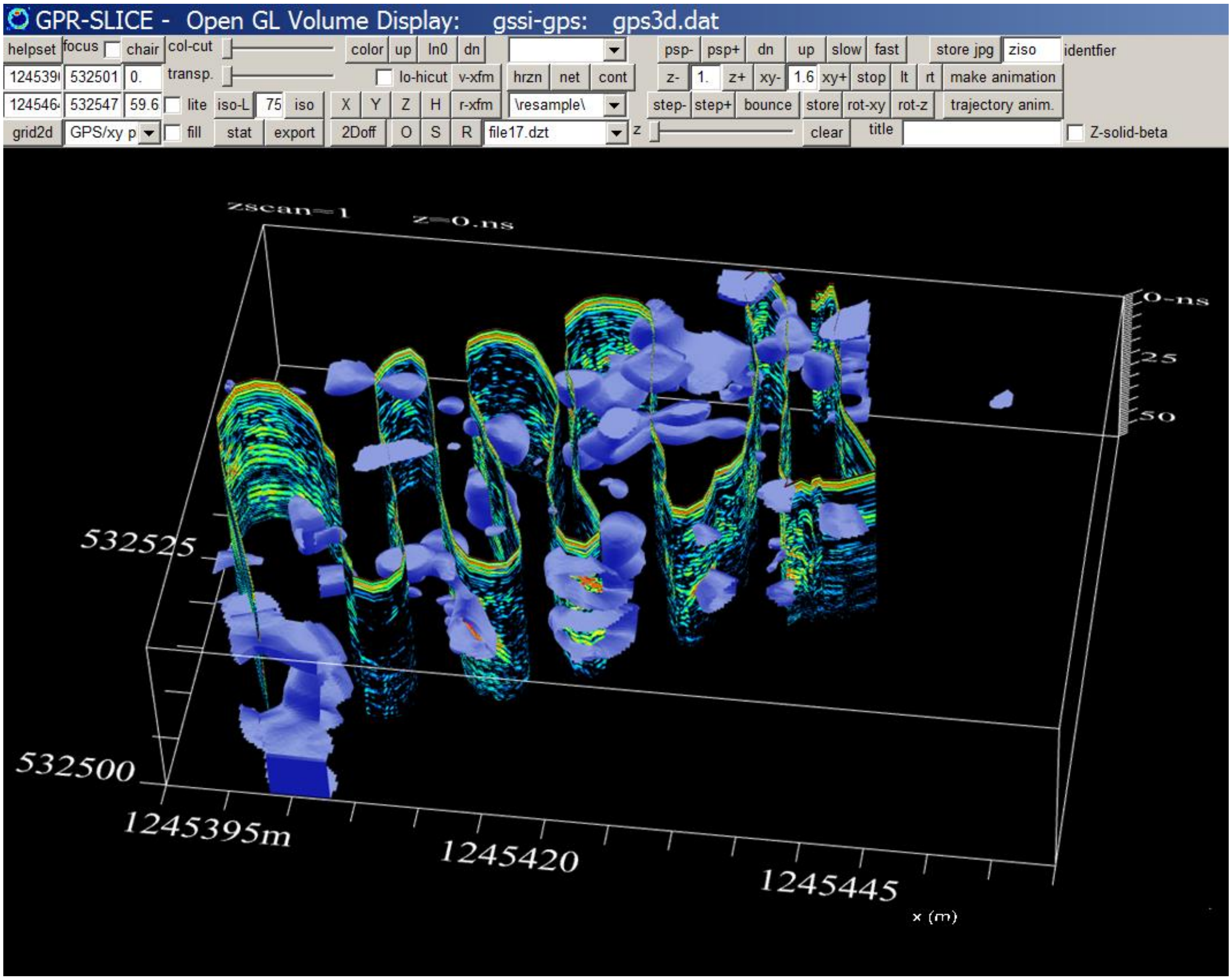
True real-time lighting of isosurfaces is now available using the ISO-L button in Open GL Volume. If this button is clicked Open GL lighting will engage. Rotating the volume one can see the shading on surfaces real-time. Open GL volume currently uses a two light source hardwired in the display which gives a nice real-time shading to the isosurfaces.



The advantage of ISO-L is that it will follow the color table of the corresponding isosurface threshold, in the 3D volume. The color will have lighting applied to give it a real time depth appearance with shading. This will better help to show anomalies that are colorized within the volume feature. Several examples are shown in the next diagrams.

In the diagram on the previous page, an example of post tension cables and rebar are illuminated with an isosurface (shown at colors corresponding to green threshold reflection amplitudes in the 3D volume). This dataset is from the Kistachie Advanced Users notebook available to all users on the ftp site (www.gpr-survey.com/practice)

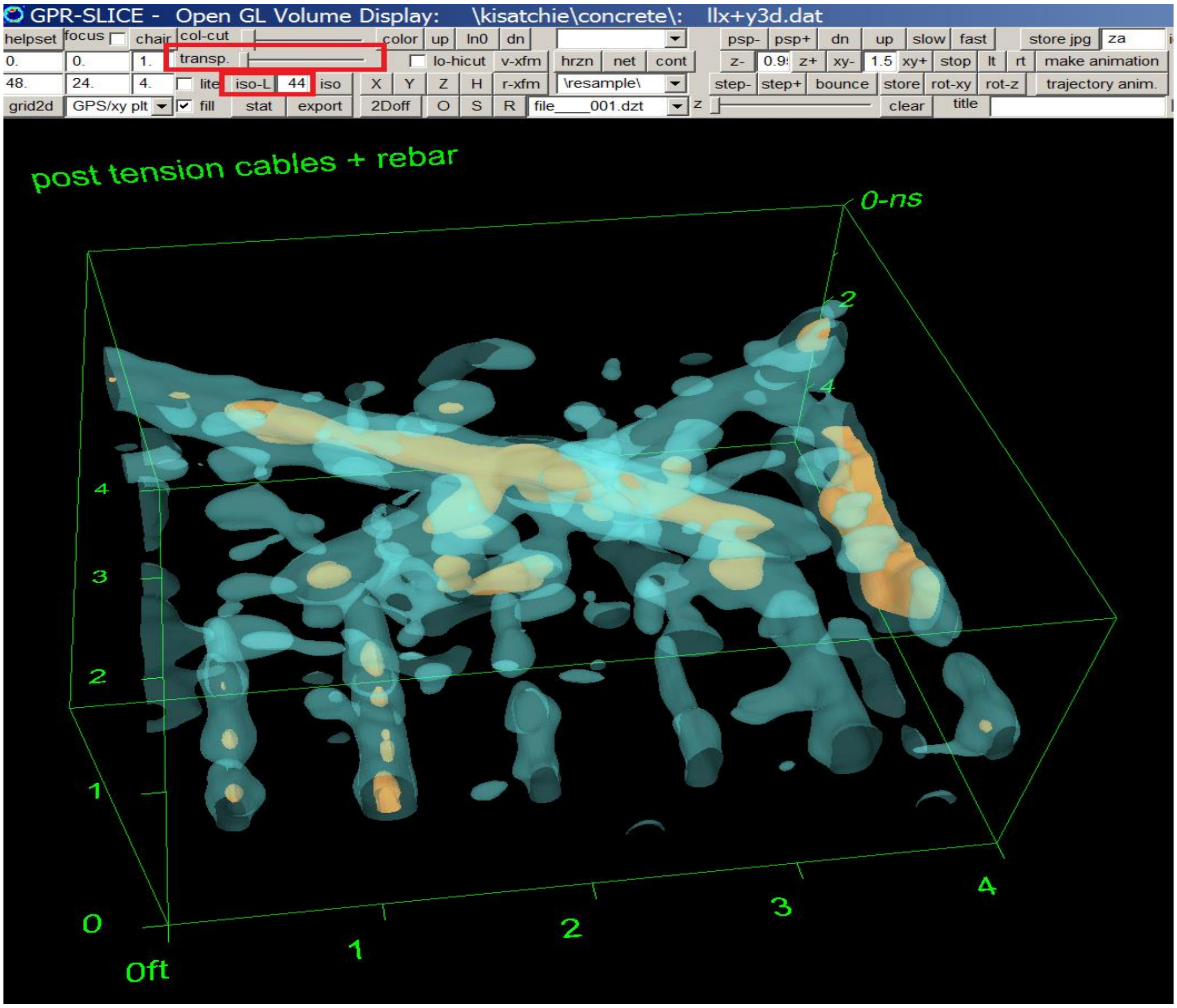
Note: Turning on lighting will automatically click on the lighting checkbox in the menu. Lighting will also have some effect on displayed 3D fences depending as the volume is rotated and tilted, as well as radargrams drawn to the volume. Un-checking the lighting switch and then redrawing any of the XYZ fences or radargram will show these elements without the lighting on. Isosurfaces can also be mixed with GPS radargrams:



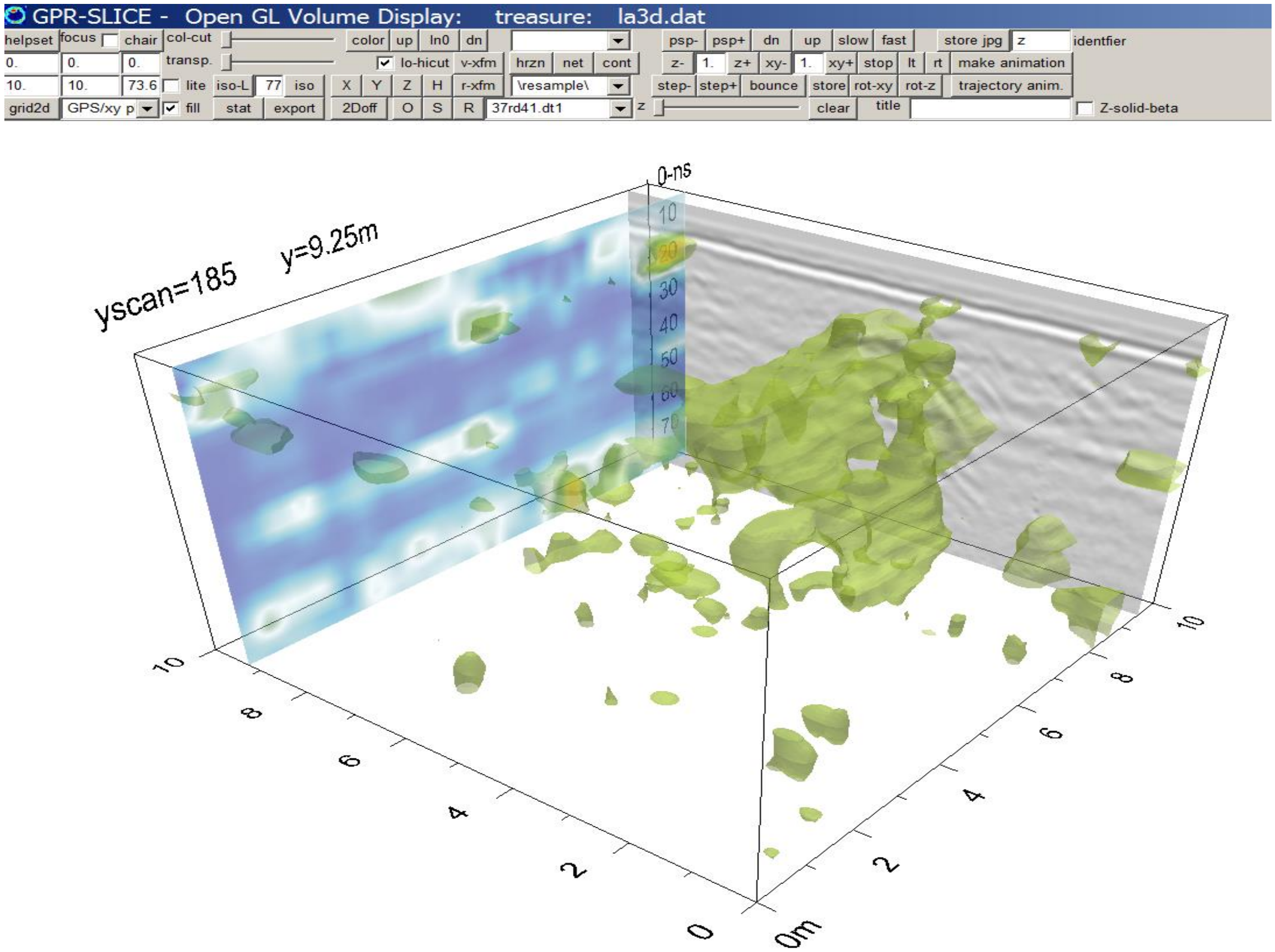
Open GL Transparent Displays

Transparent displays in Open GL can be achieved using the Open GL Volume Texture Method – Beta method menu. In this example an opacity slider bar is used to set the amount of transparency. Completely opaque elements can be placed in the Open GL volume and these should be done first before transparent images are drawn. With the slider bar completely to the right 100% opaque drawing is done. The example shown has an isosurface within an isosurface by first storing an iso-l isosurface at (85%) then using the opacity slide bar and drawing a weaker isosurface (at 42%) on top of the previously displayed isosurface. Any element can be placed into the volume including XYZ fences or radargrams as well.

Note: As a requirement of Open GL, opaque elements should be placed into the volume before transparent elements are stored!!

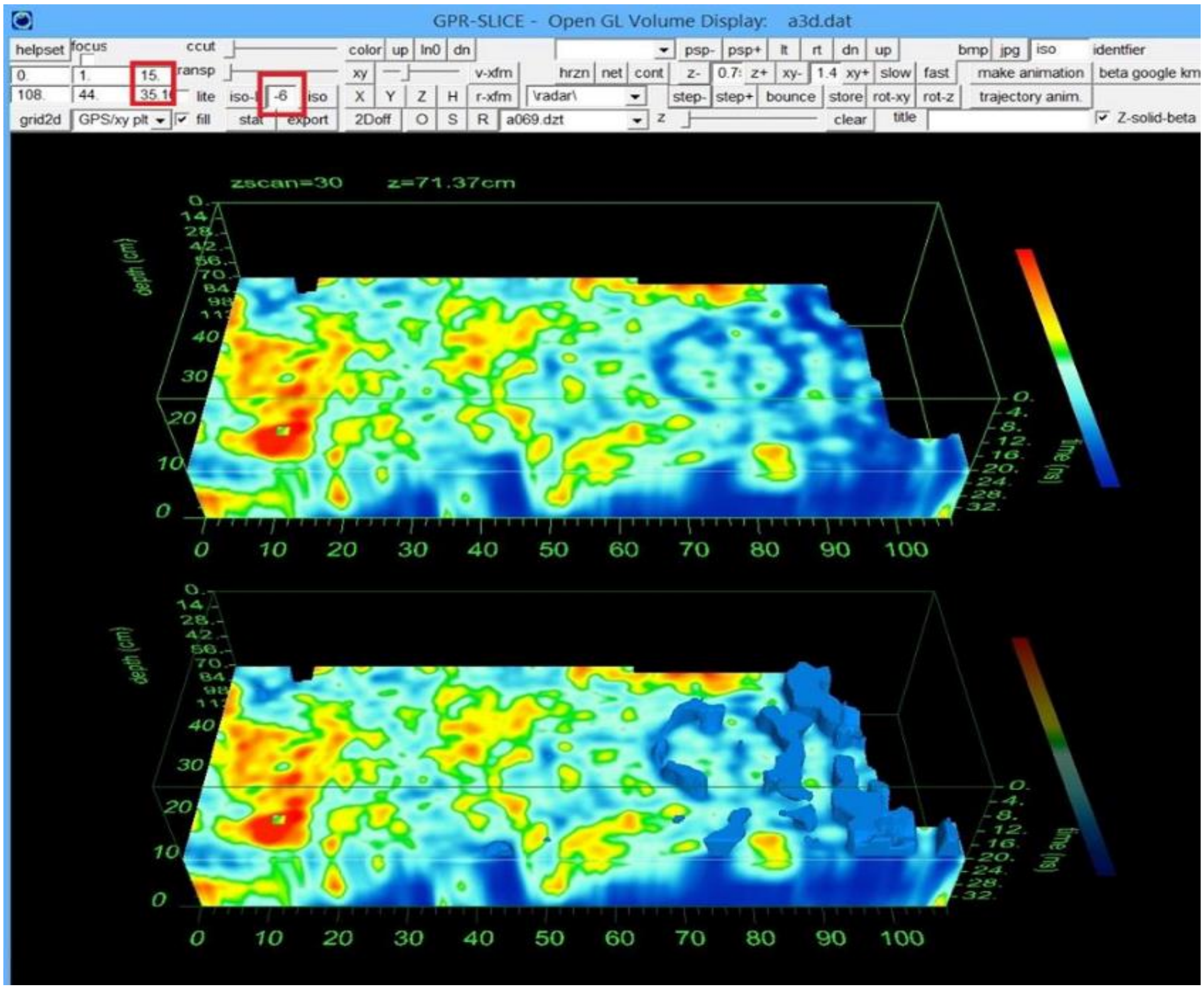


Another possible combination display with transparency is shown in the next figure:



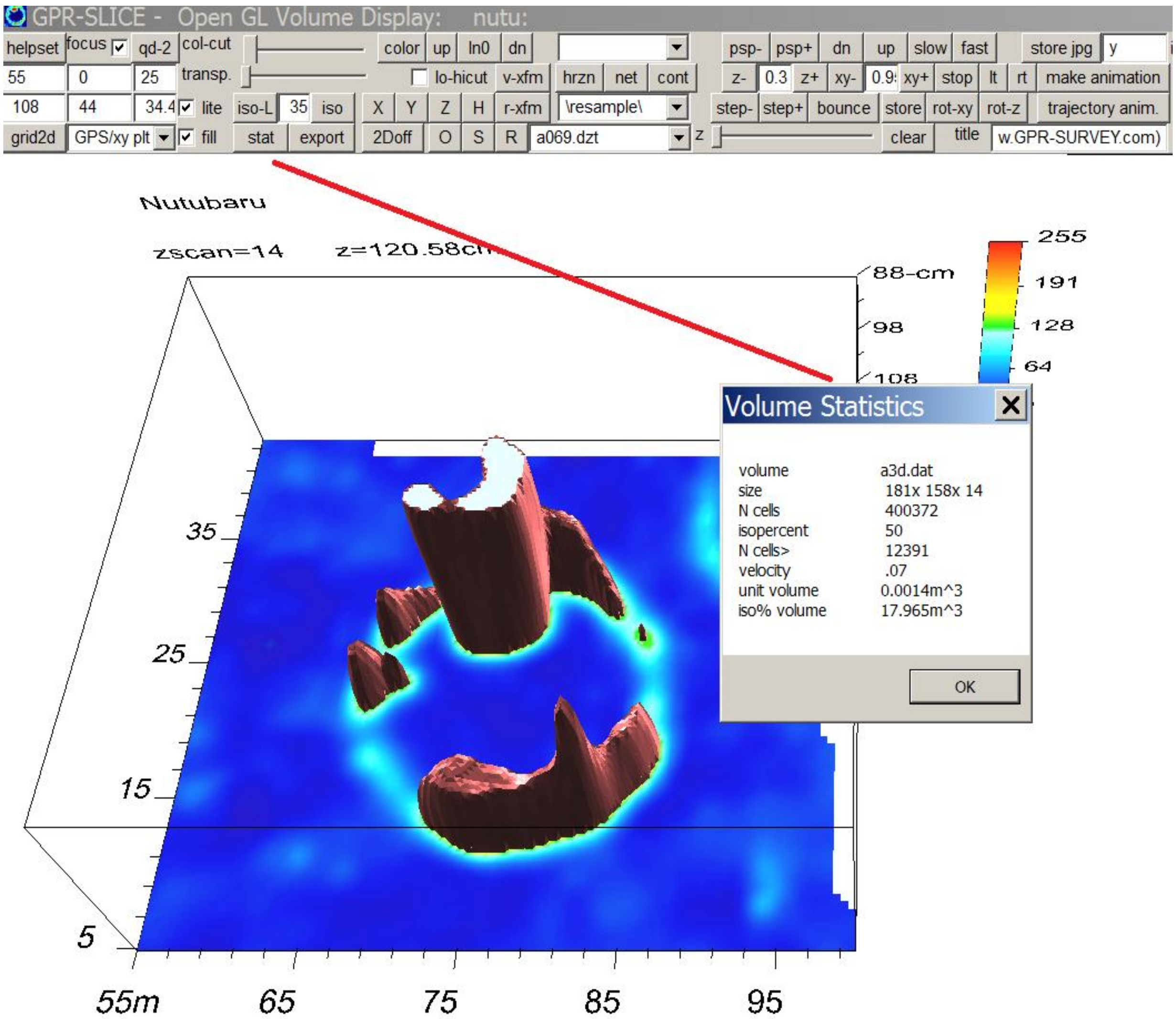
Negative/Opposite Isosurfaces

Isosurface displays in GPR-SLICE have typically been used to render the 3D surface of the strongest amplitude thresholds in a volume. Sometimes, the low amplitude surface has more pertinent subsurface information that is needed than just the strong amplitude portion. For this reason, the isosurface displays have been extended to render the weak reflection portion of the volume. To implement this option, a negative value for the isosurface percent threshold in the OpenGL Volume menu can be set (Figure 6). An example for the Nutubaru burial mound is shown. A weak circular reflection is seen which represents a subsurface moat. The moat reflections are weak at this level since the radar waves have not yet encountered the bottom of the moat and are just transmitting through the homogenous soil fill within the moat. Using a negative isosurface, the weak - blue portion of the volume and the moat can be illuminated. In this example, the top portion and surface reflection in the volume are removed by setting the top time z level at 15ns to remove all reflections to this level (see upper left hand menu slot items in the OpenGL Volume screen shot).



Isosurface Statistics and Export

Open GL Volume has an option to provide statistics on displayed isosurfaces. A new button called ***stat*** (for statistics) located below the isosurface options, will generate a dialog giving the number of grid cells, and the volume of these grid cells associated with the isosurface. The calculated volume is a function of the nominal velocity of the site (set in the Options menu). An example of isosurface statistics is shown in the next menu screenshot. The focus option can also be engaged to only show a desired portion of the isosurface volume to the screen.



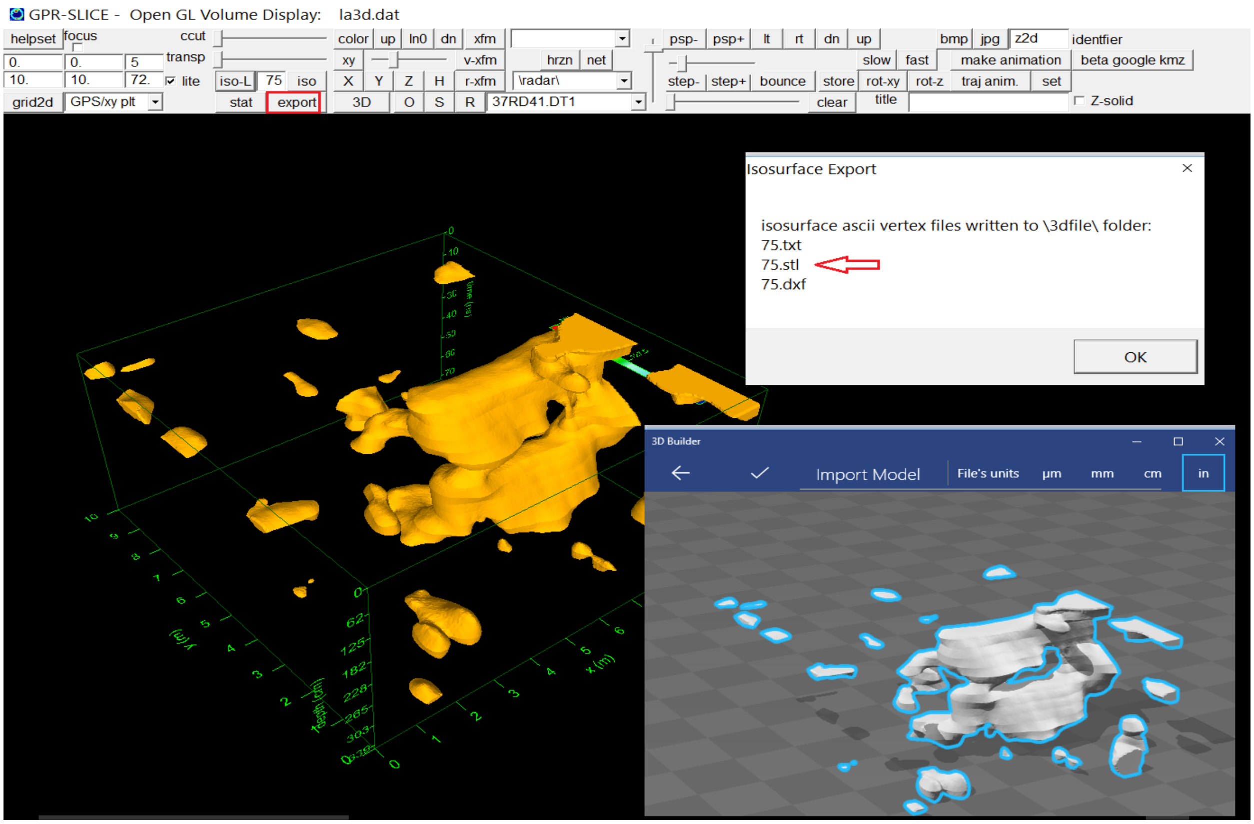
Several export formats for the drawn isosurface can be exported in the OpenGL window including:

*.txt – csv 9 column format with the xyz vertices of the isosurface triangles

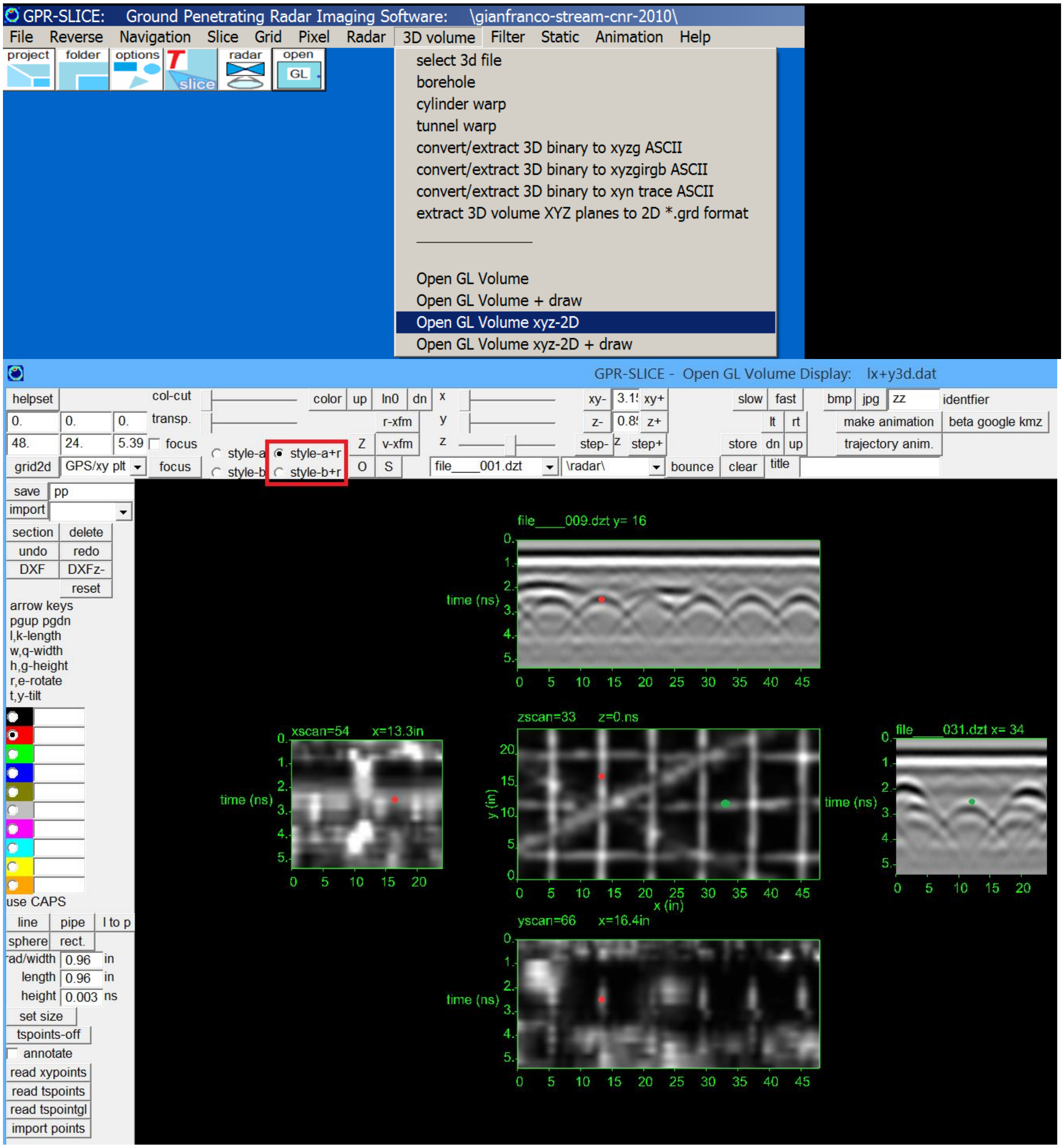
*.dxf – an autocad readable format for triangles that form the isosurface

*.stl Standard Stereo Lithography CAD software export format

An example of a *.stl format isosurface and read in a freeware in Windows is shown in the following figure:



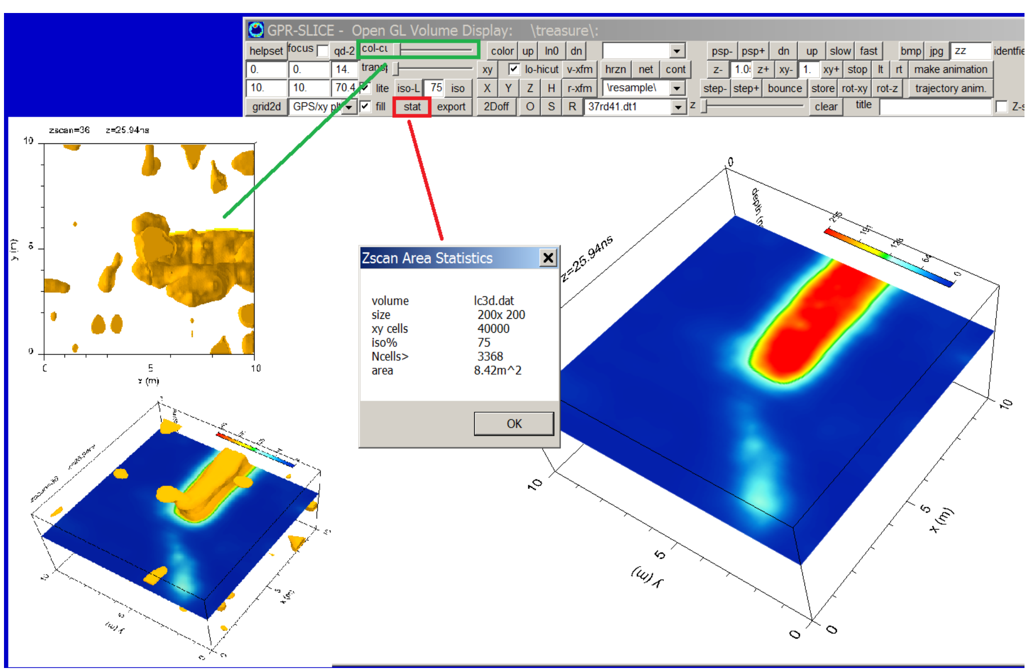
Open GL Volume XYZ-2D Menu



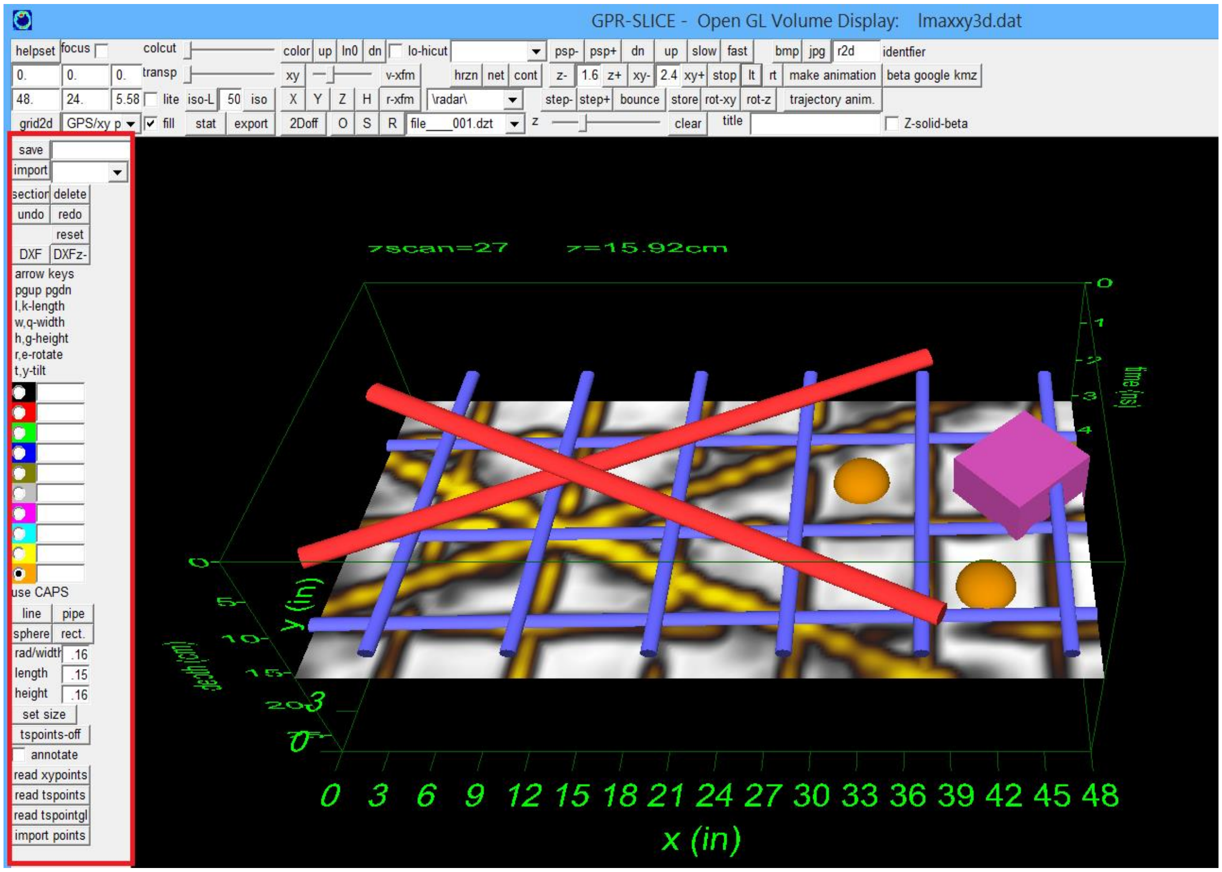
The Open GL Volume XYZ-2D menu allows for simultaneous displays of the X, Y and Z planes in the volume as well as the radargrams from any folder. Clicking the mouse on the Zscan plot will simultaneous show that cut in the volume along the X and Y planes real time. A mouse pointer will be displayed simultaneously in the X and Y that is lock onto the clicked anomaly location on the Zscan. If the bouncing of the Zscan is engaged, the pointer will cycle up on the corresponding location on each of the planes. The pointer size/colour can be set in the Open GL Volume XYZ-2D+Draw menu. There are also style settings that will make the y cut rotated as well as a style setting to rotate the z plane 90 degrees. The Style a+r setting will include the display of the nearest radargram that is detected from clicking the Zscan anomaly for an XY survey. (GPS radargrams displays are not available in this menu).

Time Slice Area Statistics

The ***stat*** button in OpenGL Volume can also provide 2D area statistics based on the isosurface percent setting. Just clicking the Z plane and showing it to any level in the volume, then clicking the ***stat*** button in the menu will give the total area on the time slice greater or equal to the desired isosurface threshold (Figure 10). If you just show the Z plane, you will not really know the exact location of the area. The best way to see the area is to show the isosurface first – store it - then display the desired z plane – followed by clicking the stat button. One can also first place the isosurface – then place a z plane – followed by adjusting the slider bar to match the isosurface – followed by clicking the stat button. The focus option can also be engaged to only provide the area statistic from a selected part of the volume. It is common for geotechnical firms to provide estimates of the areal size of anomalies such as for delamination on bridge decks, void sizes, measurements of fill areas etc. The ***stat*** option will make reporting this information easier.



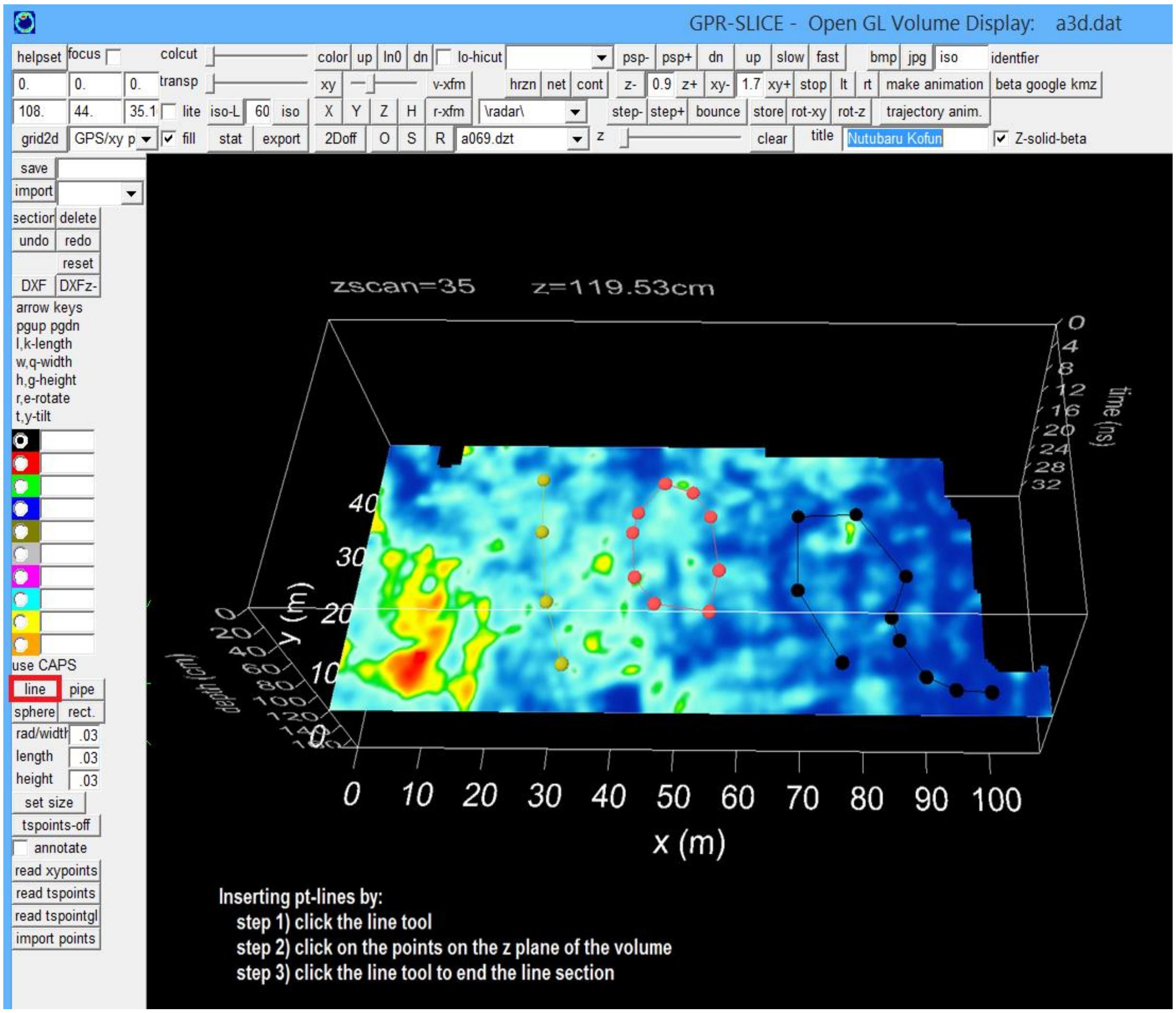
Open GL Volume Drawing Tools



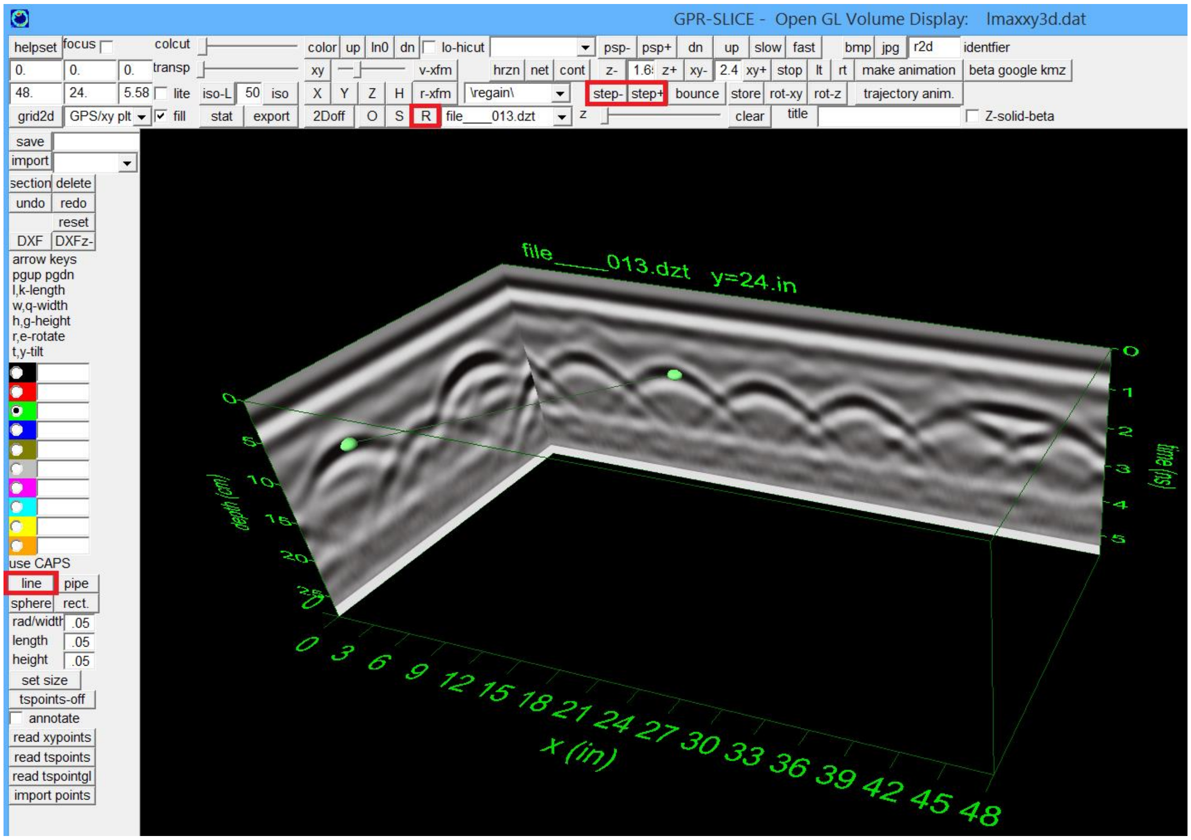
GPR-SLICE is equipped with Open GL drawing tools to assist in the interpretation of 3D volumes. These options are found by using the Open GL Volume Draw menu on the 3D Volume pulldown menu. The drawn objects inside the 3D volume can also be exported to DXF file format for input into AutoCad software

Currently 4 objects can be inserted into a 3D volume: cylinders/pipes, spheres, rectangles and lines/lines+pts. The user has keyboard controls to adjust length, width and height of these objects as well as to rotate/tilt. All the control keys also have reverse keys to undo rotation/tilting width/height/length etc. Repositioning is handled with the arrows keys along with the page up/dn keys or also the mouse. There is a section button which allows the user to go to any inserted object and delete it from the mix. All the drawn objects are stored in a file called **openglobjectdraw.dat**, which is an ASCII text file with various columns of information. The user can take their own data and modify these files to insert information from external sources as well.

Pt-line sections can be added to the drawn tools by clicking the line tool, then clicking the desired location on the Z plane. The section will be closed off when the line button is clicked a second time. Clicking the line button again will start another line section. Different colors as well as options to number of the points using the annotate checkbox are available. An example is shown in the following screen shot:



The drawing tools were also enhanced to sync to any X,Y, or Z plane as well as any xy radargram . The drawn object will get locked to that chosen plane or radargram. During drawing the plane or radargram can be changed and the newly stored object will lock to the newly drawn plane. A simple example of just drawing 2 points connected between to cross radargrams is shown in following screenshot:

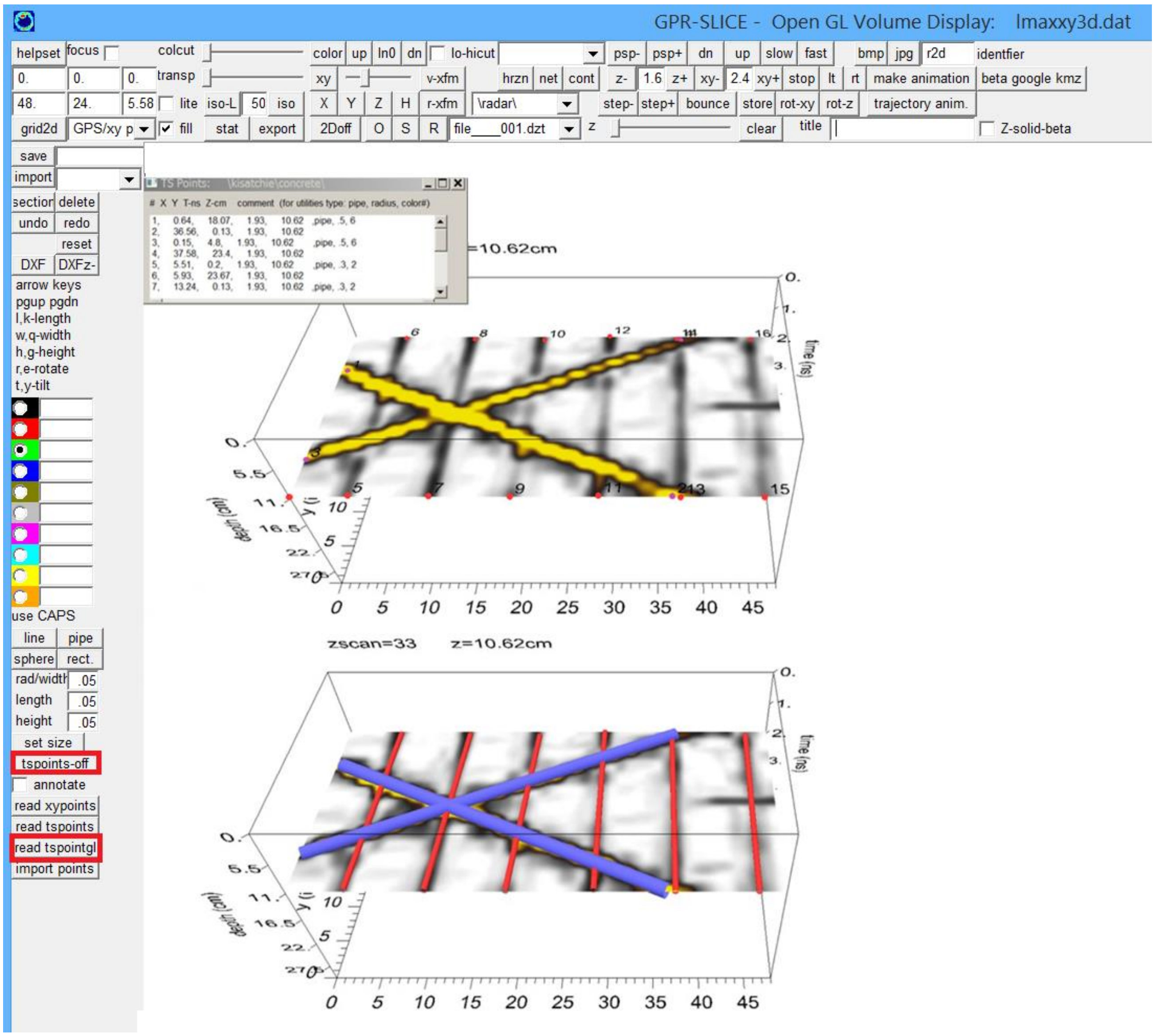


Open GL Volume - Anomaly Picking + Conversion to Pipe Features

Open GL Volume + Draw menu has options to store handpicked anomalies. by launching the TSPoints button in the menu. The points clicked on will be stored in an online dialog and also written to two user files:

- TSpoints-GL.dat file - containing all the information in the online dialog
- Tpoints-xy.csv - containing only the xy points of the chosen anomalies.

An annotation checkbox is available to turn on numbering of the chosen points. Different X, Y, or Z planes or XY radargrams (not GPS radargrams currently) can be drawn to the screen and the TSPoints will follow the desired plane and output points in these planes when clicked on. The size of the drawn pt. can be controlled with the Set Size button and the desired width, height, length of the pointer. On reentering the TSPoints option the original data will be uploaded to the online dialog. A space will be placed between new points that are added to the anomaly file.



TS points chosen can be easily exported into pipe features directly in the OpenGL Draw menu. This operation can allow easily identifying pipes via point mapping in 3D and then quickly get them into a 3D look. Drawing pipes with tilting and rotation etc., can be done but is less efficient then using point drawing initially. TSPoints operations in OpenGL Volume

Draw allow collecting chosen anomaly points on either X, Y, Z slices of the volume as well as on any non-GPS radargrams. These connected points can then be converted to pipe features. The procedures are:

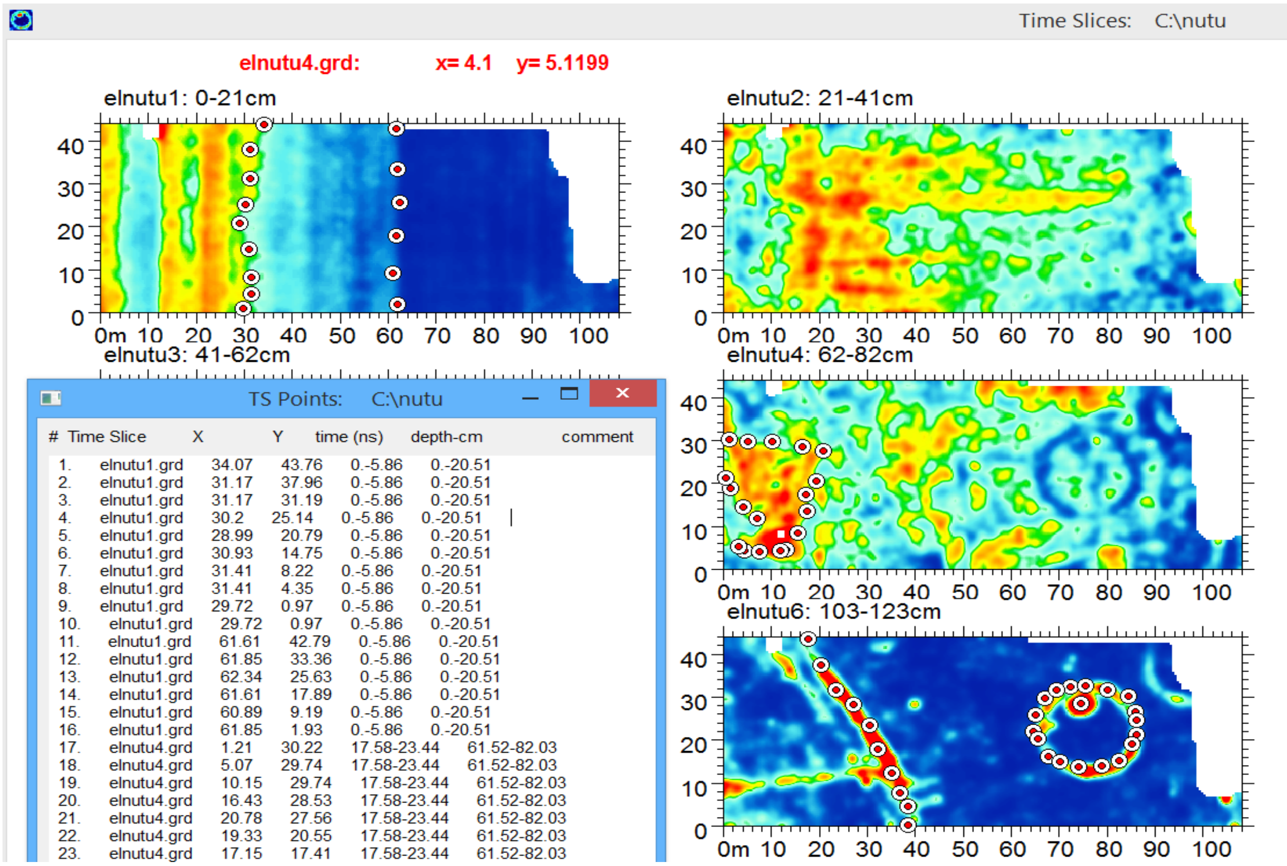
1) Click TSPoints on any X, Y or Z slice of the volume and at any level. Points can be chosen anywhere in the volume as well as along X, Y radargrams. (Figure 5)

2) After defining the lines, the comment section of the TSPoints dialog can be modified with the word pipe, radius, and the color #.

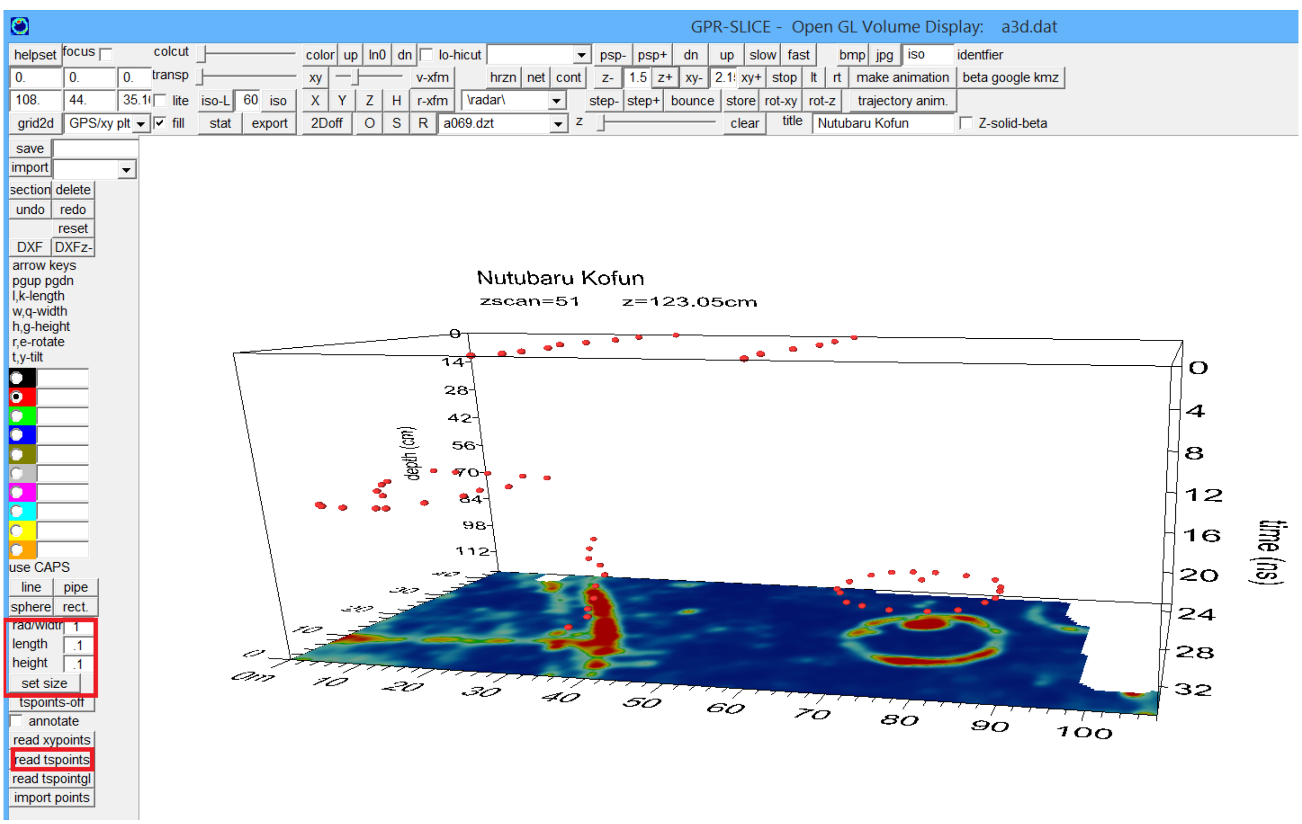
3) The TSPoints button is clicked to convert the drawn points into a continuous pipe features.

Points or utility features chosen on the time slices can also be imported into OpenGL Volume. The steps here are to choose anomalies on the times slices. If the anomalies chosen are just points to import, then the comment section of the TSPoints dialog is left blank (as shown in the following example. For pipes, identify these in the TSPoints dialog in the comment section). Once the anomaly points are chosen, then in Open GL Volume, one then clicks the import TSPoints button to get those features to appear. The size of the points and the desire color can be changed after import or after clicking the Read TSPoints button in the OpenGL Volume draw menu.

Similar operations are available in XYPoints using the radargram and then clicking the Read XYPoints button to import these to OpenGL Volume. In addition, another button in OpenGL Volume called Import Points will simply read and x,y,z comma delimited file to show these points in the volume. The color and size of the imported points can also be adjusted by clicking the Import Points button and after editing to the desired settings.



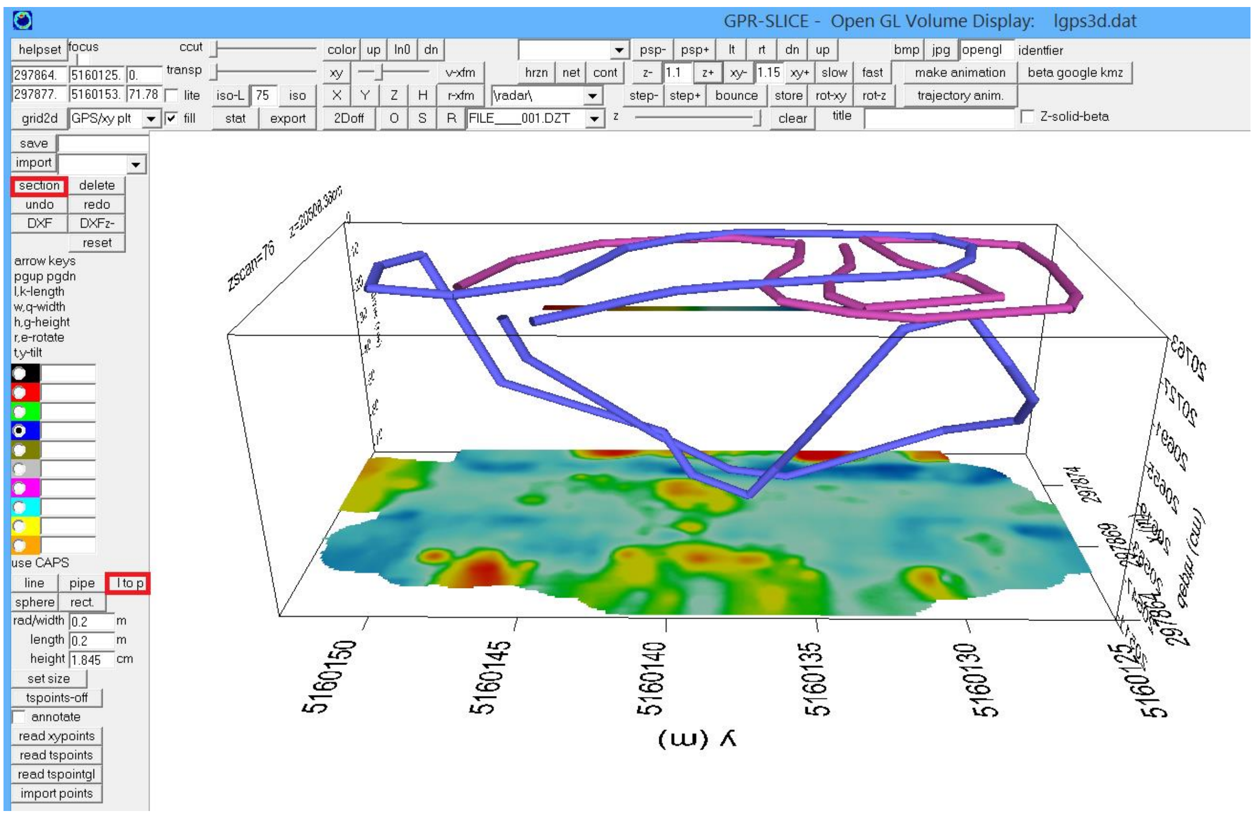
Time Slices: C:\nutu
elnutu4.grd: x= 4.1 y= 5.1199
elnutu1: 0-21cm
elnutu2: 21-41cm
elnutu3: 41-62cm
elnutu4: 62-82cm
elnutu6: 103-123cm
0m 10 20 30 40 50 60 70 80 90 100
TS Points: C:\nutu
Time Slice X Y time (ns) depth-cm comment
1. elnutu1.grd 34.07 43.76 0.-5.86 0.-20.51
2. elnutu1.grd 31.17 37.96 0.-5.86 0.-20.51
3. elnutu1.grd 31.17 31.19 0.-5.86 0.-20.51
4. elnutu1.grd 30.2 25.14 0.-5.86 0.-20.51
5. elnutu1.grd 28.99 20.79 0.-5.86 0.-20.51
6. elnutu1.grd 30.93 14.75 0.-5.86 0.-20.51
7. elnutu1.grd 31.41 8.22 0.-5.86 0.-20.51
8. elnutu1.grd 31.41 4.35 0.-5.86 0.-20.51
9. elnutu1.grd 29.72 0.97 0.-5.86 0.-20.51
10. elnutu1.grd 29.72 0.97 0.-5.86 0.-20.51
11. elnutu1.grd 61.61 42.79 0.-5.86 0.-20.51
12. elnutu1.grd 61.85 33.36 0.-5.86 0.-20.51
13. elnutu1.grd 62.34 25.63 0.-5.86 0.-20.51
14. elnutu1.grd 61.61 17.89 0.-5.86 0.-20.51
15. elnutu1.grd 60.89 9.19 0.-5.86 0.-20.51
16. elnutu1.grd 61.85 1.93 0.-5.86 0.-20.51
17. elnutu4.grd 1.21 30.22 17.58-23.44 61.52-82.03
18. elnutu4.grd 5.07 29.74 17.58-23.44 61.52-82.03
19. elnutu4.grd 10.15 29.74 17.58-23.44 61.52-82.03
20. elnutu4.grd 16.43 28.53 17.58-23.44 61.52-82.03
21. elnutu4.grd 20.78 27.56 17.58-23.44 61.52-82.03
22. elnutu4.grd 19.33 20.55 17.58-23.44 61.52-82.03
23. elnutu4.grd 17.15 17.41 17.58-23.44 61.52-82.03



GPR-SLICE - Open GL Volume Display: a3d.dat
Nutubaru Kofun
zscan=51 z=123.05cm
depth (cm)
time (ns)
read xypoints
read tspoints
read tspointgl
import points

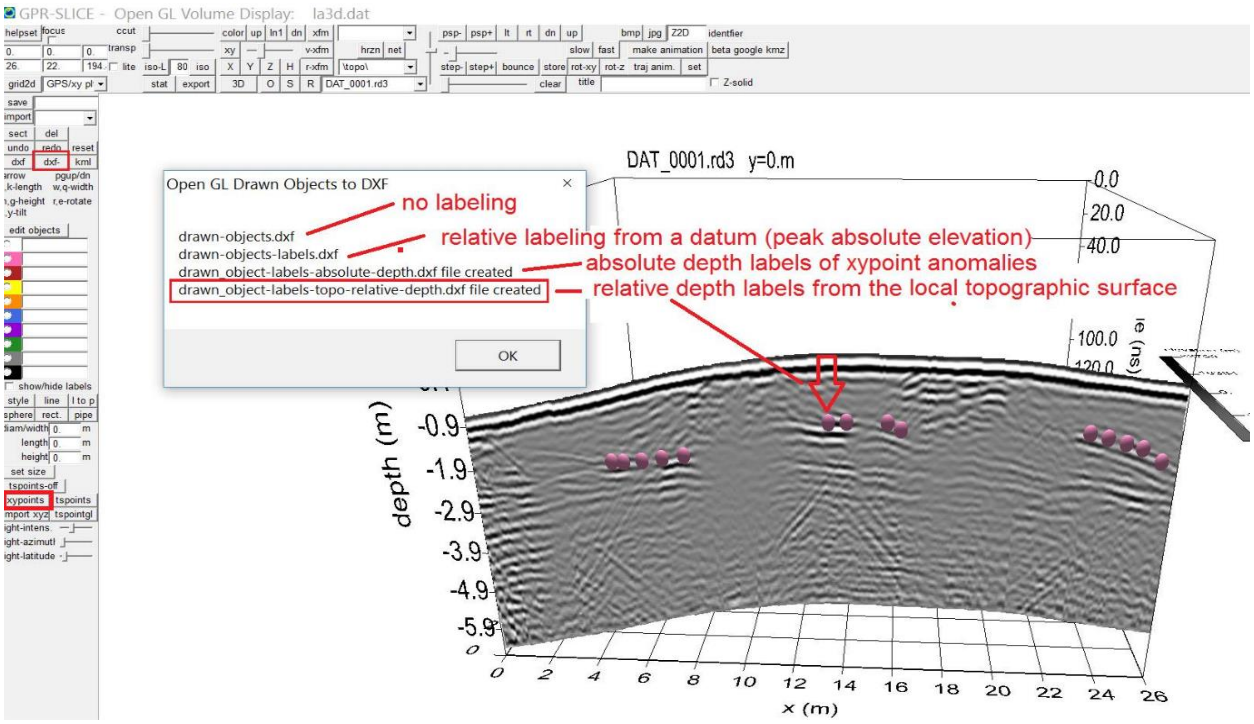
Conversion of Line Objects to Pipes for Quick Drawing

For drawing pipes in 3d can be time consuming to connect all the sections as the rotate and tilt keys need to be used. To help speed up the process, the user can draw the pipes quickly as a continuous line function in 3D, and then press the new L to P (line to pipe) button (seen in the next screen shot). The operation will read the current radius set in the OpenGL Draw menu and apply this to the current drawn pipe section. Before the button is pressed, the Section button will need to be toggled to get to the first desired drawn line section to apply the conversion.



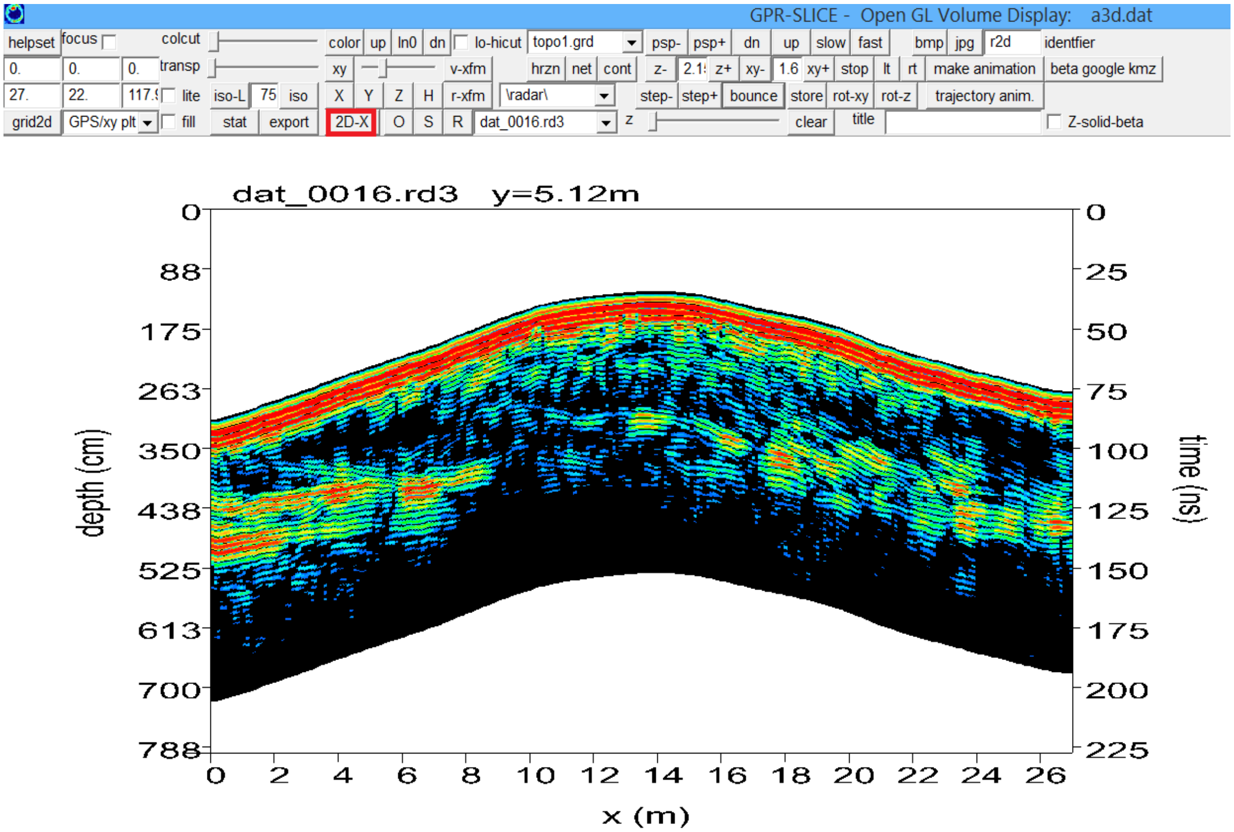
DXF Export of Depth from the Local Topographic Surface

In the OpenGL Volume Draw menu a variety of DXF export files are made to accommodate user requests. The latest export option provides a DXF export file that will report the local depth from the local topography for the drawn object (Figure 9). For this option to work, there must have been a topographic grid created that was used to generate the binary corrected topographic radargrams in the project. Anomaly points are then chosen in the 2D radargram menu on the \topo\ folder (in the following screen shot). With import to OpenGL Volume Draw using the XYpoints button, DXF export will write the absolute depth as well as display the local depth as labels from the ground surface for the anomaly points in AutoCAD.



2D Perspective Switch in Open GL 3D

2D perspective switches are available for X, Y and Z planes to shut the perspective off the 3D volume and allow for 2D flat perspective displays for any volume element, including radargrams, to be shown. This option is useful for making 2D output from the 3D volume display. The 2D perspective button should be clicked to toggle to the desired X, Y, or Z perspectives. An example of using the Open GL Volume (Topo Warp Volume) menu to display a radargram warped from topography in a 2D perspective is shown below:



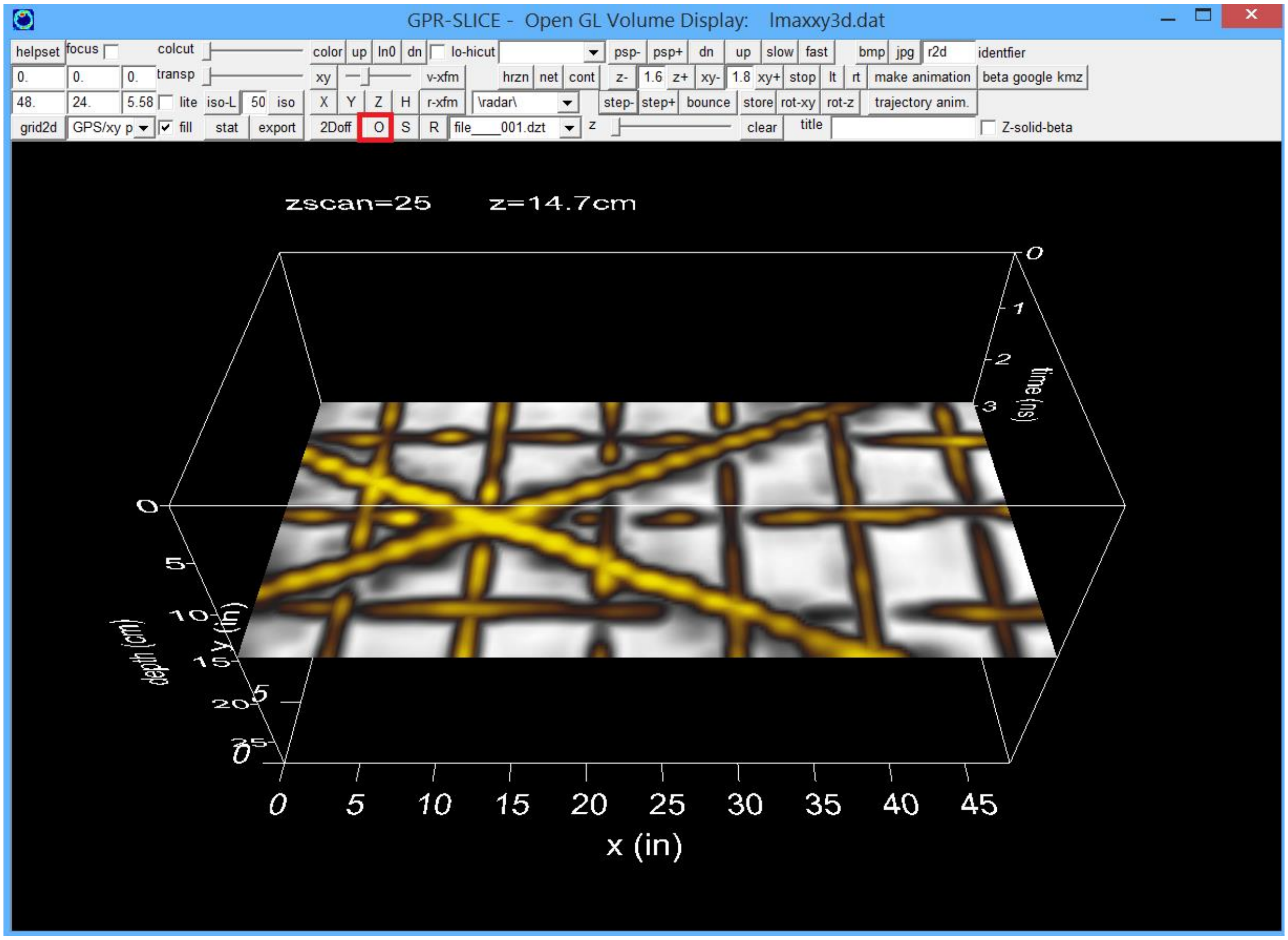
4 positions for the 2D perspectives on the 3D volume:

2D off - no flat project (default)
2D Z - projection looks down on Z axis
2D X - projection looks down on X axis
2D Y - projection looks down on Y axis

The 2D on/off button is toggled till the desired X, Y or Z plane flat perspective for the desired projection on the currently drawn element. The 2D projected volume is rotated in the Open GL Volume display, it will show a non-perspective/orthogonal 3D display which will look a touch strange. Clicking the prsp+/- button one can manually place perspective back into the graphic. Clicking the 2D button till 2D off appears will also automatically place perspective in the graphic as well.

The 2D perspective allows easy generation of topographic radargrams or regular radargrams without having to do binary corrections (see the Static section) for display.

Overlay Analysis in 3D



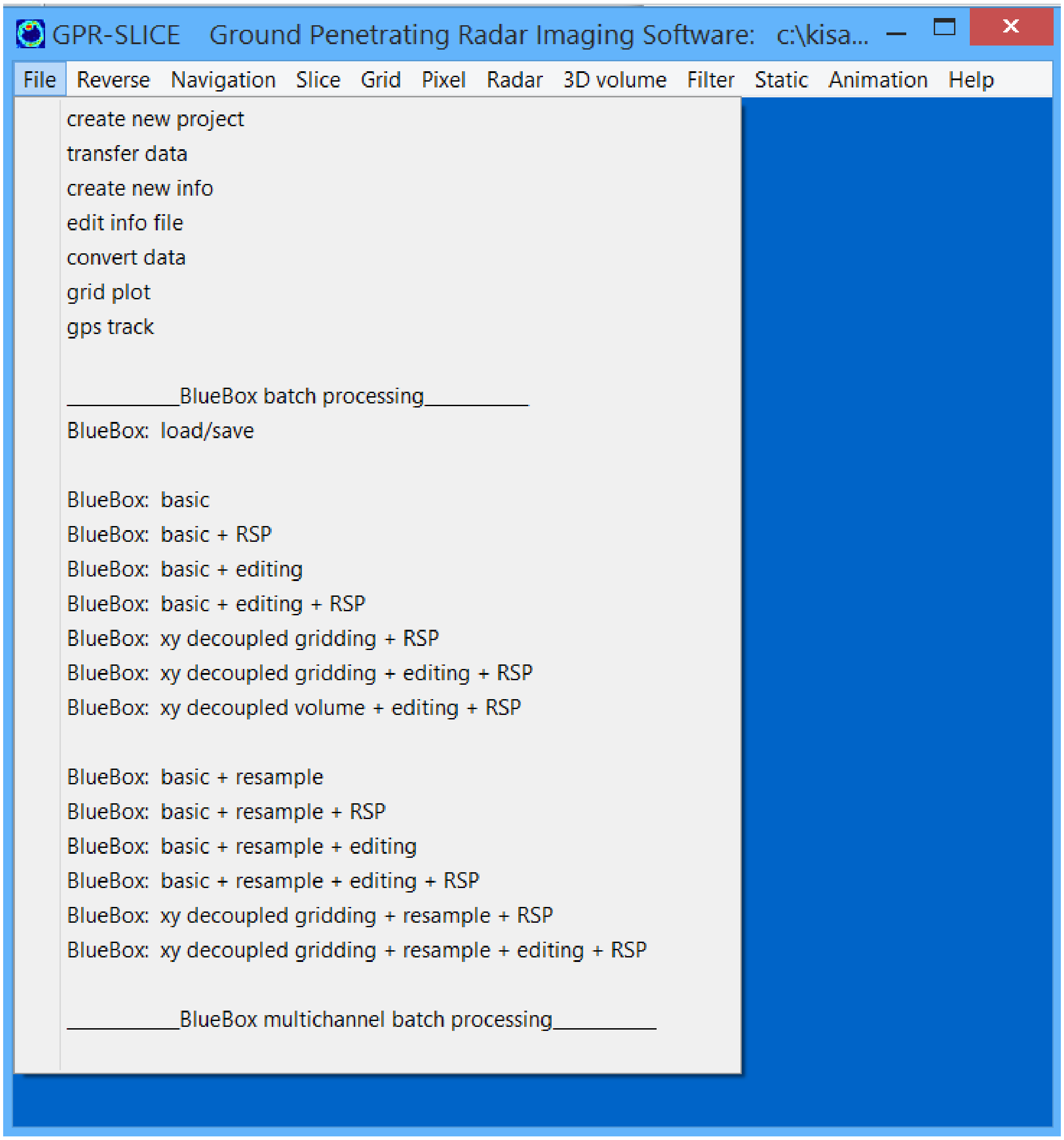
Overlay analysis provided in GPR-SLICE allows the user to overlay the relative-strongest-reflectors onto a single time slice map. This functionality has been available in the 2D Time Slice menu since the inception of the GPR-SLICE for DOS. The 2D time slice menu was the only location one could apply this very useful imaging technique. The overlay analysis is now available in the 3D Open GL Volume menu as well (although you have more flexibility in the 2D time slice menu). The "O" button will add the relative-strongest-reflectors onto consecutive time slice levels. To start the overlay one can click the "Z" button, step or bounce to the desired level, then click the "O" button to start overlaying the reflections from below the current level onto a single – overlay image.

An example of the "O" button to make 3D overlay displays is shown below. In the 3D display the individual transforms for each level cannot be adjusted as they can be for 2D overlay analysis operations in the T-

Slice menu, as a global transform is applied across the entire volume. Nonetheless, visualizing the overlay analysis options in 3D provides another way to present, observe and report adjacent and continuous reflections that are variable reflection depths - onto a single 2D image.

An S button for skipping z levels in overlay analysis in Open GL Volume is available. This operation requires clicking the 0-overlay button, clicking the step+, then clicking the S button, followed by any number of step+ clicks which will skip these levels in the overlay. Subsequent clicking of the O button will continue the overlay process.

BlueBox Batch(c) Processing



GPR-SLICE v7 has complete batch processing for single channel as well as for multi-channel GPR systems. BlueBox Batch processing is a complete data operation stream from conversion of raw data to building a final 3D volume - all via a single click of one button! Launching the BlueBox, the software will automatically run through and show all the different menus and real time processes in the those menu as the batch run is operating. BlueBox Batch processing includes complete customized radargrams signal processing (RSP) as well as 0ns editing operations. The concept of “BlueBox” is introduced since the user - not software - is required to set the necessary information in each of the menus, before running the complete batch process – it is not a completely blind “blackbox” process!

GPR-SLICE menus in v7.0 can record all the settings the user makes even if no operations were run in all the menu. Once all the desired settings are made, the BlueBox Batch run can be launched. For single channel equipment there are 13 BlueBox processing streams available:

- BlueBox: Basic
- BlueBox: Basic+edit
- BlueBox: Basic+RSP
- BlueBox: Basic+edit+RSP
- BlueBox: XY decoupled gridding + RSP
- Bluebox: XY decoupled gridding+edit+RSP
- Bluebox: XY decoupled volume+edit+RSP

The Bluebox designations

- Basic – refers to all basic processes to make time slices
- Edit – includes automatic 0ns corrections to the radargrams before time slice operations
- Resample – adds resampling of radargrams during slicing operations
- RSP – includes a set of user defined geophysical signal processes to be applied to the radargrams before slicing operations commence
- XY decoupled gridding – refers to separating x and y lines and applying elliptical gridding operations before grid math
- XY decoupled volume – refers to pulse volumes where elliptical gap interpolation is applied independently to x and y volumes before volume math is executed

The Bluebox operations are given fuller descriptions in the following pages:

BlueBox Basic

Basic processing includes all the steps required to make 3D volumes of GPR reflection data from raw data. This basic BlueBox process will make time slices and 3D volumes all the way from raw data with one button click. The 10 steps outlined in the BlueBox Basic batch run include:

Step 1: conversion
Step 2: reverse
Step 3: navigation
Step 4: search 0ns
Step 5: slice/resample/xyz
Step 6: grid helpset
Step 7: gridding
Step 8: grid smoothing
Step 9: 3D file
Step 10: Open GL

Prior to running the BlueBox the gain curve can be drawn in any of the Convert menus and the software will now record and remember the settings upon exiting this menu. Convert gain menus are still required for most GPR equipment such as Mala and Sensors and Software since these equipment are recorded with 16 bit ungained radargrams. Other manufacturers' record with gain, but these can also be optimized on conversion. Settings in all the other menus such as the # of slices, should be set and the desired time slice identifier placed in the Slice/Resample menu. You do not need to set the 0ns as this can be automatically found.

All the operations are indicated with checkboxes which the user can set for their customized datasets. In general all the checkboxes will be clicked on before running the BlueBox. For instance, if the radar lines were collected in a zig-zag survey in the field, then the Reverse checkbox would be clicked on. The user will also need to pre-define which lines are reversed before starting the BlueBox run. If the lines were all collected in the forward direction, then the Reverse check box would be unchecked. For GPS datasets, the Reverse checkbox will be disabled to insure these lines are never reversed since they are defined by the GPS track.

Navigation for BlueBox operations currently has only 2 available: Artificial Markers or GPS Trace# options. Field marker options are not yet provided for BlueBox runs because these datasets often need user editing to adjust the number of recorded markers to match the information file. Navigation operations will automatically check the *.GPS files to see if the 5th column of the files contains scan numbers or is just set to 1. "1" indicates that there is no corresponding scan numbers with the listed navigation and simple artificial markers are generated based on the total number of scans and the total number of GPS listings in the information file. Trace # navigation is only read if *.gps files have scan #'s in the 5th column of the navigation files. All other surveys are assumed to be from survey wheel collected datasets.

Slice/Resample/XYZ is run on the \radar\ folder where the navigation was applied. Prior to running Slice/Resample/XYZ the user can have the Search 0ns detection run all automatically as well. Next the Grid Helpset operation followed by Gridding and Grid Smoothing will be executed. Currently, the Grid Smoothing will use the 3x3 lo pass matrix or another filter should that have been highlighted in Grid menu.

After gridding is completed and grid smoothing, the Pixel Map menu is launched and grid interpolation and 3D file compilation are done. The user can have any number of interpolations compiled. In addition, the normalization can be set to whatever is desired. For most archaeological applications, relative normalization is useful. However, for stratigraphic (geologic mapping) or even engineering applications, sometimes the Absolute normalization that follows the gaining in the radargram pulses can be used with some success. Finally, the 3D volume can be automatically opened in Open GL.

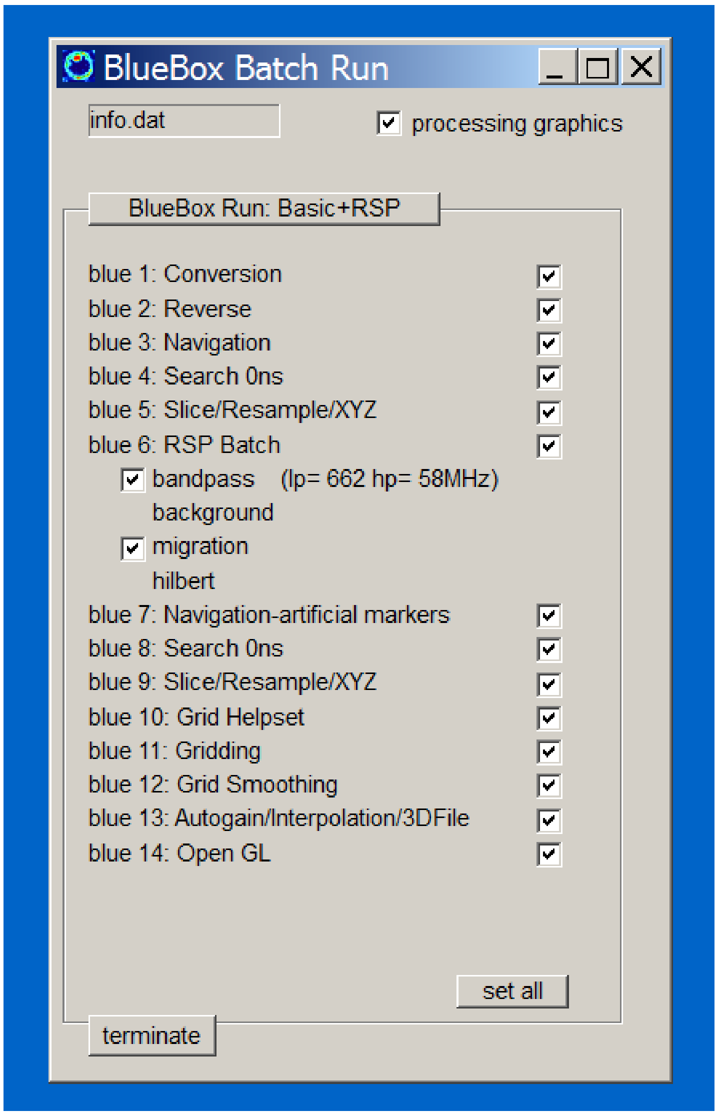
Note: The user can make successive BlueBox basic runs and change any items they want, such as identifiers and other items. However, if they use helpset buttons, then the defaults from these button operation will prevail and reset what the user may have adjusted. For instance, if a users want a specific customized grid setting in the Grid menu, they could manually set these, then click "Grid Helpset checkbox to "off" in the BlueBox run, insuring that there customized settings are used in gridding operations.

Bluebox Basic + RSP

BlueBox Basic + RSP batch runs include all the Basic operations previously shown along with radargram signal processing. The desired radargram signal processes are set in the Filter menu first under the RSP batch heading. In the following example bandpass, background filtering, migration, and Hilbert transforms are the RSP to be applied to the radargrams. There are checkboxes next to the bandpass filtering as well as the migration operations. If the checkbox is highlighted this means that during the batch operations the software will prompt the user to either insert the bandpass cutoff frequencies manually for bandpass filtering. For migration, the checkbox on will prompt the user in the

Hyperbola Search menu to set the velocity curve or value to be used in migration. For Regain operations, checkboxes for prompting for the gain curve can also be engaged.

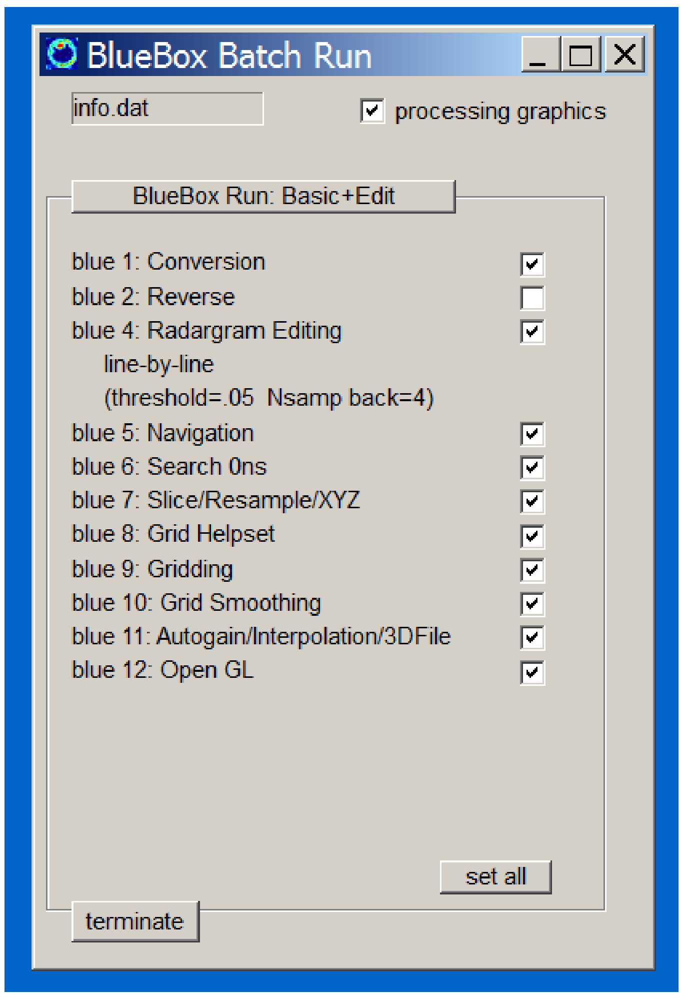
The Basic + RSP BlueBox Batch run will generate time slices of the final RSP radargrams, and then starts back in the Navigation menu (e.g. Blue 7:) to set markers and then continuing on to slice/resample/xyz operations. Initially the \radar\ data is resampled to the \resample\ folder. The final filtering operation that is completed on the radargrams in the Filter menu becomes the input directory for running the navigation operation.



Note: For Basic+RSP runs, the time slice grids will automatically be appended with the extra identifier "rsp-" on time slice creation.

BlueBox Basic + Edit (Ons correction)

Many users often have datasets with varying 0ns offset. The varying 0ns offset might have been caused by the user making variable settings or by drift within the equipment. Also, multi-channel systems almost always have variability in the 0ns position between channels. For this reason, radargram editing and truncation to a common 0ns position and scan depth is required. BlueBox operations are predefined to do these kind of additional processing steps. Shown in the next diagram is the Basic+radargram editing menu detailing all the necessary steps:

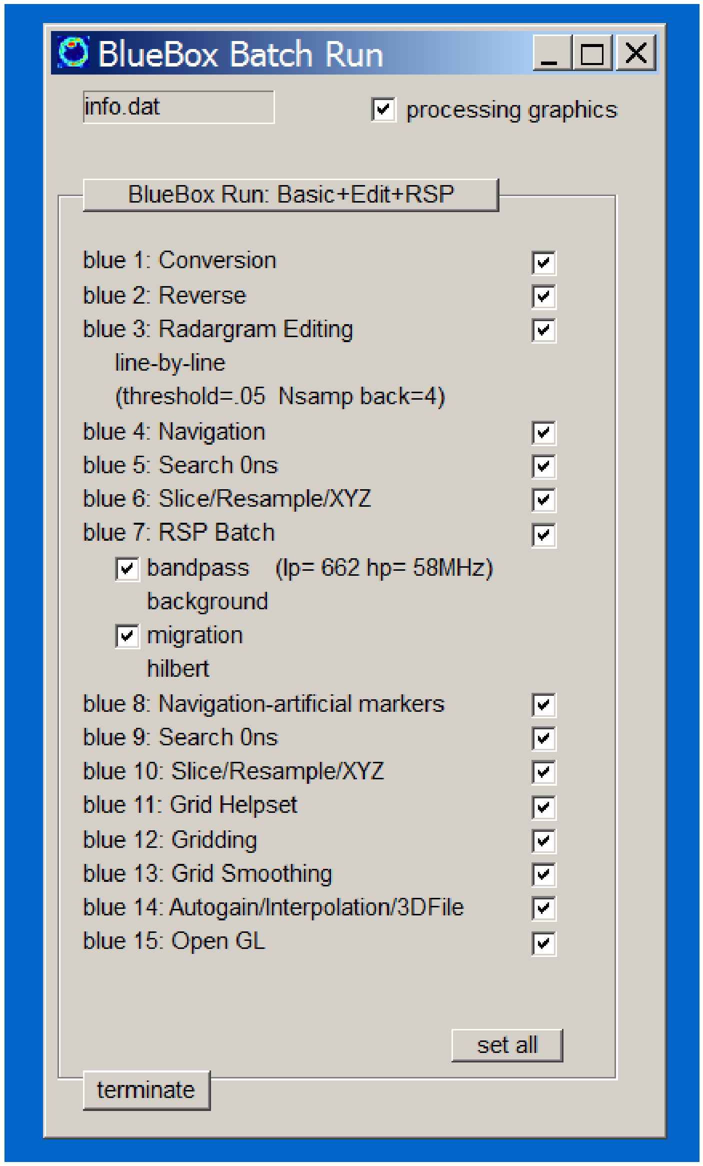


The most important steps in doing radargram editing to recap in the menu is that radargram editing is applied to the \radar\ folder, the results are written to the \work\ folder, the Navigation operations are applied to the \work\ folder followed by Search 0nS, Slice/Resample/XYZ etc.

Search 0ns on the radargram edited radargrams will usually discover the 3rd sample as the new 0ns position. This is correct – it will not be sample #1 or sample #2 since the first 2 data of GPR-SLICE radargrams are header information detailing whether a scan has a navigation tag or not. (A side note, this is similar to GSSI radargram format where the first sample describes whether 8 bit or 16 bit is present, and the 2nd sample describes whether a navigation marker is present or not). Slice/Resample/XYZ operation will be run on the \work\ folder where the radargram edited radargrams reside. The results for resampling will then get written to the \resample\ folder. Gridding operations, etc., then continue after that all the way to generating a 3D volume.

BlueBox Basic + Edit + RSP

The Basic + Edit + RSP BlueBox run provides all radargram editing along with complete RSP are combined into a single-complete batch operation. Radargram editing is done to make corrected 0ns radargrams in the \work\ folder, navigation and Slice\Resample\XYZ operations are run to generate resampled radargrams which are then RSP batched for filter operations. The navigation menu is returned with the last output folder from RSP batch operations, followed by Slice\Resample\XYZ operation again, gridding, and then 3D file generation



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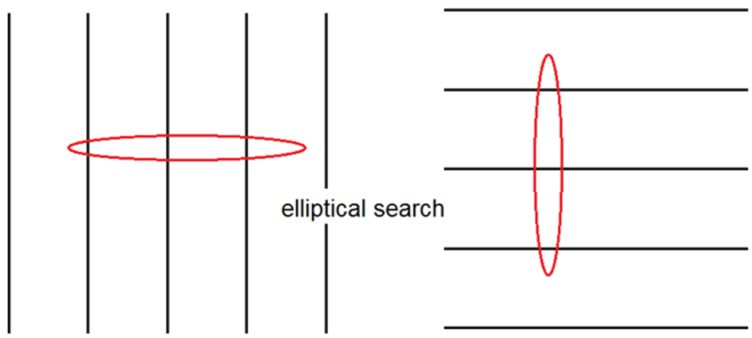
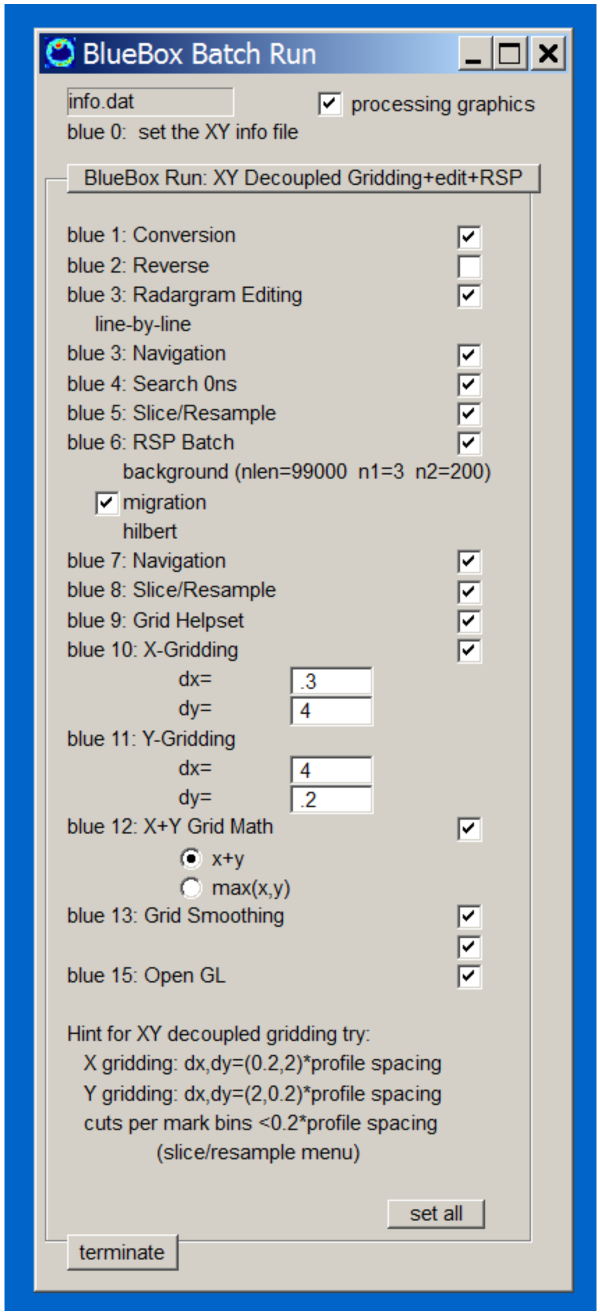
BlueBox XY decoupled grid generation

Back in December 2009 newsletter (and also see discussions on page 339 of the manual for actual examples) we discussed how to enhance linear features where XY cross grid surveying is done. The method of XY decoupled gridding is where X lines are separated from the Y lines and grid maps are made with differential search radii (see figure next page). An example of differential searching is depicted where the search radius transverse to the profile direction is large and conversely made narrow along the search direction. The separated X lines and Y lines grids are then added back mathematically. The method of decoupled gridding is very useful for geotechnical surveys and particular for concrete and infrastructure imaging where linear features such as rebar and piping are buried.



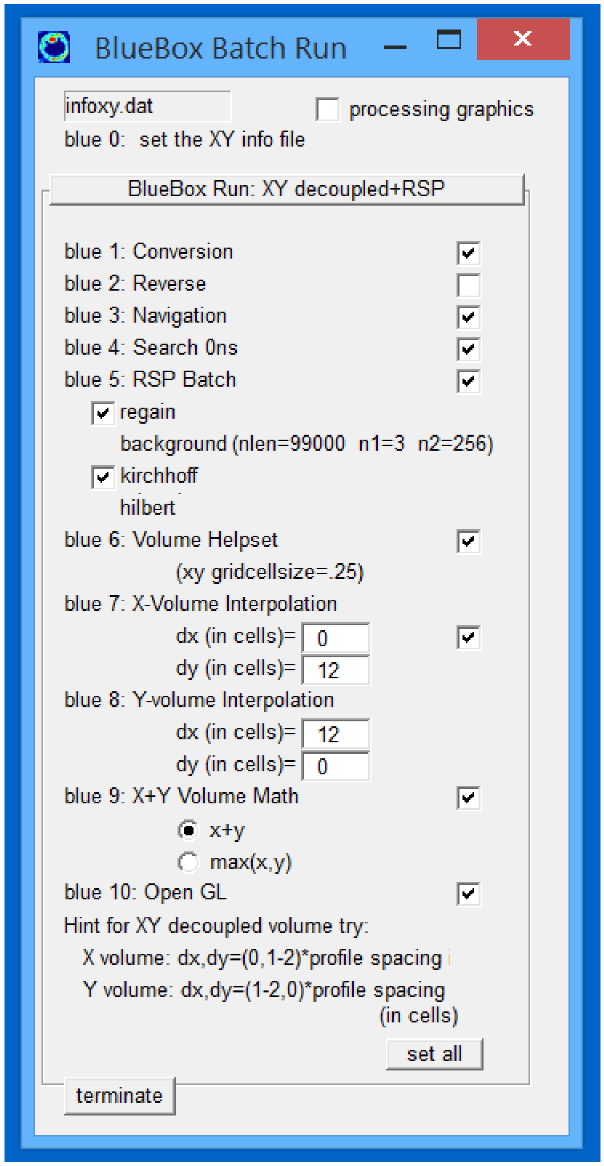
Differential searching of data for interpolation

A BlueBox Batch menu is now available to completely run this data processing flow all the way from raw data conversion to a volume made from processed radargrams used in decoupled gridding calculations. To start off the BlueBox operation, the user needs to insert the XY cross grid information file, e.g. infoxy.dat and then simply start up the batch operations. The user can set the RSP Batch operation in the Filter menu before starting the BlueBox to include up to 8 different signal processes. In this example, bandpass filtering, migration and Hilbert transform operations are done in the RSP batch flow. The software will automatically sift through the information file and generate separated info files (writing work files infoxx and infoyy along the way) where differential grid search radius is read from inside the BlueBox menu. For X lines, the user might set the x search to less than .2 or .1 the profile spacing or even smaller; and the y search to maybe about twice the profile spacing. For Y lines, the user can set the x and y search radius to just the opposite. One of the key settings in the XY decoupled grid operations is also to use a high number of bins per mark set in the Slice/Resample menu. Spatial bins should not be too long. The binning can be set to just encompass a few scans as well. Once all the X grids and Y grids are independently generated, they are then added back together. Grid math is used to add the decoupled grid maps back together and all automatically done in the BlueBox operation. This BlueBox option is available with radargram editing for the 0ns offset as well.



BlueBox XY decoupled volume generation

A specialized BlueBox operation XY decoupled volume – will independently generate separated X and Y volumes using elliptical volume generation and then add back to the volumes together. This macro is used only for surveys which are normally collected on concrete or high density profiling in both directions. This BlueBox can allow the user of single channel equipment to generate pulse volumes when the density of lines is approaching or better than the Nyquist spatial frequency. Currently this BlueBox is only available to multichannel users (but will be released to single channel licenses in 2016)



Note 1: Most of the BlueBox runs except for the XY Decoupled Volume also have an identical set of macros with radargram resampling should these operations need to be run.

Note 2: BlueBox runs also have several standalone settings in several menus including the

- Slice/Resample menu
- Radar Edit Menu

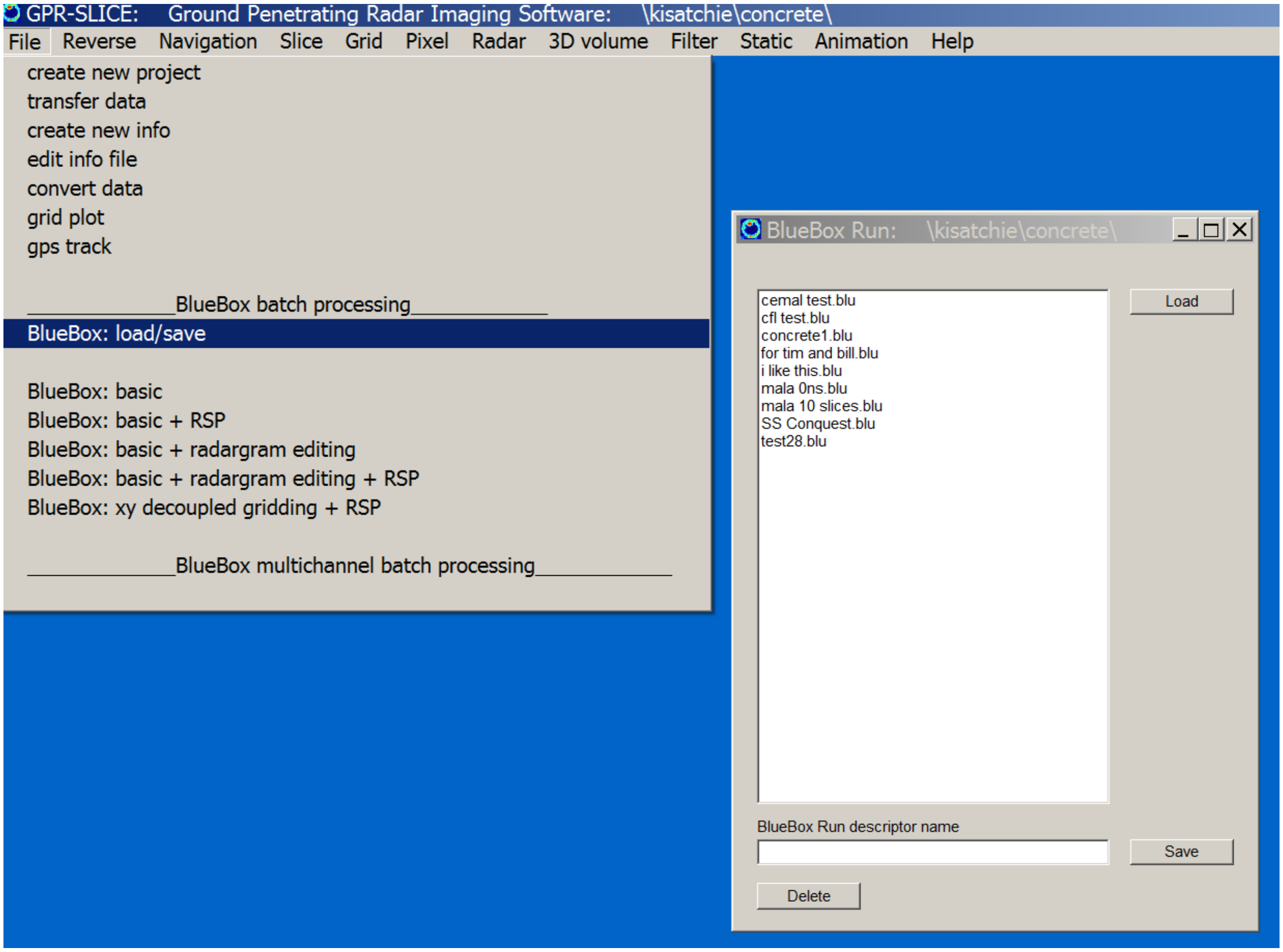
- Convert menu.

The Slice/Resample menu has settings for telling the software to compile the XYZ as regular, 0 mean line, 0 mean grid etc. Radio buttons are shown in this menu for the user to define what XYZ compilation they want. The Radar Edit menu on BlueBox runs has settings to tell the software to run scan-by-scan or line-by-line 0ns truncation during BlueBox batch runs. The Convert menu also has a setting to let users convert 16 bit native data to either 8 or 16 bit during a BlueBox batch run. Normally all operations on conversion should be done with 16 bit.

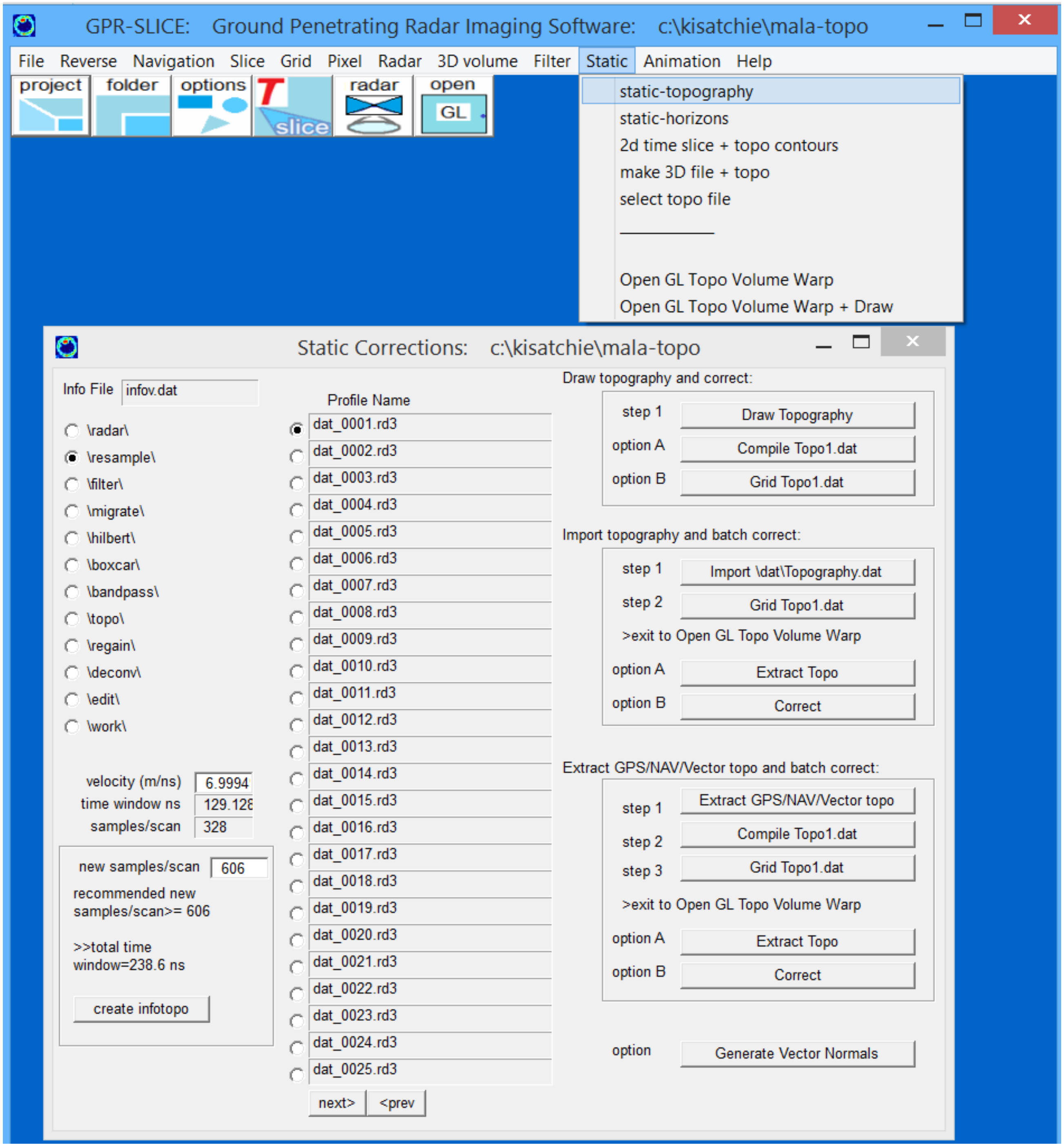
BlueBox Run: Load/Save

BlueBox operations allow the user to save any customized settings and menu items and to recall these settings. The BlueBox Load/Save menu under the File pulldown menu. The user can give a customize descriptive name to all the settings for their BlueBox runs. These settings are similar to the complete installation files, and are saved under a new folder called called \slice\v7.0\bluebox. The BlueBox macros have the extension *.blu. Up to 100 different BlueBox scenarios can be saved and/or recalled at the click of the mouse. The various runs can have different RSP engaged or different gridding parameters etc. Any customized setting or operation can be stored and recalled with the click of a button.

Note: The options are endless for generating various processed 3D volumes in batch using the BlueBox operations in GPR-SLICE v7.0. BlueBox operations however, should really only be used after the user has familiarized themselves with all the manual operations in every menu in GPR-SLICE. The potential for errors in running the software blindly through the BlueBox menus, without properly setting all the relevant parameters in each menu, is highly likely and remains a drawback for complete automated processing for beginning users.


GPR-SLICE: Ground Penetrating Radar Imaging Software: \kisatchie\concrete\
File Reverse Navigation Slice Grid Pixel Radar 3D volume Filter Static Animation Help
create new project
transfer data
create new info
edit info file
convert data
grid plot
gps track
BlueBox batch processing
BlueBox: load/save
BlueBox: basic
BlueBox: basic + RSP
BlueBox: basic + radargram editing
BlueBox: basic + radargram editing + RSP
BlueBox: xy decoupled gridding + RSP
BlueBox multichannel batch processing
BlueBox Run: \kisatchie\concrete\
cemal test.blu
cfl test.blu
concrete1.blu
for tim and bill.blu
i like this.blu
mala 0ns.blu
mala 10 slices.blu
SS Conquest.blu
test28.blu
Load
BlueBox Run descriptor name
Save
Delete

STATIC Menu: Overview



This Static menu can currently be used to do almost any kind of topographic adjustment to data in GPR-SLICE. There are 5 pulldown menus and various submenu procedures below the Static pulldown:

- Static - Topography

- Static - Horizon
- 2D Time Slice + Topo Contours
- Make 3D File + Topo
- Select Topo File
- Open GL Topo Volume Warp
- Open GL Topo Volume Warp + Draw

Static - Topography

The Static - Topography has 3 operations available to the users to make topography corrected radargrams:

- draw topography with the mouse and perform topographic correction, writing new binary radargrams

- import a topography.dat external file that is x,y,z comma delimited, grid it, extract the topography for each profile over the topography grid file, and batch correct for topography making new binary radargrams for all the files in the project

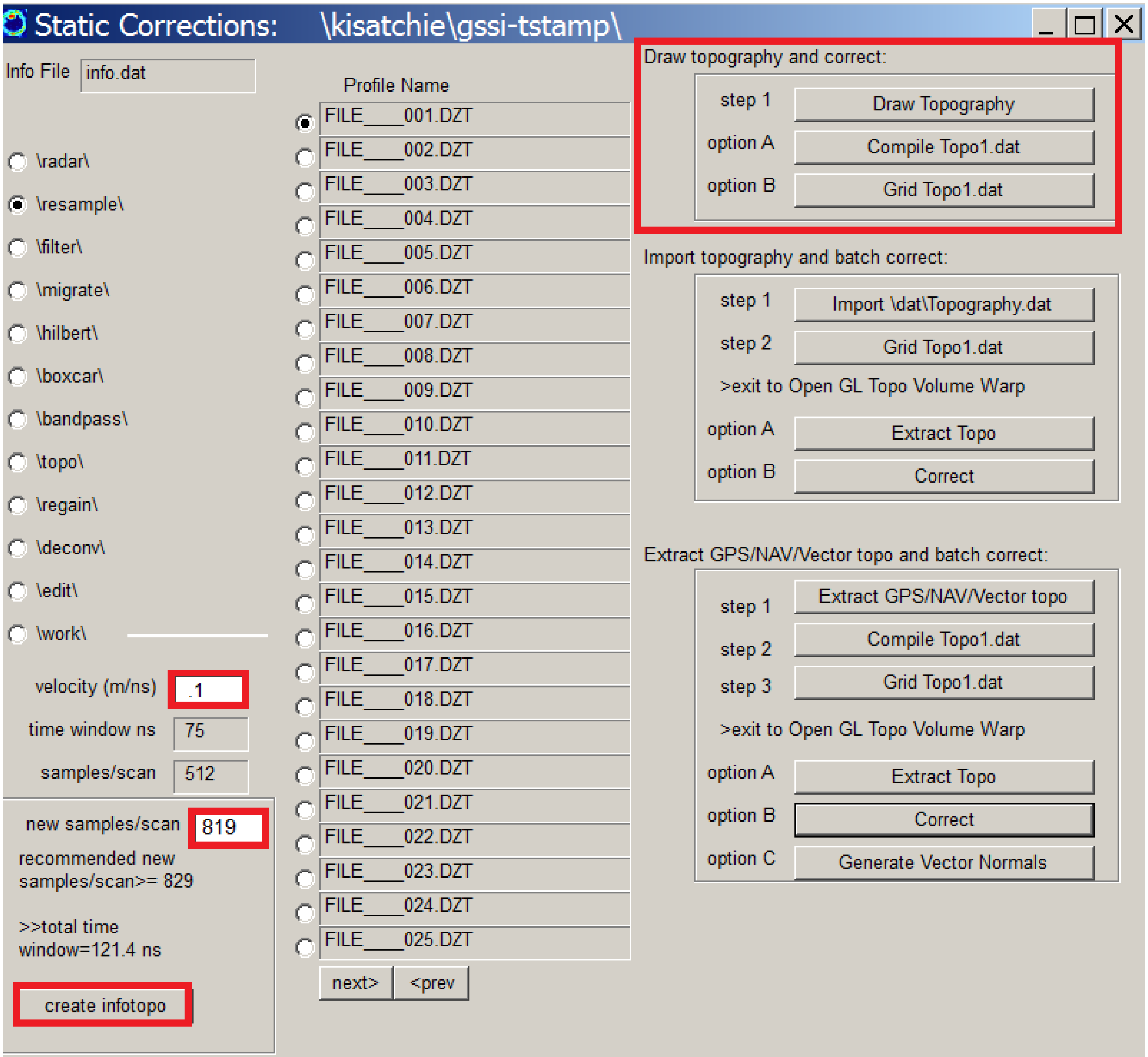
- extract topography from the *.gps navigation, grid the compiled topography, extract the topography for each individual GPS radargram, and batch correct for topography making new binary radargrams for all the files in the project

These methods, explicitly written in the Static menu are shown in the screen shot (previous page), and are all designed for implementing topographic corrections.

However, it is no longer necessary to go all the way through these steps to explicitly make new binary radargrams which are topographically corrected. The preferred method is to generate the topography grid file (called topo1.grd) and graphically warp the volume and the associated radargrams using the Open Gl Topo Volume Warp menu! This does not require running the batch operations to all the way through to make new radargrams with the topography - this can all be done graphically without rewriting new radargrams! This is why in the menu there is written after the topography grid file is made and before all the optional steps before binary corrections to **">exit to Open GL Topo Volume Warp**".

Nonetheless, in this manual we will describe all the original options to also make binary topographic corrections to the radargrams as well as detail making the corrections via graphical warping.

Draw topography and correct:

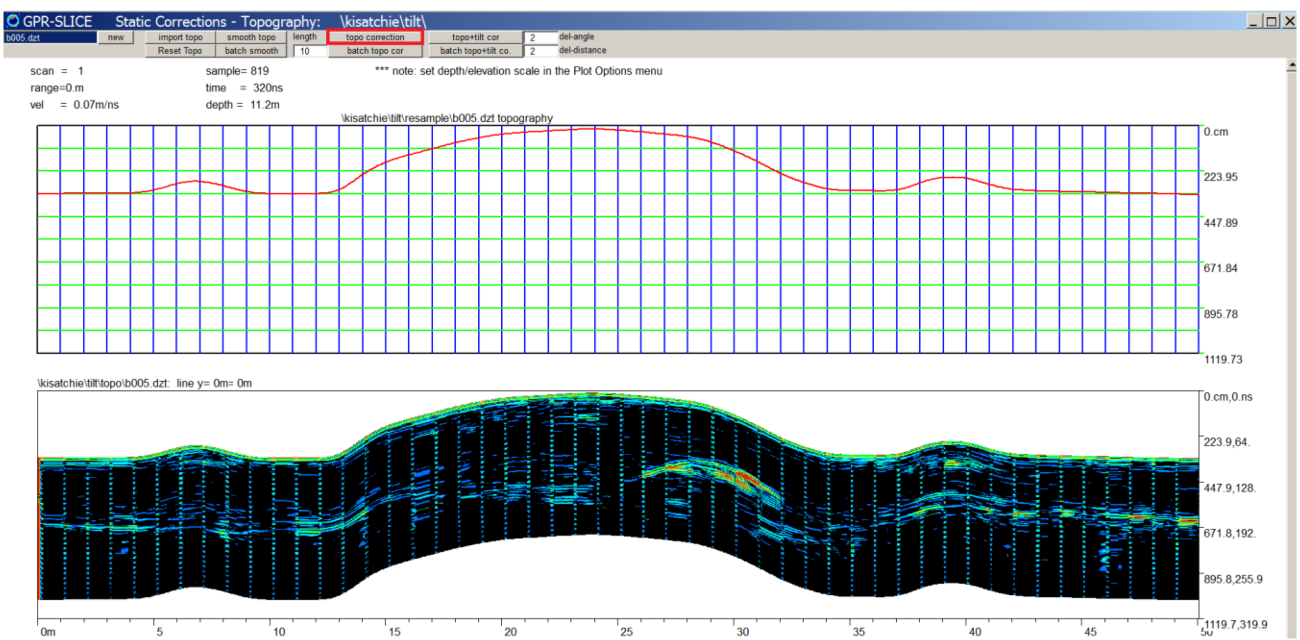


The first steps to do are to set the velocity of the site, the new samples/scan to make corrections over. The new samples/scan recommended will be made if a known topographic dataset is imported, however on first drawing the topography with the mouse, the recommended new samples/scan is not yet know. You can set this value so that entire radargram will appear in the correction menu when topography corrections are being run. Or you can calculate what will be needed. For instance, if your total elevation change over a site is 3 meters, and the velocity is 0.1 m/ns, and given the digitization of the radargrams is 512 and a 100ns time window, the recommended new samples/scan would be:

$$\begin{aligned}
\text{new samples/scan} &= 512 + \text{elevation}/(\text{penetration depth})*512 \\
&= 512 + \text{elevation}/(TW*V/2)*512 \\
&= 512 + 3/(100*.1/2)*512 \\
&= 512 + 3/5*512 \\
&= 819
\end{aligned}$$

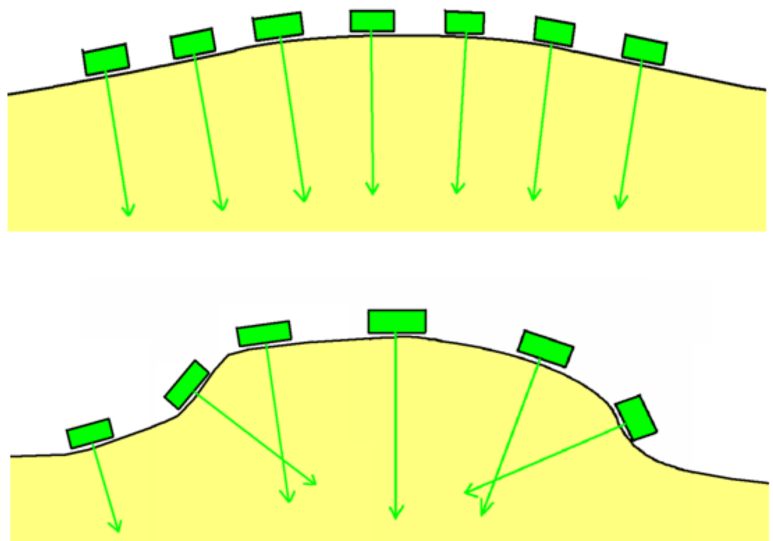
Because we always want to preserve the original digitization of the radargram, the extra samples/scan to account for the total change in elevation in terms of its equivalent scan depth is added onto the corrected radargrams.

Shown below is the topography for a radargram that was drawn with the mouse, and after being corrected with a standard topographic correction. Once the topography is drawn, it will be saved to the project is after the topographic correction is run. If the topographic correction is not run, the active drawn topography is lost on exiting the menu. On reentering the menu, if the topography had previously been created and stored by running the topographic correction, it can be imported back into the menu by clicking the Import Topo button. The "standard topographic correction" simply shifts the radar scans vertically to account for topography. This is the most basic way to account for topographic variation along and to generate to corrected radargrams.



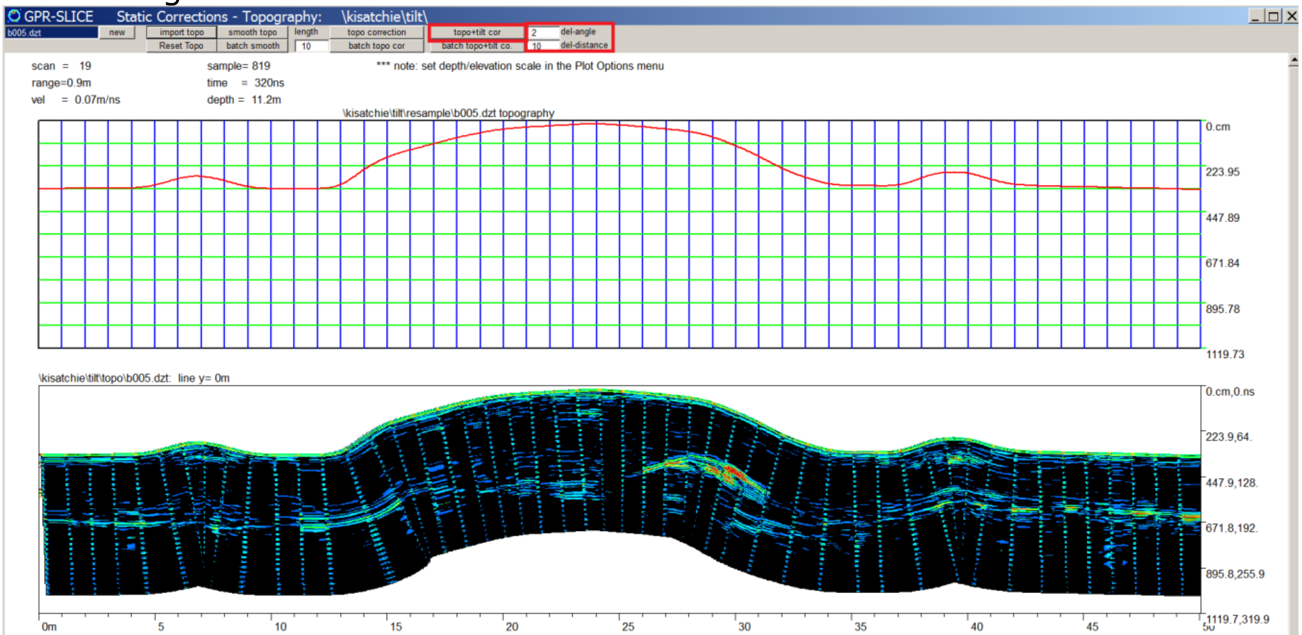
Topo + Tilt Correction

Mild vs Abruptly Changing Topography

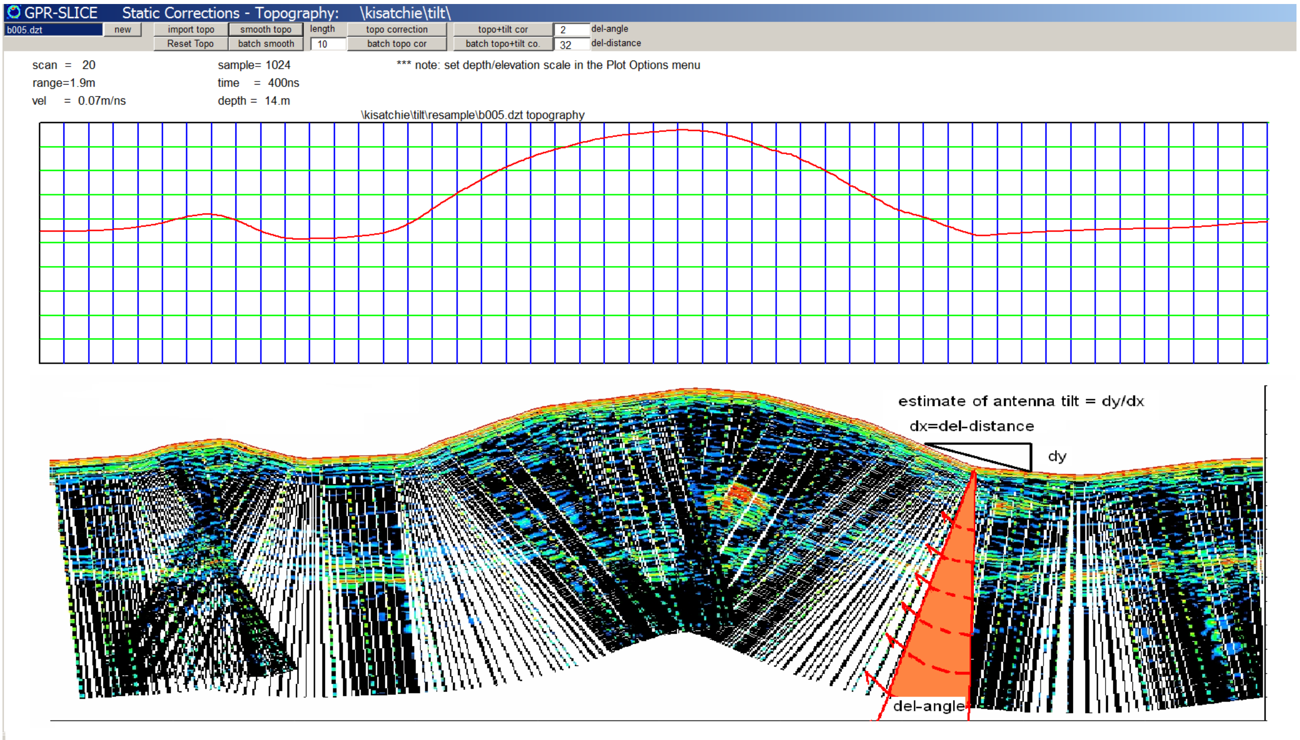


Another possibility for correcting the radargrams, is one in which the tilt of the antenna over a site with topography, is also accounted for (Goodman et al, 2006). Shown above, is the effect that topography can have on the angle of radar waves going into the ground. In the topography menu, an option called "topo+tilt" correction is available. This correction algorithm will determine the direction of the normal ray to the topography and insert the radar scan at the appropriate angle in the binary file. If the data is not sampled sufficiently enough, e.g. the scan density is low, blank values or region can appear in the topo+tilt corrected radargram. A del-angle setting is available. Making this value 1 or 2 degrees will sweep the radar scan over a small angle to fill in blank areas over the radargram. The del-distance setting is used for determining over how many scan lines – distance – over which to estimate the slope of the topography. Using a very small number of scans, can give yield estimates of the topographic slope that are very abrupt.

An example of the same radargram being corrected for tilt of the antenna is shown in the next figure. This radargram was for a velocity of 7cm/ns and a del angle of 2 and a del distance of 10 scans. (An old radargram that had meter markers stored in the radargram was used to show how the tilt correction gets implemented and is easy to see how the scan change there location.

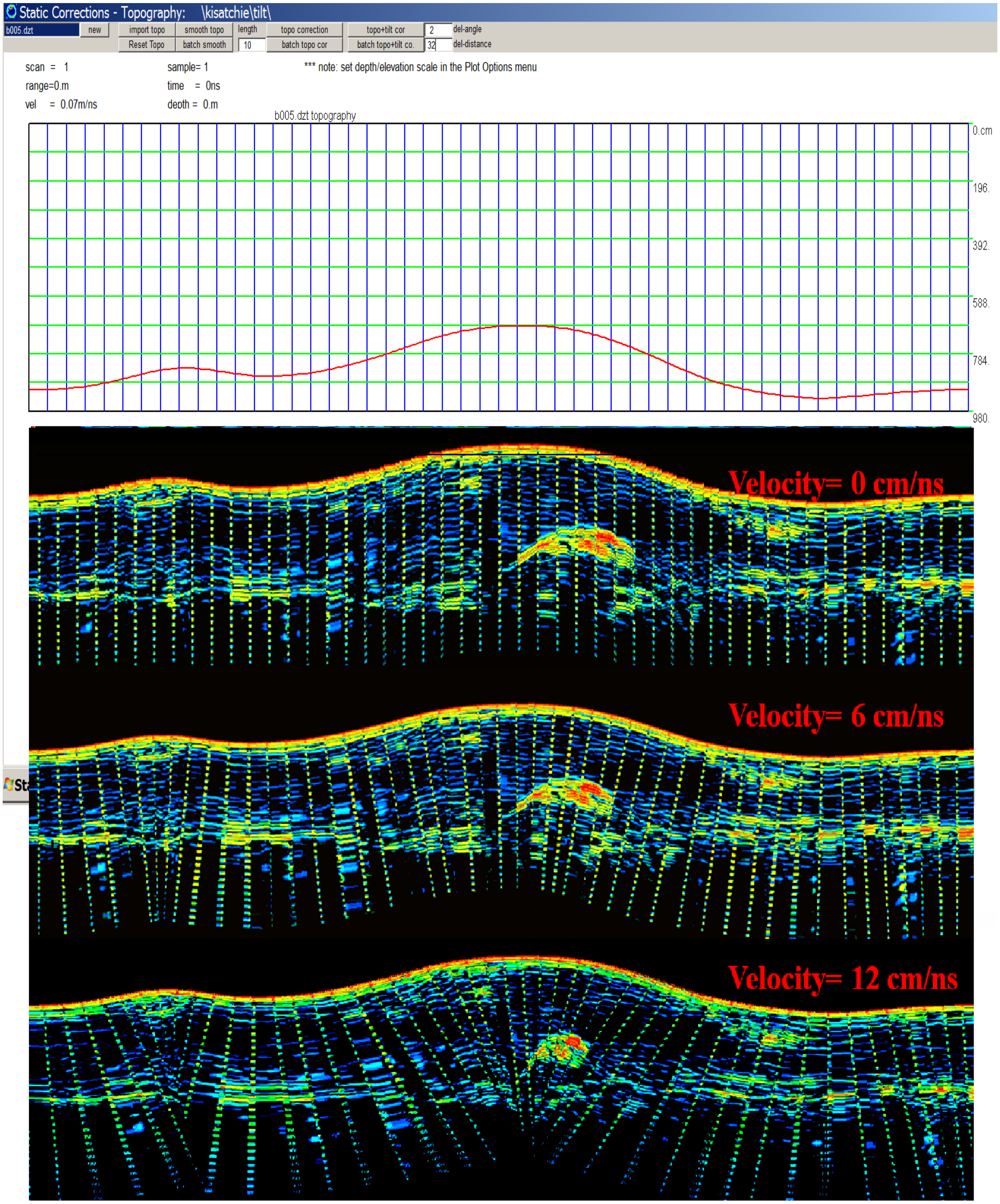


Note: In the tilt correction process the tilt of the antenna is measured from a derivative of the given topography. The user must set a nominal microwave velocity for the radargram in order for the software to correct for the antenna tilt across the ground surface. The appearance of the radargram for topo+tilt correction can change significantly depending on the nominal velocity used. If the slope changes abruptly along the ground, it is possible that blank areas can be created in the radargram binary file during the topo+slope correction process. (See the figure in the next page). To alleviate this problem, 2 interpolation settings: del-angle and del-distance are provided. Del-angle is the angle over which a radargram scan will be swept or rotated into the binary radargram to fill in any gaps. A setting of 3 for instance will sweep the radar scan over an angle of 3 degrees. The radar scan will fill all values that are blank in the binary radargram (see the following diagram). The del-distance setting is the number of scans (distance) over which to estimate the topographic slope. Using a larger value for this setting will have the effect of smoothing the topographic slope calculation out. One would not want to make this setting very large, but using a value that may correspond with about a meter or so, or some value that gives a good local topographic slope calculation without having extremely abrupt slope changes is desirable.

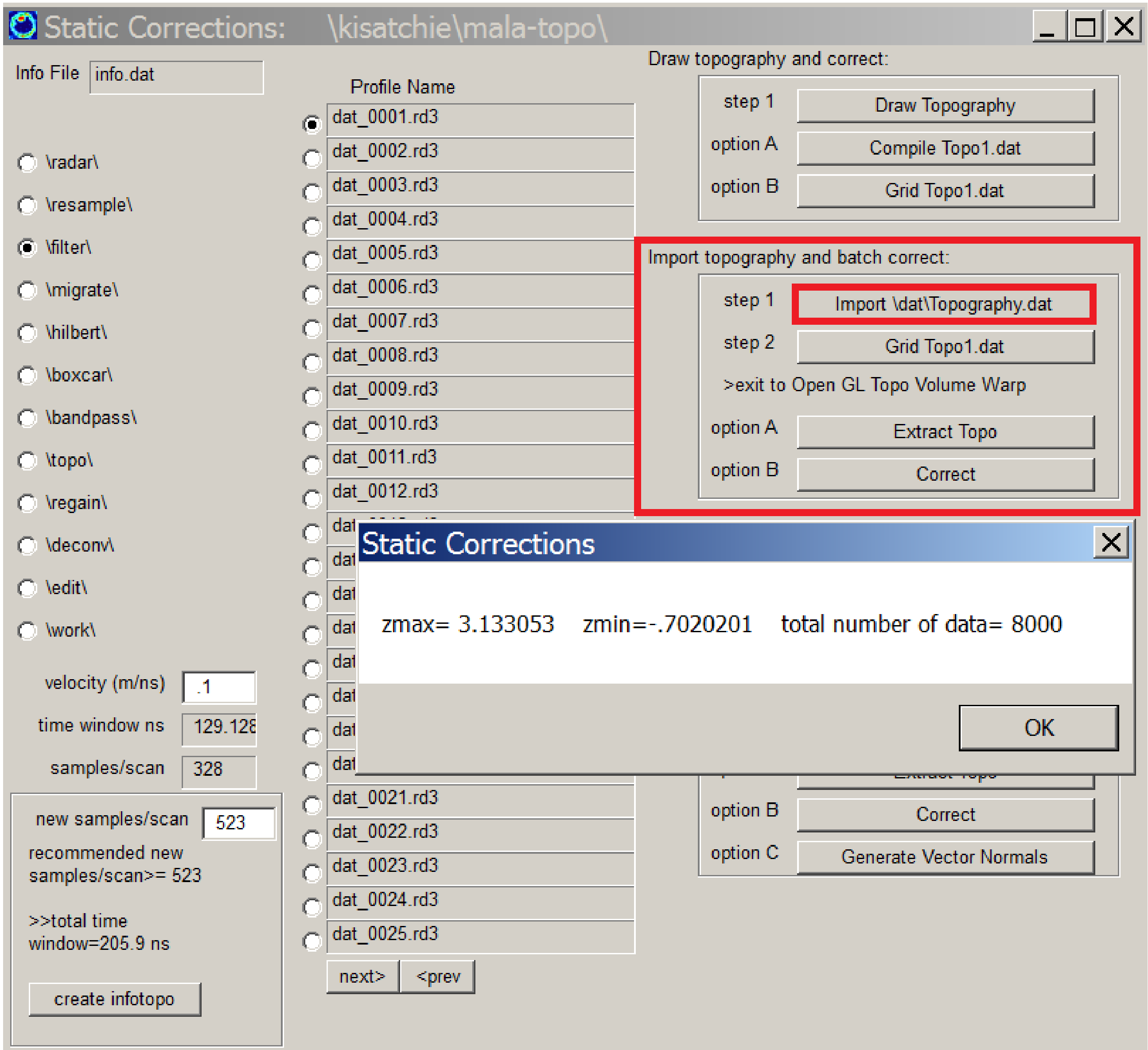


If the user still any holes in the radargram after running the topo+tilt (or batch topo+tilt) correction, then the del-angle and/or the del-distance setting should be increased slightly. The topo-tilt correction with large values of del-angle will solve some large changes in the topography however, processing time goes up exponentially. Also, for very severe topography changes, even with radar scan sweeping, there can be gaps in the radargrams. To partly help in the reconstruction of these kinds of sites, it is useful to have more density of the scans per unit distance resampled during the slice/resample process. The resample scans per marker can be adjusted in the Edit Info Menu followed by rerunning the slice/resample process to get denser resampled radargrams.

For purpose of illustrating the importance and the effects that tilt has on a radargram with different nominal velocities of 0cm/ns, 6cm/ns and 12 cm/ns being used, is shown (after Goodman et al, 2005) is shown. For higher velocities some subsurface features can be projected to be much smaller or larger depending on the topography profile. When the velocity is 0 - the typical standard topographic correction will ensue.


Static Corrections - Topography: \kisatchie\tilt\
b005.dzt
new
import topo
smooth topo
length
topo correction
topo+tilt cor
2
del-angle
Reset Topo
batch smooth
10
batch topo cor
batch topo+tilt co.
32
del-distance
scan = 1
sample= 1
*** note: set depth/elevation scale in the Plot Options menu
range=0.m
time = 0ns
vel = 0.07m/ns
depth = 0.m
b005.dzt topography
0.cm
196.
392.
588.
784.
980.
Velocity= 0 cm/ns
Velocity= 6 cm/ns
Velocity= 12 cm/ns

Import topography and batch correct



Topography can also be automatically developed for radargrams from a digitized contour map, a digital elevation model or any file describing the topography. The name of the file to import must be:

- called topography.dat
- exist is in the \dat\ folder of the project
- must be 3 columns, comma delimited file x, y, t where x and y can be any distance unit but the t **must be the elevation in meters**

Once this file is placed in the \dat\ folder, the velocity of the site is set, and the desired new samples/scan is placed into the menu (see previous section) the user clicks the button Import \dat\topography.dat button which will read the file, report the zmax and zmin in the file as well as the total number of elevation points (see screen shot). Absolute elevations or relative elevations can exist in the file. (GPR-SLICE can also report absolute elevation in terms of relative elevations by setting the desired display of data in the Options menu).

Explicit steps are:

Step 0.1) Set the radargram directory to the resample or a filtered directory. (Note: It is important to use resampled radargrams which have a constant number of scans per unit distance. Survey wheel data also has this feature but in cases where the user had hand marker navigation, the resampled radargrams or radargrams filtered from resampled radargrams should normally always be used to topo corrections).

Step 0.2) Set the microwave velocity in meters/ns that was discovered in the Search Hyperbola process in the Filter Menu.

Step 0.3) Set a New Samples/Scan length for the set of new radargrams to be written into the \topo\ directory. For instance, if the total topographic relief of surveyed site is 2 meters and for example the total penetration depth was by chance also 2 meters, then the user should set the New Data/Scan to twice the recorded data/scan. (See previous section for more discussion on setting the new samples/scan)

Step 0.4) Click the Create Info Topo button to make a secondary information file appended with the name topo. This new information file will contain the updated samples/scan for the static corrected radargram. This new file should be made active on display of all corrected radargrams – but it should not be active in the Edit Info File menu while the initial corrections are being done. If binary corrected radargrams are not needed since only Open GL Topo Volume Warping displays are needed, then skip this step.

Step 1) Import a topography.dat file by clicking the Import Topography button, which creates a topo1.dat. Note that the topography.dat file should have 3 columns that are comma delimited and without any header. The columns are x, y, and z where z is elevation in meters. The elevation can be relative or absolute as the import option will convert absolute elevations to relative measurements.

Step 2) Click the Grid Topo1 button which will open the Grid Menu. Grid the topo1.grd file. Make sure the xstart, ystart, xend and yend values for the grid are all inclusive for the radargram locations in the information file. Exiting the Grid Menu will bring the user back into the Static Menu.

Step 3) Click the Create Topo button, which will extract the individual topography profiles for each radargram (and write them to the \topo\ folder).

Step 4) Click on the Draw Topography submenu and choose between the batch buttons for either standard topo correction or the batch operation in the Static Corrections menu. If you are going to work on just a single radargarm, don't forget to click the Import Topo button to get the topography profile read in. If it is not read in, then whatever the active topography - even if it is set to 0 - will be overwritten. On Batch operations, the software will automatically read in all the topography profiles before running the correction.

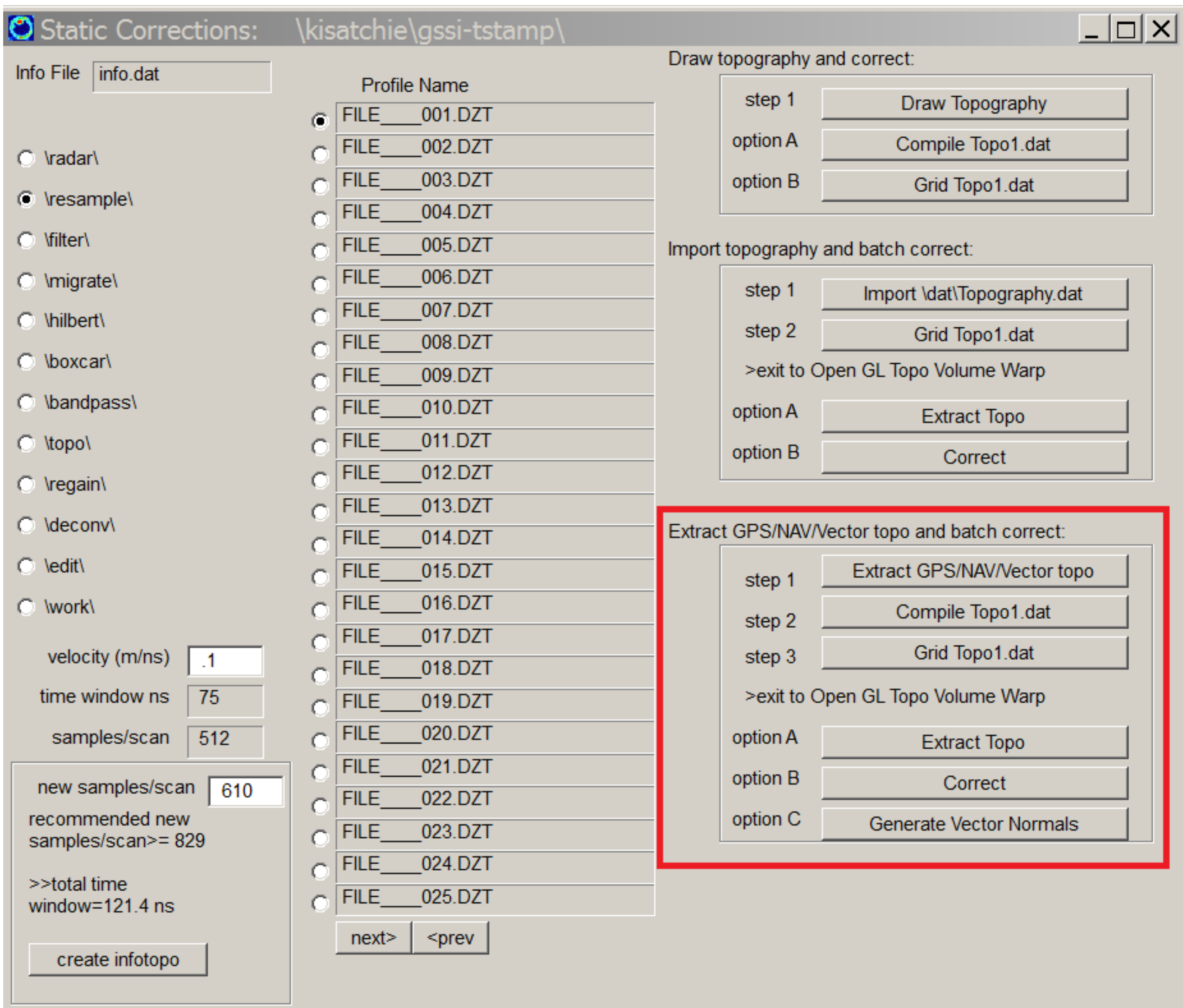
Note: To view the topographically adjusted - binary radargrams in the Radargram Menu, the user must click the Create Info Topo button in the Static menu. This will create a replica information file (e.g. infotopo.dat), with two different settings - the samples/scan is adjusted to match the New Data/Scan value used when correcting for topography and a new time window will also be computed. The new time window reported in the infotopo.dat is given by:

New time window=Old time window*(new samples scan)/(old samples/scan)

Extract GPS/NAV/Vector Topography and Correct

Automatic elevation correction for GPS radargrams can be implemented in the Static menu. GPS elevation corrections using the elevation information stored in the 3rd column of the standardized GPR-SLICE *.*.gps files that are generated from the raw gps log files. This is done for all manufacturers log files converted to GPR-SLICE that are recorded. There are 2 main steps in doing batch corrections for GPS surveys. The steps are outlined under the heading of Extract GPS/NAV

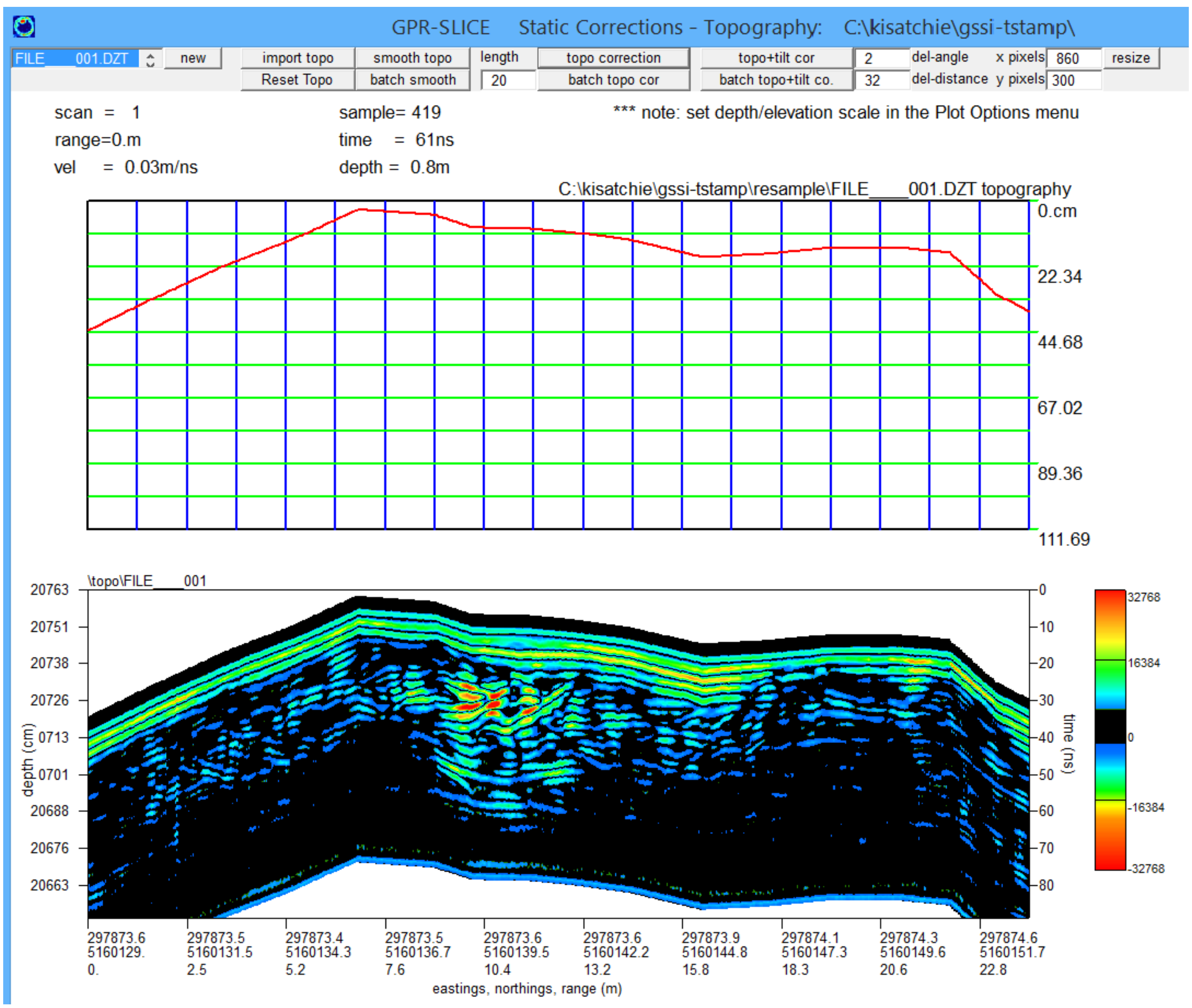
Topo and Batch Correct. Clicking the button Extract GPS/NAV/Vector topo will cause GPR-SLICE to read all the *.*.gps files and store the 3rd column into work files. (As is done in typical elevation correction, GPR-SLICE uses a file generated called *.ctm located in the \topo\ folder for the project which has the elevation converted to equivalent scan depth for each recorded scan in the radargrams).



If the GPS is recorded every second or every constant number of scans, GPR-SLICE will interpolate the GPS elevation to generate an elevation correction for each individual scan when the Extract GPS/NAV Topo button is clicked. The next step is to run the Correct operation which will launch the Static Correction menu. From here the user can either do batch processing or single line processing, in addition to topo +

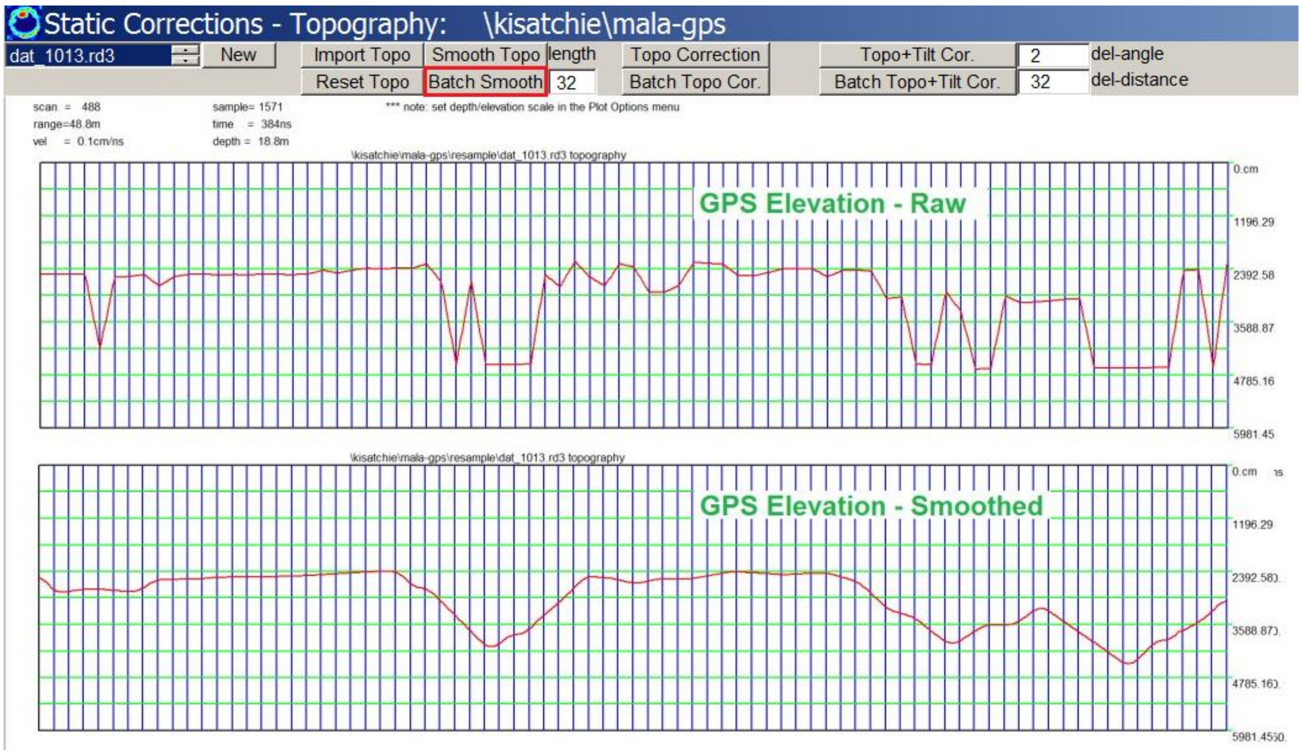
antenna tilt or corrections without compensating for the tilt of the antenna. An example of automatic GPS elevation correction is shown in the following diagrams along with the complete orientation of the GPS radargram in 3D space.

Note: Just like normal topographic corrections, the user needs to first set the velocity and the new samples/scan in the Static menu. In the example below topography over a GPS radargram is drawn. Note that the bottom of the radargram is cutoff in a few locations. Should bottom part be desired or if more of the bottom part of the new radargram is desired to be cutoff, the new samples/scan must be adjusted first in the Static menu.



Topography smoothing

The user can also use grid smoothing on the Topo1.grd to create a filtered-smoothed topography grid. Or directly in the Static Correction menu, the user can click the Smooth Topo or Batch Smooth button. The user should make sure to use enough grid cells so that when the corrections are implemented into the radargrams, that the topography looks continuous and not blocky. If it looks block on extraction, then it is useful to use the smoothing button in the menu.



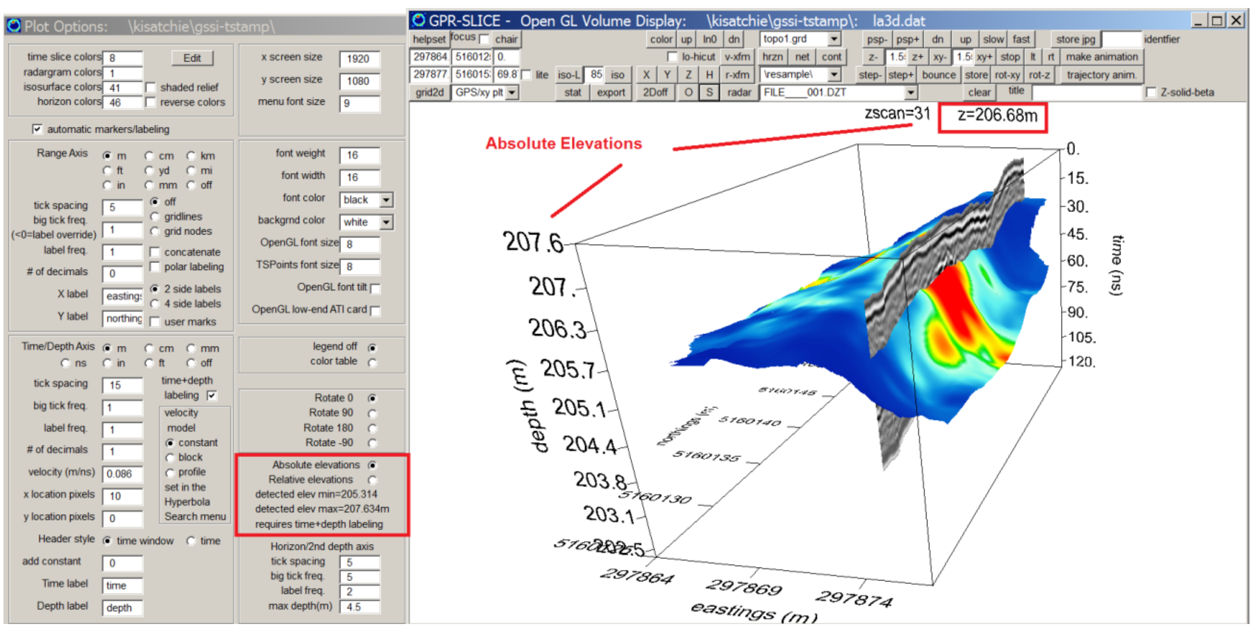
Topography smoothing can be implemented in batch operations in the Static Menu. These operations can be done on regular or GPR/GPS surveys. Particularly for direct GPS elevation profiles, topography smoothing prior to correction is sometimes necessary since these direct files can often be noisy. An example of a topography smoothing operation using a filter length of 32 is shown in the diagram above. Data of this quality is very subjective on whether to actually use it or not. However, in lieu of poor elevation recording with the GPS equipment, using highly smoothed elevation profiles may be preferable to no corrections being done at all.

Note: Batch correction for standard topographic corrections are very quick - however topo+tilt corrections can take 5-10 time longer to execute.

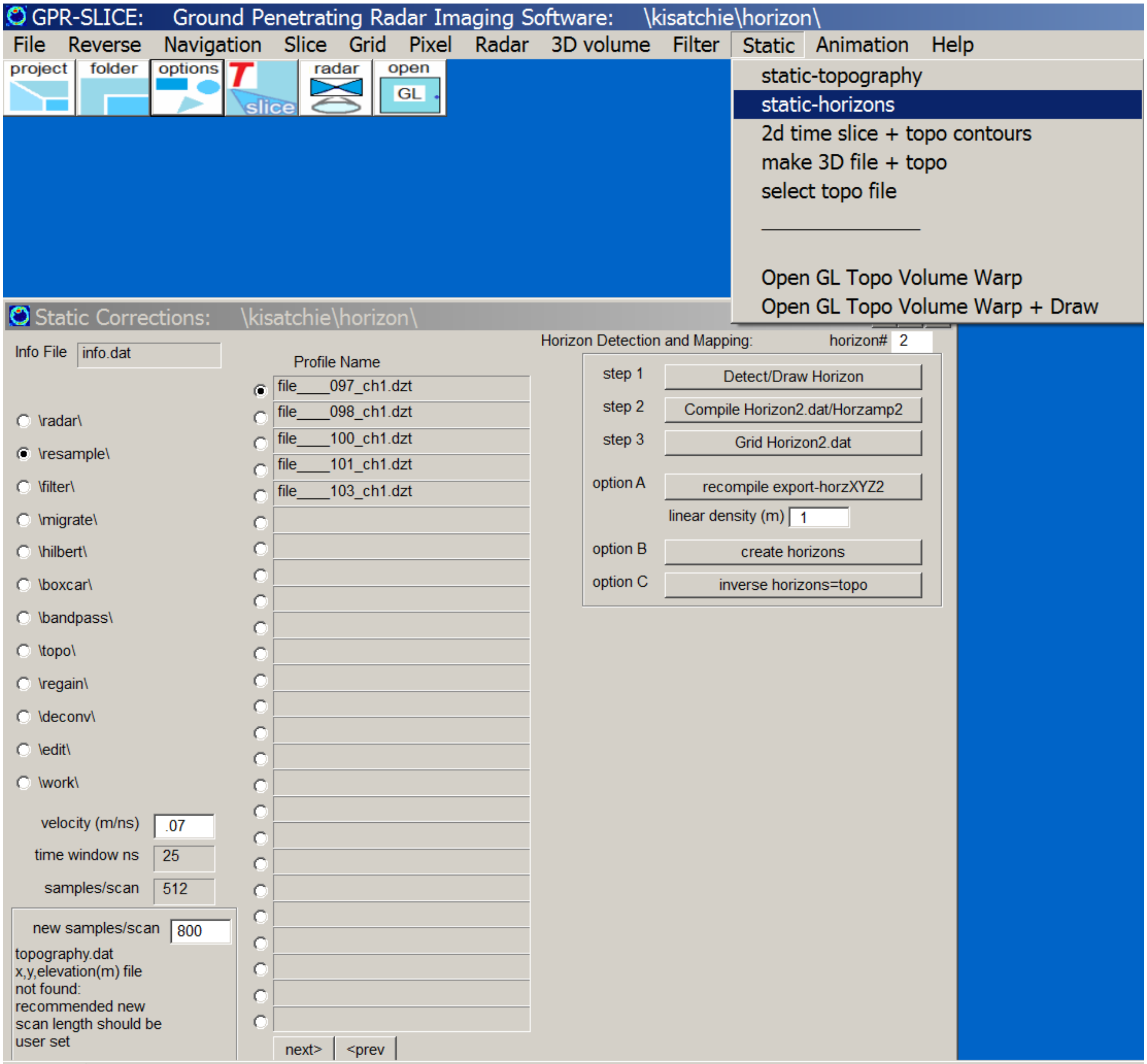
Absolute elevation in Open GL and Radar 2D menus

Time slices, radar menus,or Open GL Volume menu with topography warping can show relative or absolute elevations. The flag is set in the Options menu for the desired elevation display. Setting the option to Absolute will show depth labels with Z decreasing downward and starting at the true elevation either detected in the topography.dat files imported, or from the NMEA strings and the elevation in the *.*.gps log files.

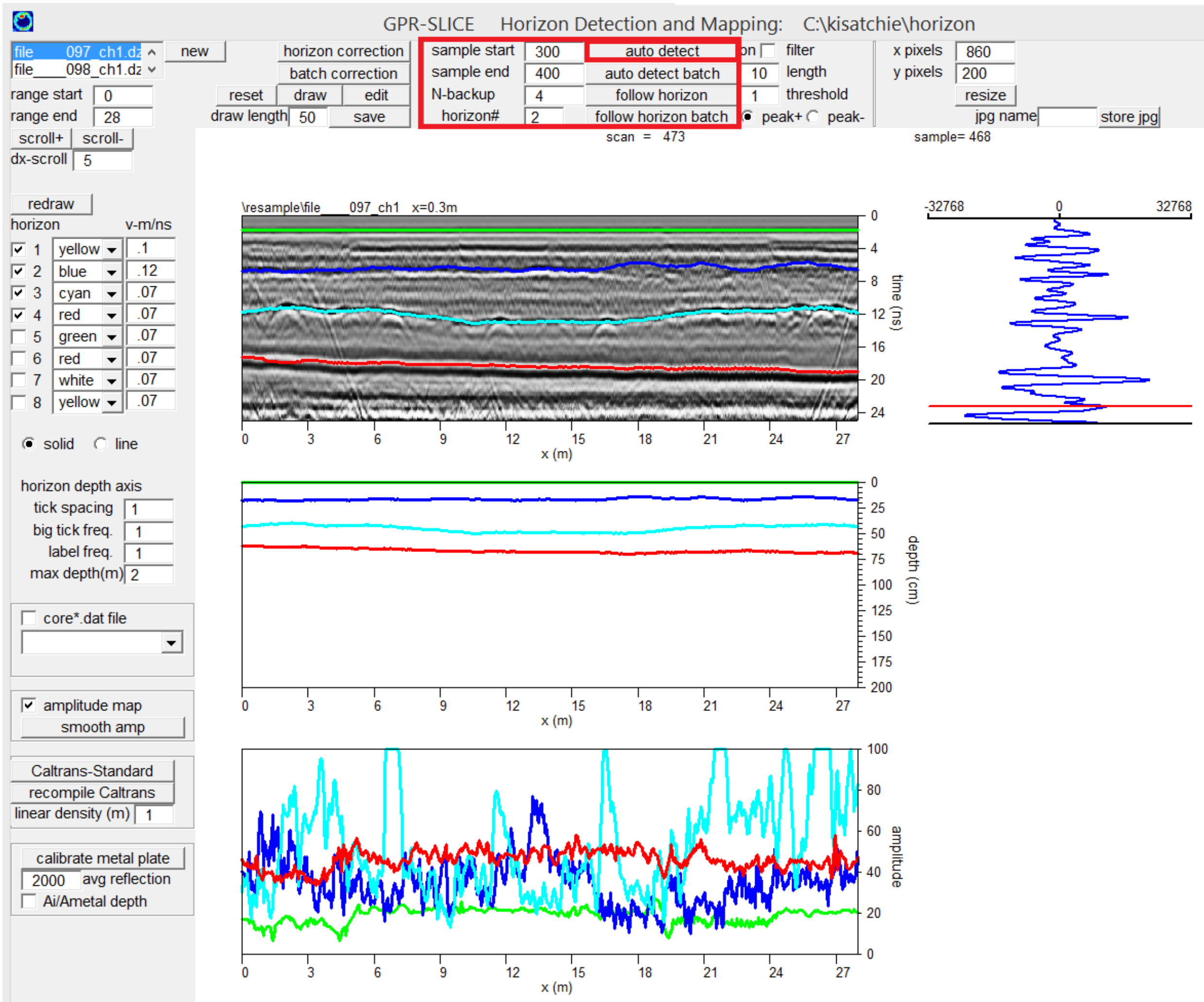
An example of a GPS data warped into topography and labels with absolute elevations is shown.



Horizon Detection and Mapping



An option to automatically detect and map 8 subsurface horizons has been implemented in the Static Menu of GPR-SLICE v7. The Static-Horizon submenu can now automatically discover the peak reflection within a user specified scan-sample window. Shown in the following is an example of the operation of the menu. The sample start/end is the range for discovering the peak reflection. Running the **Auto Detect** will discover and display the peak response. There is an auto filter switch which is available in the menu. The auto filter switch will compare a moving average with the discreet profile to try and remove noisy points



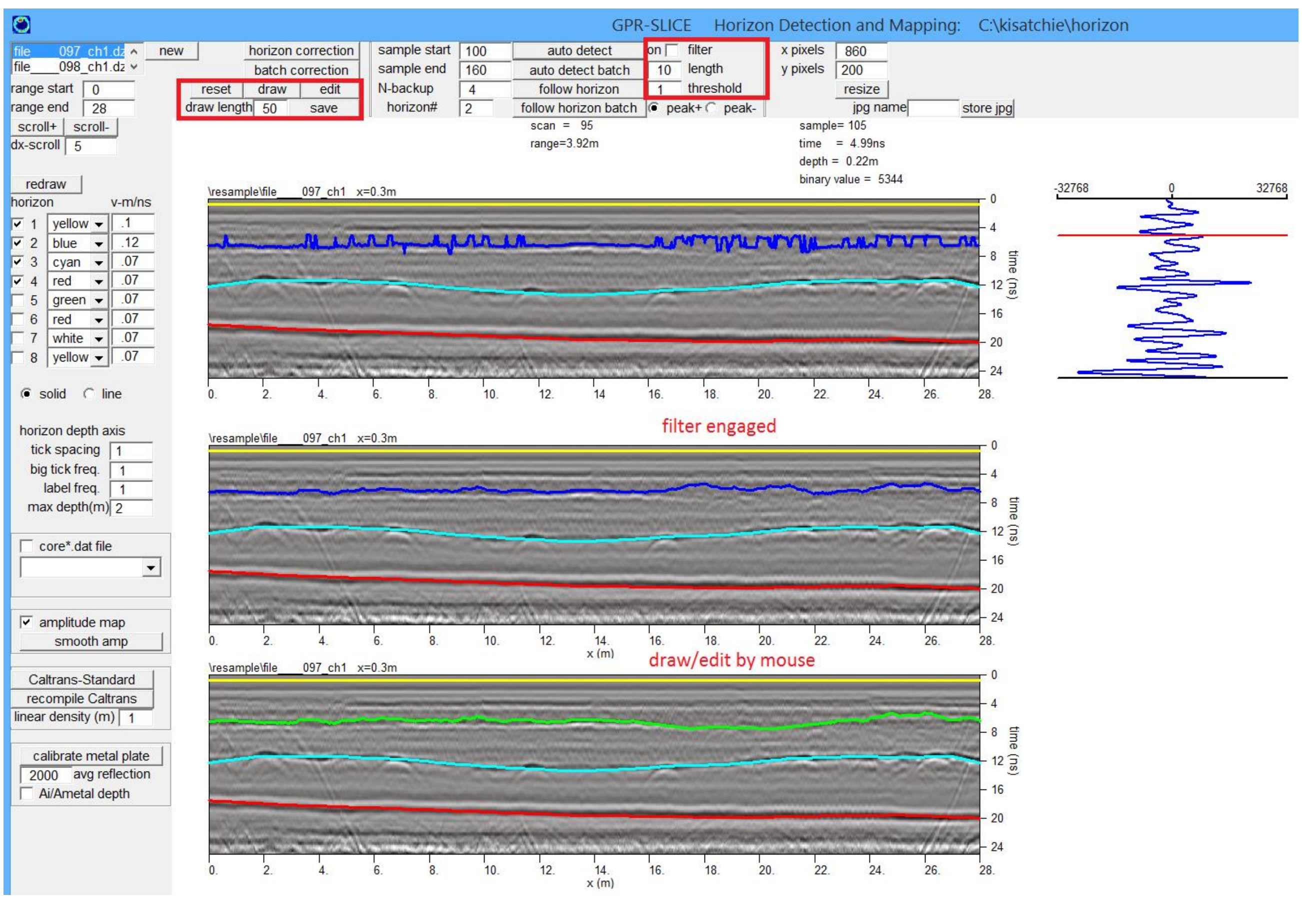
real time along the profile. In the case when the filtered profile still has problems, the user can click the **Import/Edit Horizon** button and fix the profiles with the mouse very quickly. A N-scan wide mouse cursor is used to help quickly re-draw bad points along the profile that are not well predicted. The automatic horizon detection can be run in batch as well using the **Auto Detect Batch** button.

To start the automatic horizon detection the user should

1. set the sample start/end over which to search the peak response
2. set the Nbackup which will back up or move forward a desired number of samples of the digitized scan on the detection
3. set to search the peak + or the peak - part of the pulse over the sample window
4. set the Horizon # to assign for detection

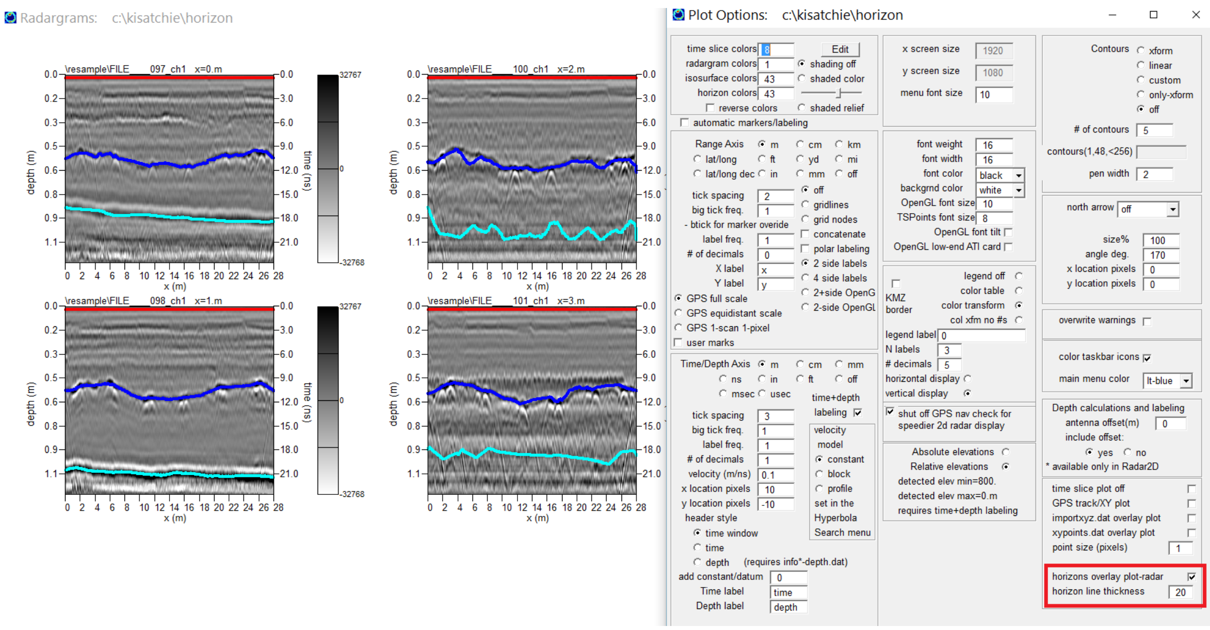
5. Click the Auto Detect button to start the horizon search and mapping

Once the horizon is detected it will be drawn on top of the radargram with the assigned colour for that horizon that is set in the menu. Once the horizon is drawn, the user can either engage a filter to smooth the detected horizon. The filter works by taking a scan length and a threshold. A moving average of the detected horizon is computed. If the local point is N threshold samples different than the moving average, then the filter will reset the local horizon to the moving average. Shown in the next figure is an example of a noisy detection which is easily fixed by run the Auto Detect with the filter engages (in this example the filter length is 10 scans and the threshold is 7). The user can also highlight any detected or drawn horizon by clicking the Draw/Edit button and then modify this horizon with the mouse if desired. Clicking the Save button will update the active horizon.



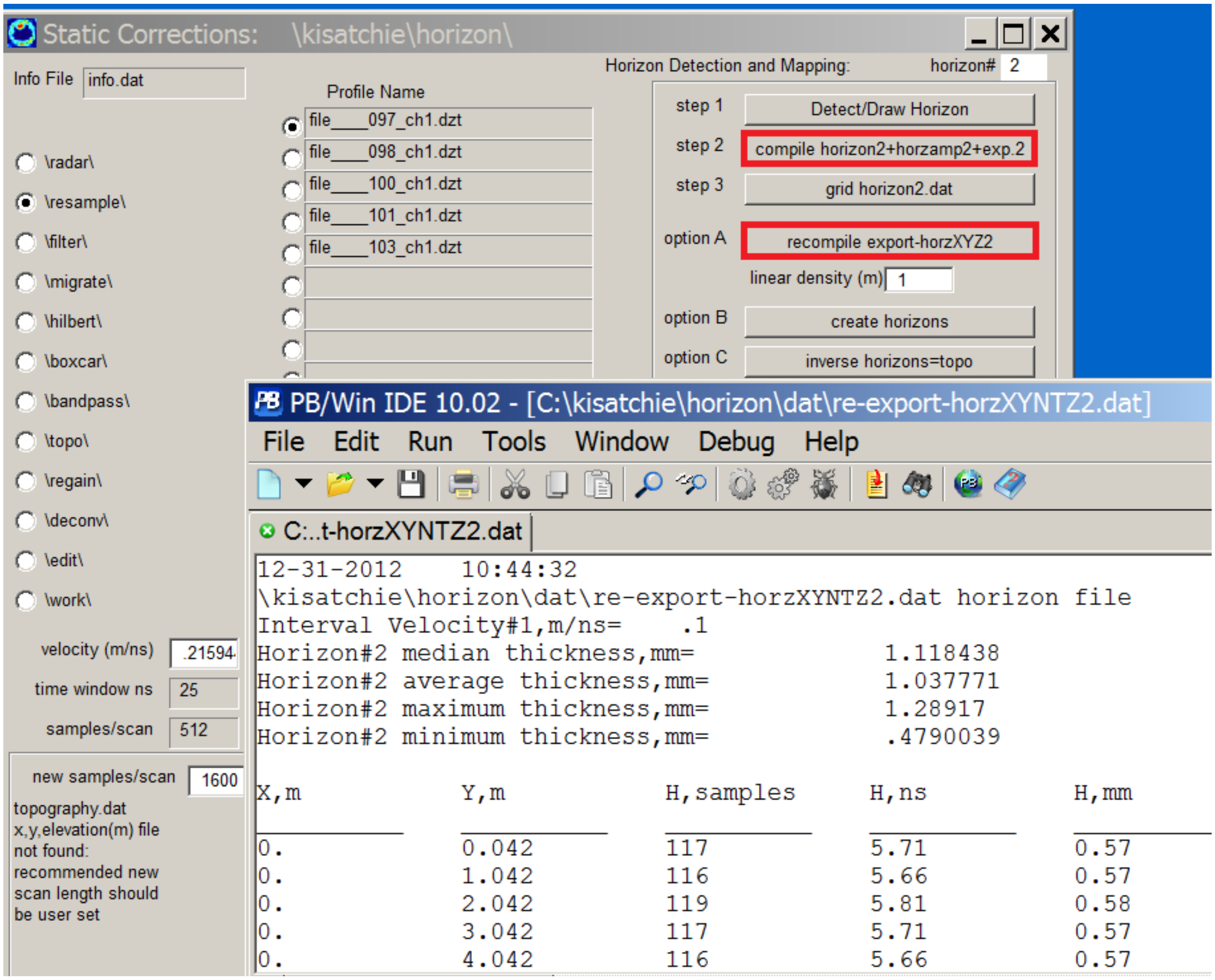
In addition to mapping the horizon depth using set velocities for each layer, the /amplitude of the horizon can also be shown. The previous diagram shows the amplitude of each detected horizon. (All licenses are given access to these options. Metal plate calibration layer thicknesses shown in the section after Auto Horizon Filter Settings are only available for licenses for GPR-SLICE v7.0 that include the full road license option).

There are options to have all the detected horizons to be displayed on multi-radargram displays in GPR-SLICE by using the flagged checkbox in the Options menu (as shown in the following figure):



Horizon Reporting

Once horizons are detected they can be compiled in several formats. The **Compile Horizon#+Horzamp#+Exp#** + **Recompile Export-HorzXYZ#** operations (where # is the desired horizon) will write 4 files:



There are several options available once the horizon profiles are created. The user can compile (step 2 in the previous screen shot in the Static menu) all the drawn/detected horizons to 4 different files:

horizonN.dat – A file written that contains the x,y and depth of the Nth horizon based on the velocity model used in the Horizon Detection and Mapping menu. The depth of the horizon is written in equivalent sample-scan depth corresponding to the radargram.

horzampN.dat – A file containing the x, y and amplitude of the Nth horizon, where the amplitude is the actual binary recording on the horizon.

export –horzxyz.dat – A file for export that is x, y, zn, zns, zd, where zn is the depth in digitized samples on the pulse, zns is the depth in nanoseconds, and zd is the depth based on the velocity model and for every scan in the radargram

re-export-horzxyntz.dat – A file for export that contains statistics and x, y, zn, zns, zd, where zn is the depth in digitized samples on the pulse, zns is the depth in nanoseconds, and zd is the depth based on the velocity model. Export is made at the desired linear density along the radargram. (For GPS radargrams the linear density is found by integrating along the track for reporting).

Export horizons can be recompiled to any desired linear density along the GPR track using the **Recompile Export-HorzXYZN** operation. This operation will create a Re-export file on the desired horizon that will also contain the median, average, maximum and minimum in the file. An example of the file is shown in the previous diagram. All the horizon reporting files are written in the \dat\ folder of the project.

Either of the horizon.dat or horzampN.dat files can be gridded (step 3) in the GPR-SLICE Grid menu to create a 3D horizon slicing surface or 2D horizon amplitude maps. These files are all written to the \dat\ folder in the project. The 3D horizon surfaces can be shown in Open GL Volume menus. The horizon surface grid files can also be processed or smoothed just as any normal grid files are processed.

Sometimes when the horizons are drawn by hand, a small 3x3 low pass filter is often useful to smooth out the bumpiness in the hand drawn or auto-detected horizon profiles that were detected without a filter engaged. The horizon profiles can be "re-extracted" from the smoothed grid file for all the radargrams by clicking the "Create Horizons" button (Option B). Making the horizon correction followed by time slicing the horizon corrected radargrams, essentially give one horizon slices as opposed to our normal 2d "flat" time slices.

Another option (C) that is available in the Static Menu for horizon operations, is the ability to create "inverse – horizons" or apparent topography profiles from the horizon profiles. In the case when a known stratigraphic reflector at depth is flat across a site and that site also has above ground topography, horizon correcting this layer to be flat, the apparent topography of the site can be detected. The topography is simply the inverse of the horizon profile. Clicking the "Inverse Horizons = Topo" button, will generate *.ctm files from the Horizon1.grd file, for each radargram contained in the survey. (Note: The *.ctm files can then be compiled to the topo1.dat file and gridding options here can be done to create the topo1.grd file if desired).

Metal Plate Calibration – Automatic Dielectric Calculations for Layer Thickness

GPR-SLICE has been programmed to do automatic dielectric calculations of the surface layer using air launched – horn antenna. In this highly practiced technique in road surveys, a metal plate is used to measure reflections back to an air launched antenna. These calibration amplitudes are then compared with ground surface reflections. The dielectric of the top surface E1 can be found using the formula (after:

$$E1 = [(1 + A/Am) / (1 - A/Am)]^{2}$$

where A=Amplitude reflection from top surface
Am=Amplitude reflection from metal plate

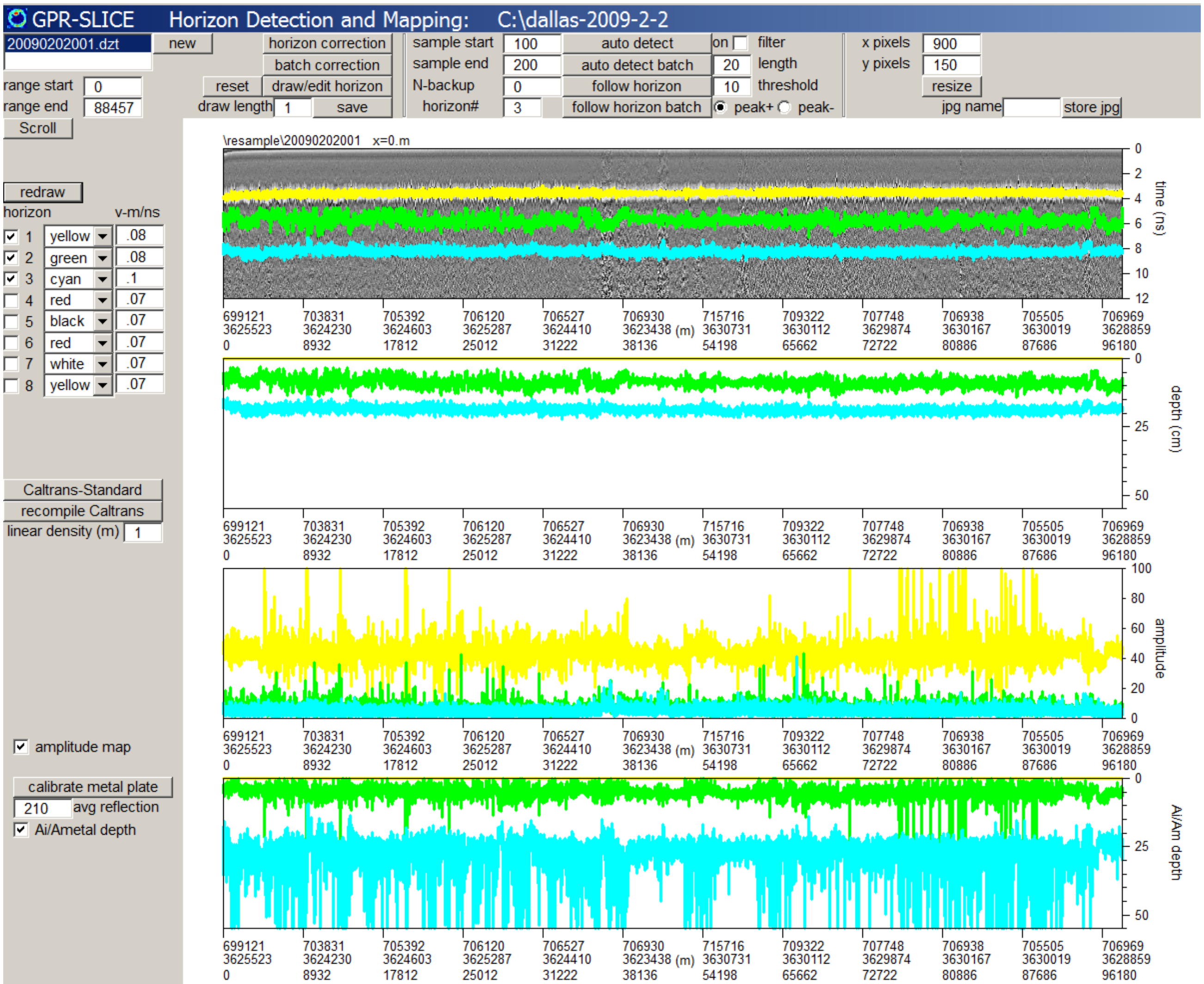
(after Saarenketo, 2009. NDT Transportation p395-444, in ***Ground Penetrating Radar Theory and Applications***, ISBN 978-0-444-53348-7).

The method can be extended down to the next layer yielding the dielectric of the 2nd layer interface as (after Saarenko, 2009)

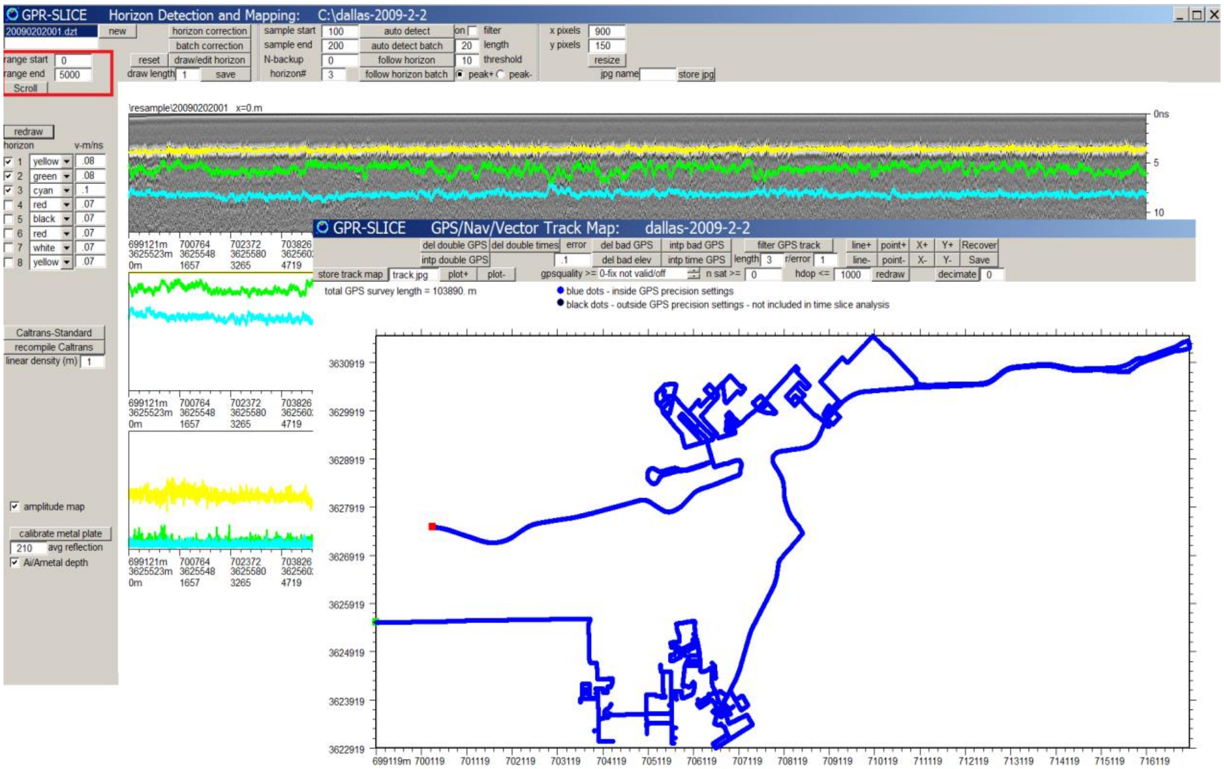
$$E2 = E1 \frac{(1 - (A1/Am)^{2} + (A2/Am)^{2})^{2}}{(1 - (A1/Am)^{2} - (A2/Am)^{2})^{2}}$$

With these automatic measurements, layer thicknesses of the top two layers can be generated. To use this feature, a file called metal plate.* must exist in the \resample\ folder of the project, and the Horizon detection must have been run on it. Clicking the button "Calibrate Metal Plate", the average amplitude reflection across the first detected – ground surface reflection – will be computed and stored in the menu item slot on the left side of the menu

Shown in figure on the next page is an example of the Horizon Detection and Mapping menu displaying 1) detected horizon profiles, 2) set layer thicknesses determined from velocity settings for each layer, 3) horizon amplitudes plots, and 4) layer thicknesses computed automatically using the metal plate calibration formulas. In this particular example some dispersion can be seen between the 2nd and 4th plots, but some correspondence is seen. Neither layer thickness plot is absolutely correct since attenuation is assumed to be nil in the metal plate method, and the constant velocity assumption for the 2nd plot could be an over simplification of the actual velocity variations in the subsurface layers.



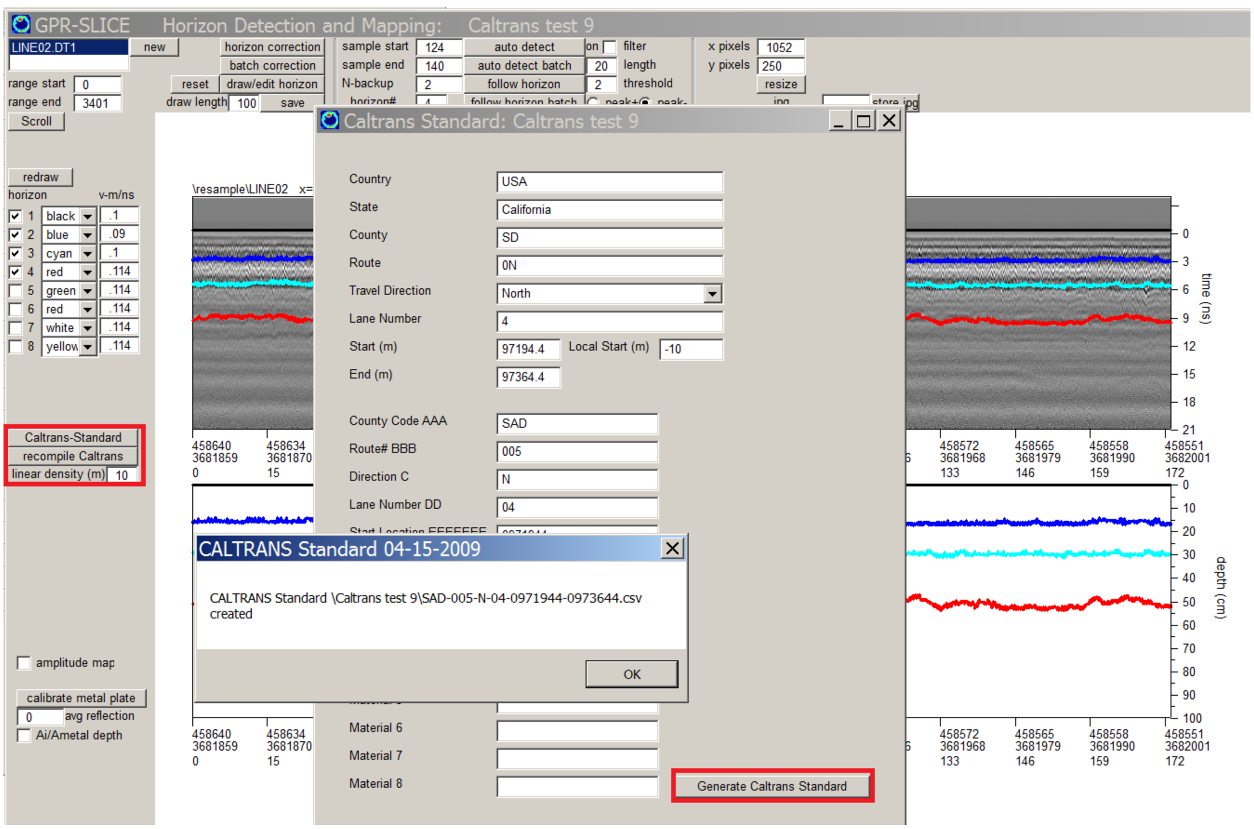
In the above diagram a screen shot of the Horizon Detection and Mapping menu launched from inside the Static menu is shown. With typical licenses, automatically detected horizons and the layer thickness plots are available (top 2 figures). With expanded Road license capabilities, surveyors can report horizon amplitude plots as well layer thicknesses computed from metal plate calibrations. The Caltrans Standard button for generating the California Dept of Transportation required data reporting is also accessed from this menu.



The Horizon Detection and Mapping menu is quite flexible in generating displays of very large datasets and placing these in to any size screen. In the above example taken from a 20km survey of downtown Dallas using horn antennas, a total of 88457 GPS pts were collected. The horizon detection can be shown for all 88457 pts or any portion thereof. By setting the range start/end and clicking the Scroll button any portion of the super long radargram profile can be displayed to the screen. The scrolling length of the window can also be changed to any desired length. This example was made to show on a single screen, however, the X pixel length setting in the menu could easily be set to 3000 or 5000 pixels for example and 3-5 screen lengths for showing the desired horizon mapping could be generated. The dialog can also have a jpg dialog dump which is not limited to the size of the computer display – but is set to the length chosen in the menu by the X and Y pixel length. Any portion of the data – and any size of output can be easily generated with GPR-SLICE v7!

CALTRANS Standard for road layer evaluation completed for the California Department of Transportation

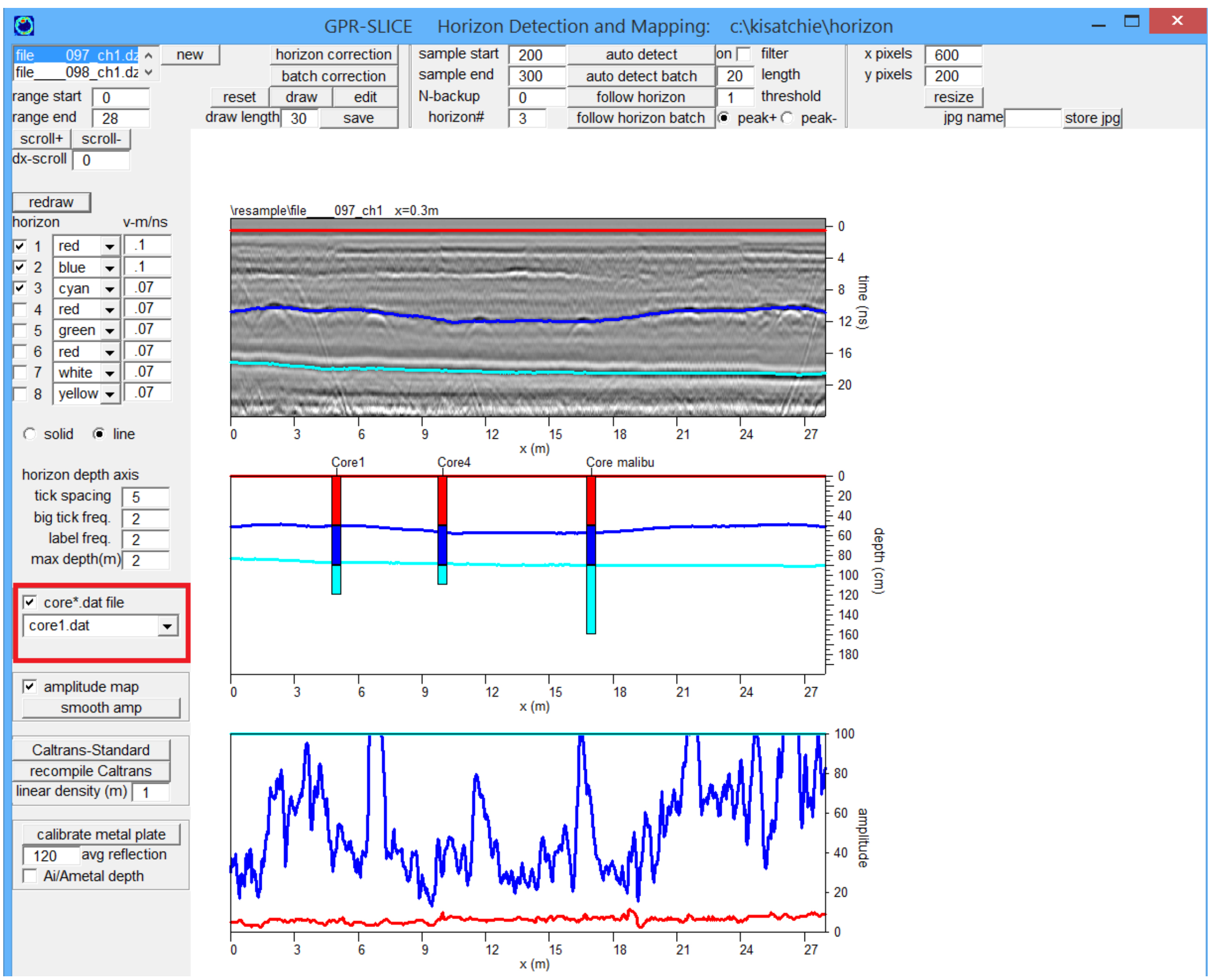
Along with the new layer calculation capabilities in GPR-SLICE, an operation to provide reporting all the layer thickness into a standardized format for road evaluation including GPS information, highway marker information, road types and host of other information are now included for advanced licenses. The information for reporting is contained in a California Department of Transportation publication and what is called the Caltrans Standard (California Department of Transportation) from here on out in the software. A button called ***Caltrans Standard*** in the menu will open up a dialog and allow for manual insertion of the necessary header items to go along with the required automatic layer detection information that needs to be reported.



Specialized options to report road layer thicknesses have been tested and further developed to meet the CALTRANS Standard. The module contains all the necessary analytical operations for road layer horizon mapping and to report these results in the CALTRANS Standard file format. An operational button to recompile the road layer results to any desired density on the ground was implemented to complete the CALTRANS Standard reporting.

Note: The functionality for recompiling horizon mapping results to any desired output density is also available for all regular GPR-SLICE licenses as well, in the Static menu. A comma delimited file export-horzXYZN.dat where N is the horizon number will be written to the \dat\ folder of the project. The file will contain the detected horizon for all the radargrams in the project. (Non CALTRANS reporting is available to all GPR-SLICE licenses in the Static Menu – see Horizon Reporting section a few pages earlier).

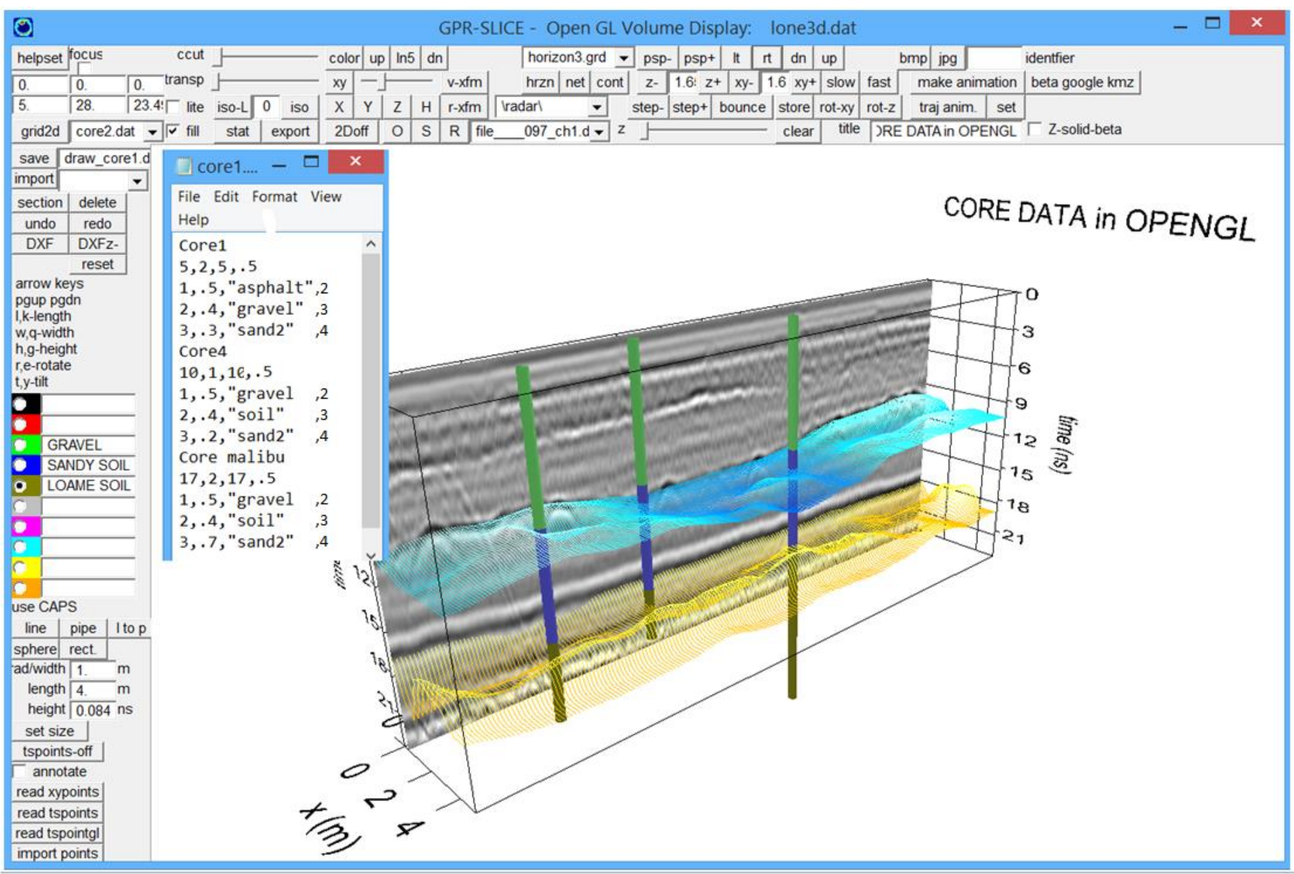
Drill Core Information Overlay



Information from drill cores on a site can be displayed in the Horizon Detection and Mapping menu as well as in OpenGL Volume Draw menu. The information from the drill core are written to files that must begin with core*.dat and are stored directly in the main project folder. The format of the core file should be

Core***
Range along profile, x, y,core radius
1,thickness,”material name”,,color number (1-10)
2, thickness,”material name”,color number (1-10)
Etc
N, thickness,”material name”,color number (1-10)
Core*** repeat

An example is shown in the previous screen shot with 3 cores in the Horizon menu and the same data in OpenGL Volume Draw menu along with a screen shot of a core file format below. The radius of the core can be customized in the file. If it is not set the default radius in the OpenGL Volume Draw menu will be used.



Depth Radargrams

Almost always, radargrams that are displayed are usually shown in time. Often a depth scale is provided which is based on a nominal velocity across the site. These radargrams are usually though just referred to as “time” radargrams as they do not account for laterally varying velocity layers. Using the Horizon menu and detecting up to 8 horizons including the ground surface, an actual depth radargram can be converted using the layer velocity model and the horizons detected. GPR-SLICE will adjust the depth the binary values in a radargram based the actual velocity between chosen layers and using their interval velocities. If some layers have very slow velocities, these regions of the radargram will look much narrower in actual depth then as seen on a time radargram. Likewise, layers with much higher velocities will be adjusted to their true variable thicknesses across the radargram and these regions will be much thicker than in the time radargram display.

To make a depth radargram, the user will first set horizon 1 – the ground surface horizon, followed by the next horizon #2 and so on in the Horizon Detection and Mapping menu found under Statics (see next screen shot). Once the horizons are set along with their respective velocity, a z cell size along with the maximum depth desired to convert the radargrams is chosen. The cell size will determine the digitization of the depth radargram in the vertical. One should currently choose a value - along with a maximum depth setting - that will generate a depth radargram that is slightly lower in the original time radargram digitization, such that no null cells are created. Clicking the Depth Radargram button, will start the conversion from time with the final depth radargram being written to the \topo\ folder. After execution, a new message box detailing the info-depth.dat information file and the corresponding samples/scan of the depth radargram will pop up to the screen. The depth radargram can then be independently displayed in the Radar 2D menu (see screen shot following pages). A special radio button in the Options menu will force the y axis display to be just in depth. For depth converted radargrams, the time window is replaced with the depth in the profile information file!

Note: Depth radargrams will not be flat on the bottom depth range if velocities are different between the layers. Null binary values are recorded in the radargram on the bottom. One can adjust the end sample display if they wish to cutoff the variable bottom in the Radar 2D menu and not show the null data.

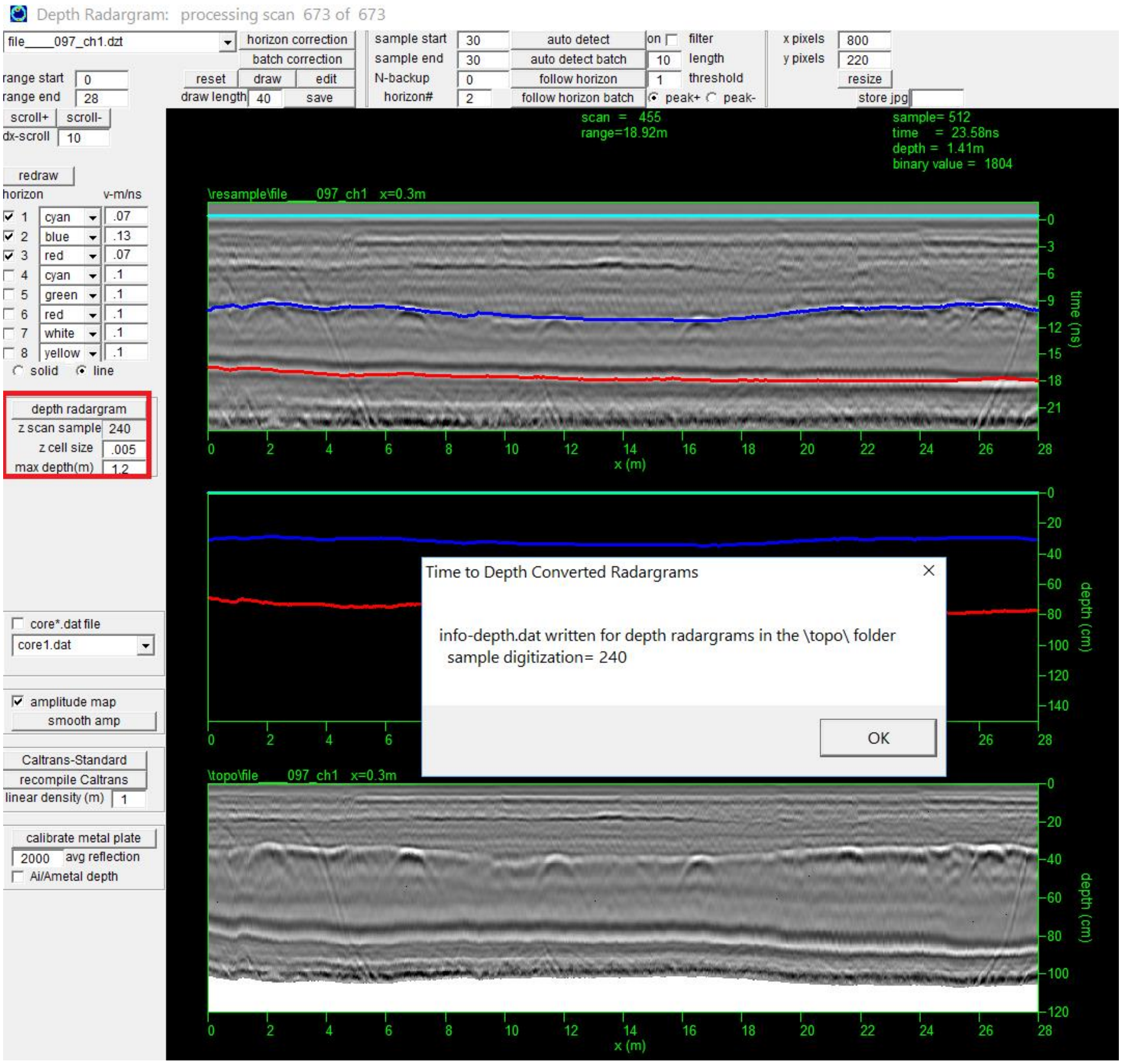


Figure 1. Depth radargrams, converted using the layer velocity models, are now available in the Auto Horizon Detection menu.

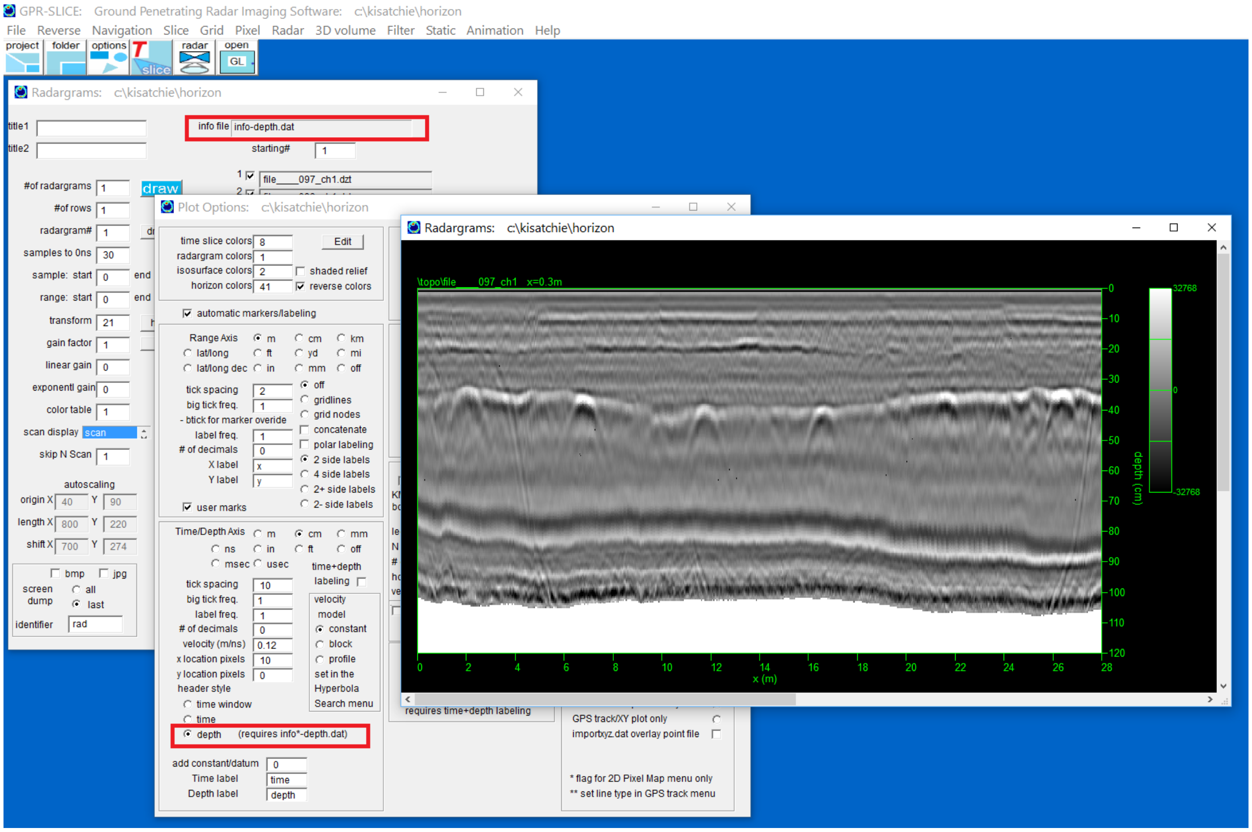
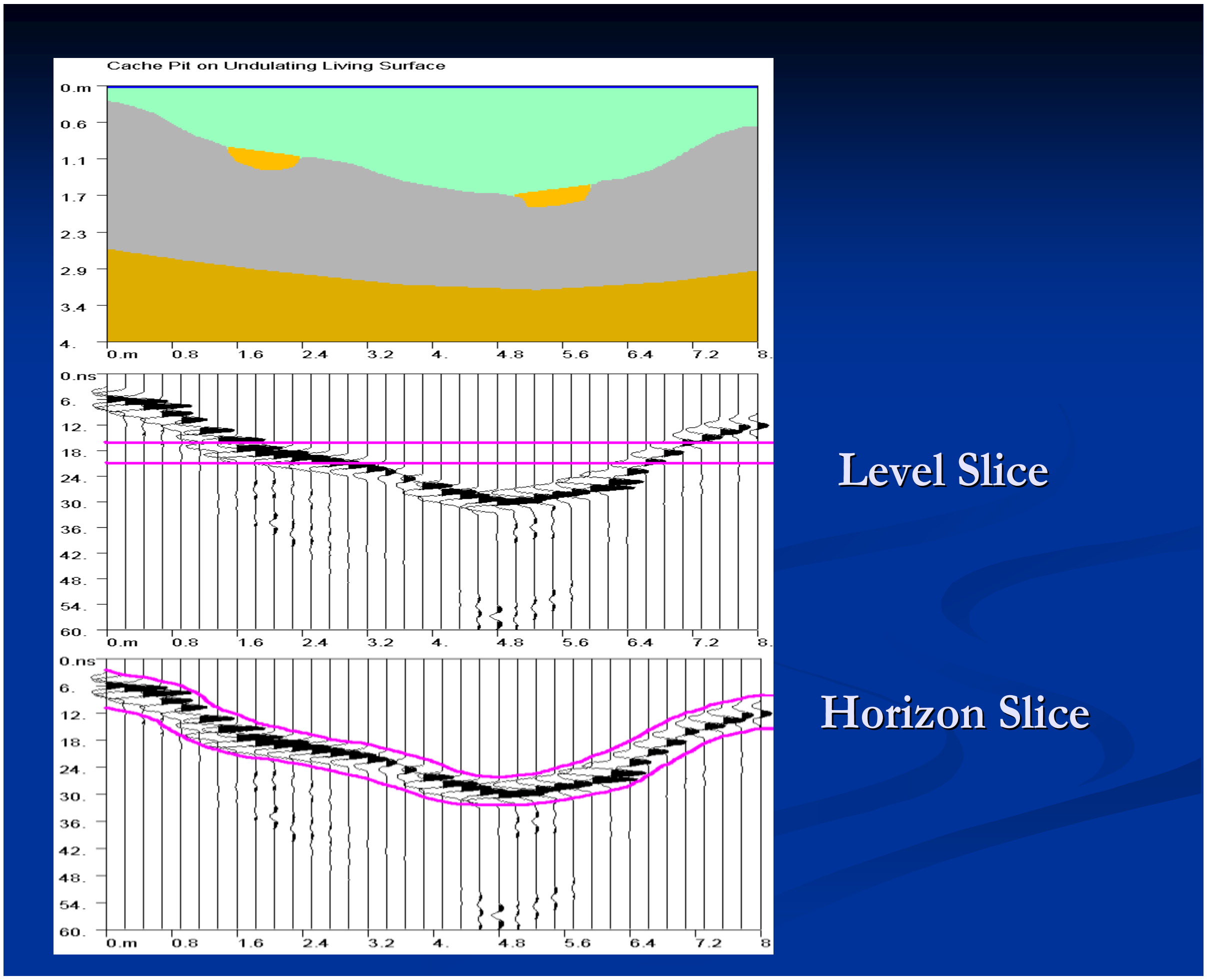


Figure 2. Converted depth radargrams can be displayed with only depth labeling using the "depth" radio button in the Options menu.

Horizon Correction

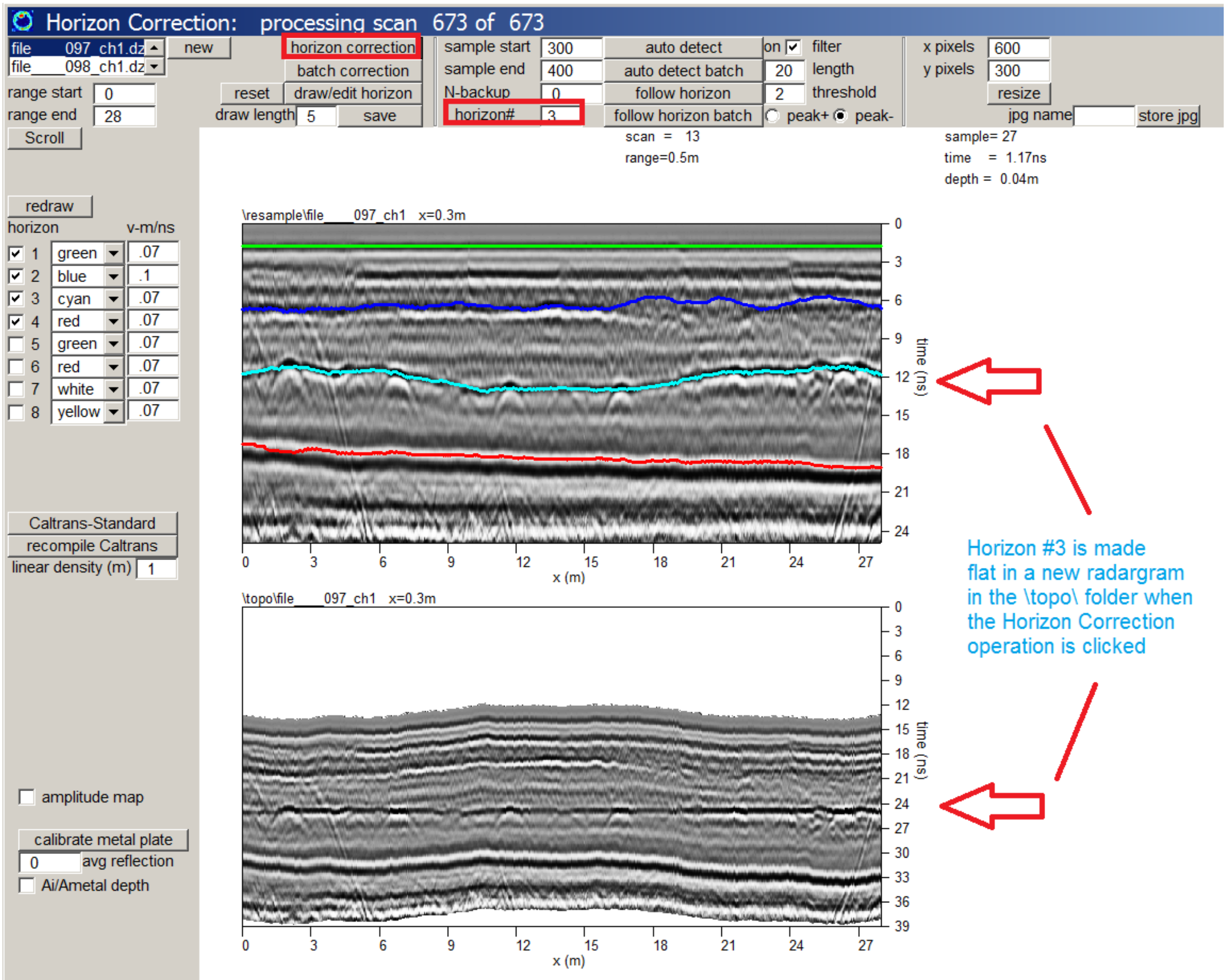
The Draw Horizon Menu has options for drawing a horizon profile across a radargram following a stratigraphic layer. The horizon correction will "back correct" the horizon to be flat and write a horizon corrected radargram. All static corrections for both topography and horizon operations on radargrams are written to the \topo\ folder. Horizon corrections are useful when time slices that are not level across the radargrams is desired. Once the radargrams are horizon corrected, then regular time slice processes are applied to this dataset. In essence, a 3D slicing surface can be generated in order to create "horizon slices" – slices that follow the 3D surface.

Shown below is an example of when horizon slices are more useful the level time slices. If one wants to find anomalies within an undulating subsurface layer, then making level slices in time will create anomalies which are more sensitive to stratigraphic changes. A horizon slice which follows the undulating layer will have a better chance of imaging anomalies which are buried within the undulating layer. Horizon slices have been used to map pit dwellings within undulating living surfaces from the Jomon period in Guma Prefecture.



In the Draw Horizon Menu, the user can draw a horizon profile across the radargram and then run the Horizon Correction process. The process can also be run in batch by importing an xyz horizon file following the steps similarly given for the batch topography operations. The microwave velocity and an appropriate new samples/scan need to be set in the Static Menu before beginning horizon operations.

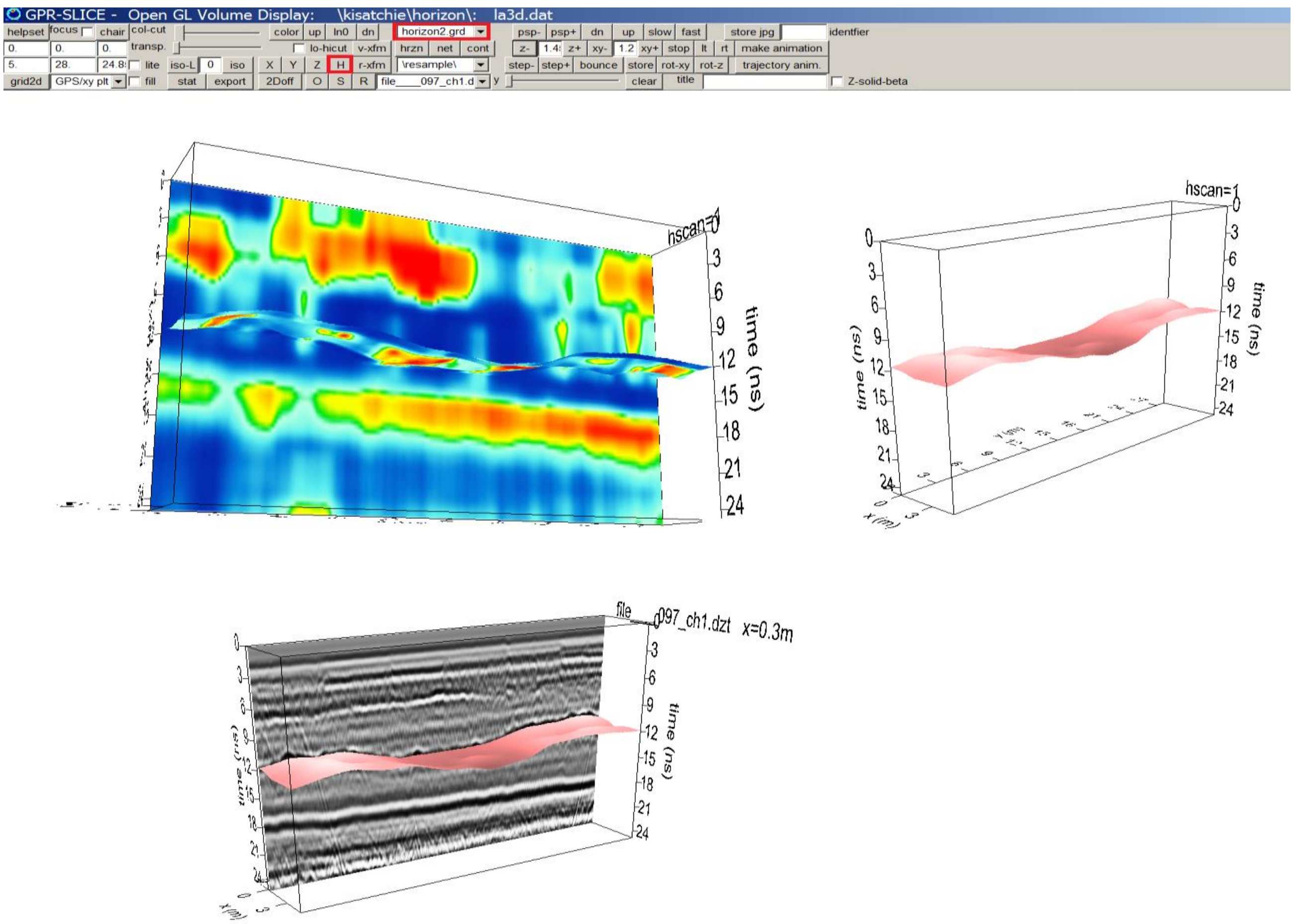
Horizon corrected radargrams are also written to the \topo\ folder. Running the standard slicing procedures on the \topo\ folder (making sure to create a new info file, e.g. infotopo.dat with the new samples/scan included), horizon slices will be generated. Horizon profiles are stored as *.hoz files in the \topo\ folder for each radargram. An example of a horizon correction made on a is shown below for the 3rd Horizon detected.



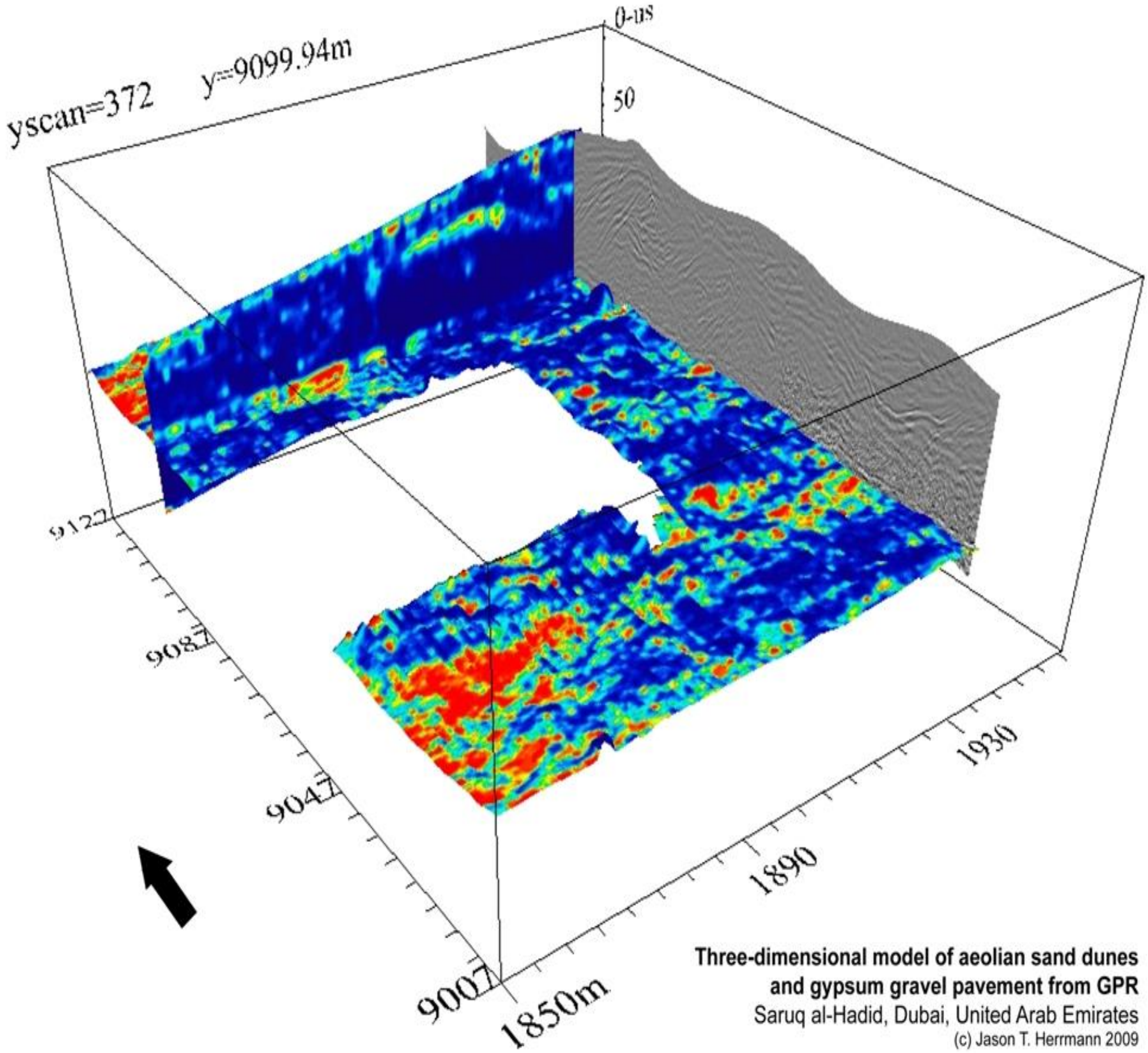
Horizon Slicing

Horizon surfaces which are generated in the Static menu can be used to slice the Open GL Volume using the new "H" button. To access this feature, the desired horizon detected is highlighted in the Horizon listbox. Clicking the "H" button will display the horizon surface and the amplitudes within the volume. Horizon surface amplitudes are particularly valuable in finding amplitude changes following variable subsurface stratigraphy. In archaeological applications, non-level ancient living surfaces can be mapped and reflection changes following this ancient surface can yield areas where pit house or other archaeological features may be hidden. Simple level time slices would have imaging artifacts associated with slicing through subsurface topography which would usually hide buried features.

An example of horizon surface mapping is shown below. This horizon project is part of the Kisatchie Advanced Workshop folders available on the ftp site (www.gpr-survey.com/practice).



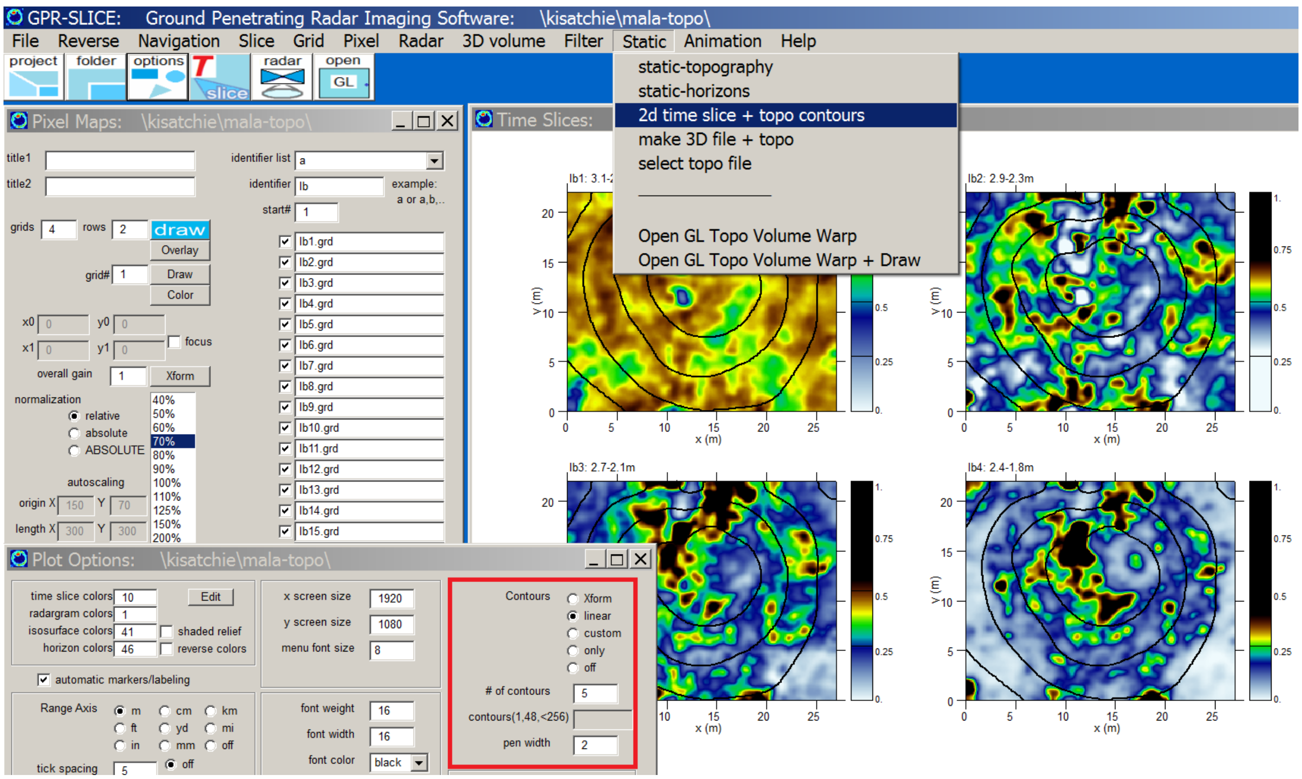
Another example of a horizon mapping image was developed by Jason Herrmann from the University of Arkansas and used in his study of ancient living surfaces beneath sand dunes in the United Arab Emirates. Jason's has used topographically corrected radargrams and then detected horizon surfaces using the automatic features in the Draw Horizon menu. He then compiled and gridded the horizons from the Static menu and displayed these surfaces in the Open GL Volume menu.



Note: The horizon surfaces displayed are made from the time windowed - and spatially averaged reflection amplitudes for generating the 3D volume. An alternative horizon dataset can be generated which represents just the peak response of the detected horizon – using a single value of the peak response. When the auto detection process is run in the Horizon Detection and Mapping menu, in addition the horizon profile, the amplitude of the detected horizon is output to a file in the \topo\ folder called horzampN.dat as previously discussed. These horizon amplitude files can be gridded and displayed in the regular 2D Pixel map menu. These values represent just the peak response of the detected horizon and do not represent windowed horizons which are generated in the 3D volume. Either the peak + or peak – response can be detected and reported in the output files.

Note: To get the best horizon slices it may be necessary to increases the number of interpolations to generate rather denser 3D volumes in the z direction for import to Open GL.

2D Time slice + Topo Contours



Time slices can be overlaid with the topographic contours. This option is entered through the Static pull down menu. An active topography file which has the exact same starting and ending locations as well as the same grid cell size as the time slice must be used. The topography file will normally be imported in the Static correction menu and then gridded over the same area and grid cell size as used for the time slice maps. Level plane time slices made from either topography corrected radargrams or even extracted from topography adjusted 3D volumes can be displays with the topo contours. Even imported data (e.g. from mag or resistivity or em) can be overlaid with topo contours as long as the grid sizes and cell sizes are the same.

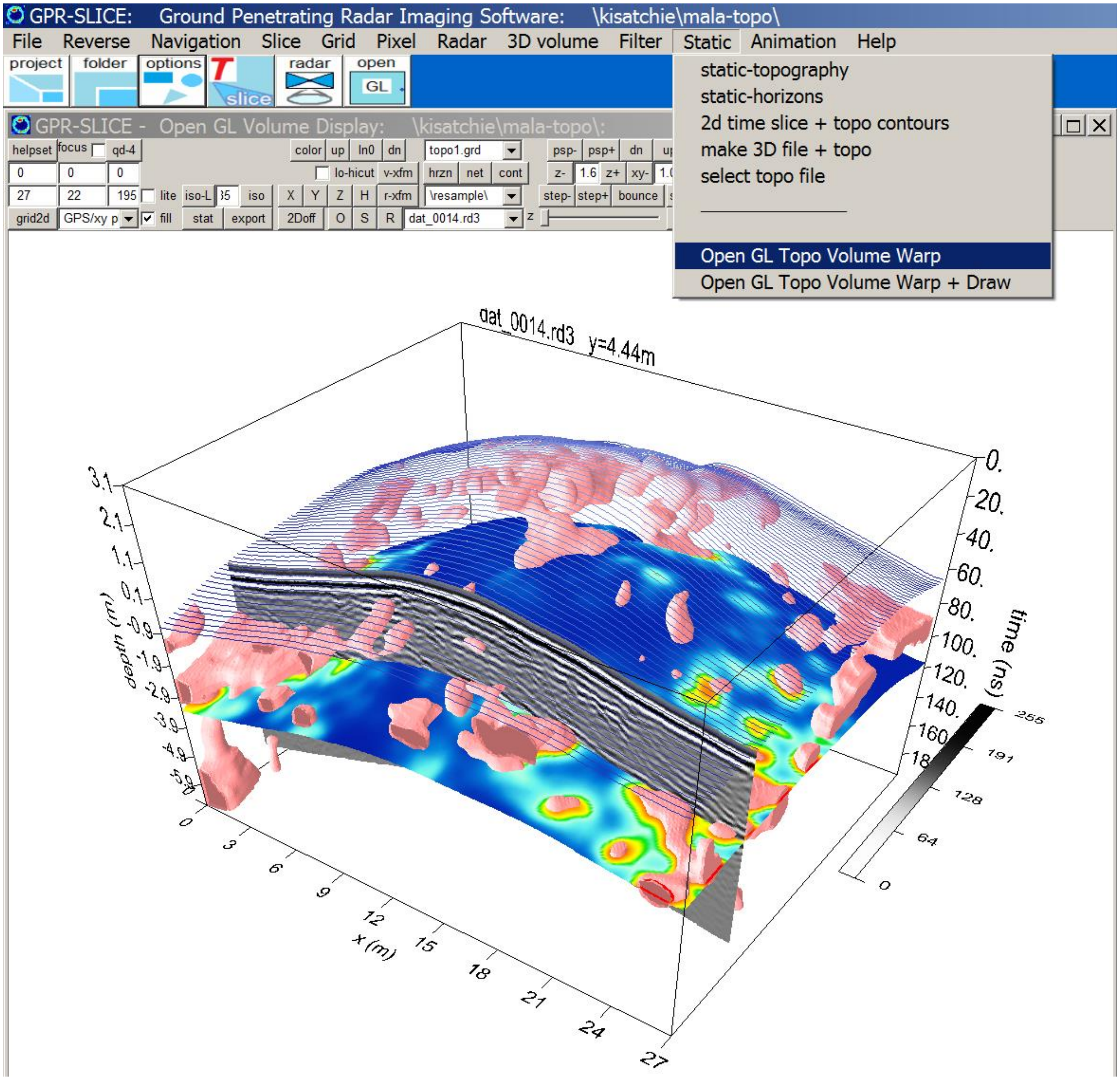
Note: The number of contours to use for the topo map is set in the Options menu along with the contour pen thickness.

Open GL Topo Volume Warp

Most of the discussion in the static options in the software is concerned with correction of datasets for topography before display. This means the datasets/files are actually rewritten on disk to account for elevation changes across a survey. For binary radargrams, new binary radargrams with extended samples/scan are written to account for elevation, and for 3D files, new binary file is rewritten to account for elevation. These files can get very large on disk and sometimes displaying them with available graphic resources can be problematic. Particularly for sites where the elevation change is much larger than the depth of the digitized radargrams, showing a topographically adjusted radargram that is rewritten on disk, may not be able to display if the size of the new binary radargram is beyond the limits of the graphic memory.

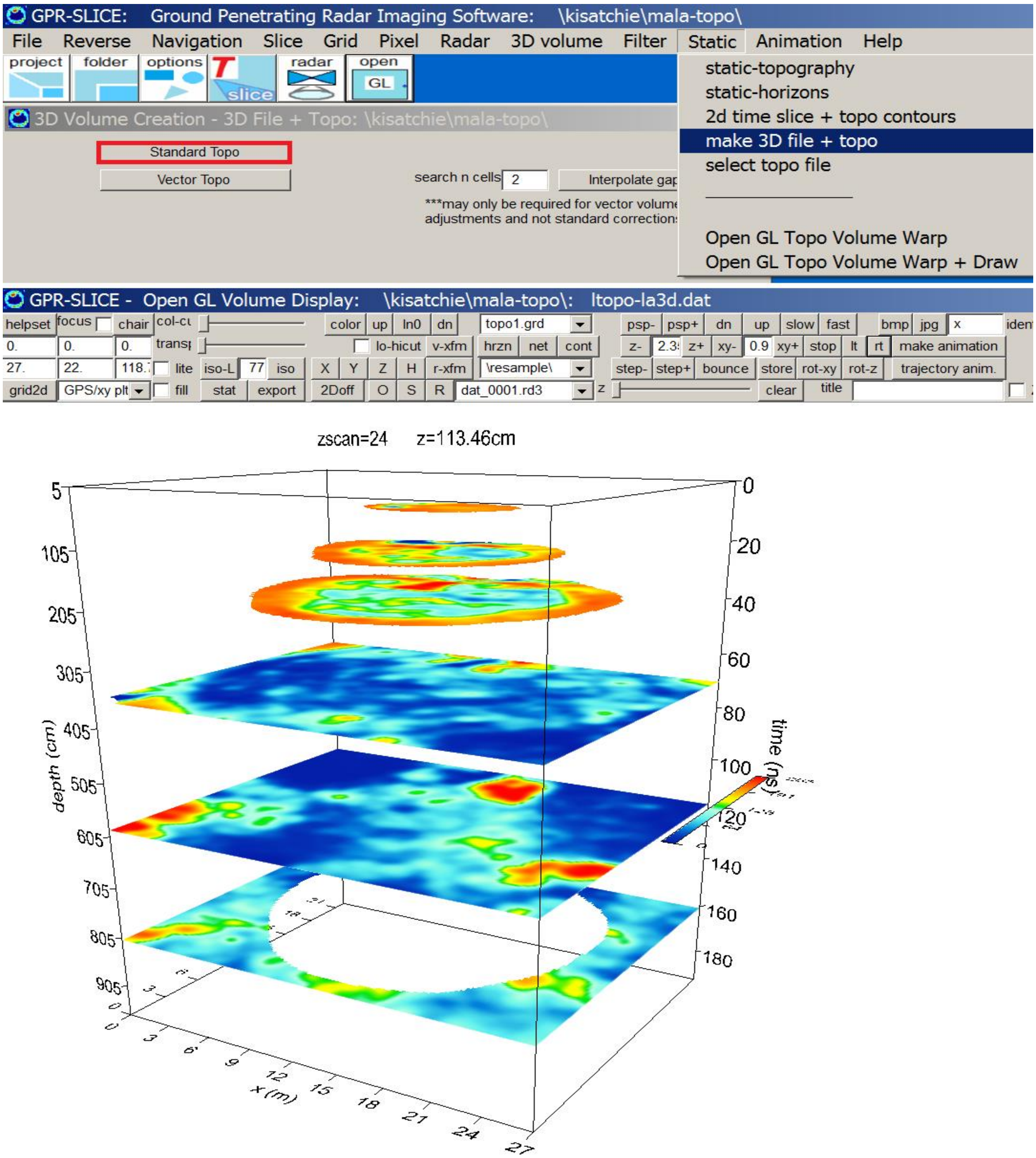
An option now exists in Open GL Volume to simply warp elements into the topography grid without actually having to read topographically adjusted files. The option called Open GL Topo Volume Warp will import a flat rectangular volume and then warp the volume following the topography grid file. In addition, this menu can also warp radargrams as well as isosurface to follow the topography. The advantages of these displays are they are faster to display and only require the topography uncorrected files in doing the warping. The Open GL Topo Volume Warp menu is limited to showing topo time slices and cannot show level plane time slices. To show level plane time slices, corrected data volumes must first be generated as discussed in the previous sections, and then these corrected volumes are slice horizontally in the regular Open GL Volume menu (described in next section).

An example of a 3D volume which is simply warped into topography is shown in the next screen shot with a radargram, isosurface, z topo plane as well as the net topography display. Using the Net button, the topography can be placed inside the graphic dialog. Clicking the Net button several time cycles through various hardwired density of the displayed net line.



Level Plane 3D Slices – Making a 3D Binary File + Topo

An option exits in the Static pull-down menu to create a standalone 3D binary file which has been adjusted for topography (see the next diagram). Normally, one can create a 3D binary file that is uncorrected for topography. Then, after the topographic grid is generated, the 3D binary file can be adjusted for topography. The requirements are that the X and Y dimensions of the 3D binary file and the topography file must be the same. The new topography adjusted 3D file will have a Z dimension which is the addition of the 3D file Z dimension plus the effective sample depth of the topography. One should be careful in creating these topography files as the size of the 3D topography adjusted files can be quite large. Sufficient computer resources may be required to actually be able to read in these files for 3D displays.

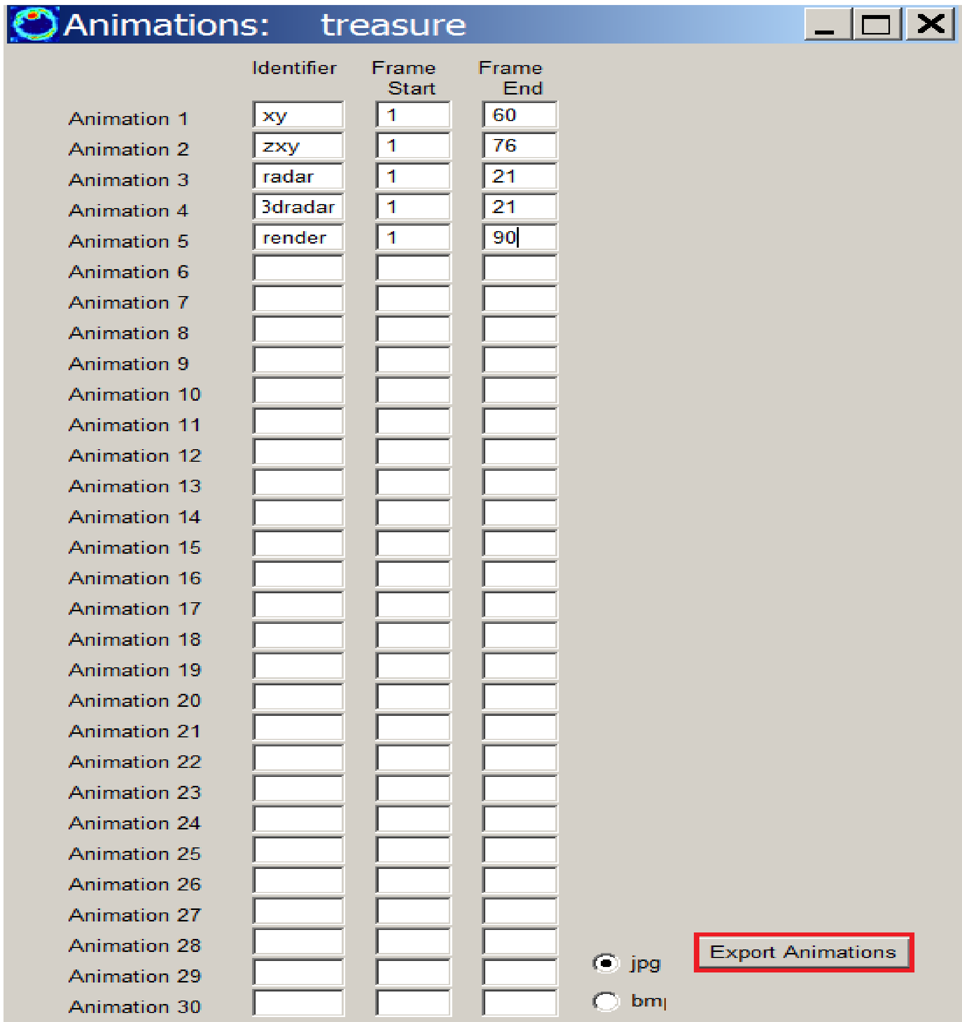


The new filename for the topography adjusted 3D file is automatically written automatically as “topo- + original 3D filename.dat”. This filename can be entered into the Select 3D File slot in the 3D Volume menu and all the 3D volume display options are available. The advantage of using the 3D topo adjusted file is that the user can make 3D level plane time slices in the normal Open GL Volume menu.

One advantage of creating level plane time slices using the 3D topography adjusted volume is that one can avoid the “peeling effect” which often accompanies making time slices of topography adjusted radargrams. The peeling effect comes from time slicing raw topography adjusted radargrams and is caused by the strong ground reflection signal which dominates the outside data contours. The peeling effect subsides after the time slicing is completely below the ground surface reflection when considering the topography as well. The topography adjusted volume, since it is normally created with normalized time slice maps, the ground surface or upper time slice is not necessarily dominating the reflection volume. Level plane slicing of this dataset will **not** show a strong edge effect at the border of the topography where the slicing is made. The peeling effect in time slicing of topography adjusted radargrams can however if background filtered radargrams are used rather than raw radargrams. Nonetheless, the topography adjusted 3D volume which is first generated from slicing flat-uncorrected radargrams, removes the peeling effect without having to apply background filters to the raw data. Background filters can often remove important features in the data. The features from creating the 3D topography adjusted volume can help the user to preserve the original integrity of the data which may better assist them in detecting real subsurface features.

Animation Menu: Overview

Creating a Stand Alone Animation Folder



The user can create a stand-alone folder which contains all the animations created in their GPR-SLICE project. The animation software is available to GPR-SLICE users and they can give this portion of the code to their clients free of charge without a license. To create a standalone animation folder, do the following:

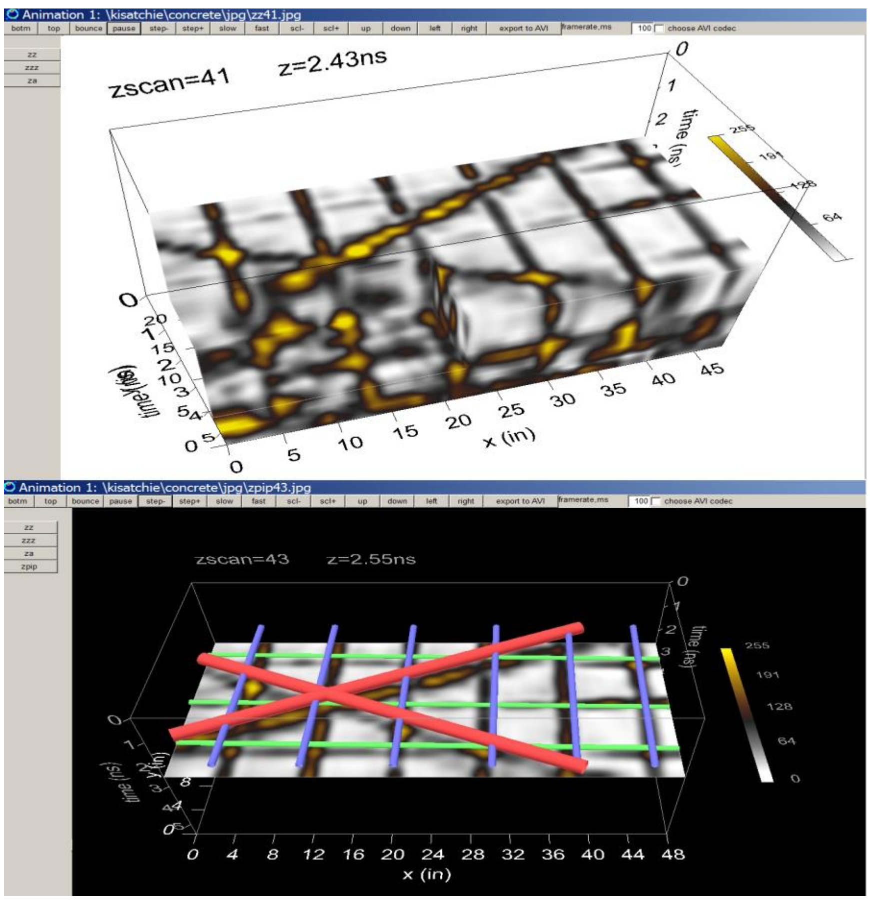
1. Create your animations, currently up to 30 per project

2. Click the "Export Animations" button at the bottom of the Animation List Menu (see menu picture below) …. that's all

The action on step 2 will create a separate folder in the project called \animation\. This folder contains the GPR-SLICE Animation.exe and the necessary dlls (dynamic link libraries) for the exportable animation to run. The folder will also contain a copy of all the JPGs (BMPs) that the user created for the animation.

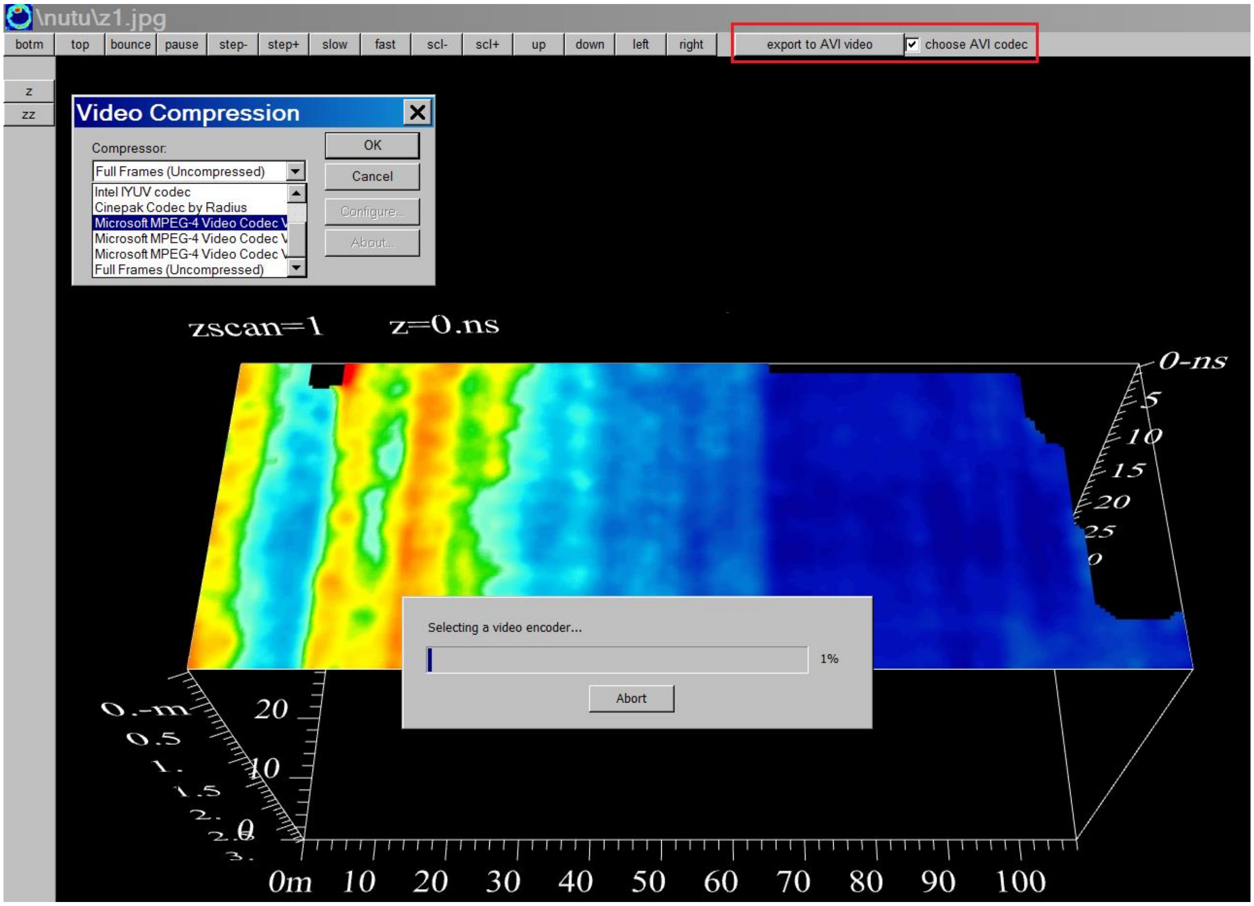
GPR-SLICE has the capability to show 2 animations running simultaneously on the computer screen. Whatever animations are kept in the Animation list, will appear as button on the left side of the animation menus. To get an animation to run, first click the desired animation button, then click the Bounce button. The animation will run from the top down. The user can pause, or step through the animation one-by-one by clicking the appropriate menu buttons. A convenient scaling button is also on the menu. Scaling the animation can degrade the picture for the animation since raster graphics are being used.

An example of 2 different animations that the user can generate and have run simultaneously as different threads is shown:



AVI creation

We have had several requests to provide for AVI video creation of the GPR-SLICE animations. I gave this task to Justin Klein and he was able to find a seamless solution which we now provide for in the Animation menu. A new button called **export to AVI video** will read the jpgs and create an AVI using the installed codec (shown in the diagram below). Updates to GPR-SLICE for AVI generation required 2 new files from version v6.0. One file is a dynamic linked library with the name Img2vid.dll, along with a uc_ms_mpeg4_pack.exe executable. The executable will install mpeg4 codec should you want this format installed. There is a **choose AVI codec** option as well that if clicked on, will allow for different installed codec. One may want to check the format of the installed codec to make sure the video sizes will acceptable. Some of the formats can generate AVI files which are several 100mb or more which are probably not wanted. Mpeg4 will have the fastest video creation and also have the most packed video file format without much loss of resolution.



Special Topics

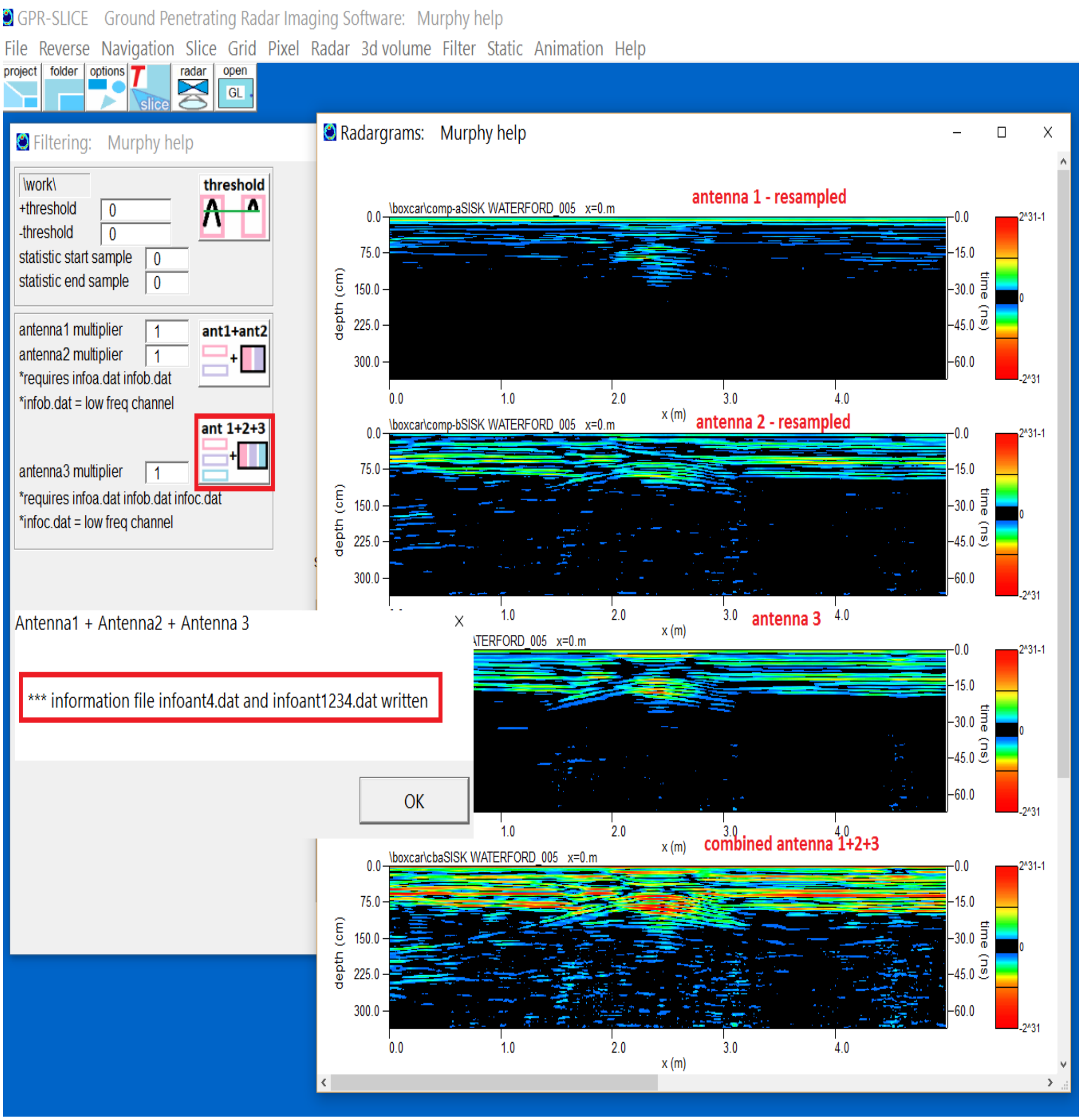
Combining multi-frequency antennas

A new option is available in the Analytics pulldown menu to combine low frequency and high frequency antenna (see following figure). The operation will combine either dual frequency or triple frequency radargrams. For some manufacturers, the time windows are different between the low and high frequency channels. For dual frequency operations, the high frequency and low frequency information files must be named infoa.dat and infob.dat with infob.dat being the low frequency channel (the channel with the longest time window). For triple frequency blending (such as for data from US Radar's Quantum Imager system or from UTSI Electronics), the software looks for infoa.dat, infob.dat and infoc.dat with infoc.dat being the low frequency channel having the deepest time window.

To accommodate for the variability in time window and pulse digitization between the different antennas, the software operation will automatically scan resample the high frequency channels and make separate channels with equal time windows. The bottom of the resampled channels will have null – 0 data. The filename for these generated channels is appended with the name "comp-" to signify compression – which is essentially the mathematics that is applied to match the digitization of the time windows for each channel. These scan resampled radargrams with the "comp-" identifier are written to the exact same processing folder highlighted.

After the operation is run 2 separate information files are written. For combining just 2 frequencies the software will generate the infoant3.dat and the infoant123.dat files. Infoant3.dat has just the name of the combined radargram which is appended with the name "ba" on the blended radargrams. The information file "infoant123.dat" will contain the names of the low frequency resampled channel, the high frequency channel and the combined radargram name. Similarly, for combining 3 antenna frequencies, the info file names generated are infoant4.dat and infoant1234.dat which will have the combined radargrams and the separate 3 frequencies and the resultant radargram. The infoant123.dat and infoant1234.dat files will make it easy to examine all the separate frequencies and the combined radargram for viewing in the Radar 2D menu.

Note: Currently the operation assumes that time 0ns is the same between the different antenna. If time 0ns is significantly different, then radargram editing operations should be run prior to combining the different antenna frequencies. Each antenna can also be blended with their own multiplier constant. If the constants are set to 1 for each channel, there is a potential for the combined radargram to have clipped pulses that go beyond the binary resolution of the data recording. In this case, one might opt to set each antenna multiplier to 0.333 for the combining operation.



Mosaic Correction

Ground Penetrating Radar (GPR) radargrams can be subject to a host of noises, including mosaic noises. Mosaic noises represent abrupt changes in background reflection strengths recorded between adjacent or nearby survey fields. The abrupt changes can be a result of equipment noises, geological noises, and/or varying field conditions caused by weather. In addition, untrained operators of GPR equipment can also accidentally insert mosaic noises into the data if inconsistent radar control unit settings are used to study a site. GPR surveys which occur over several field days will often lead to inherent mosaic noises in GPR datasets, since soil conditions can vary significantly day-to-day.

Whatever the cause for mosaic noises, their removal during post processing is essential to detecting continuous subsurface features across a site. In GPR-SLICE v7.0 Software, several methods currently exist for removing mosaic noises. Some are in the stand along Mosaic Correction menu and others are located in the Slice/Resample menu with corrections made to the ASCII time slices. The most time consuming corrections but which can always give the best results involves making subgrids, adjusting the transforms individually and appending the subgrids to combined grid in the Pixel Map menu.

Among the mosaic corrections available are:

- Screen capture and gaining (Mosaic Correction menu)
- A variation on screen capture with regridding (Mosaic Correction menu)
- 0 median grid/ 0 mean grid (Mosaic Correction Menu)
- Transform matching and grid appending (Pixel Map menu)
- 0mean grid/ 0mean line/ Edge matching /Histogram matching (Slice/Resample menu)

The first method involves capturing rectangular areas which have different gains and then adjusting real time. A variation on the first method where the gains used in the real time adjustments on blocks are then used in the re-grid calculation. The other methods involve breaking a large survey grid into numerous sub-grids where mosaics are identified and then applying some kind of data transforms to best match all the sub-grids. A composite grid containing all the transform adjusted sub-grids can then be synthesized. Another method involves simply capturing individual mosaic regions from within the large image containing mosaic noises, and applying gaining to individual areas real time. Some statistics can be applied which can match the median or background values between sampled areas automatically.

Mosaic corrections have been successfully applied in many GPR surveys, including a survey at the Irebaru site in Chatan City, Okinawa by the Geophysical Archaeometry Laboratory. Severe weather conditions caused extreme noises in the time slice datasets. Shown in the diagram in the next page is a time slice map with a mosaic problem. The mosaic was caused by rainy conditions that altered the background reflections above y ranges of 20m

Mosaic Correction Method: Screen Capture and regaining

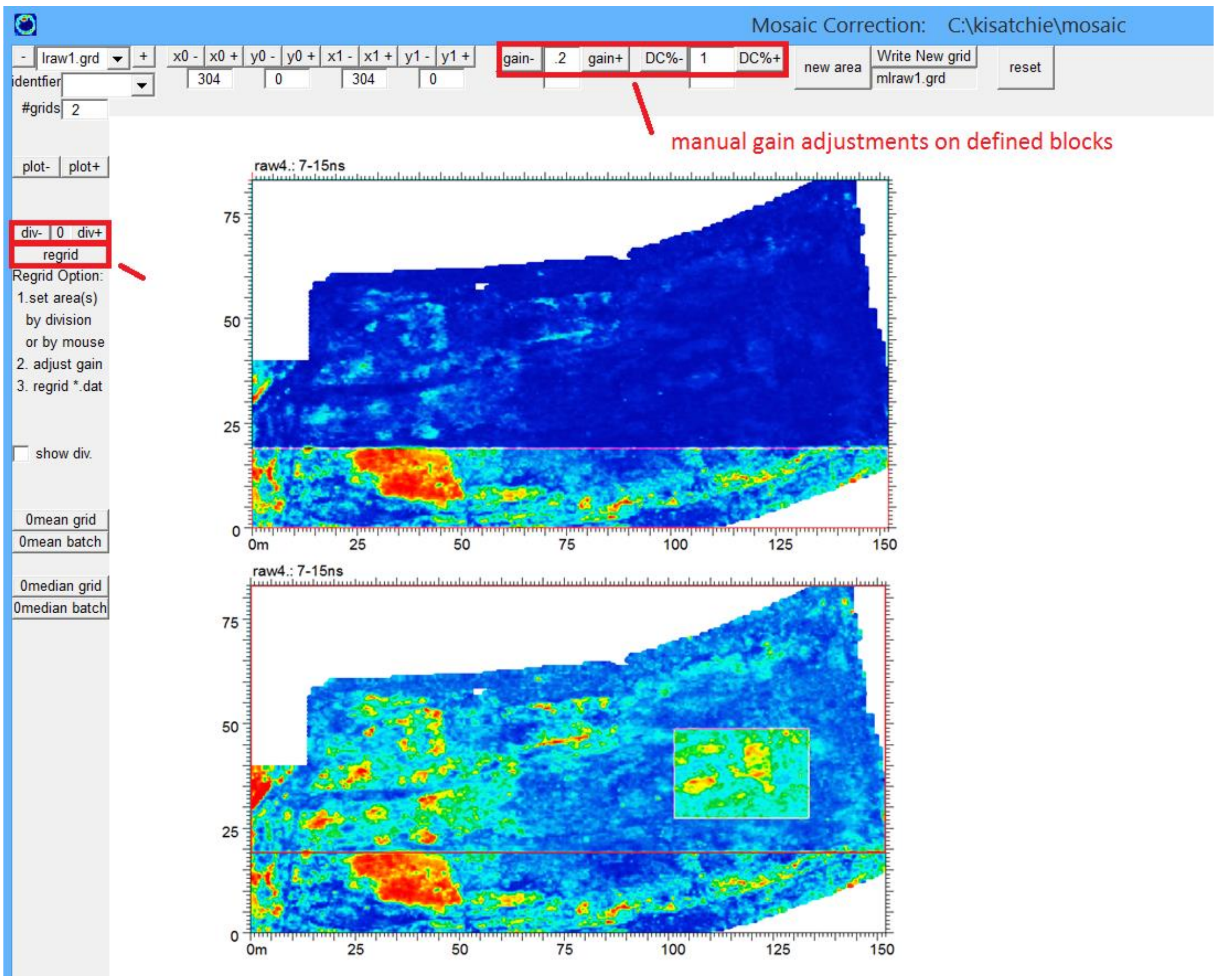
The easiest way to fix mosaics is too launch the Mosaic Correction Menu located on the Pixel Map pull down menu (see diagrams on the next page). In this menu the user has the ability to capture areas with a mouse and then apply or decrease the gain in the area. Clicking the gain+/- switches will add or decrease the reflections in the captured area. The user can use their eyes to determine when a good match is made. If they like the correction, by clicking the "Write New Grid" button, a new grid with the prefix "m" will be written. The time slices displayed in the menu are chosen from the setting in the Pixel Map menu. The user can import other grid numbers in the dataset in this menu. Also, a button to add, rather than multiply grid values over the captured mosaic region is available. Clicking the DC +/ will add or subtract values. Adding values rather than multiplying will bring colors up gradually across the whole map (In future versions, some statistic will be available which will automate some of the processes in the Mosaic Correction Menu).

The user can also use the Div +/- buttons in the Mosaic Correction. In this application, the user must first set the division file in the Edit Info File menu where the radargram blocks begin. The first radargram will always need to be checked on in the Division file followed by checking every radargram where a new block of data with noises exist. Once these are set, clicking the Div +/- will automatically discover the rectangular regions across the grid corresponding to those different sub-grids that have mosaic noises. As the Div +/- button is incremented the online box will increment to different blocks.

The menu options can also be used to highlight an individual area within any chosen part of the time slice map, as is shown on the mosaic corrected image in the following page where a small rectangular block is emphasized.

Note1: In implementing mosaic corrections, it is often better to work with the unsmoothed grid set. After mosaic corrections are made, the user can apply a lo-pass filter to the corrected grid, e.g. either a 3x3 or 5x5 lo-pass filter, to better blend the edges of the mosaic regions.

Note2: In correcting for mosaics, it is best to gain the area of the time slice maps which have either real weak colors or too strong of colors contrasts. For instance, in the example in the following page, the region above the line y=20m has overall weak colors in the map – e.g. too much blue and reflections are weak overall. The area below y=20m shows a well balance in color contrasts across this region. It is thus best to adjust the top region to match the bottom region in order to create maps with more "equal" contrasts in them.

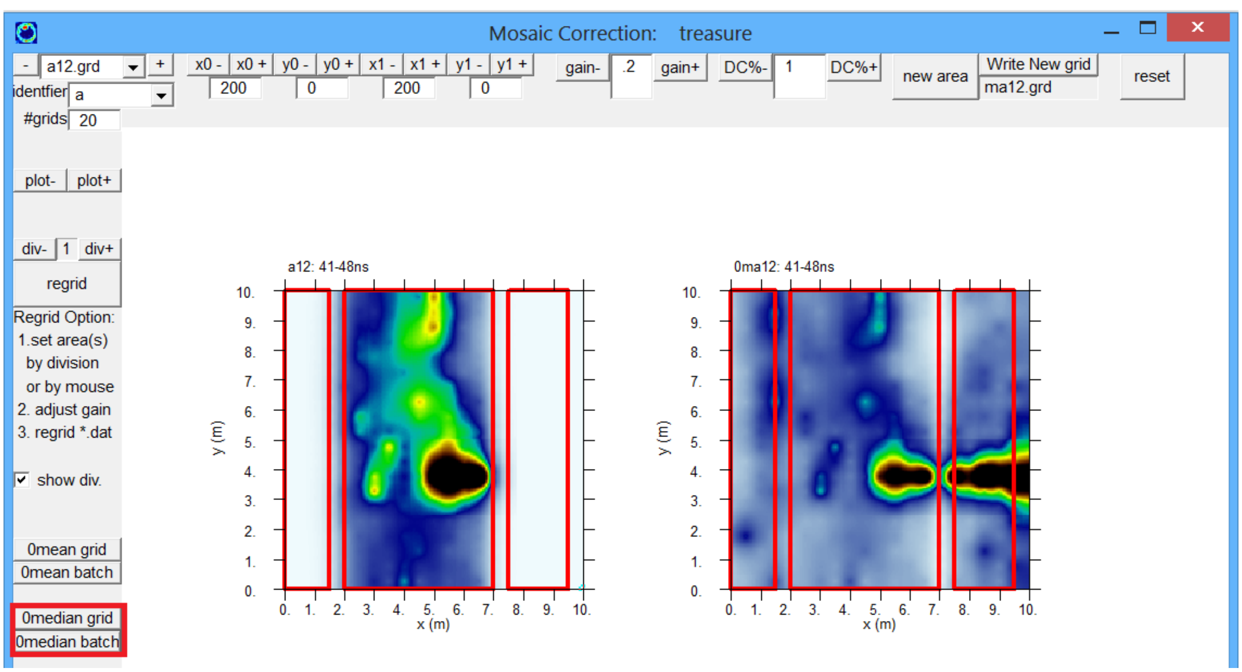


Variation on Screen Capture with Re-gridding

The Re-grid option can also work very effectively in the menu to adjust mosaic noises. In this operation, the user sets the desired block with the div+/- button, adjusts the gain or the dc offset to balance the data with a nearby block, then uses the Re-grid button to re-grid the *.dat using the adjustments. While applying the gain or dc adjustments to the actual grid, edge effects will be seen in the drawing along the block edges. This is to be expected since the gridded data at the edges were generated with unmatched searched data from both nearby blocks. However, on re-gridding, the original *.dat is used to recalculate the grids and those edge effects will not be present after the operation. For 0 median and 0 mean grids, new *.dat and *.grd data are generated with the "0m" appended identifier. For the Re-grid option, the *.grd is overwritten with the original name. For 0 median and 0 mean operations and the Re-grid option, the original *.dat must exist for the corresponding displayed grid file. Direct gaining on the *.grd file real time with writing to the "m*.grd" file is available and does not require *.dat data to exist.

Mosaic noises (top) and a mosaic corrected time slice (bottom), method #1. A highlighted area is also shown as an option for display in this menu.

Mosaic Correction Method: 0 MedianGrid/ 0 Mean Grid

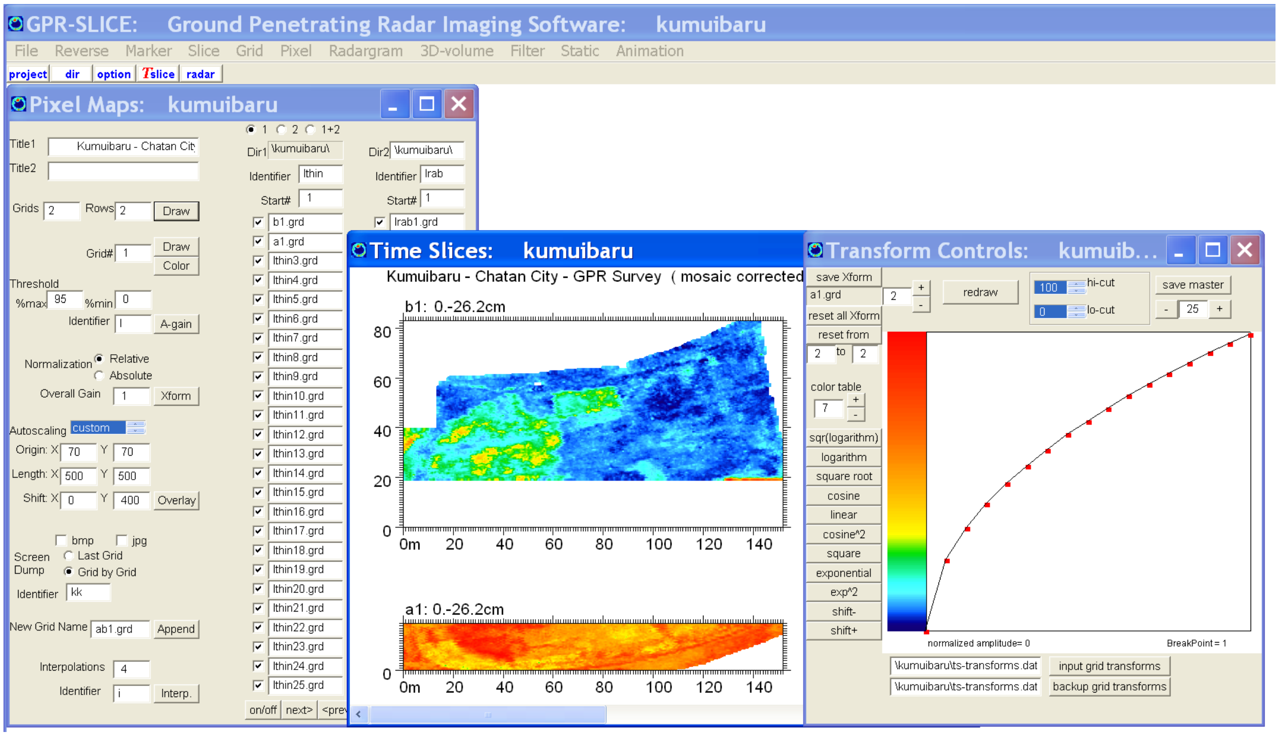


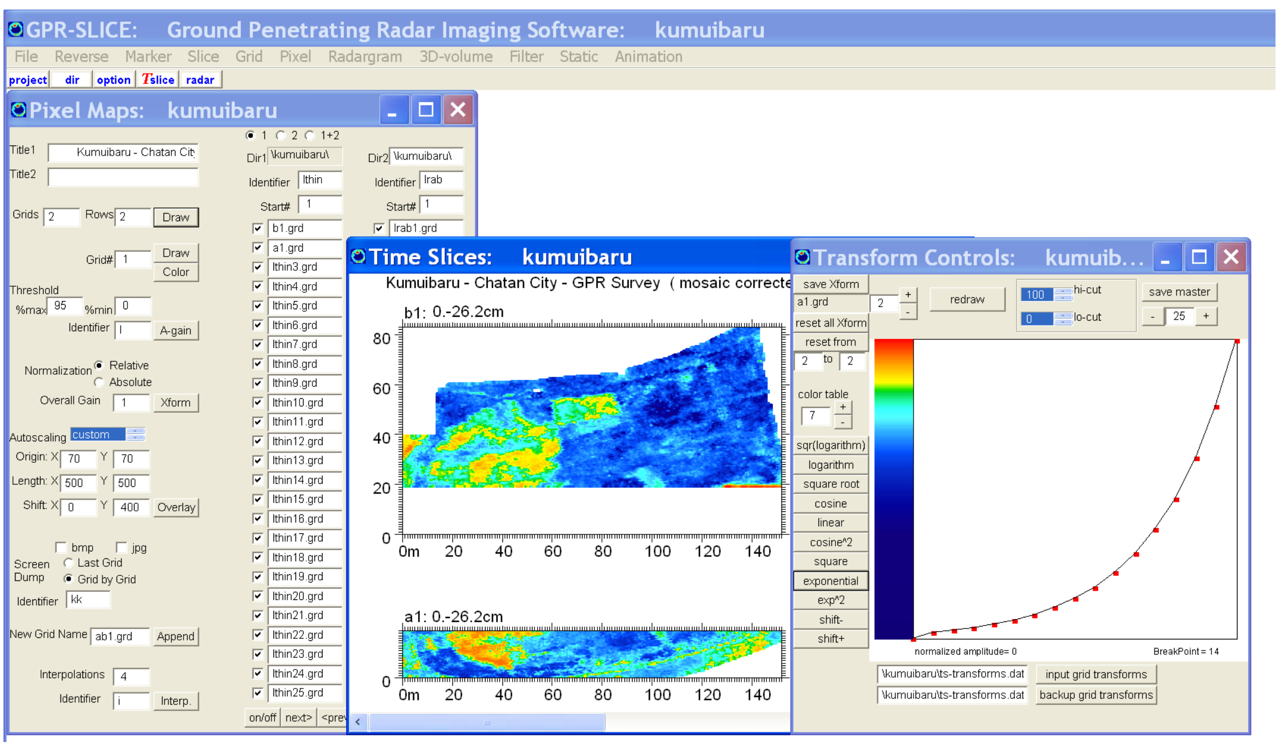
An algorithm to try and automatically correct mosaic correction is available in the stand-alone Mosaic Correction menu. The operation works by calculating the median value of each defined grid division (set in the info menu) and then normalizing all the blocks by their median value. For certain kinds of surveys noises the median grid algorithm may work to balance the different survey blocks. This method is best suited to surveys where the distribution of data is similar in each of the blocks. e.g. the same number of weak, medium and strong anomaly areas are about the same density in each of the blocks. 0 mean grid operations are also now provided in the stand-alone Mosaic Correction menu. To properly view the 0 median corrected grids, the user should run the operation on grid #1 so that this grid set will appear in the Pixel Map for further viewing an display.

Mosaic Correction Method: Transform Matching + Grid Appending

One of the problems with the first method for correcting mosaics is that sometimes non-rectangular areas have mosaics. Currently the Mosaic Correction Menu only provides for capturing rectangular areas to correct. Also, even with making a good match between areas along with lo-pass smoothing, there may still be a significant looking streak at the edges of the mosaic regions. A more involved method which can give similar if not better results is to break the grids with mosaics up into 2 (or more) different grid sets. For instance, the radargrams up to an including the first mosaic can be used to create the a*.grd files, and the second set of radargrams can be used to create the b*.grd files. Once these are generated the user can type by hand, the grid names a1.grd, b1.grd into the 1st and 2nd positions in the Pixel Map menu. The next step is to display the time slice maps and then one can adjust the individual transforms to get a match in color between them. Once a good match is made, clicking the “Append” button will write a new grid, in this case “ab1.grd”.

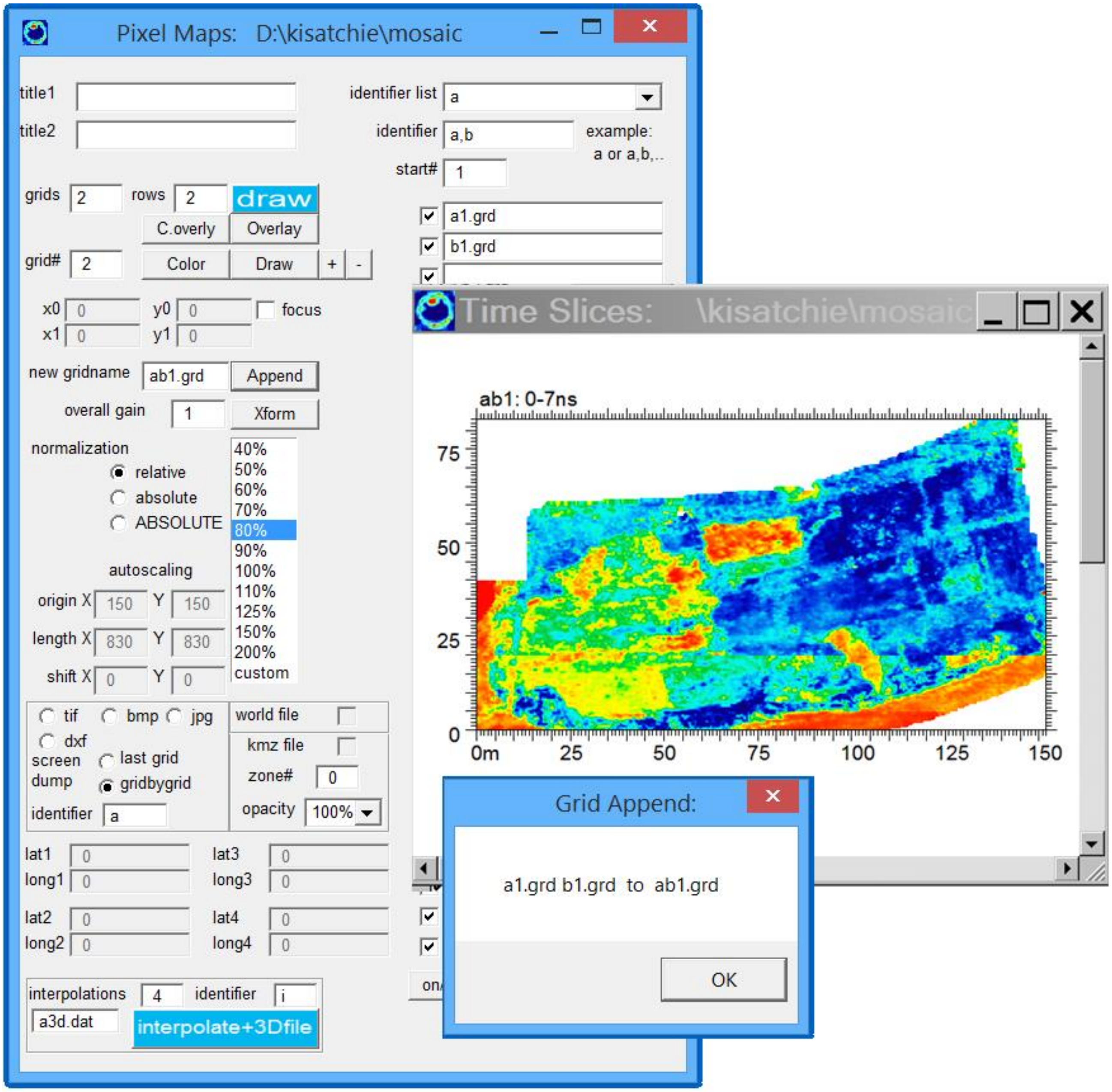
Both time slices for this example had the same initial color transform applied (square root). To match the maps a transform which lowered the overall reflection in the bottom time slice was manually drawn (bottom diagram). An example of showing the two grids with different mosaics broken into an “a” and “b” grid set is shown in the following diagram.





Mosaic noises in two adjacent grids (top) and mosaic adjusted maps showing the transform used on the 2nd grid to match colors with the first grid (bottom).

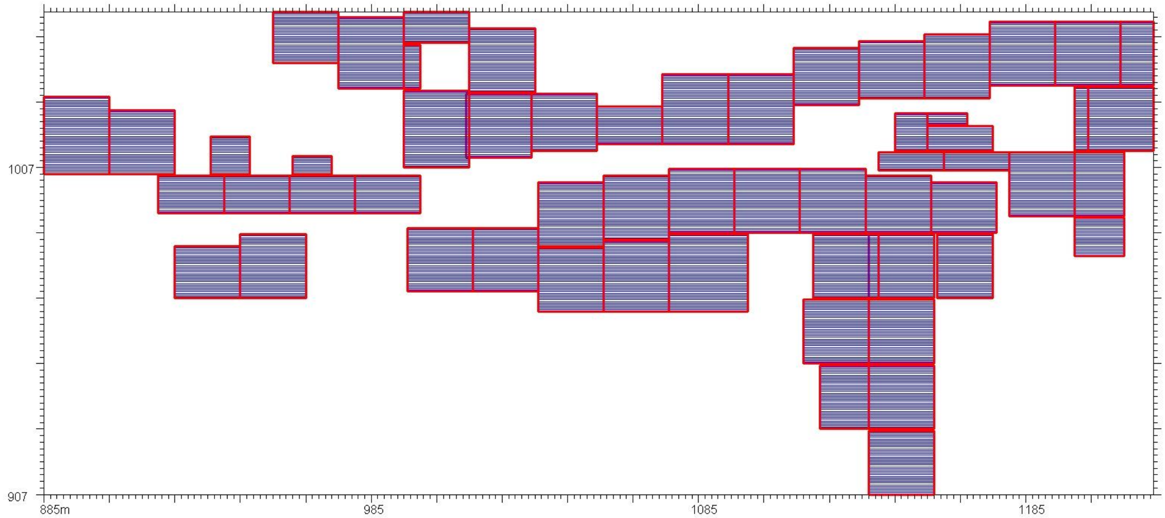
An example of the appended grid from using transform matching is shown in the following screen shot:



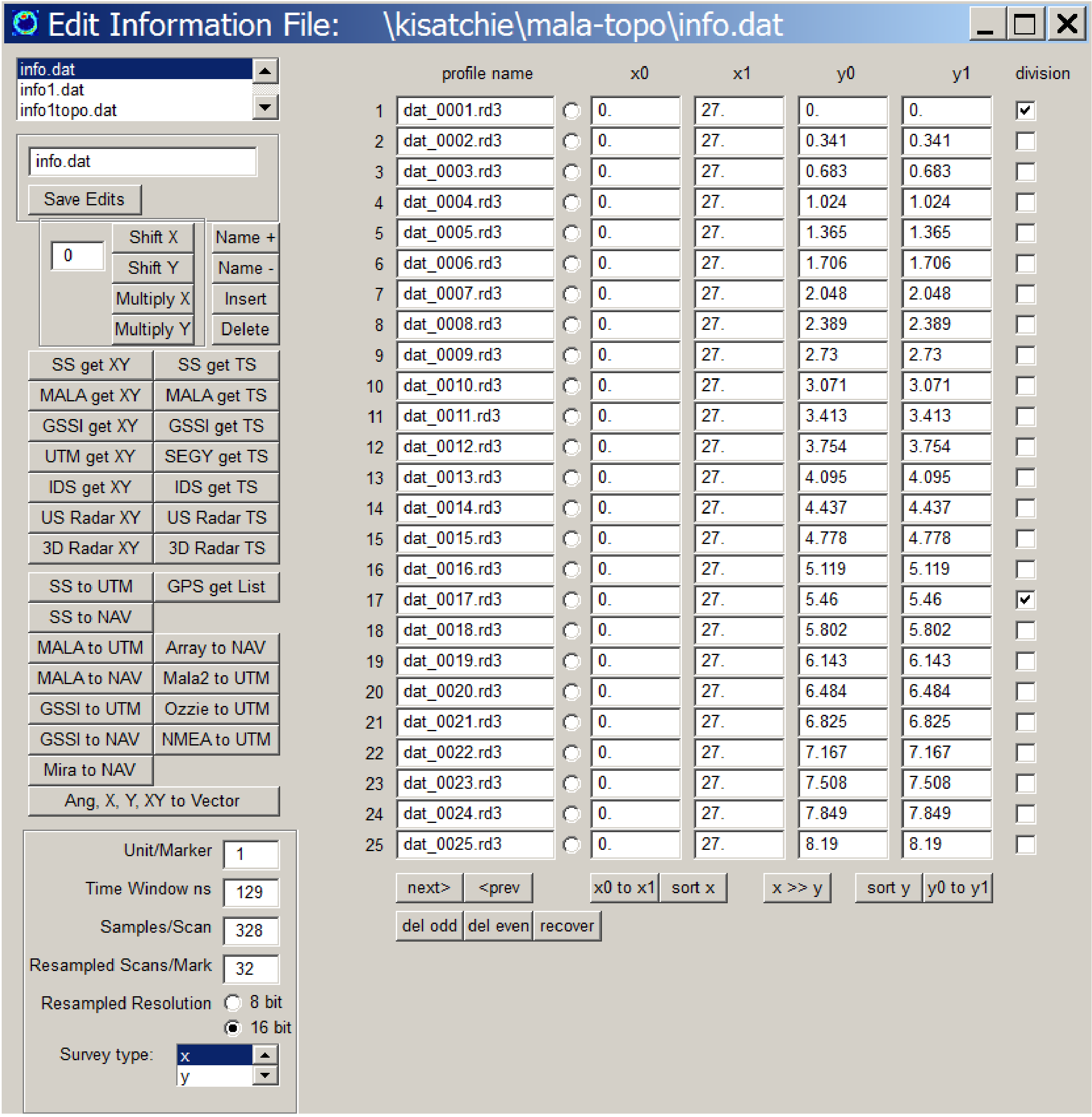
This method of transform matching can be expanded for more than 2 areas where mosaics appear in a large site that surveyed. In this case the a,b,c, …. Gridsets are created and then transform adjusting and finalized by appending all the grids to a single grid.

Automated Mosaic Corrections: 0mean grid /0mean line/ Edge Matching / Histogram Matching (Slice/Resample menu)

Automated mosaic corrections are also available during compilation of the time slice data in the Slice/Resample menu. 0 mean grid, 0 mean line, edge matching, and histogram matching have been developed to automatically correct for mosaic. The automatic mosaic correction involves several steps which the user must implement in order to use this new options. As an example, we shall show some data courtesy of Dan Elliot of the Lamar Institute. Dan collected about 35 kilometers of data at a site on Ossabaw Island, Georgia as part of his studies into remote sensing of features associated slave dwellings on the island. Dan and his group were very meticulous and recorded a total of 58 GPR survey grids across the site, as is shown in the next diagram:



1) To set the grid divisions, the user can click on those radargrams in the Edit Info File menu that are at the start of each new block as shown below in the following menu screen shot:

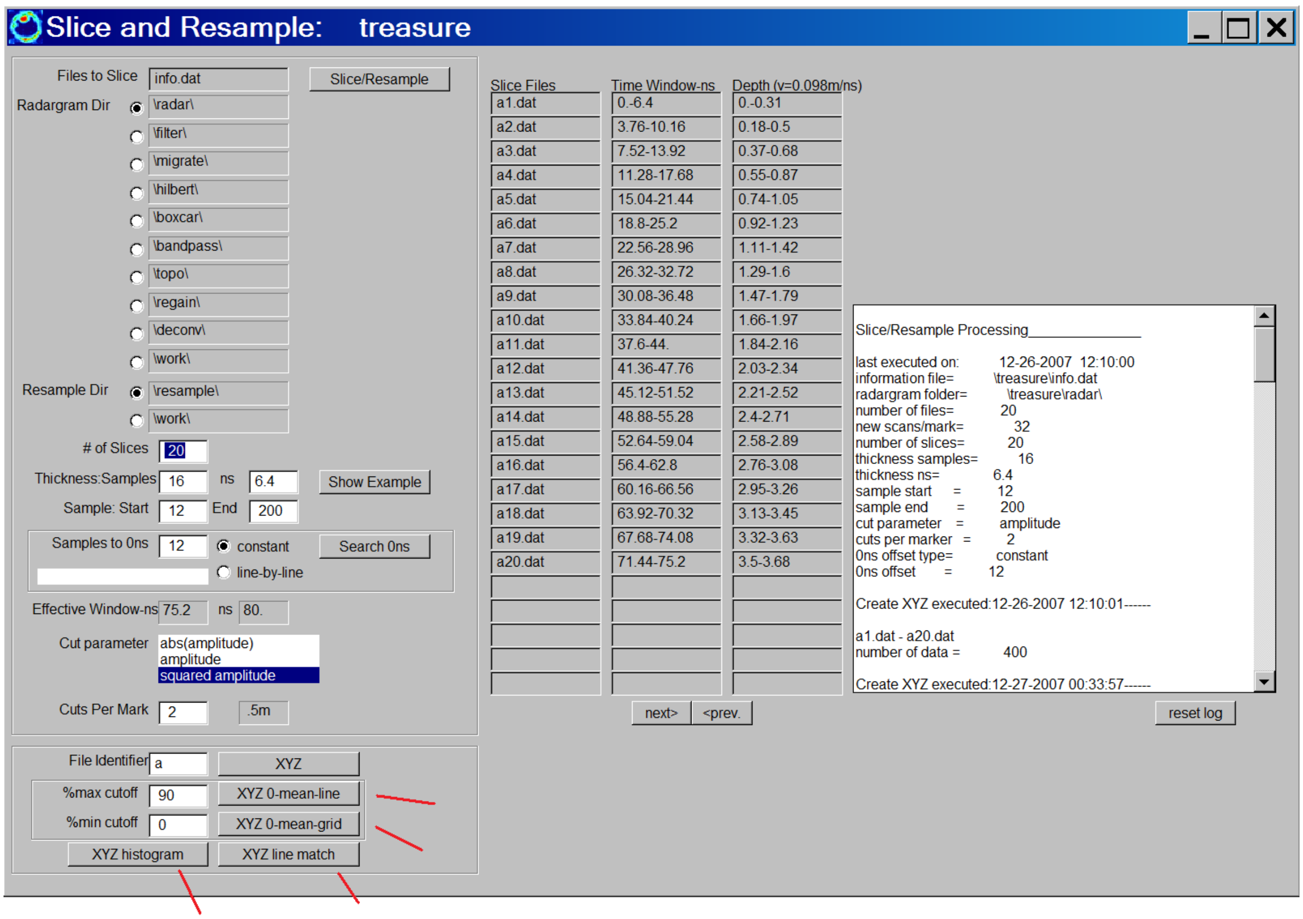


When the divisions are chosen, the individual grid blocks will be drawn in red as was shown in Figure 1. Note, the user must click on only the first radargram in each block as they first appear in the information file. In the above example we can see that the 1st file and the 17th file are start of different grid blocks and are thus clicked on.

2) Next, the user proceeds as usual in time slice analysis, e.g. reversing profiles, applying navigation, and slicing. The user can then

create several optional time slice datasets that can effectively remove mosaic noises:

- 0-mean-grid XYZ time slice – XYZ datasets where the mean from every individual grid block is subtracted from data in that block to create a "0 mean" for every grid block.
- 0-mean-line XYZ time slices – XYZ datasets where the mean along every individual profile is subtracted from the time slice data on that profile to create a "0 mean" for every profile.

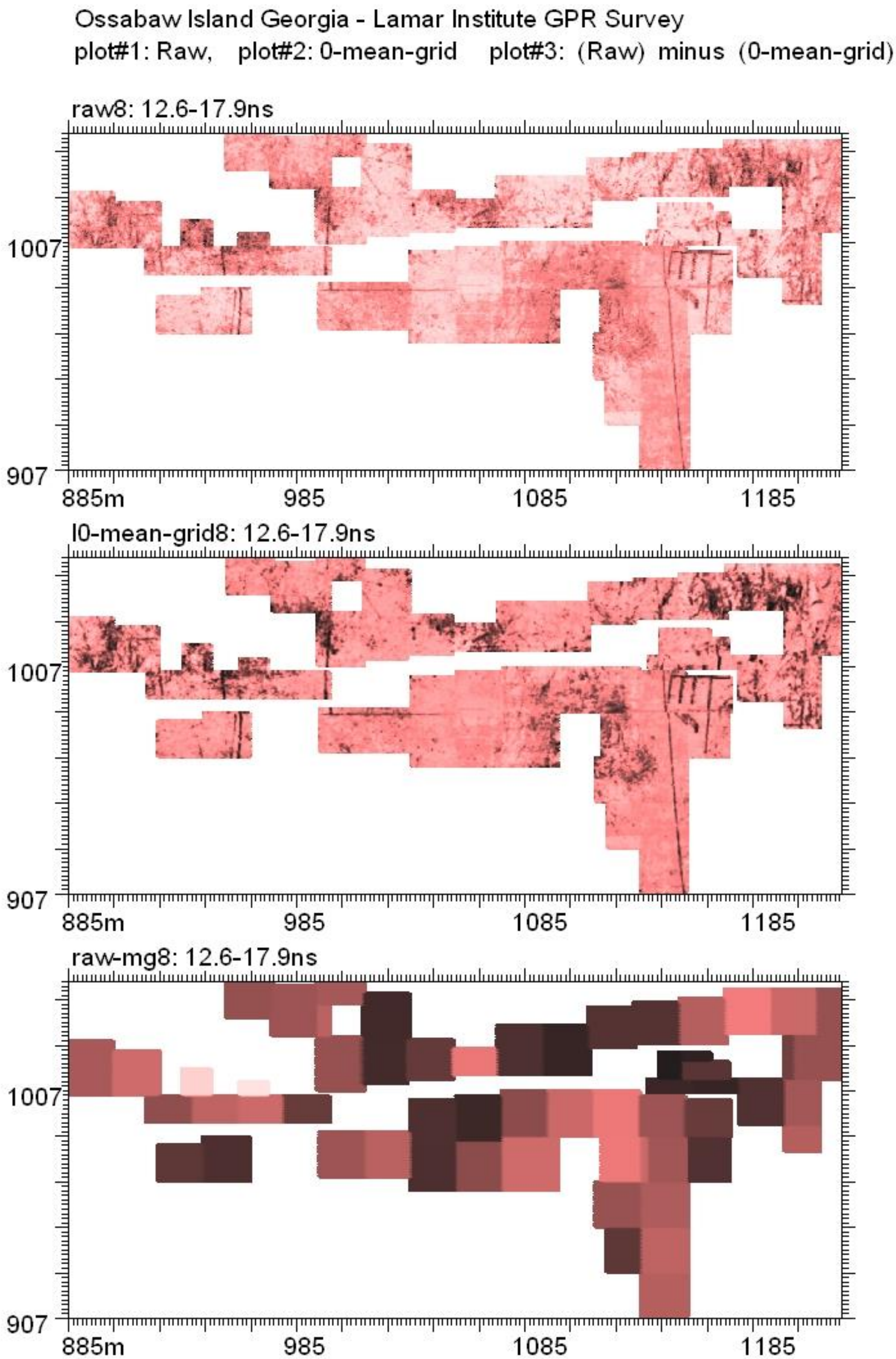


Several options for creating mosaic corrected time slice maps are available in the Slice/Resample menu. Each of the options may be more appropriate than the other depending upon the nature of the recorded data and the mosaic noise appearance. The options are found just below the normal XYZ time slice creation. For the 0-mean-line time slice dataset, in the case where linear features parallel to the profile and large reflective features are not present, the 0-mean-line data can provide a useful method for matching overall reflections across a large dataset. If horizontal features are present that were parallel to the profiles, they could be effectively removed from the time slice images. In this case, the 0-mean-line XYZ dataset creation should not be applied. The 0-mean-grid time slice dataset will remove the average within each block. Thus, if a single line or two is parallel to a profile in the image, these reflections will be preserved since only a single mean value is being subtracted across the whole separate grid. Seeing several plot examples will better help the user to see the effects of these 2 essential and important time slice calculations.

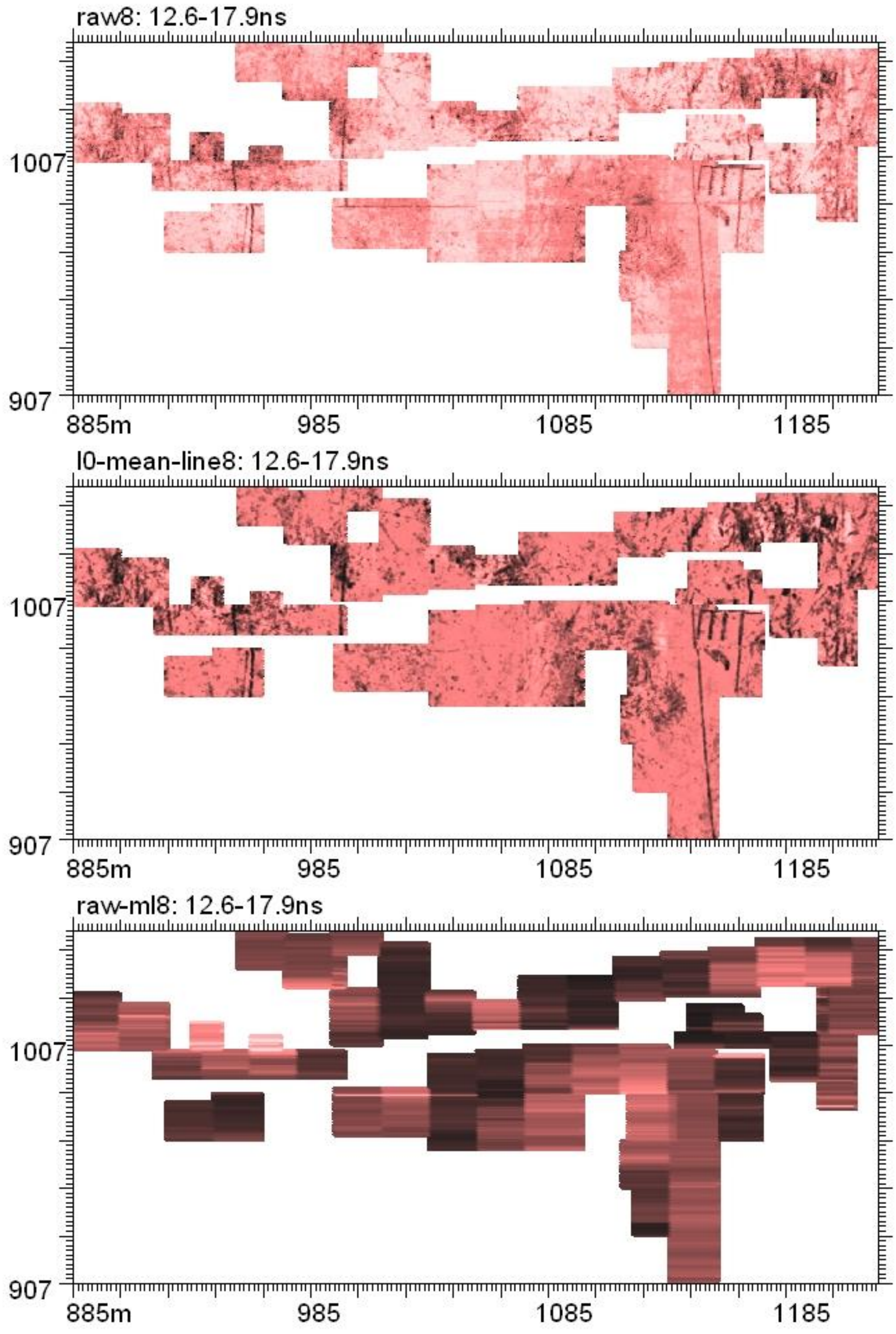
0-mean-grid and 0-mean-line calculations for the Ossabaw Island Georgia dataset are shown in the following pages. The top time slice is the raw time slice, the middle is the 0-mean-grid time slice, and the bottom is a time slice using the grid math option in the Grid Menu to subtract the raw and the 0-mean-grid images. The 0-mean-grid image shows very good matching in overall reflections between the 58 different grids. Mosaic noises are much more prevalent in the raw time slice. The subtracted image shows the overall gains subtracted from each of the different grid blocks. If there were no mosaic noises existing between the separate blocks, then the difference image would be solid – in this case we can see that mosaic contributions are prevalent and could be effectively removed by using the 0-mean-grid time slice creation.

Examining the 0-mean-line time slice, we can see that the difference image on the bottom shows mosaic noises are removed – in addition – streaks parallel to the profiles can be seen embedded within the mosaic components. The streaks are reflections from line noises that were running parallel to the profiles. These are also effectively removed from using the 0-mean-line XYZ time slice creation. One horizontal utility running from about the range 990-1060m in the time slice image, can be clearly seen in the raw and the 0-mean-grid, however, the 0-mean-line time slice shows this horizontal reflection significantly decreased and nearly invisible.

The 0-mean-line and the 0-mean-grid calculations can be assisted using the %max Cutoff and the %min Cutoff settings residing next to these processes in the Slice/Resample menu. The cutoff settings are to help in making better estimates of the mosaic noise background levels. The plots in the examples for Ossabaw Island Georgia, were made with the %max Cutoff set to 75% and the %min Cutoff set to


Ossabaw Island Georgia - Lamar Institute GPR Survey
plot#1: Raw, plot#2: 0-mean-grid plot#3: (Raw) minus (0-mean-grid)
raw8: 12.6-17.9ns
1007
907
885m
985
1085
1185
l0-mean-grid8: 12.6-17.9ns
1007
907
885m
985
1085
1185
raw-mg8: 12.6-17.9ns
1007
907
885m
985
1085
1185

Ossabaw Island Georgia - Lamar Institute GPR Survey
plot#1: Raw, plot#2: 0-mean-line plot#3: (Raw) minus (0-mean-line)



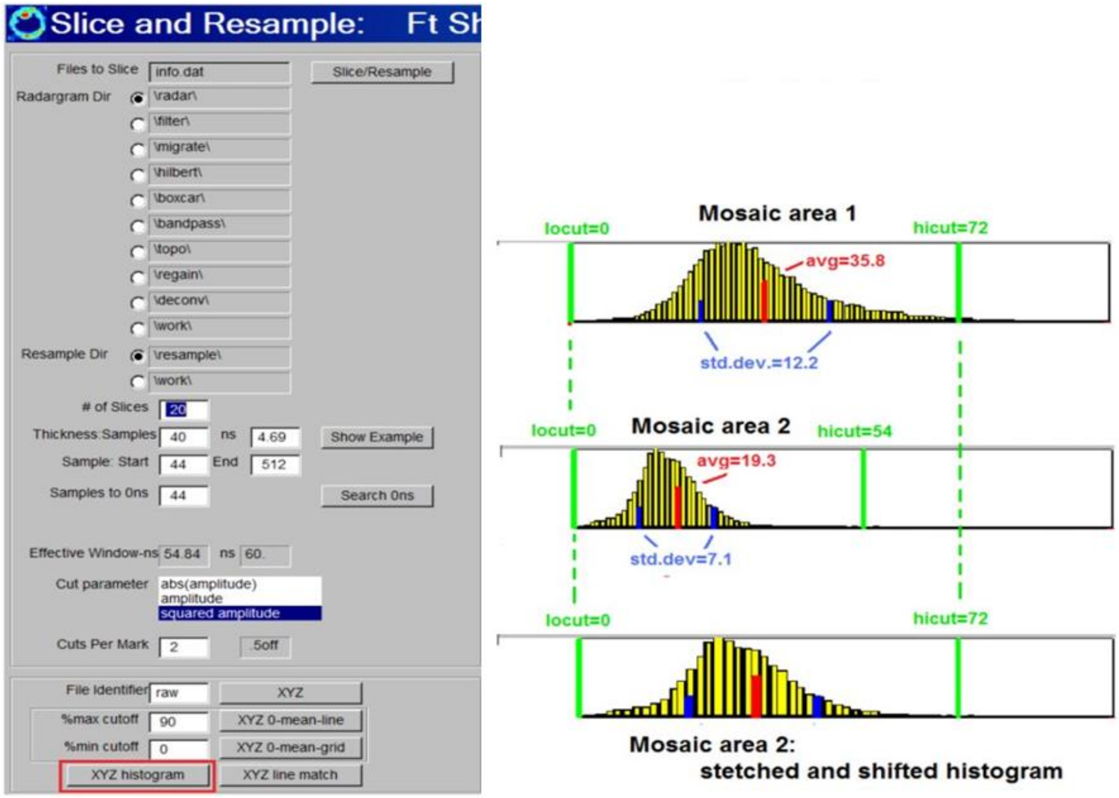
0%. The 75% setting will include all the data in the grid which is the bottom 75% in strength – e.g. the top 25% reflectors are not used in determining the average of the block. Similarly, the settings are also active for the 0-mean-line XYZ creation, and will throw away the top 25% strongest time slice values found on the profile and will only use the bottom 75% values to determine the average reflection strength. The reason that this works is that the mosaic backgrounds are usually not the strongest reflected energy recorded. Mosaic noises are usually at the lowest reflected strengths in the time slice images. If the entire data were used in determining the filter, then areas that had a strong reflection would overweight the filter and when the mean were subtracted from either the line or the grid calculation, the overall average reflection or the median reflection would be much weaker than the 0 mean. A median calculation in addition to the mean might also work, and this may be examined in the future.

XYZ Edge Match requires the user to set the division file in the Edit Info File menu. Edge matching will adjust the block of data based on the reflections between two adjacent radargrams in each of the two different blocks.

XYZ Histogram Matching

Another mosaic correction method examines the histograms of different blocks of data and will try to match the histograms for solving mosaic noises. The operation will look at 3 standard deviations away from the average time slice value and will apply a gain factor to datasets to stretch or shrink the histogram so that the junctures where the 3 standard deviations on each side of the mean matches. The junctures on the histogram are defined in the Transform menu by the lo-cut and hi-cut thresholds. The process will also shift the means so that these also line up. This process is available in the Slice/Resample operation and is operated on the data before the ASCII time slices are generated.

Note 1: Remember, the divisions need to be set in the Edit Info File menu to define blocks of radargrams from different grid sets where mosaic noises exist.



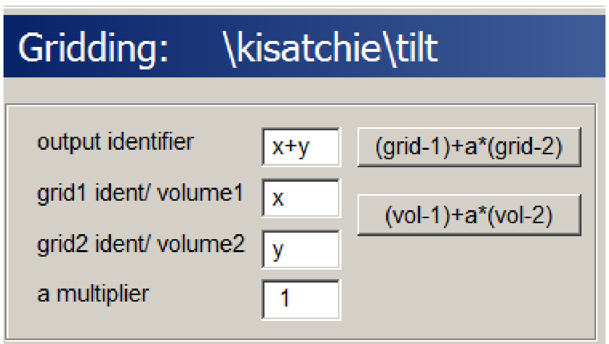
In all data processing steps, it is always useful to compute the raw time slices without any processing. Raw time slice XYZ datasets are compiled at the XYZ button in the Slice/Resample Menu.

Grid Math Option: Adding x+y grids to create xy grids

The user has several options in GPR-SLICE to create time slice grids from data collected in both the x and y directions for a survey site. In the traditional method, the user can create a comprehensive information file containing the names of all the radargrams and their location within the grid. The user would normally create an infox.dat file and then an infoy.dat file and append these together to the infoxy.dat file for example, in the Create Info File submenu.

Often, the data collected in the x or in the y direction may have been recorded at significantly different times than the other orthogonal direction. Also, some investigators often will change the control settings after collecting in one direction to improve the appearance and gain of the raw radargrams. This is not recommended for creating useful time slice images. In any event, from either diurnal variation in temperature or other factors, the overall gain of either the x or the y dataset over a site may be slightly or significantly different than the other set of data normal to it. In doing gridding using the comprehensive dataset, digital noises can arise, particular for kriging gridding operations if significant amplitude changes are recorded nearby or in the same locations from the x and y datasets. The time slices computed from those radargrams which are only going in the same direction and examining these datasets, are sometimes more useful and less noisy than the combined xy time slices.

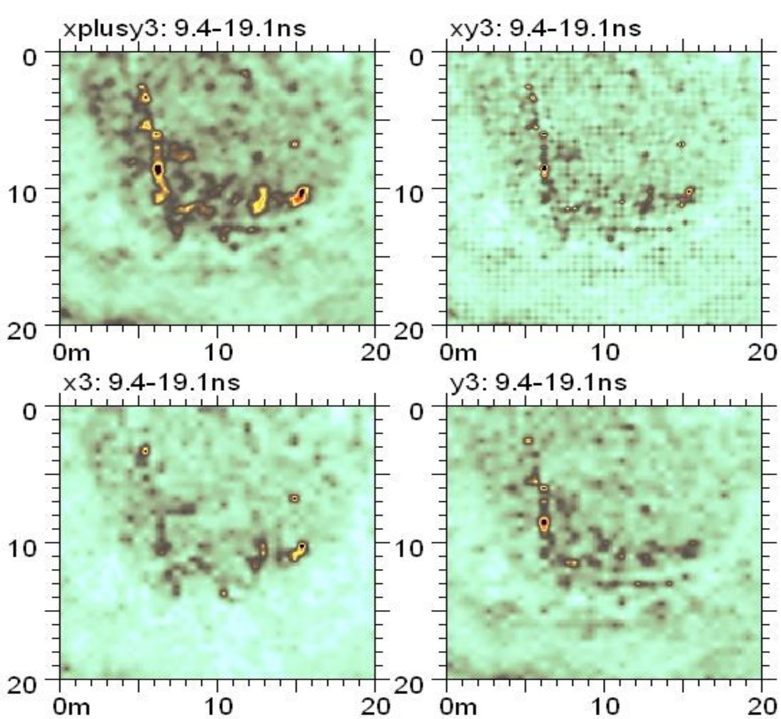
In the case when digital noises can arise from gridding different overall gains between x and y datasets, and the user would like a comprehensive map, it is useful to combine the individually computed x and y time slices using grid math. Grid math can be done between two time slice grid sets in the Grid Menu. The user inserts the identifier the x*.grd dataset and y*.grd dataset, and sets a new output identifier. In the case below, the x and y grids will be added with equal weight (e.g. a multiplier = 1) to a new set of time slices called the xplusy*.grd.



Shown in diagram on the next page, is an example of a dataset collected along both x and y directions and comparison with, gridding using the complete xy dataset, and another dataset created by physically adding the individually computed x and y time slice grid maps. The site shown is provided by Steve DeVore of the National Park Service. The area surveyed in orthogonal directions is a grave site. The x3 and the y3 time slices were computed individually, and the xy3 time slice was computed using the regular xy kriging gridding. Some spotty digital noise can be seen in the xy3 time slice map. Some hi-resolution anomalies can be observed on the xy3 time slice map, amongst the digital noise.

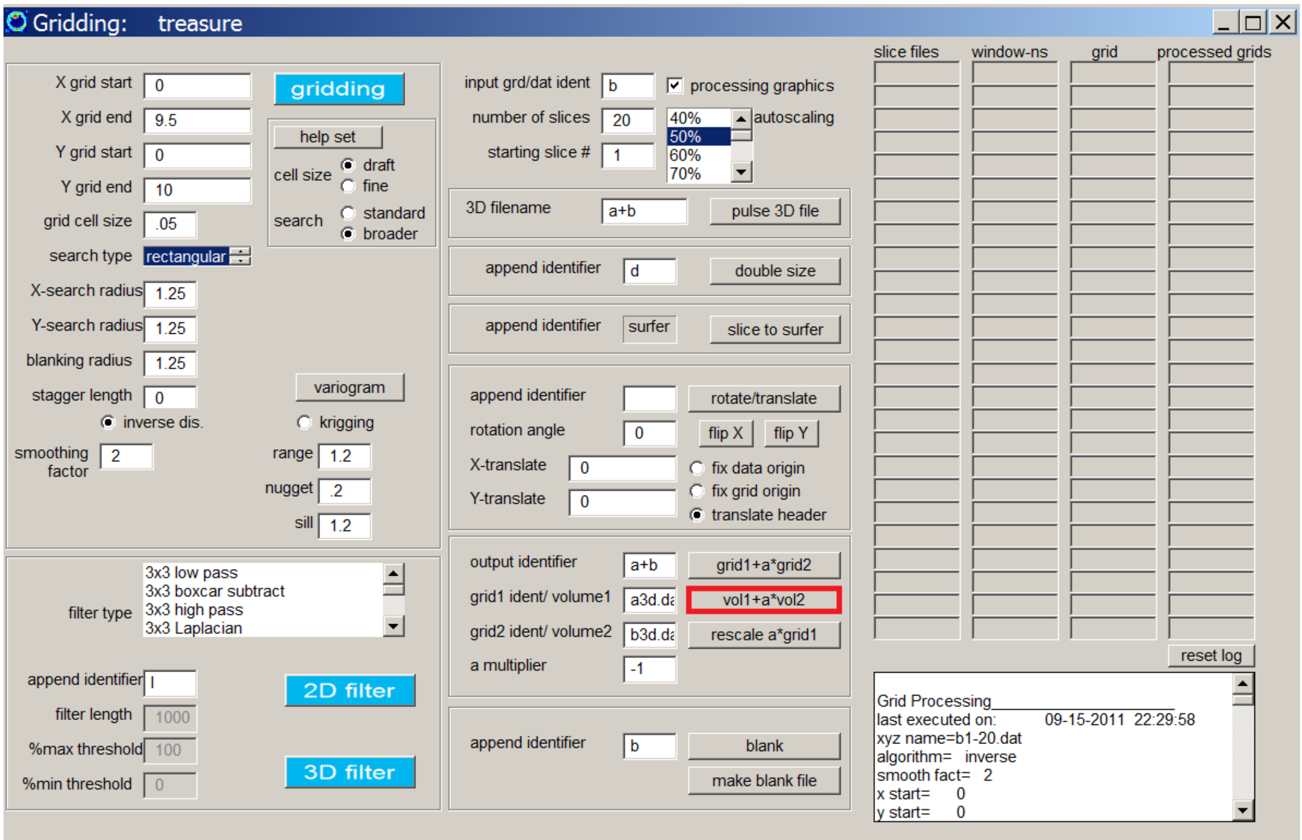
Because there is more spatial coverage using xy comprehensive datasets, a smaller search radius allows for getting more reliable higher resolution maps from these datasets. Nonetheless, the digital noise is apparent and some of this noise might be erroneously interpreted as reflections from rectangular burial pits. The time slice map xplusy3 was computed by adding x3 and y3 grids directly using the grid math option. This dataset has more structures combined into the final image. Nonetheless, even with the noise, it is up to the user to determine which of the datasets is most useful for their researches and is more representative of the suspected subsurface structures.

Courtesy of Steve DeVore - National Park Service

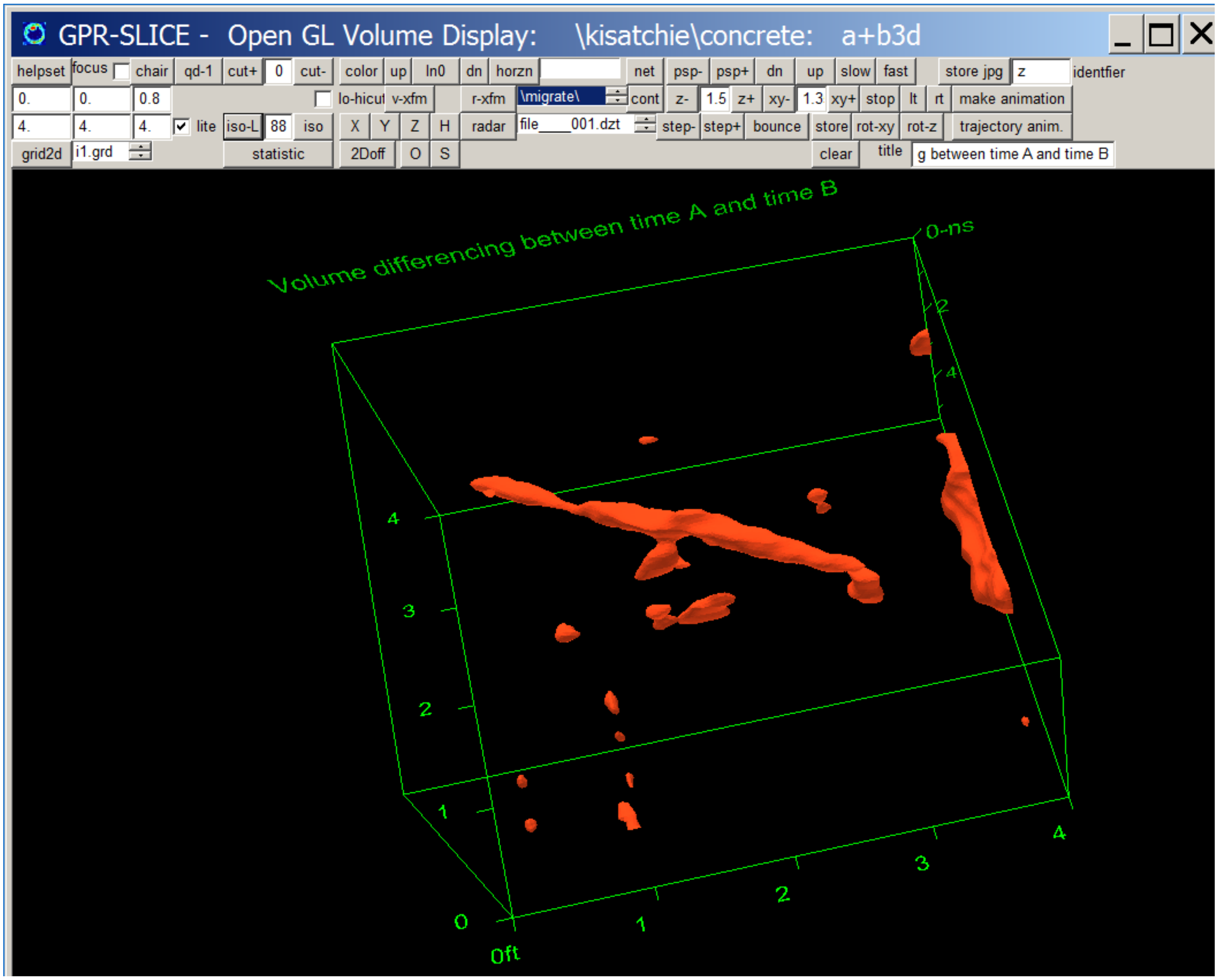


GPR Monitoring: Volume Math Option

GPR-SLICE can be used in volume monitoring of a site to measure changes between recorded reflections collected at different times. Just as single time slice grids can be differenced, since Jan 2011, 3D binary volumes can also be differenced (or added) using the volume math option in the Grid menu:

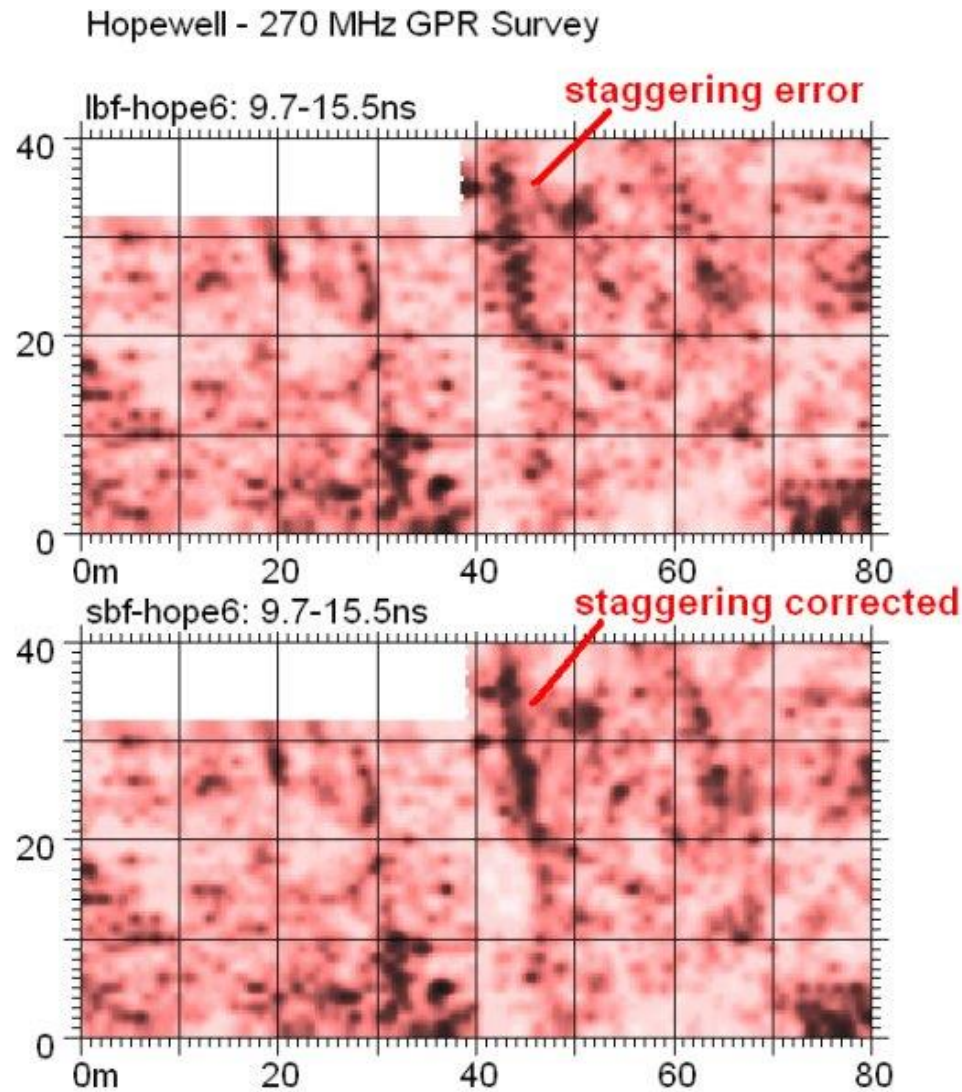


The multiplier allows the user to either difference volumes (with a=-1) or to add volumes with different weights between them if desired. The user must explicitly write the entire name of volume 1, volume 2 and the name of the output volume in the menu slots here. After clicking the (vo1)+a*(vol2) button, the math operation which show the % processing completion on the Windows title bar. An example of differencing 2 volumes is shown in the next screenshot:



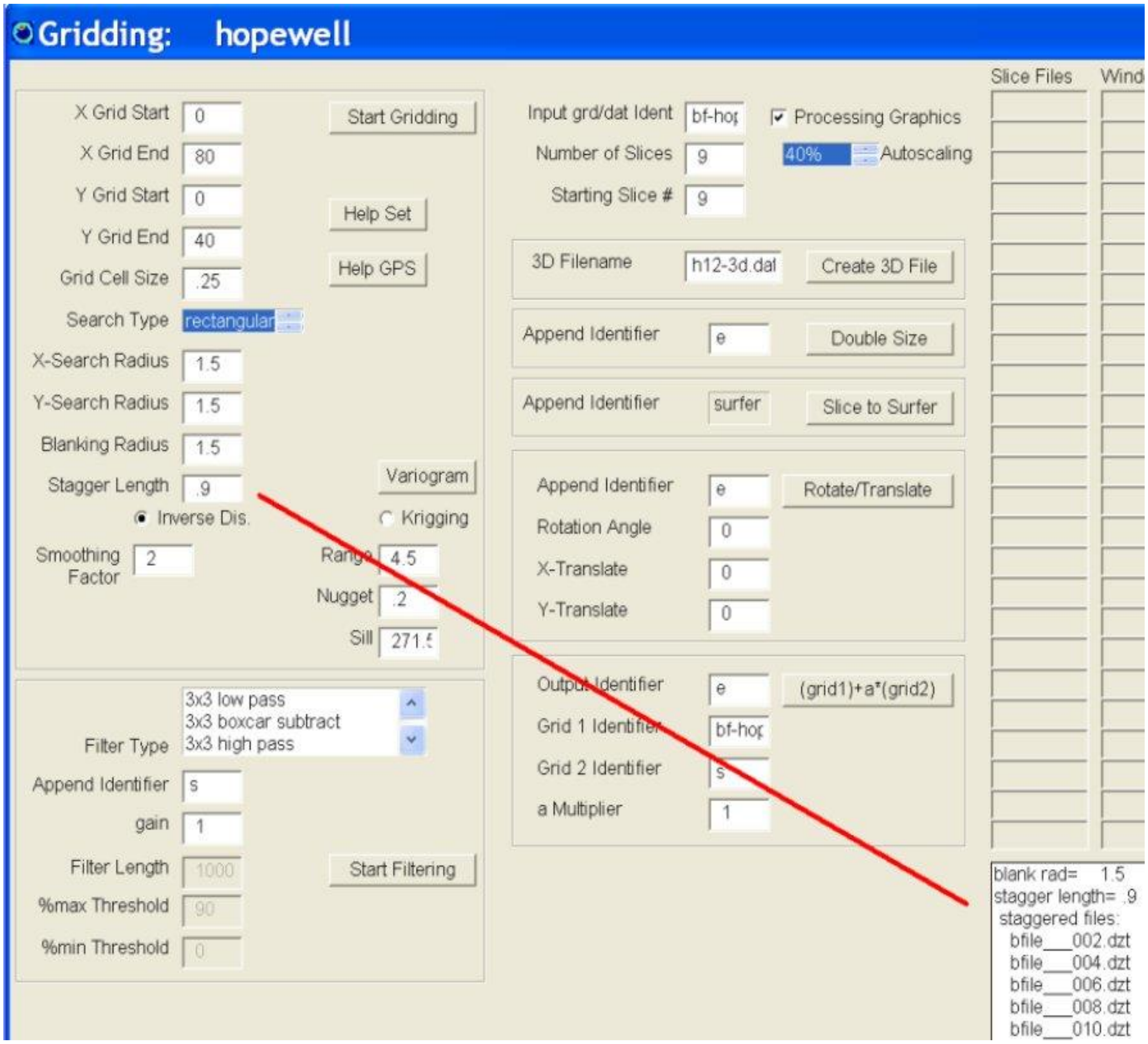
In addition to volume math, grid differencing - rather than grid addition - can also be run in the same location using the Grid1+a*Grid2 button and a value of a=-1.

Staggering Correction



Staggering errors can occur in doing zig-zag data collection. The staggering error can see in an example time slice images made for the Hopewell Indian site that was collected during the National Park Service Archaeological Prospection workshop in Chillicothe, Ohio. The staggering can be seen between adjacent lines in the top time slice map above which shows a jagged reflection (caused from a straight earthen wall that is buried).

The staggering can be caused by several factors including operator errors or from small delays in the radar control systems which create the staggered effect. Staggering is not always apparent in every collected zig-zag dataset so it is not going to be a universal approach to processing all GPR datasets. Recently, one user created a staggering error because they forgot that the center of the antenna is where navigation should be tagged. They were using the back wheels of their equipment as the start and endpoints for profiles - thus they created a staggering which was about the length of the cart system they were using since the antenna was in the center of the cart.

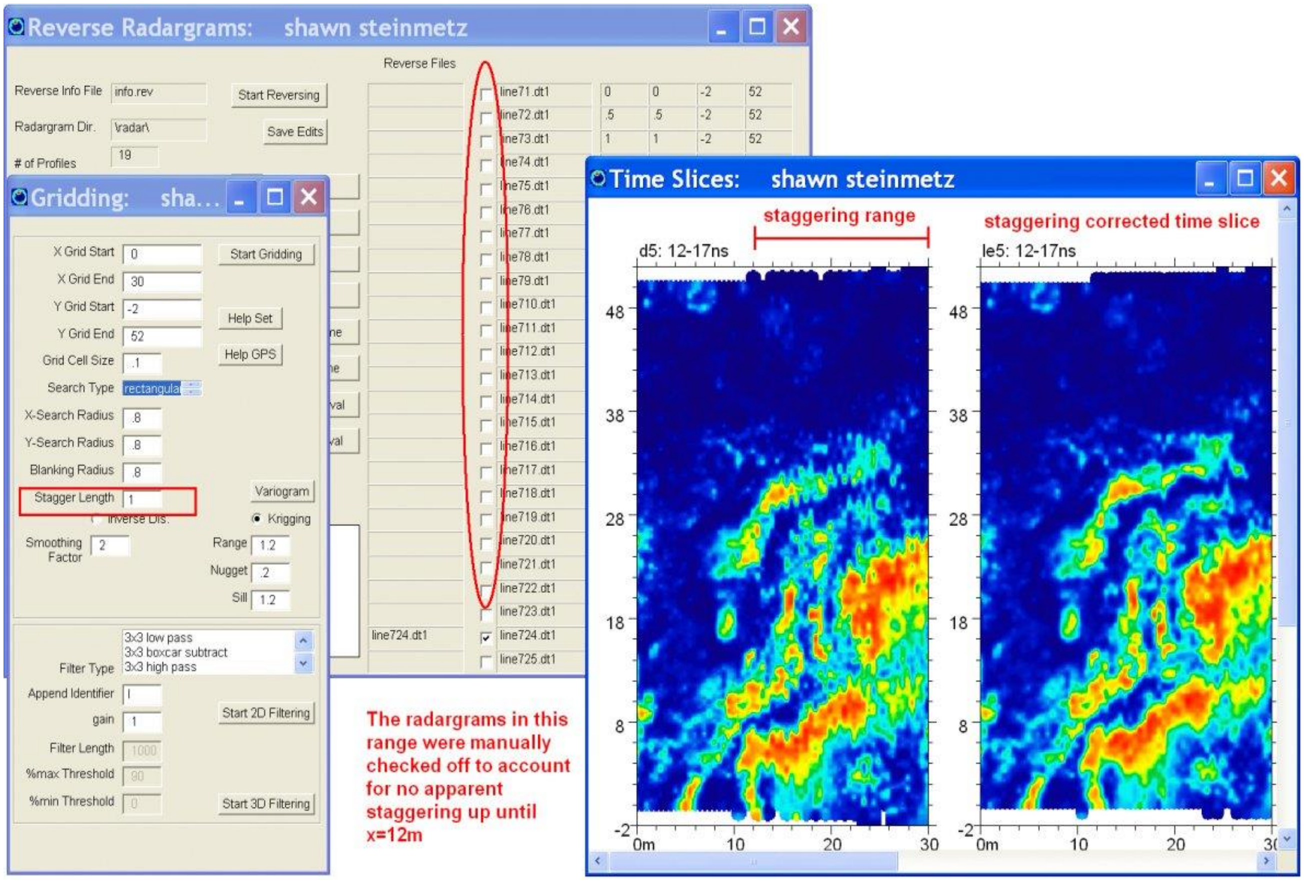


To correct for staggering there is an input in the Grid menu called "stagger length". The user must manually set the distance they estimate exists between the staggered lines. In the example above an estimated stagger length of 0.9 meters is used. The staggering is applied to the xyz *.dat datasets that are read in and is used to shift lines that were collected in the reverse direction. The grids are then calculated using the shifted lines. The bottom image is a time slice corrected for staggering. The Grid menu will look at the active info.rev file in the Reverse Menu to see which lines were collected in the reverse direction. When the user creates grids when the staggering is set to something other than 0, a log will be kept in the Grid menu to let the user know which lines were staggered.

Differential Staggering

In some images it is possible to have staggering that is not always present in some of the reverse lines. An example of an image is shown in the following diagram. Ranges greater than about x=12 m shows staggering noises in the image, however, ranges<12 m do not show staggering. The causes for the differential staggering noises across the radargram is not completely known, however, in this case it may have been because of the result of some ground disturbance caused by a trench surveyed over on part of the site. Whatever the cause of differential staggering, to correct this image one does not want to simply apply staggering to all the reverse lines in the file, but only to those files that the staggering appears in.

To implement a differential staggering correction the user must return to the Reverse menu and clicked off those radargrams that do not appear to have any staggering problems (e.g. up until x=12 m in this example) The edits are then saved to the info.rev file using the Save Edits button - noting that the radargram reversing operations are **NOT** run again. After redefining the info.rev the user can return directly to h Grid menu, set the staggering length and then recalculate the grids. The stagger corrected image looks significantly better than the raw uncorrected image.

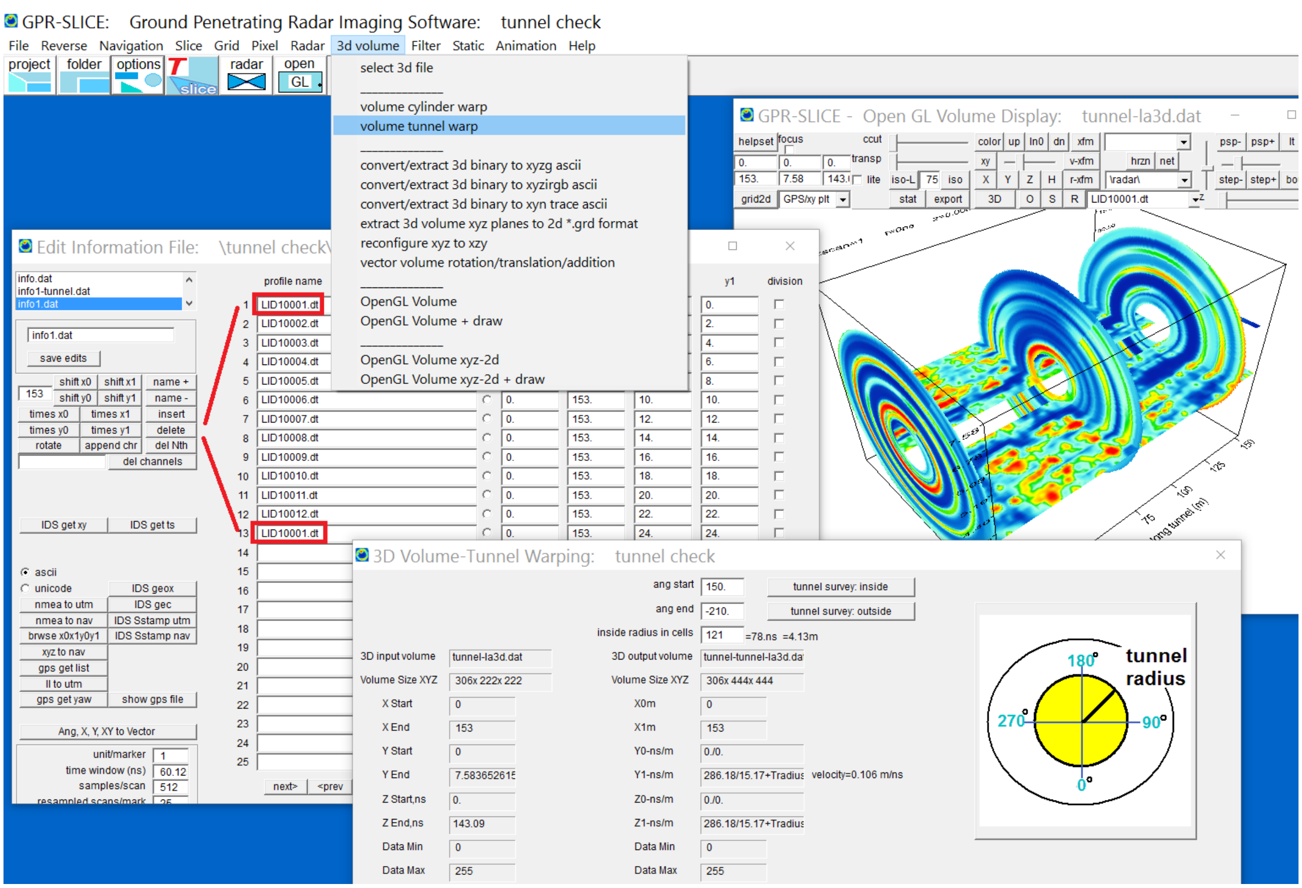


Note: One must be careful if they are using multiple information files for a project and to make sure that the active info.rev file corresponds to the xyz *.dat files which are going to be gridded. There is a button option in the Reverse menu called "Save Edits" to allow the user to click on files to reverse and then save to the universal info.rev file without actually running the reverse process. This may be necessary to use when multiple information files and subgrids exist in a project folder and then one decides to re-run grid creations with staggering.

Tunnel and Cylindrical Warping

GPR-SLICE has options to "warp" 3D volumes into cylinders or tunnels. Cylindrical warping is useful for examining radar data collected on timber or pillars. Tunnel warping is useful for showing radar surveys made on the inside or outside surfaces of tunnels or in mines.

To implement these new imaging features the user will proceed in the normal method to create a 3D dataset. For cylindrical or tunnel surveys, the axis of the cylinder or the tunnel should be along the x axis. After the rectangular 3D volume is created, the user then enters the 3D Volume menu and can choose the "Cylinder Warp" or the "Tunnel Warp" menu. A new volume which will append the word "cylinder" or "tunnel" to the volume name. This example was made for a start angle of 150 degrees (1'oclock) and an actual ending angle of -230 degrees (12 o'clock). To make a solid volume warp with 360 degrees, there is one imaging "trick" that one can apply: Add the first profile onto the end of the information file and then for this example, change the ending angle to -260 which corresponds to +60. This will help to smooth out the warped volume and better match the connected edges (as shown in the following figure).



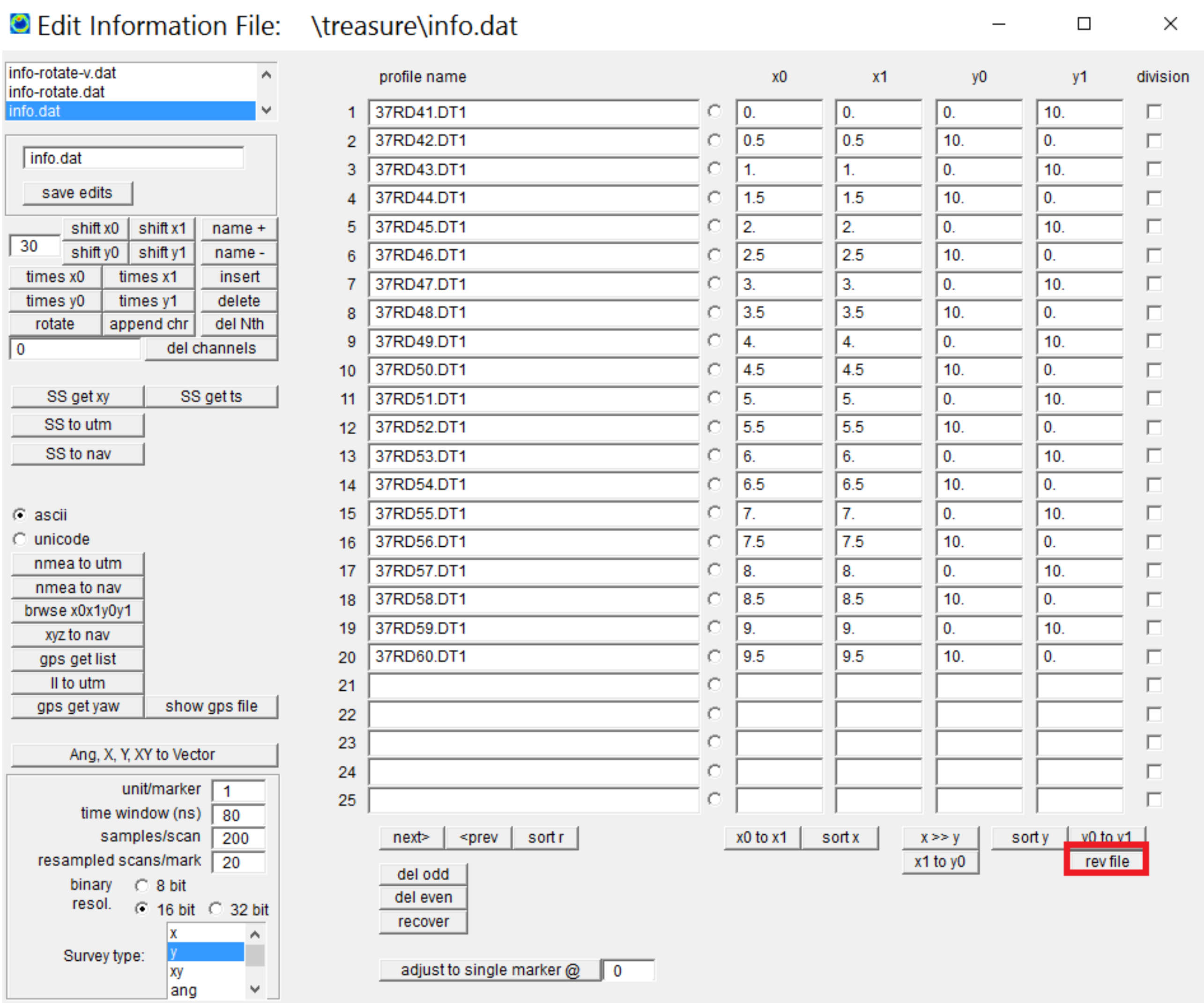
The data in this example is simulated for data collected along the axis of the tunnel. The possibility of collecting data along the circumference is also easily implementable - in all cases the x axis is the axis along the tunnel or cylinder. One would enter data taken along the circumference as radargrams in y with constant x0,x1 starting and ending locations; radargrams parallel to the cylinder axis, would be entered as radargrams in x with constant y0,y1 starting and ending locations. The circumference would be the length in the profiles for y profiles, e.g. 2*(3.1415926535)*RADIUS; along the x axis, the profile length is simply the length of the tunnel or the cylinder. The separation in the profiles parallel to the cylinder axis should be set by their distance measured on the outside circumference of the cylinder.

Zig-Zag Information Files - No Reverse Menu Operations

In the creation of the profile information file one is always required to insert line start and endpoints. If one uses the Reverse menu, then all the radargram start and end points in the information file are typed in as though the radargrams were collected in the forward direction. The reversing process in the Reverse menu flips the binary radargrams in the \radar\ folder and effectively makes the radargrams look like they were recorded in the forward direction.

The possibility also exists for the user to avoid using the Reverse menu and to write the information file with the actual start and end points of the surveying. **The Reverse menu should be skipped for information files inputted with reverse information**.

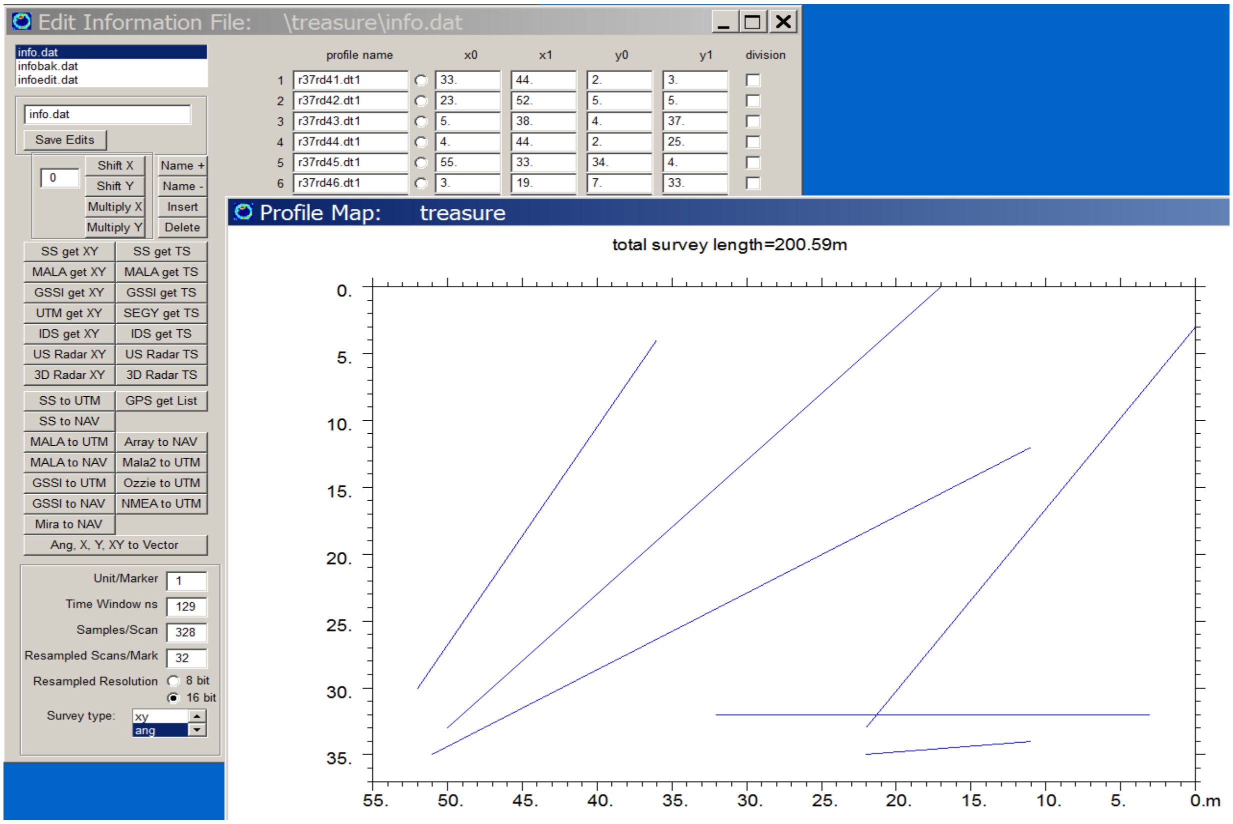
An example of an information file with reverse lines identified with x1 ranges less than x0 is shown in the next diagram. In this zig-zag survey done parallel to the x axis of the grid, every other line is recorded as going from 10 to 0m. There is also a quick button that one can use called "rev file" which will read the reverse files clicked on in the Reverse menu and will interchange the start and end points in the information file in the Edit Info File menu. So, one can create a rectangular grid and then reverse all the information using what is stored in the Reverse menu.



Note 1: Radargrams displays in the Radar 2D menu will appear reversed in the display with axis labeling going from higher to lower values.

Note2: The user should be careful in using the reverse information file designation. This potential for some to get confused and believe they need to write the profile information file with reverse information, and then also to run the Reverse process as well - this would be a mistake!

The ANG survey definition



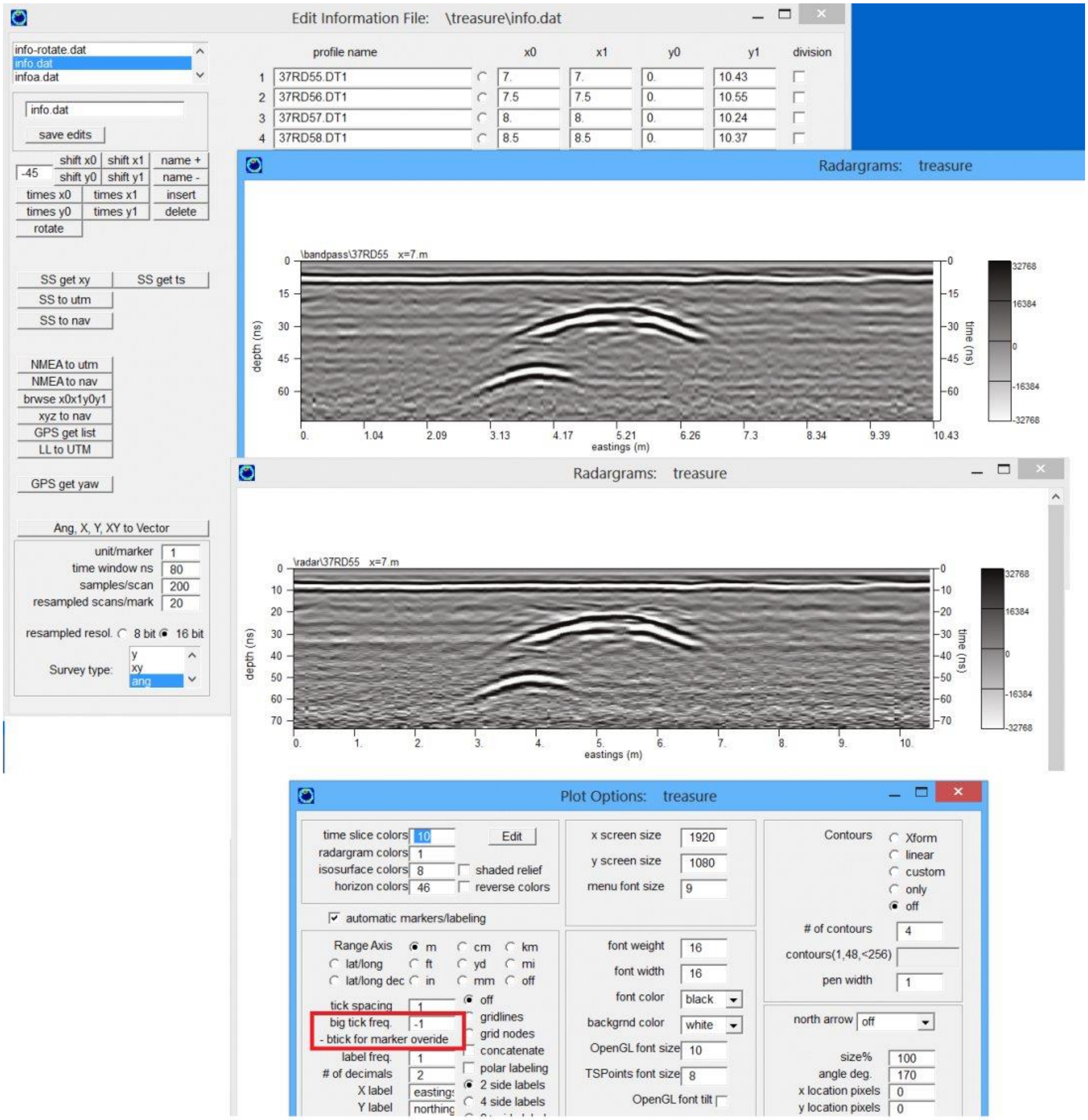
Angular line surveys can be created and processed just as regular surveys. An example of an information file designated as an ANG file and the corresponding grid plot is shown in the above diagram. The only detail that is slightly different from ANG surveys compared to an x, y or xy survey is that the line length may be a fractional length. In this instance, GPR-SLICE will compute tagged markers across the radargram to a rounded up number of markers. For instance, a 10.43 meter length radargram, will have 12 tags placed across the radargram – 1 at the beginning plus 11 more tags equally placed across the radargram. All angular lines which are of fractional length will have the rounded up integer lengths for the line plus one extra marker for the beginning. The markers are actually not placed at integral locations. The marker tags are needed for the binning process in creating time slices as well as defining navigation. X, Y or XY surveys which have fractional line lengths are actually treated similar in generating tagged scans. The only display issue from fractional line lengths are that native x axis labeling will not normally show integral labeling unless a marker tag "override" flag is engaged. An extended discussion of the implications for ANG surveys or even X,Y or XY that have fractional line lengths is given in the next section.

User defined labeling - scan header labeling override for ANG or other surveys

GPR-SLICE has traditionally only outputted labeling on 2D radargrams that comes from the scan headers where navigation tags are stored in the 2nd sample of the digitized pulse. This has been a double check on navigation - as only tagged scans can force a label in the radargram displays. Even if a radargram is defined as some length in the info.dat file and there are no navigation tags in the radargram scan header that were applied through the Navigation Menu, no labels will appear on displays. For ANG surveys, where there can be fractional line lengths, the navigation tags may not be at integral lengths in the radargrams. Navigation tags for ANG surveys can be at non-integral lengths. The reason for this is in the process of creating time slices and a need to properly include and equal weight all portions of the radargram in the time slice binning process, tags are set at non-integral locations. For instance, a 10.0 meter radargram, would get tagged with 11 navigation tags but a 10.43 meter radargram for would get 12 navigation tags (including the scan #1). The user would be able to break down the 12 tags in the radargram with the Cut Per Mark option to generate additionally smaller bins for time slice operations. With that said, because of the non-integral location that can occur with ANG survey for the tagged scans, on displays, the labeling will show at fractional numbers. This also requires that the # of decimals in the x axis display be set to something other than 0. Several users complained that they could not get out equidistantly labels at a desired graphic increment. For this reason, an old option that was taken out of the software has been re-instated (Figure 6). The Big Tick frequency, if set to a negative value in the Options menu, will override the scan header navigation - and provide a completely graphical labeling where the user can control the interval between labels.

An example of a traditional scan header labeling for an ANG survey line that is 10.43 m and what can be achieved with a negative Big Tick frequency option is shown in the following figure. In the traditional ANG survey, the labels have fractions in them. With the override engaged the user can achieve any integral display on the tick labeling. The tick labeling interval can also be sub-integral if desired by clicking off the Auto marker labeling checkbox in the Options menu.

Note: Scan marker override option is only available for X, Y, XY or ANG surveys and is not applicable or available for GPS surveys.



Assisted Auto-Hyperbola Detection and Mapping (Bridgedecks)

GPR-SLICE now has options to automatically detect hyperbolas and to output these detected hyperbolas for mapping. These options were developed at the request of companies involved in infrastructure evaluation. Evaluation of bridge decks or sites constructed with rebar or reinforcements can be assisted with GPR surveying. For these surveys, a method to quickly discover the XYZ location as well as the amplitudes of the reflection are needed for evaluation purposes. (Amplitude reporting can be used in advanced empirical theories to estimate weathering and deterioration of structures).

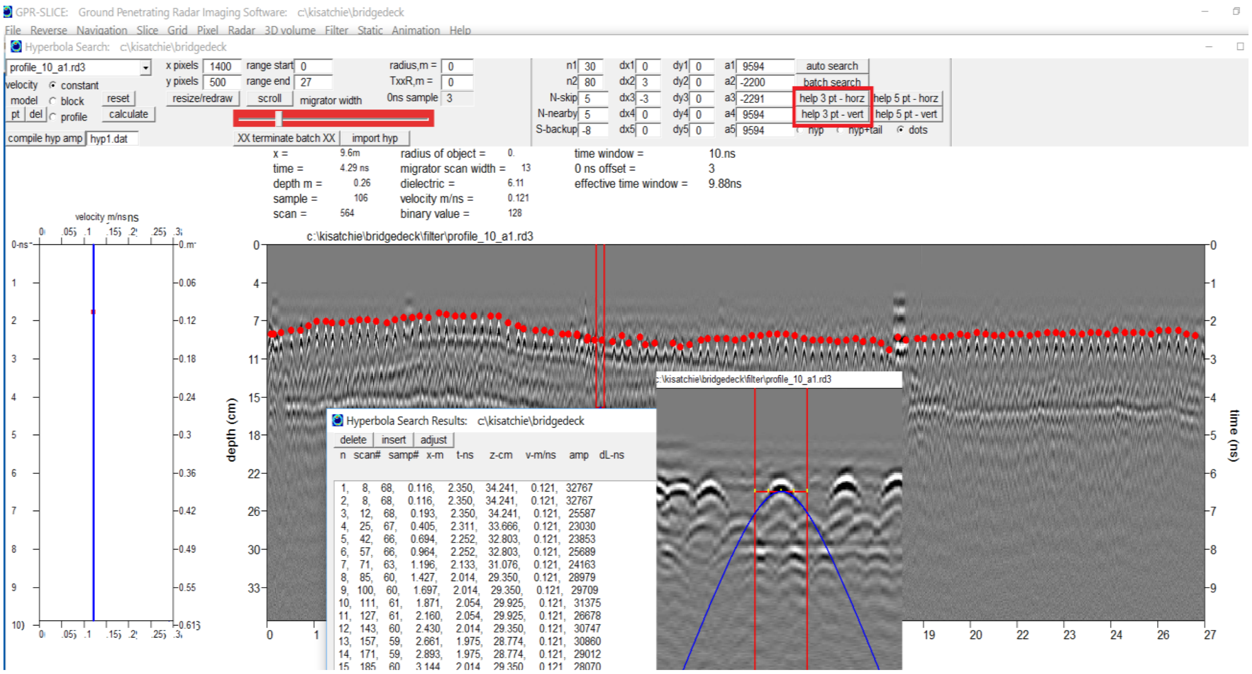
Two primary search methods are available:

Method 1: 3-point threshold detection - vertical and horizontal directions
Method 2: 5-point threshold detection - vertical or horizontal directions

(The preferred algorithm is the 3-point detection which has been found to perform better than 5-point original detection operation of looking along the entire hyperbola.)

3 & 5 Point Auto Hyperbola/Anomaly Detection

The first hyperbola detection algorithm provided in GPR-SLICE involved searching all the points along the hyperbola and counting the number of samples that breached a user defined threshold. This algorithm, although founded in good "science" did not provide for hyperbola detection in the case of variable velocities or noisy datasets so well. 3-point and 5-point search was implemented and improved detection and was placed in the menu some time later. On further testing, a simple 3 point search is found to work even better than a 5 point search. To run the 3 point search the button 3 point horizontal or 3 point vertical is clicked on and the aperture width is adjusted such that the middle point and the two adjacent 2^{nd} and 3^{rd} points are on a different +/- legs of the hyperbola (see the following screen shot). The plus minus legs can be in the horizontal or vertical direction depending on which operation is pressed and desired. Left clicking the 3 point detection in the desired location will get the amplitudes and the x,y sample locations for each point. This information will be filled out in the dx1, dy1 and aN slots in the menu. (The 4^{th} and 5^{th} points will be set to the first point values which will institute a 3 point search; a 5-point search will have all independent values and sample x,y locations). An example detection for rebar on a bridge deck is shown:



Note: Auto hyperbola and anomaly detection capabilities requires the GPR-SLICE bridgedeck license and is not available for standard licenses.

To implement the search algorithm, several additional settings are required:

N1 - The top sample in the scan to begin searching.

N2 - The bottom sample in the scan to end searching.

N Skip - the number of scans to skip in the radargram after detection is made, to begin a new search.

N Search - the number of sample points on the digitized pulse or scans to search around the detected point to find the largest peak response on the hyperbola

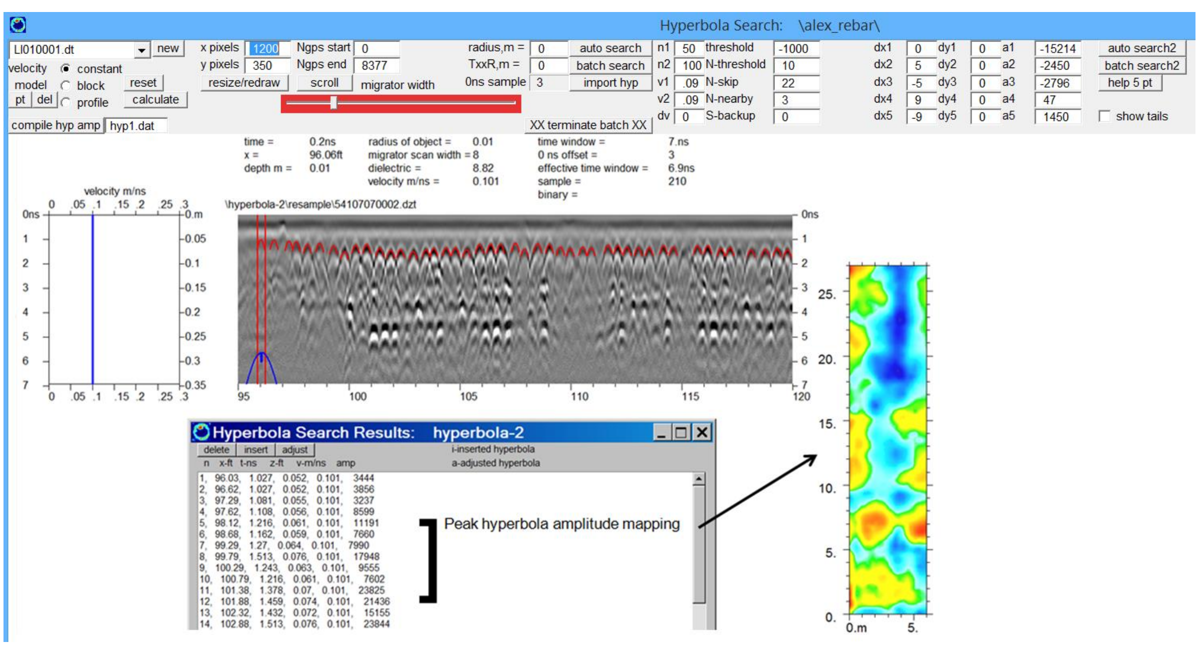
N Backup – the number of samples to place the detection above the located binary values set, allowing the user to detect the peak response of the hyperbolas but then reposition the detection at the weaker first arrival amplitudes from the rebar or anomaly to be detected

The options in the menu allow for using the peak+ or the peak– response of the scan pulse. In addition, cosmetic options to show or not show the hyperbola tails beyond the N-threshold range is available in the menu, along with scrolling options to target just a portion of the radargram are available.

Note: The search algorithm is not perfectly perfected nor will it ever be. Most sites require some user editing of automatic hyperbola search tabulations. Also, it should be noted that the search algorithm is very sensitive to the threshold settings as well as the number of scans that have to breached with the threshold before getting detected. The user is advised to "play around" with differing combinations of these setting to get the best desired results from automatic detection for method 1. This may involve actually adjusting the amplitude thresholds in the slots by hand to reduce/increase them as well as the location of detection on top of the radargram.

Compilation of rebar deterioration maps

The peak amplitude responses of the hyperbola from rebar are important for estimating deterioration of concrete and rebar (for bridge deck). As a further development of auto hyperbola mapping and bridge deck analysis, the detected hyperbola amplitudes can get compiled and gridded in GPR-SLICE. Shown in the next menu screenshot is the gridded hyperbola amplitude using Compile Hyp Amp button in the Hyperbola Search menu, followed by gridding in the Grid menu:



Removing Shielding Noise

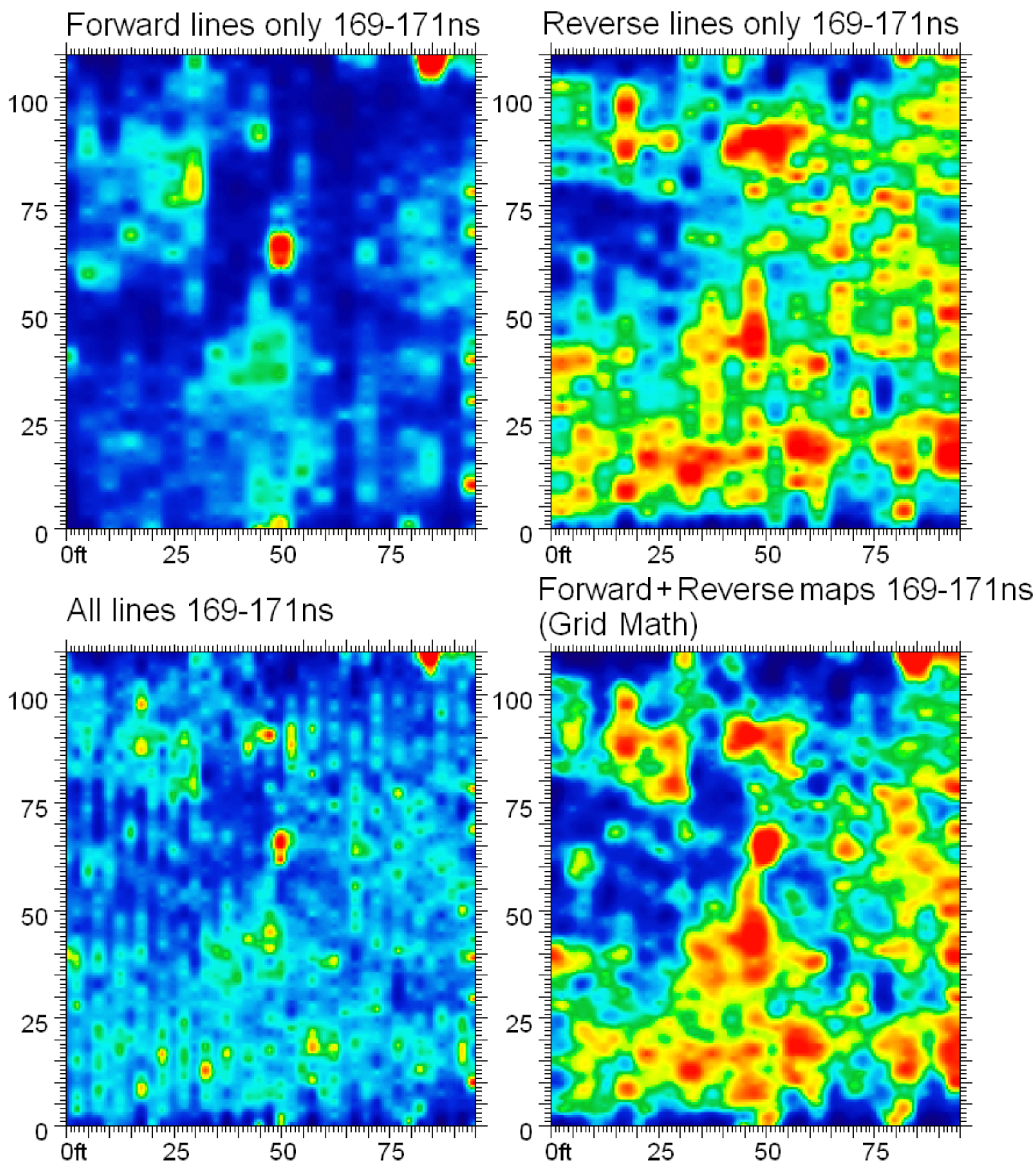
A specialized noise has been identified in GPR radargrams that we can best describe as "shielding line noise" (see the following diagram designated as "all lines"). Very often zig-zag surveys will show alternately strong weak overall recorded reflections between adjacent lines. This may be a result of some external and directional outside microwave source which may affect the overall recorded reflections. It may also be a result of some change in the configuration, perhaps the location of cables or some other field setup that changes slightly between forward and reverse lines. Whichever the case, such effects should not be in the raw radargrams unless the antenna is not perfectly shielded. We know that perfect shielding is not possible - thus this newly identified noise has been called shielding line noise.

There are useful processing steps to remove this noise. One of the best ways to do this is to create 2 separate grid maps of forward and reverse lines and the do grid math to add these time slice maps separately. The general operational steps are:

1) create info1.dat which are the forward lines
2) create time slices of just the forward lines
3) create info2.dat which are the reverse lines
4) create time slice of just the reverse lines
5) go to the Grid menu and use Grid Math to add the 2 time slices together

The time slices can be added with constant to try and match the overall reflection strengths between the forward and reverse lines. An example of applying these operations to a Mala Geoscience dataset that exhibited the shielding line noise is shown in the following diagram (data courtesy of Geoview, Florida). The individual forward and reverse time slices, the original time slice, and the time slice computed by adding the forward and reverse grid together indicates that this line noise has been effectively removed. One artifact of applying these filtering processes is that the resulting reflections anomalies look a touch more smoothed out than on the original time slice map. Nonetheless, the line noises associated with shielding problems have almost been completely eliminated.

Time Slices: geoview



"shielding noise" between forward and reversed line

"shielding noise" removed by adding forward and reverse time slice maps with Grid Math

Super Fine Time Slicing

We have discussed in the 2D Quickstart section an effective way of generating time slices as well as interpolating between time slices. For many applications, these data processes will suffice for solving many subsurface problems. There are those that may not find the process of interpolation appropriate for GPR data and do not want to recreate or estimate any data between depth slices. In addition, these GPR users may find the time slice thicknesses that are recommended, such as 1-2 pulse wavelengths to be too large. Another point that these users may disdain is the normalization process that is a byproduct of interpolating time slices. Remember, the interpolation process will create interpolated time slices which are normalized to 8 bit following the color changes between different levels and not actual reflection values.

Well, for users that want to explore GPR data in its full glory without any interpolation or without any normalization, the following data processing steps are recommend:

1) Do all the regular steps through slice/resample operations.

2) Compute the Hilbert Transform of the resampled radargrams or of any processed radargram to be used in slicing.

3) Slice/resample the Hilbert Transform folder using a very thin sample thickness (of 1 or perhaps 3-5 without too much loss of depth resolution). The number of slices one can make can be as much as the number of sample/scan (up to a limit of 1024 slices). It is recommended that the number of slices be kept under 200 though because of memory requirements may get exceeded if one will be compiling 3D binary volumes.

4) Display and process the (multitude of thin) time slices in the Grid or Pixel menu as desired.

The Hilbert Transform is recommended since this will give one the pulse envelope (or energy when the squared amplitude of it is taken). Applying the Hilbert Transform will eliminate phase components of the radar pulse which we believe distracts from making using time slice images that show continuity in strong and weak areas of reflectivity.

If these (raw) time slices that are not interpolated are compiled directly to a 3D binary file, this binary file will more or less emulate the exact reflections energy in the recorded radar pulses versus depth. One situation which can occur with these absolute amplitude 3D volumes (or 2D time slices) as well is flexibility and dynamic range in applying color transforms may be lost since some strong reflections may completely dominate the data spectrum.

Concatenating Two or More Grids Collected with Different Time Windows

GPR-SLICE can be used to make comprehensive time slice maps when several grids to a large survey were collected with a different time window then other grids. To merge these data together into a single ASCII time slice dataset to be gridded the following steps can be implemented:

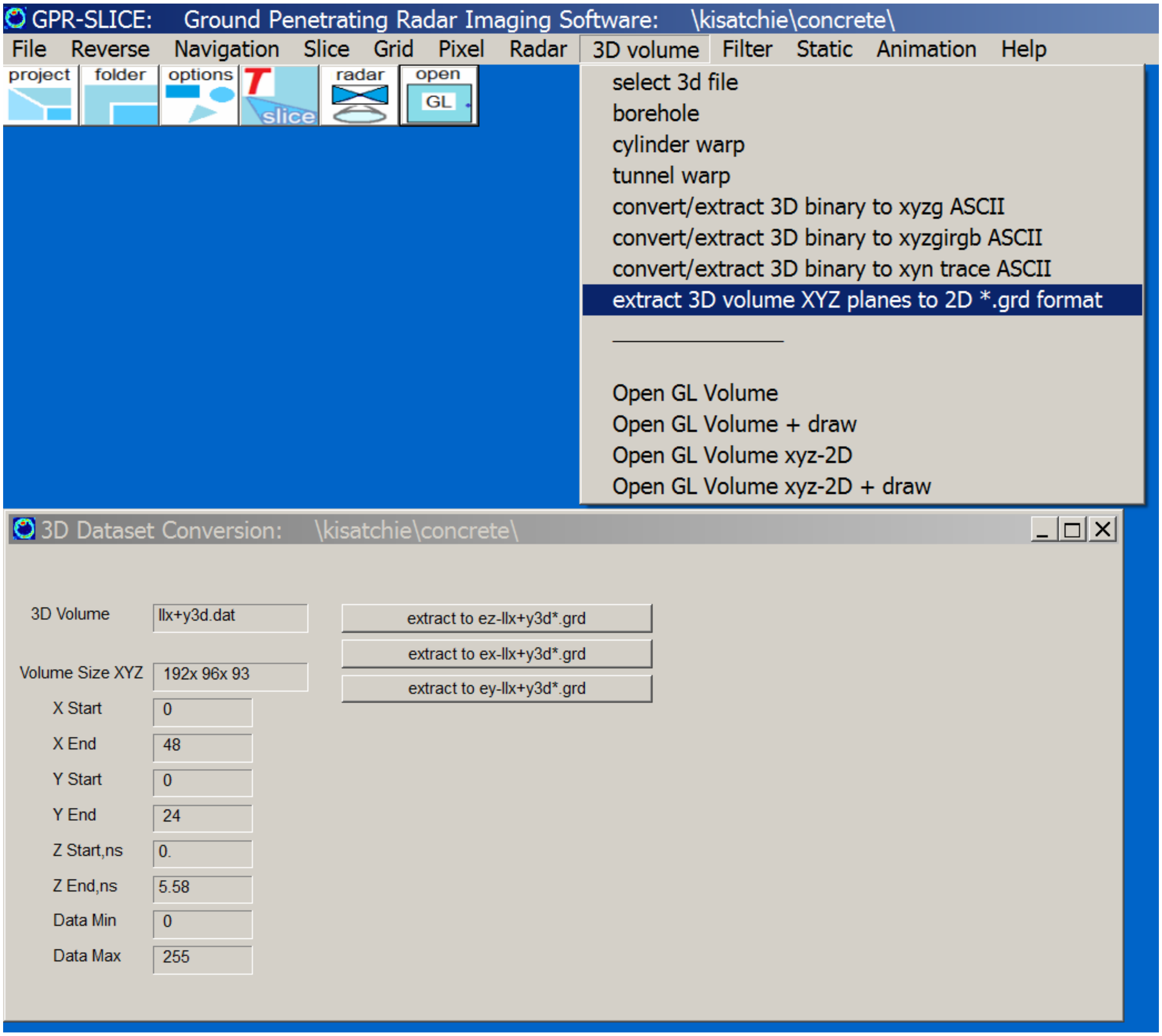
1. Create info1.dat containing the names of all the radargrams that were collected at the same time window. Go all the way to slice/resample, choosing the slicing thicknesses, number of slices and locations you like.
2. Create info2.dat containing the names of all the radargrams at the other time window used in the survey. Go all the way to slice/resample, choosing the slicing thicknesses, number of slices and locations **to be identical to those used in processing info1.dat files.** In general you will be reducing the end sample and the thickness in samples to get a similar match to the slicing windows for the radargrams data collected with shallower time window.
3. Create a comprehensive info12.dat with the all the profiles for both recording time windows
4. Skip right to the slice/resample menu and click XYZ!!

Step #4 will make comprehensive time slice ASCII files for gridding which contain the equivalent time windows from each of the two datasets. The reason this can be done in GPR-SLICE is that the slice/resample operation simply stores the time slice parameters for each line in the (transparent) subfolder called \sqwave\ which exists for every project. The XYZ process simple collects all this information and merges it with the navigation described in the information file. As long as both information files are processed with exactly the **same number of slices** and the **same number of bins per mark**, the merging of the 2 time windows can be done. The settings in the slice/resample button must also **not** have changed before the XYZ compilation button is clicked.

Appending of maps with different time windows can also be done in the Pixel Map menu where the different grids with different time windows are processed independently and then Append operations are run.

Data compiled from two or more different time windows will most likely have some amount of mosaic noises that need to be removed. This can be handled very effectively in GPR-SLICE using several methods, the best of which is a little more time consuming and involves using transform matching options for concatenating and matching the grids (this has a pretty good write up in the manual).

Extracting Individual X or Y or Z Planes from the 3D Volume to 2D Grid Files



X, Y or Z planes can be extracted to individual 2D grid files using options in the 3D Volume pulldown on the main menu. Clicking the Extract 3D Volume XYZ planned to 2d *.grd format will open up a menu allowing the user to click any plane to be extracted. The extracted planes will be appended with ex-, ey, or ez- depending on the desired direction.

3D Volume (XYZ, XYZIRGB, XYN trace) Export

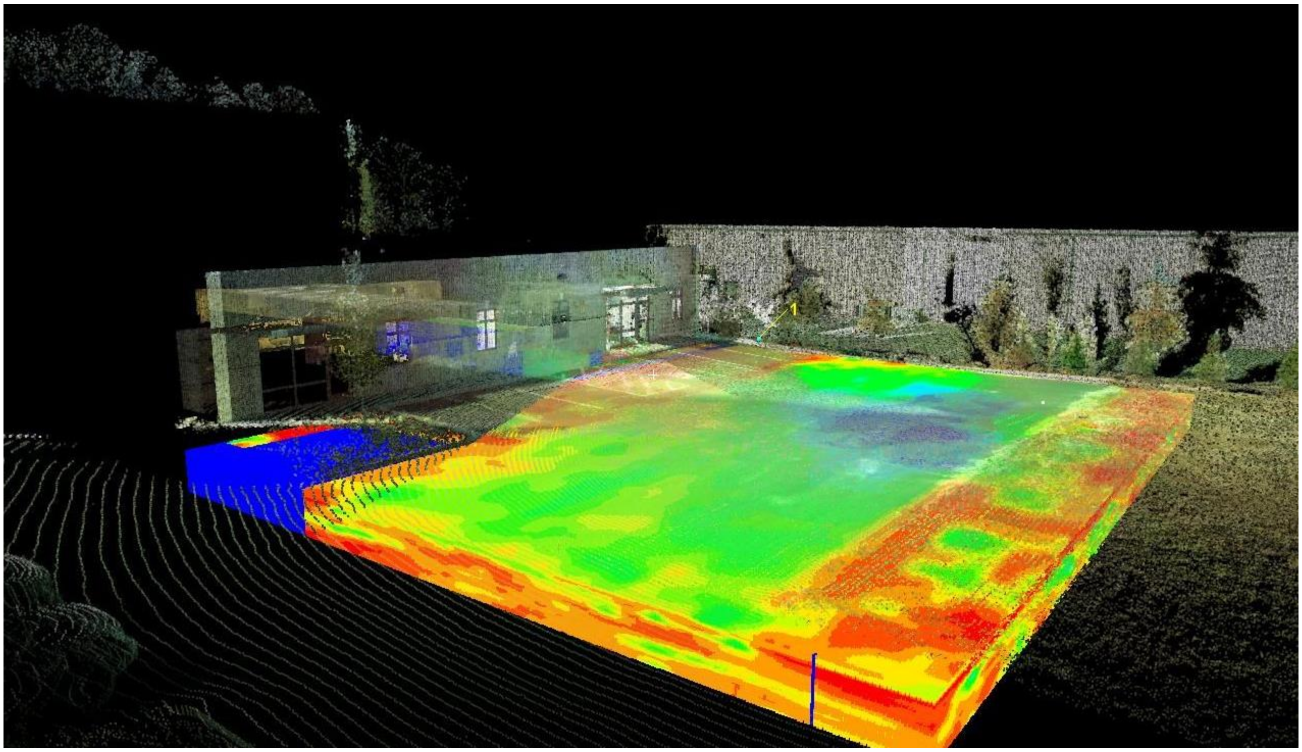
GPR-SLICE v7 provides 3 different ASCII formats for export of the 3D volume generated in the Software:

- XYZG is a comma delimited ASCII file with x,y,z, and the value of the radar refection or squared amplitude or whatever volume element was compiled.

- XYZIRGB is a 7 column ASCII export format with x, y, z the location in 3D space, I the intensity of the radar reflection recorded in the volume, and RGB are the colors from the current active color table for the display of the 3D volume. This option complements the simpler XYZG ASCII format, where G is equal to I and is the intensity of the recorded reflection at the given XYZ point. This format is useful for users involved in combining GPR-SLICE 3D volume images with Laser Scanning software. (Note: Z is made negative going down).

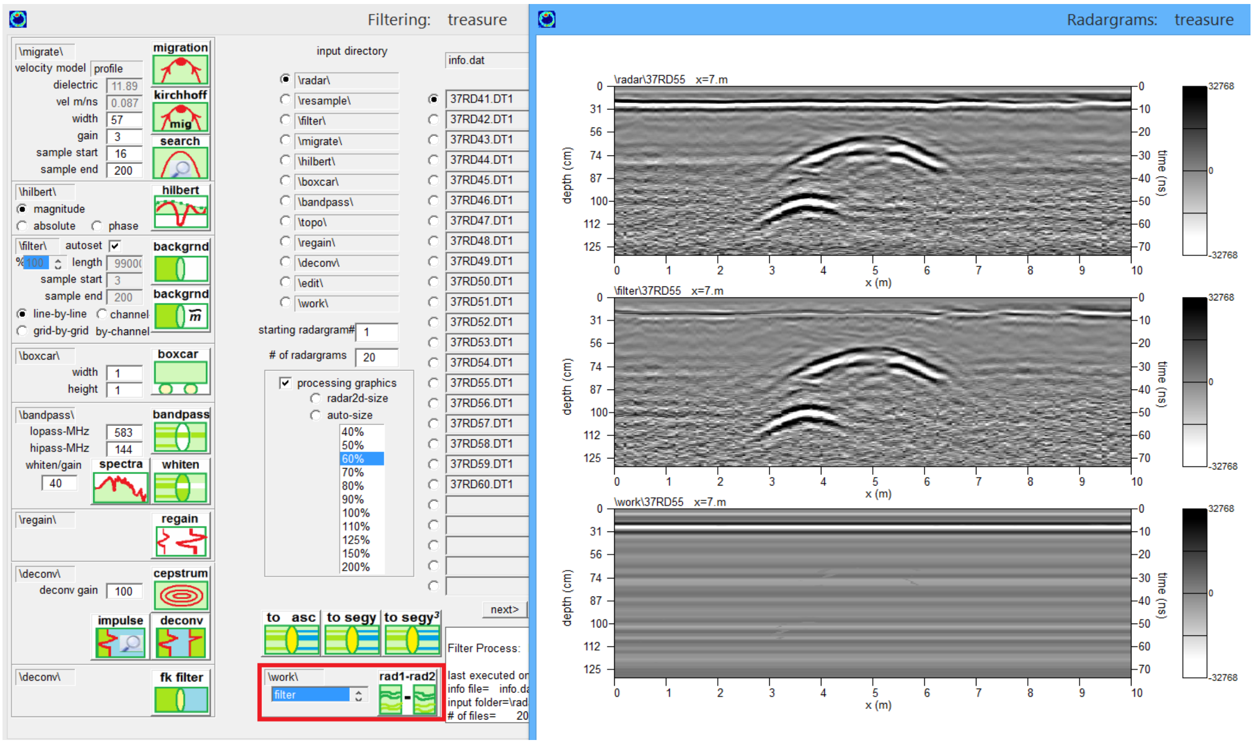
- XYN Trace is an ASCII export where the vertical cells in each location are written consecutively. When a pulse volume is generated, XYN Trace represents individual traces along the volume written one after another. If the Z cell size is 200 for instance, then each line of the file will be x1,y1,Trace1...200 followed by x2,y2,Trace2...200.

An example of a laser scanning image merged with a GPR-SLICE volume is provided by James Clay of Land Air Surveying, and Dr. Kent Schneider, US Forest Service shown in the next screen shot. The image was merged with point cloud software Cyclone which read the XYZIRGB export file.



Radargram Differencing

The radargram differencing option in GPR-SLICE has been improved to look at any two folders. The folder can be a processed folder or raw (\radar\) folder to compute the difference between radargrams. The input directory folder and the list of folders next to the Rad1-Rad2 button should be selected before running the operation. The radargrams must have exactly the same number of traces as well as the same samples/scan. The output from radargram differencing is written to the \work\ folder. Radargram differencing is an important operation to examine 4D measurements over the same profile and can indicate areas that have changed in time. Radargram differencing is also useful to see just the noise content that is being removed from the chosen filtering process. An example of differencing a raw radargram with a background filtered radargram is shown:



Filtering: treasure
Radargrams: treasure
\migrate\
velocity model profile
dielectric 11.89
vel m/ns 0.087
width 57
gain 3
sample start 16
sample end 200
migration
kirchhoff
search
\hilbert\
magnitude
absolute
phase
hilbert
\filter\ autoset
length 9900
sample start 3
sample end 200
line-by-line
channel
grid-by-grid
by-channel
backgrnd
\boxcar\
width 1
height 1
boxcar
\bandpass\
lopass-MHz 583
hipass-MHz 144
whiten/gain 40
bandpass
spectra
whiten
\regain\
regain
\deconv\
deconv gain 100
cepstrum
impulse
deconv
fk filter
input directory
info.dat
\radar\
\resample\
\filter\
\migrate\
\hilbert\
\boxcar\
\bandpass\
\topo\
\regain\
\deconv\
\edit\
\work\
37RD41.DT1
37RD42.DT1
37RD43.DT1
37RD44.DT1
37RD45.DT1
37RD46.DT1
37RD47.DT1
37RD48.DT1
37RD49.DT1
37RD50.DT1
37RD51.DT1
37RD52.DT1
37RD53.DT1
37RD54.DT1
37RD55.DT1
37RD56.DT1
37RD57.DT1
37RD58.DT1
37RD59.DT1
37RD60.DT1
starting radargram# 1
# of radargrams 20
processing graphics
radar2d-size
auto-size
40%
50%
60%
70%
80%
90%
100%
110%
125%
150%
200%
next>
to asc
to segy
to segy
Filter Process:
\work\
filter
rad1-rad2
last executed on
input folder=\rad
# of files= 20
\radar\37RD55 x=7.m
\filter\37RD55 x=7.m
\work\37RD55 x=7.m
depth (cm)
time (ns)
x (m)
32768
-32768

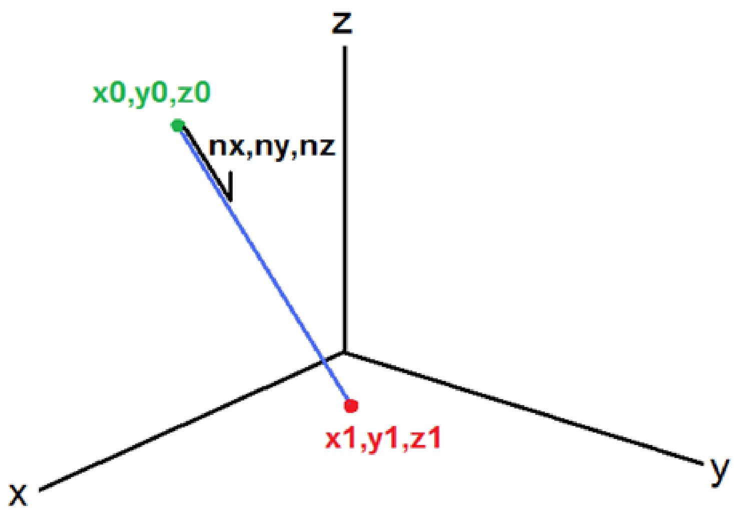
Vector Imaging

Figure Graduate student Michelle Mellon of McMaster University under the direction of Dr. Joe Boyce in the Geology/Geophysics Dept, is shown surveying a site with an accelerometer device that measures yaw, pitch and roll of the GPR antenna. The survey is being conducted to evaluate the biomass volume at the site.

GPR-SLICE is equipped to handle complete random antenna navigation in 3D space considering both the xyz location as well as the antenna orientation. GPR-SLICE can display a GPR radargram in any position and orientation in 3D space and from any possible geometry or path that an antenna is used to survey. Showing radargrams collected along a tunnel, along a meandering tunnel, on the surfaces of walls or even non-rectangular surfaces is all possible. Any orientation is possible!!

The navigation formats for doing what we have termed "Vector Imaging" - to distinguish it from other imaging where the antenna orientation in 3D space is not considered, is already provided for in the expanded *.*.gps. The geometric description is shown below:

Transformation of a sample on the digitized pulse located in xyz space after vector adjustments



x0,y0,z1 - starting scan sample location in xyz (columns 1,2, and 3 in the *.*.gps files

nx,ny,nz - (unit) vector in the direction to project the GPR scan columns 9, 10 and 11 in the *.*.gps files

nxyz - magnitude $|n| = sqr(nx^2 + ny^2 + nz^2)$

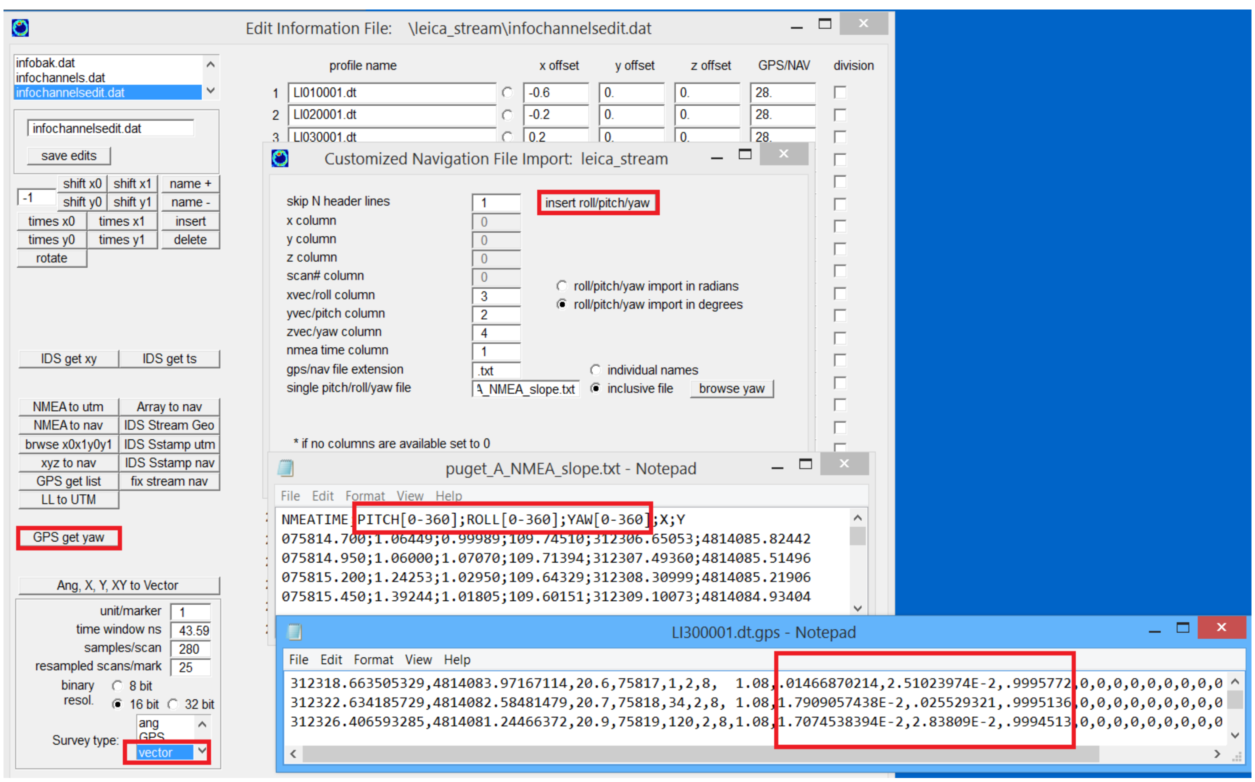
x1,y1,z1 - scan sample location after vector transformation

x1 = x0 * nx / nxyz
y1 = y0 * ny / nxyz
z1 = z0 * nz / nxyz

The *.*.gps files are the most generalized formats available, when using the 9th, 10th and 11th columns of these navigation files which hold the antenna orientation in 3D space. The antenna orientation is entered as a vector normal (rather than the roll, pitch, yaw). The vector normal is the direction the GPR scan has in 3D space as x, y and z corresponding to the 9-11th columns of the *.*.gps file. The vector normal does not necessarily have to be a unit vector as unit vector normalization is done within the software.

Roll/Pitch/Yaw included in Generating 3D Volumes (for Multichannel Licenses)

In the future, roll, pitch and yaw measurements may start to become standard field procedures for some surveys where extra precision is needed for example in utility mapping. There are currently no standards on the recording formats as the manufacturers have yet to incorporate these measurements into their control units and to monitor the orientation/attitude of the surveying antenna. Several organizations are independently recording these values externally and need to include these measurements in the analysis.   Recently, a flexible import operation of roll, pitch and yaw were modified and generalized to read either individual files associated with each recorded radargram, or to read a single global file (screen shot below).   For surveys with specified individual files for each recorded radargram, the GPS Get Yaw button has flexible reading of a comma delimited file specifying the roll/pitch/yaw columns to be imported. For surveys where just a single – global roll/pitch/yaw file is recorded, the NMEA time is searched in this global file and the bordering NMEA time in the *.*.gps files is compared and appropriate interpolation between these times is used in the import. Flexible degree or radian import can be used to import the external custom file.



In this example a single global file inclusive of the entire NMEA time span and with roll/pitch/yaw is converted to the normalized vector and placed into columns 9, 10 and 11 of the *.*.gps navigation files made in GPR-SLICE. The definition used in the conversion of roll/pitch/yaw angles to the normalized vector is by coordinate transformations:

```
sy = SIN(yaw(j))
cy = COS(yaw(j))

sr = SIN(roll(j))
cr = COS(roll(j))

sp = SIN(pitch(j))
cp = COS(pitch(j))
```

rotation around x-axis:

```
qy=0
qz=1
yy= qy*cr - qz*sr
zz= qz*cr + qy*sr
```

rotation around y-axis:

```
qz=zz
qx=0
zz= qz*cp - qx*sp
xx= qx*cp + qz*sp
```

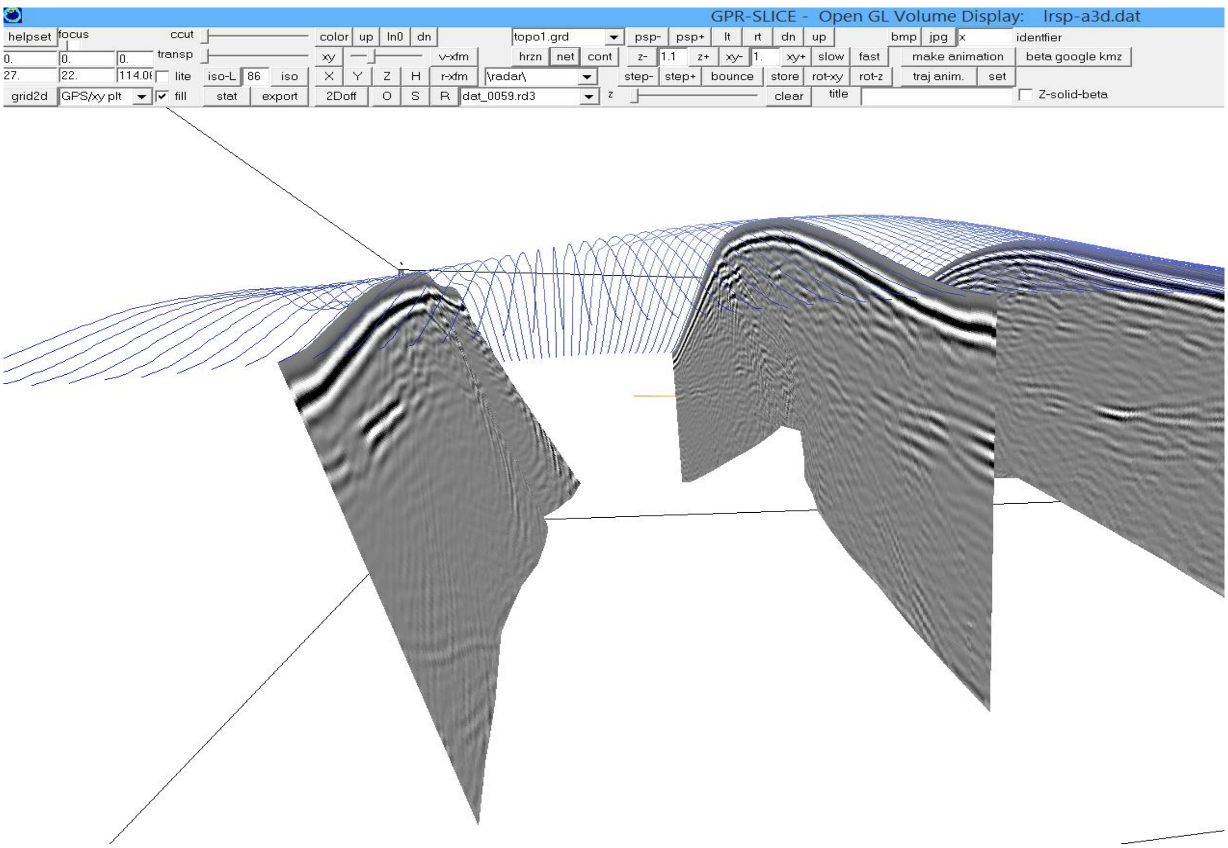
rotation around z-axis:

```
qx=xx
qy=yy
xx= qx*cy - qy*sy
yy= qy*cy + qx*sy

xvec=xx
yvec=yy
zvec=zz
```

To correct for the roll/pitch/yaw in compilation of 3D volumes (for multichannel datasets), the "vector" survey definition for the information file must be active.

A screen shot of Open GL 3D Vector Radar is shown for several radargram collected on a burial mound. The vector display shows that the radargrams are not on simply 2D planes display but have a 3D projection:



The key to using the most general form of vector imaging in GPR-SLICE v7.0 is to be able to set the vector to project the GPR scan via columns 9-11 in the *.*.gps files. GPR-SLICE currently supplies several menus to assist the user in generating vector navigation and displaying radargrams. Additional utility menus will be developed in GPR-SLICE as more surveys are being done on various kinds of variable 3D surfaces. At present the user can also modify the vector columns to supply and geometry that they might be doing with GPR. Several menus currently available in GPR-SLICE v7.0 are for tunnel applications and automatic setting of the projected scan vector is provided:

- Tunnel surveys with the radargram collected along the axis of the tunnel
- Meandering tunnel surveys with the radargram collected along the axis of a meandering tunnel
- Topographic surveys and automatic vector surface normals calculation from the active topography grid file
-

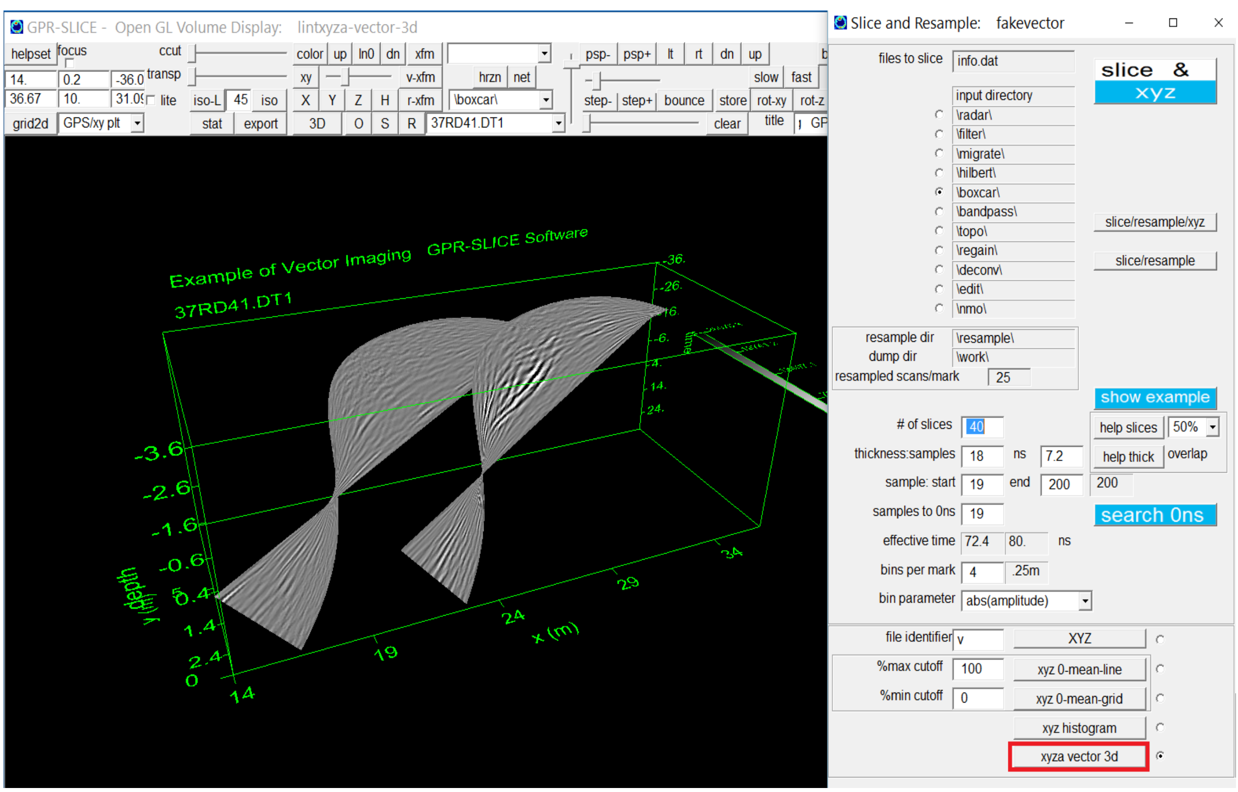
These menus are just a subset of the possible navigation with the generalized vector navigation format in GPR-SLICE v7.0. These

Vector 3D volume generation from 3D vector radargrams

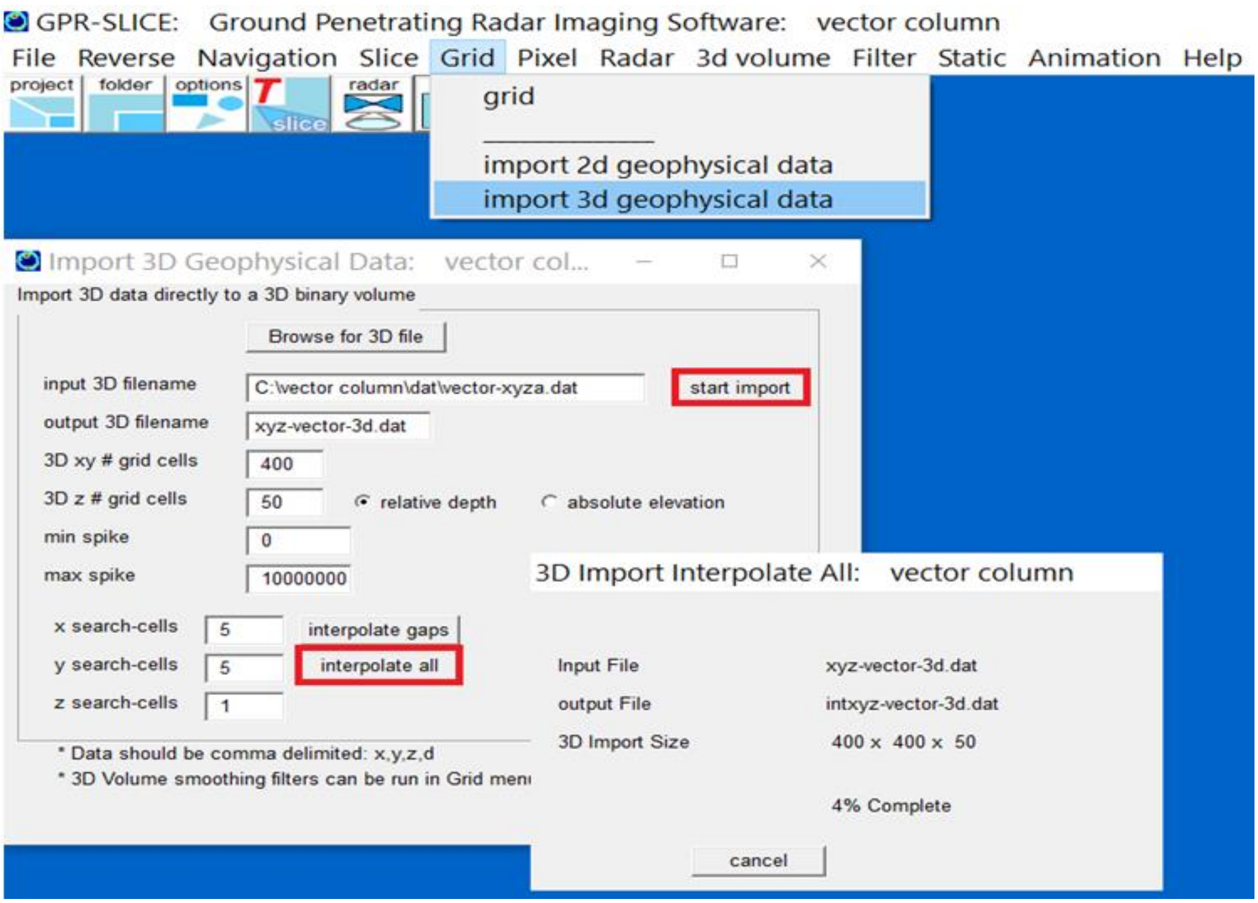
Finally, the union of vector radargrams is combined with vector volumes! This has been a long desire of mine to have any radargram in any orientation in space and to be able to generate a 3D volume from these projected radargrams. We have in the past provided simple features like tunnels, cylinders and topographic vector volumes. However, the generalized operations for any vector were not available. These are now explicitly available in GPR-SLICE!

The operations are to:

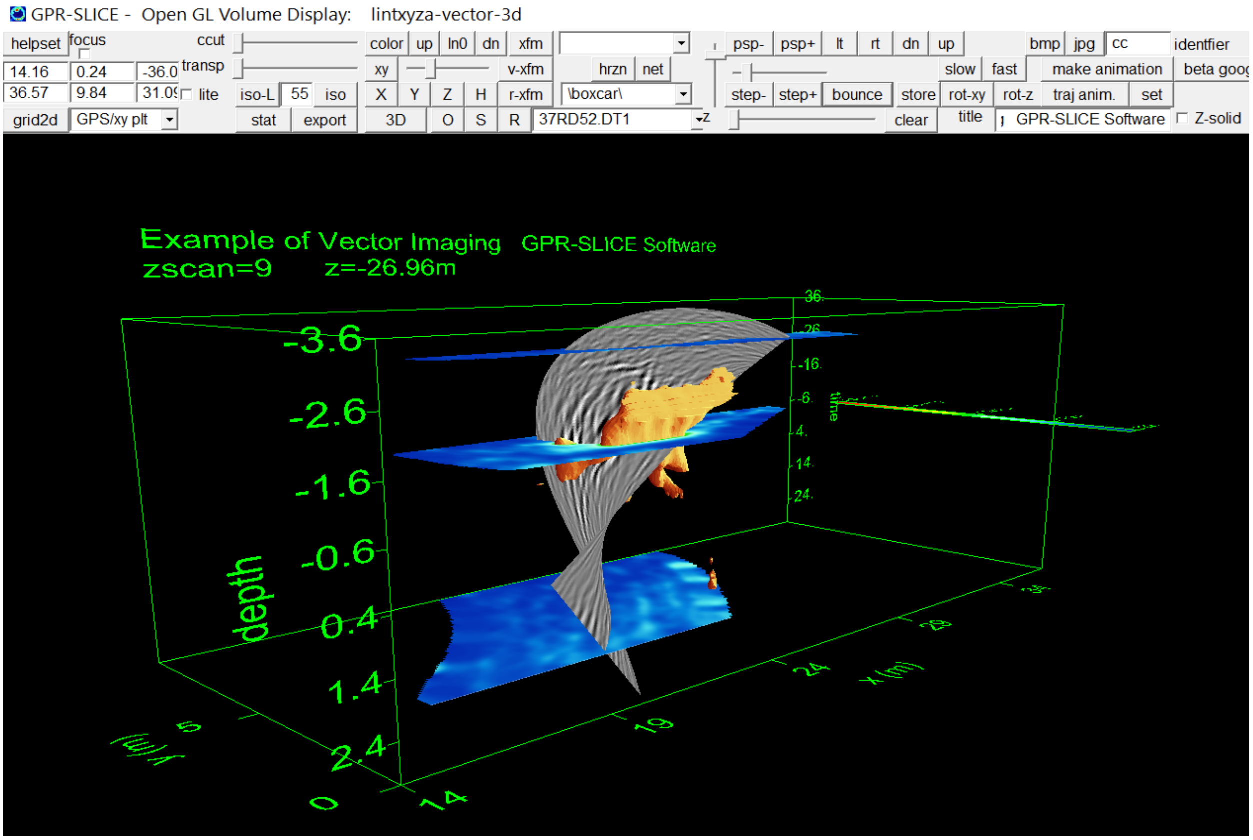
1. Generate vector navigation files in the software or import them from other sources such as yaw pitch roll sensors etc. The vectors can show the radargrams in any 3D spatial orientation. (An example of some radargrams made with a twist in 3D space is shown in the following figure).
2. The slice/resample menu is run using the XYZA-Vector compilation. This will slice and bin the data, and then the vector position of that bin in 3D space will be written to a 3D file called XYZA-vector.dat. This file is 4 columns and has the xyz position along with the bin parameter which is usually the abs(amplitude) or squared (amplitude) average in the bin.



3. XYZA-vector.dat file is a 3D file and requires 3D interpolation. Using the Import 3D Geophysical Data menu, the file is imported and this initially creates a 3D binary file for viewing in OpenGL (2nd figure). This file will generally have a lot of empty 3D cells so some interpolation is usually required. The number of cells in the XY direction and the number of cells in the Z direction can be set independently. After interpolation, the append identifier "int" is placed on the new gridded volume. The 3D interpolation currently has inverse distance gridding hardwired into the interpolation algorithm. After interpolation the Grid menu can be used to apply additional voxel smoothing to the volume if desired.

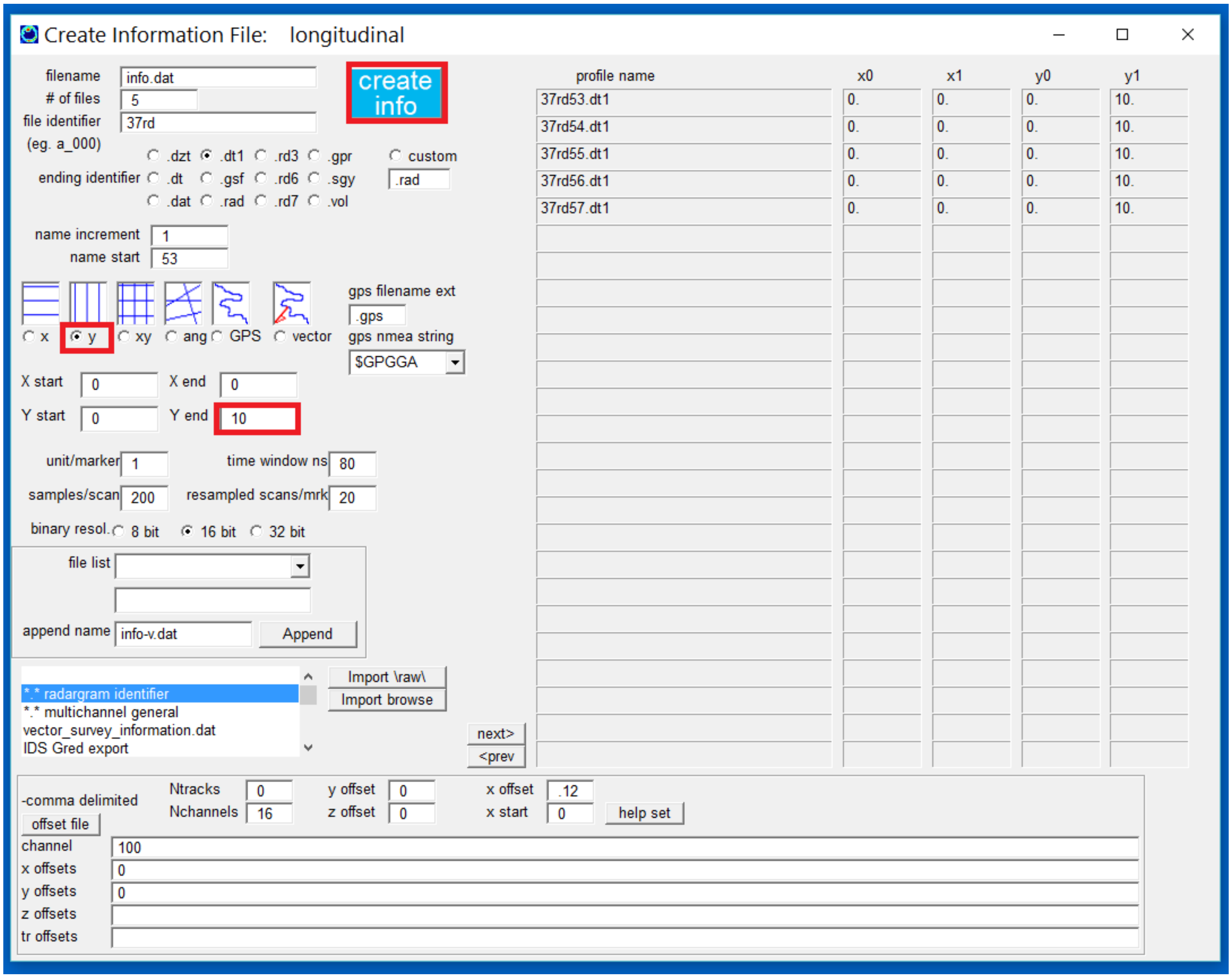


An example of a 3D volume made from vector radargrams having a 3D twist are shown in the third figure. The new operations available for vector volume generation will allow the user for instance to show isosurfaces made on all the separate walls in a room and show those isosurfaces simultaneously in the same volume! Any visualization defined by the vector radargrams can now be interpolated in 3D to create a solid 3D volume of that vector space!


GPR-SLICE - Open GL Volume Display: lintxyza-vector-3d
helpset
focus
ccut
transp
lite
iso-L
55
iso
stat
export
grid2d
GPS/xy plt
color
up
ln0
dn
xfm
xy
v-xfm
hrzn
net
X
Y
Z
H
r-xfm
\boxcar\
3D
O
S
R
37RD52.DT1
psp-
psp+
lt
rt
dn
up
bmp
jpg
cc
identfier
slow
fast
make animation
step-
step+
bounce
store
rot-xy
rot-z
traj anim.
set
clear
title
GPR-SLICE Software
Z-solid
Example of Vector Imaging
GPR-SLICE Software
zscan=9
z=-26.96m
depth
x (m)
y (m)
time

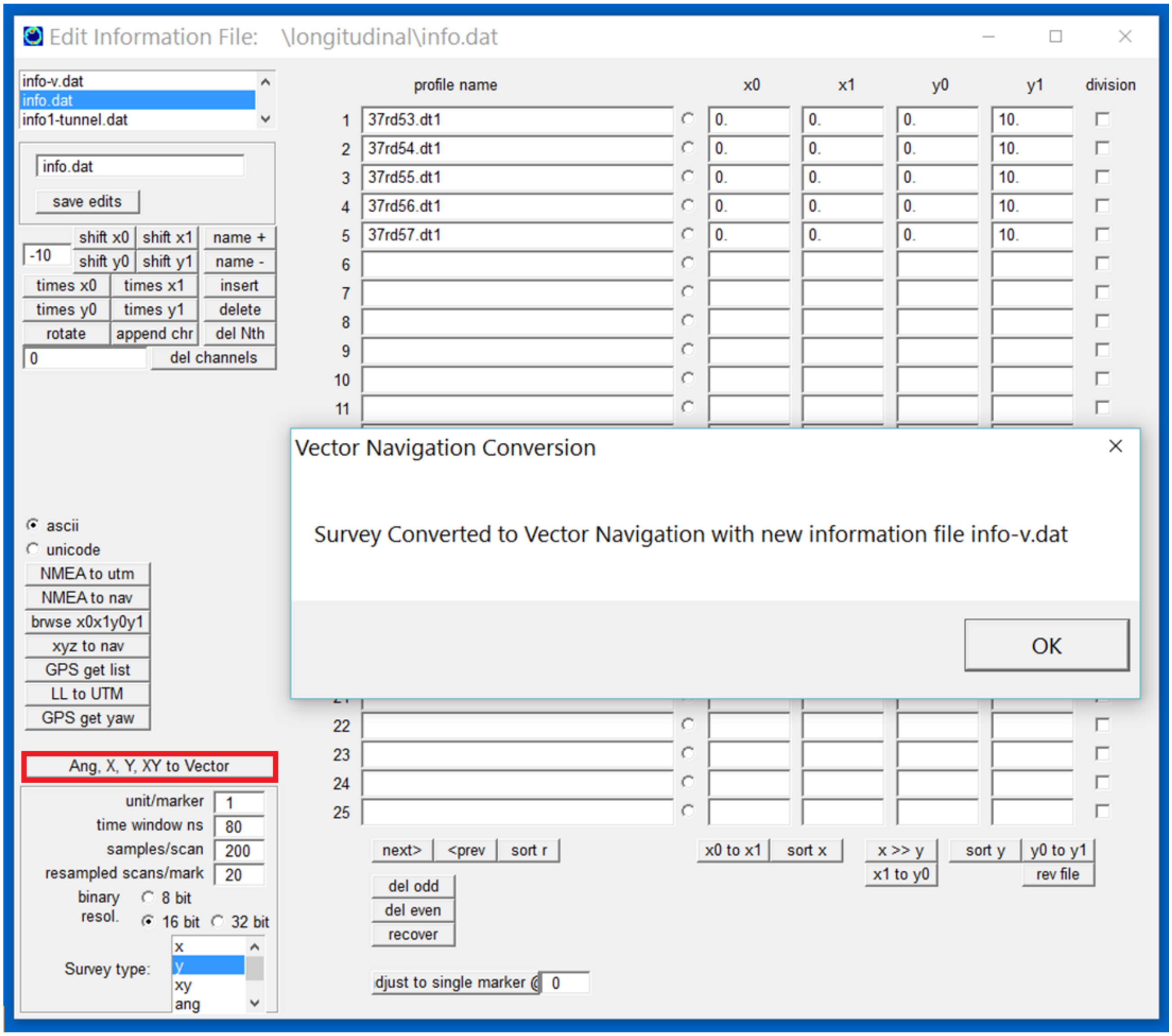
Vector Longitudinal Tunnel Survey

The steps to generate longitudinal tunnel navigation are outlined in the Vector Longitudinal Tunnel Warping menu and are also provided here as well:



Create Info File menu:

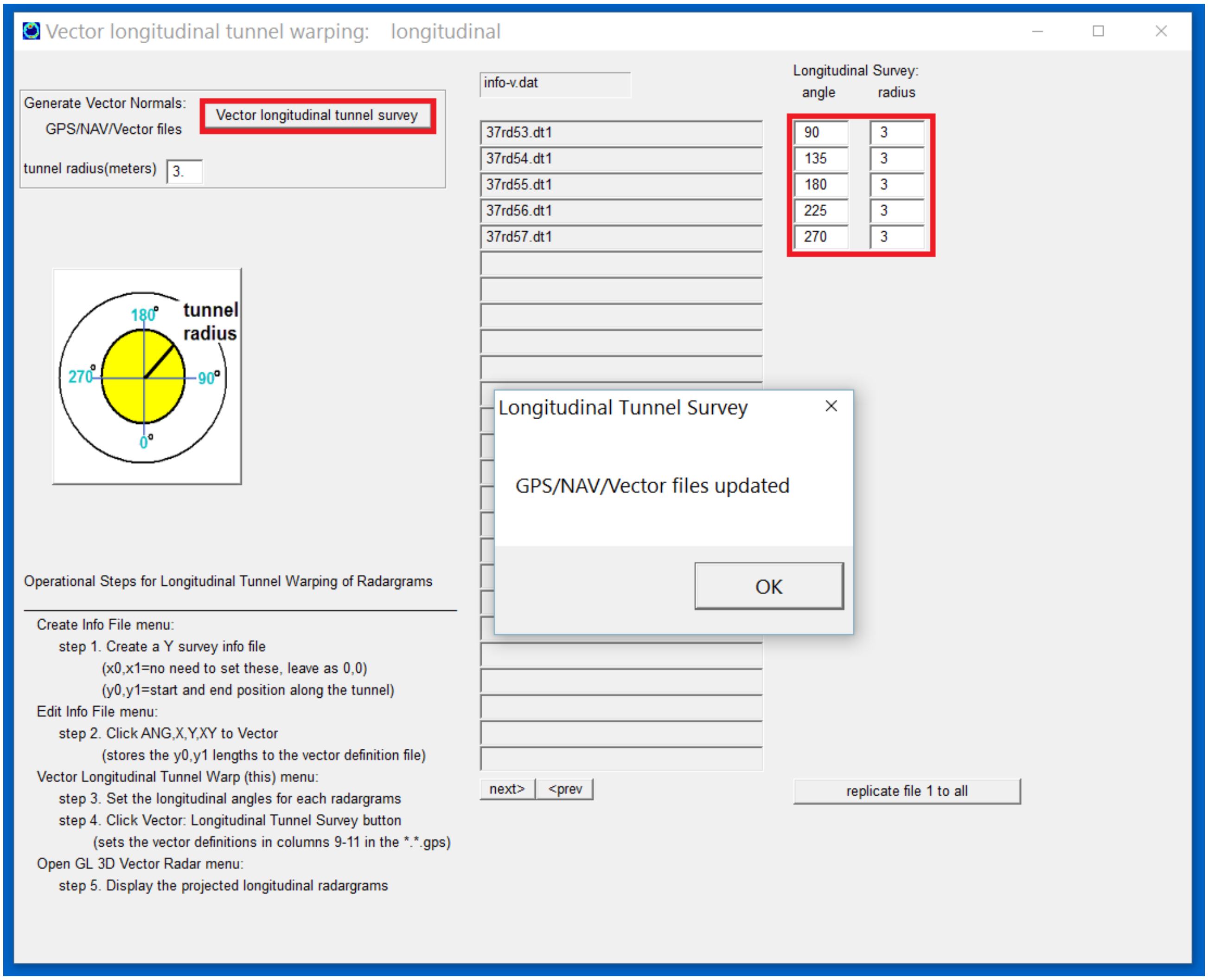
Step 1. Create an Y survey info file
(x0,x1=no need to set these)
(y0,y1=profile start/end length along the tunnel)



Edit Info File menu:

Step 2. Click the Ang X, Y XY to Vector button generating info-v.dat This operation stores the y0,y1 lengths to the vector info file.

Note: if the line lengths need to be adjusted, then edit the line lengths in the Edit Info File menu first, and then click the Ang X, Y, XY to Vector button in that menu.



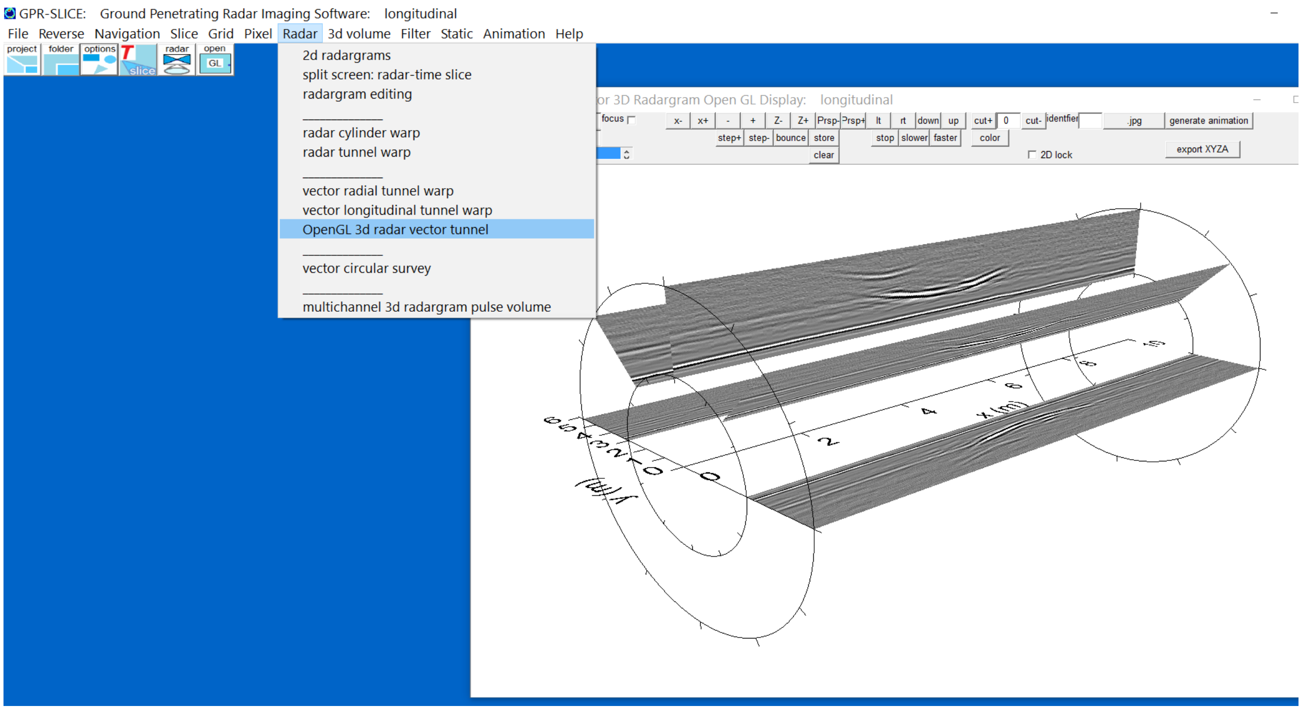
Vector Longitudinal Tunnel Warp menu:

Step 3: Set the longitudinal angles for each radargram
Step 4: Click Vector Longitudinal Tunnel Survey button
(adjusts the 9-11th columns for antenna orientation in the *.*.gps files)

Open GL 3D Vector Radar menu:

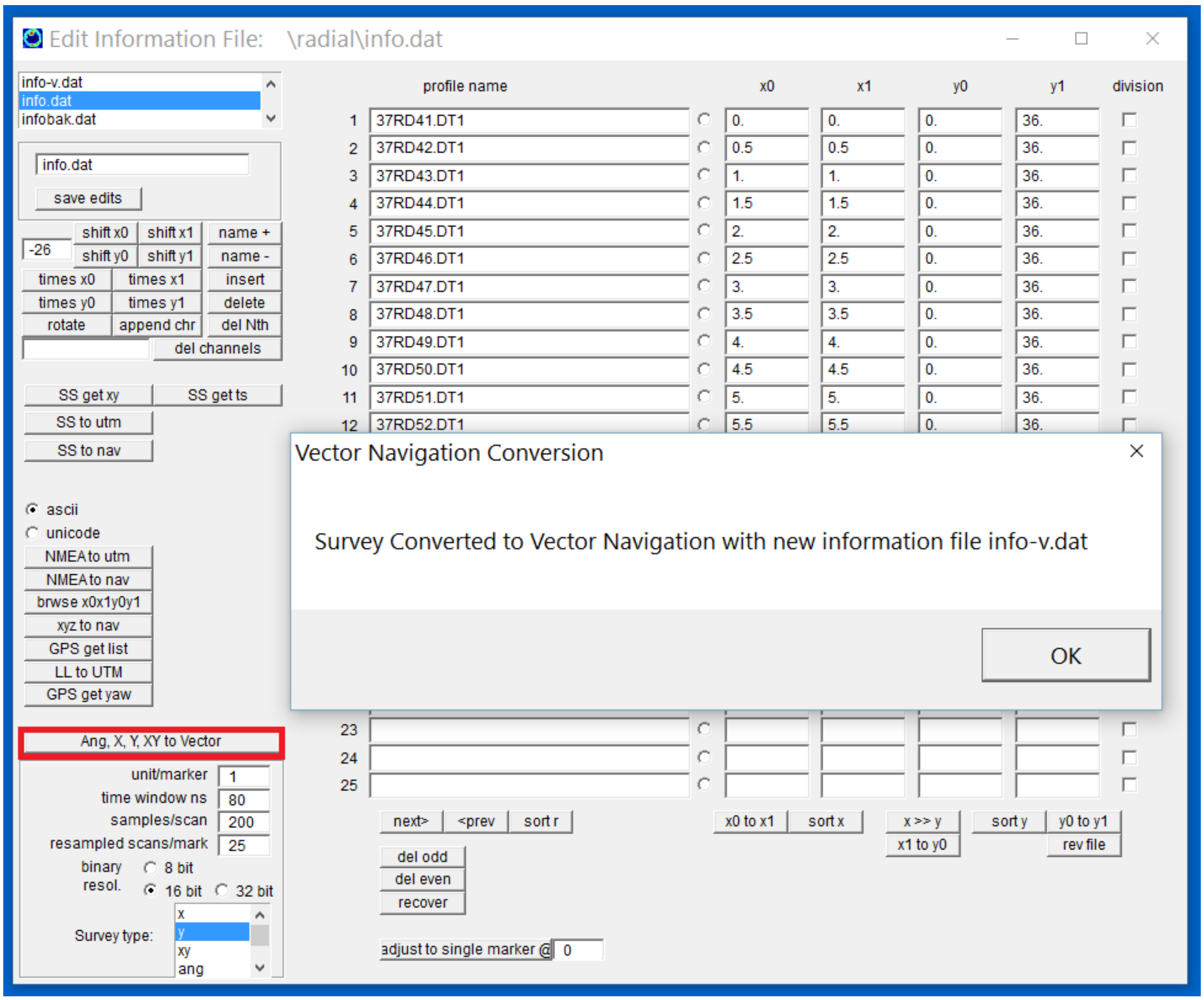
Step 5: Display the projected longitudinal tunnel radargrams.

An example of the projected radargrams collected along a tunnel is shown in the following screen shot of the Open GL 3D Vector Radar menu:



Vector Radial Tunnel Survey

Traditional methods for radargram warping are still available which entails rewriting new binary radargrams. Radargrams can be warped real time to show radial tunnel surveys using the vector formats. With the new vector descriptions, the display of radial tunnel radargrams is much faster and shows the radargrams in their true 3D positions. The steps needed to create vector radial tunnel radargrams is given in the menu explicitly and also shown here.

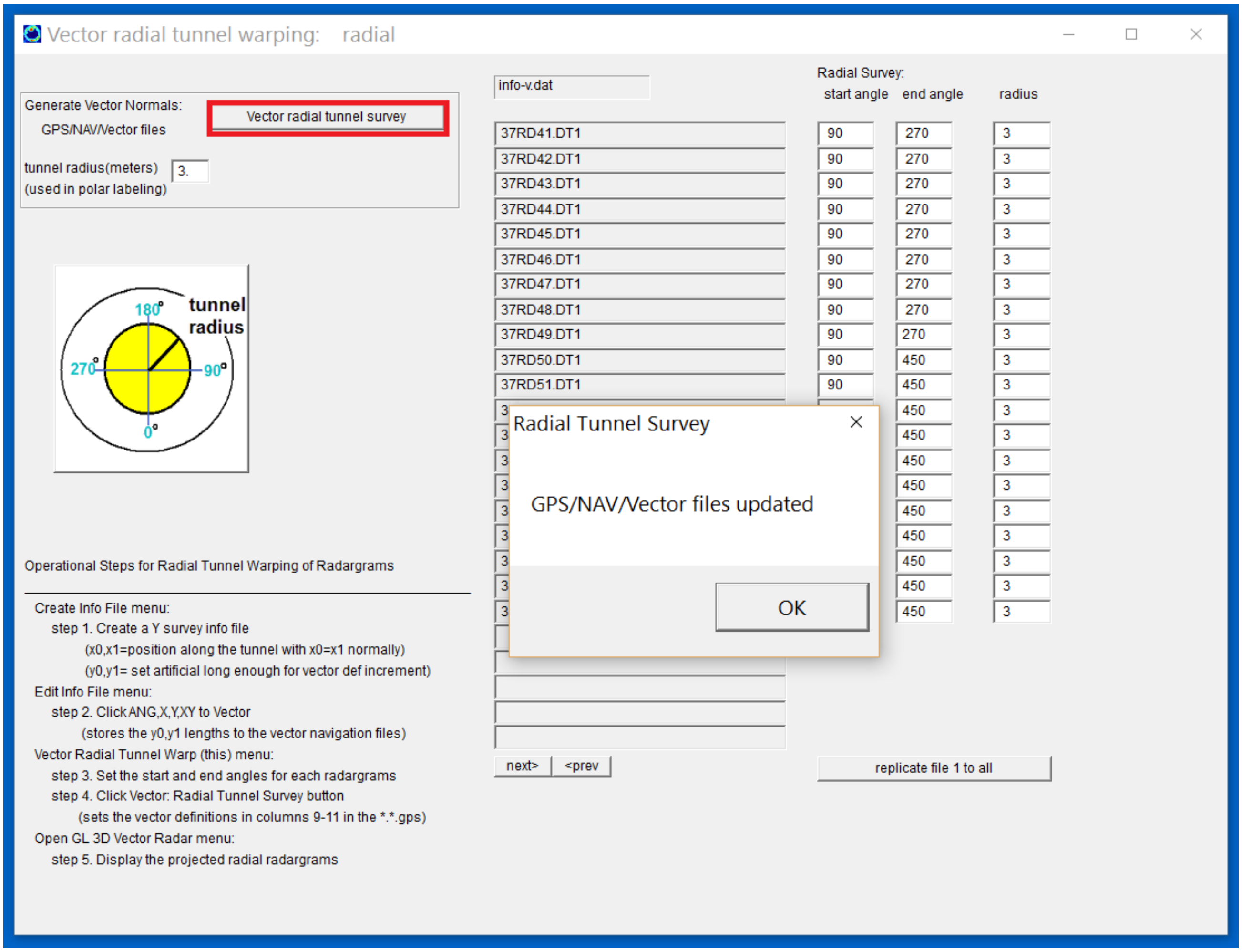


Create New Info menu:

Step 1. Create a "Y" information file with the x0,x1 defining the location along the tunnel. Set the y0 to 0 and the y1 to a number which will defined the number of vector defined for the radargram. In the example above 36 is used which will make a vector a 10 degrees. Note, if more resolution in the rounded radial display is needed the number of vector locations can be doubled to 72 or any number less than the total number of scans in the radargram.

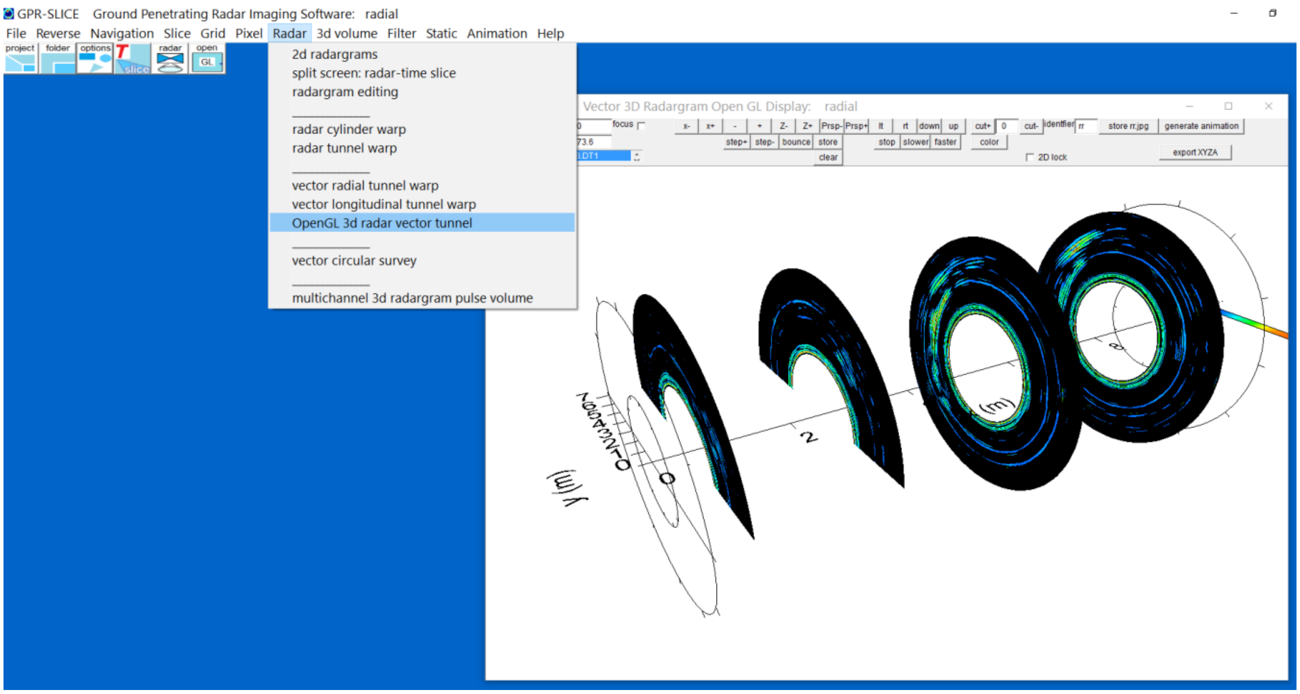
Edit Info File Menu:

Step 2. The Ang X, Y, XY to vector button is clicked in the Edit Info File menu to create the vector navigation files as well as store the position of the radial radargrams.



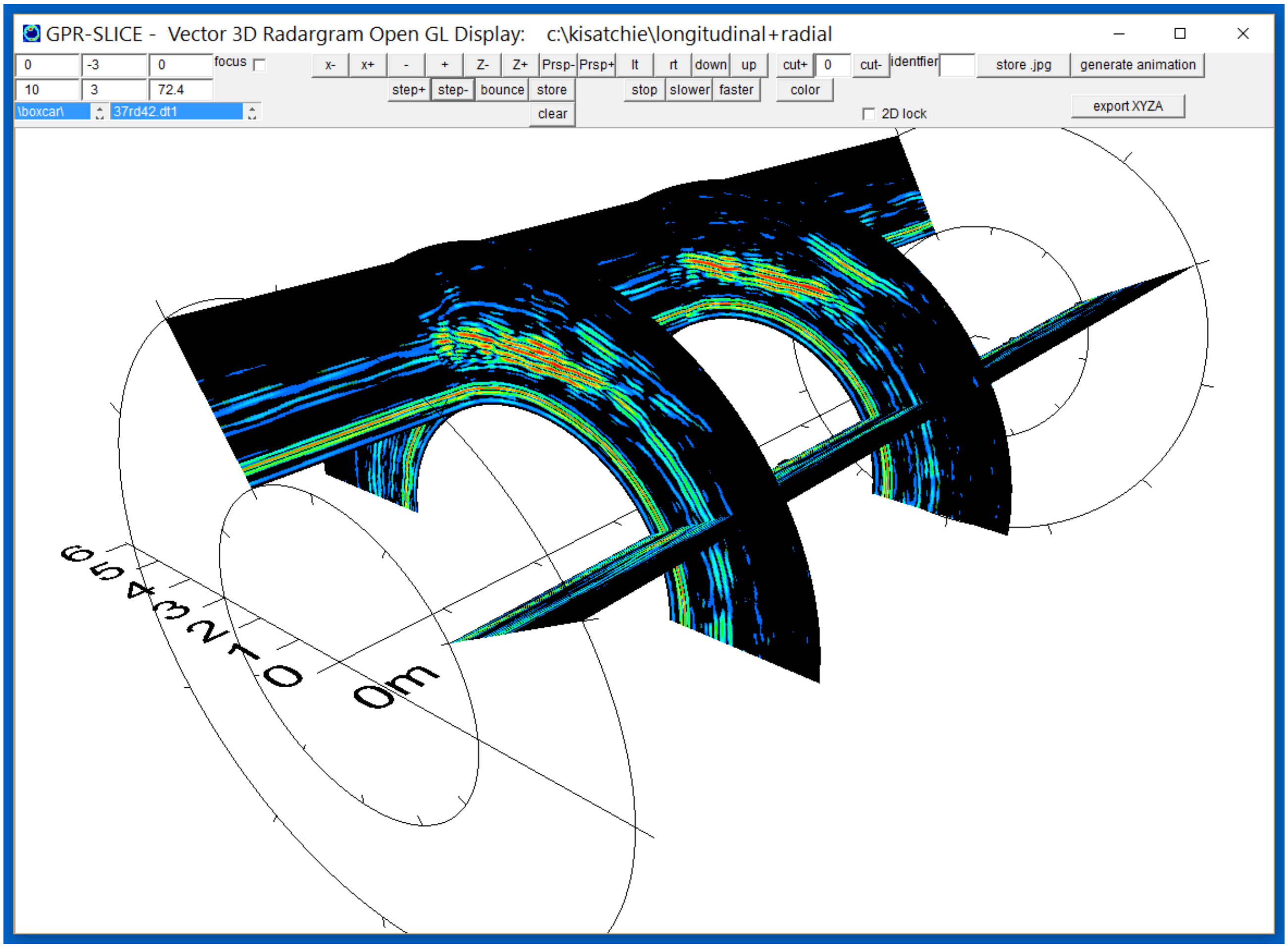
Vector Radial Tunnel Warping menu:

Step 3. Click the Vector Radial Tunnel Survey button which will read the start and end angles and the radius for each radargram and will update the vector in the navigation files. There is also a replicate button to quickly set all the radargram to the same start and end angle as the first radargram. In this example the first 10 radargrams are sent from 90-270 and the last 10 are set to 90 to 450 which would be a full 360 degree radial radargram starting at 90 and returning 360 degrees to 450. The settings in the stop and start angles are only updated and stored when the Vector Radial Tunnel Survey button is run.



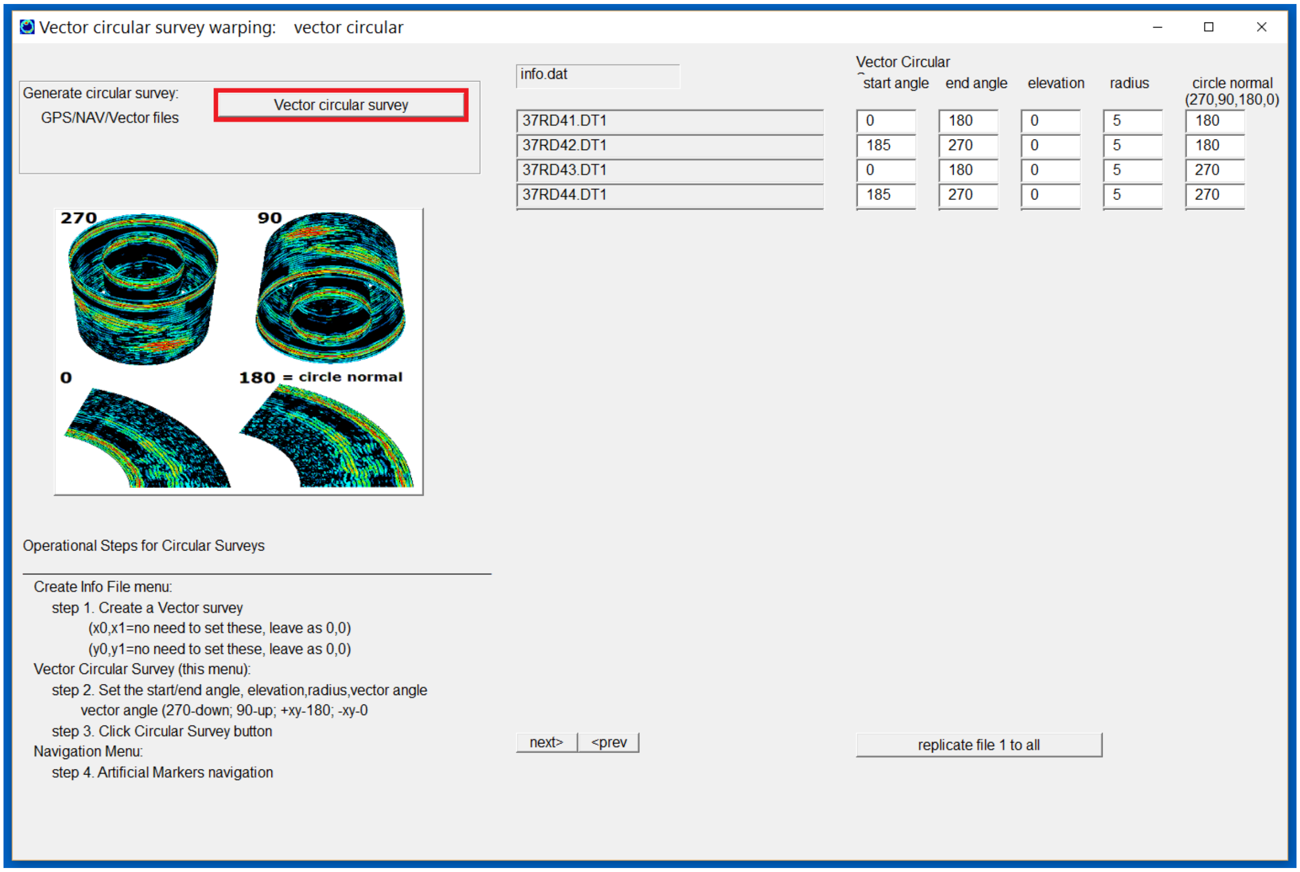
Vector imaging has endless capabilities to display any radargram in its' true 3D space. Again, the most important part of the process is "simply" to get the *.gps navigation files properly written. Both radial and longitudinal vector setting menus are available for specific cases of tunnel imaging is available.

To show the flexibility of the new imaging, we have combined vector radial and vector longitudinal tunnel radargrams into a single dataset. GPR-SLICE can show radargrams in which crisscrossing longitudinal and radial tunnel radargrams in the same volume. The following diagram is an example of both radial and longitudinal tunnel warp radargram:



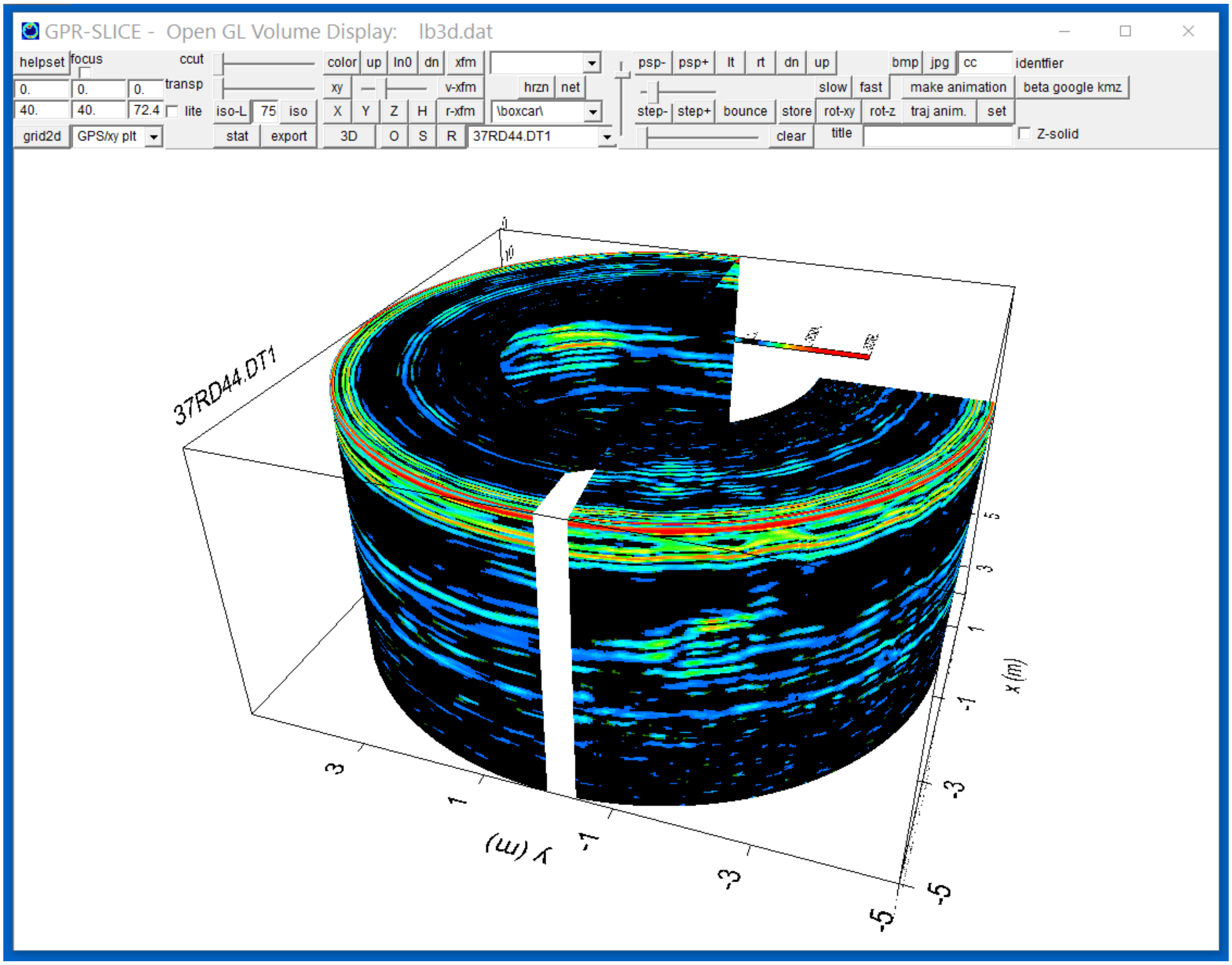
The vector imaging shown in the above diagram is just a small subset of the endless capabilities with GPR-SLICE for tunnel imaging.

Vector Circular Survey



A menu to generate circular surveys is available. The menu will allow the user to easily set the start and end angles of each individual radar profile as well their specific radii, elevation and the vector orientation. Four vector orientations are available with settings 0 (horizontal pointing outside the circle), 180 (horizontal pointing inside the circle), 90 (vertical pointing upward) and 270 (vertical pointing downward). The beginning information file should be defined as vector with all the x0,x1,y0,y1 simply set to 0. Clicking the Vector Circular Survey button will generate a vector *.*.gps file that is broken up into 99 tagged scans with positions around the defined circle for that radargram. Should the greater precision in defining the locations along a circular arc be needed, one can alter the 99 to a larger value in the Edit Info File menu and then run navigation and so on to make more designations around the circle.

An example of 4 lines with partial surveying along a circular tank with 2 radargrams measured on the tank wall from 0-180degrees, 185-270 and their normal vector defined as 180 degrees, and also radargrams over the same start and end angle and projected downward with the normal vector defined as 270 degrees is shown in the following example:

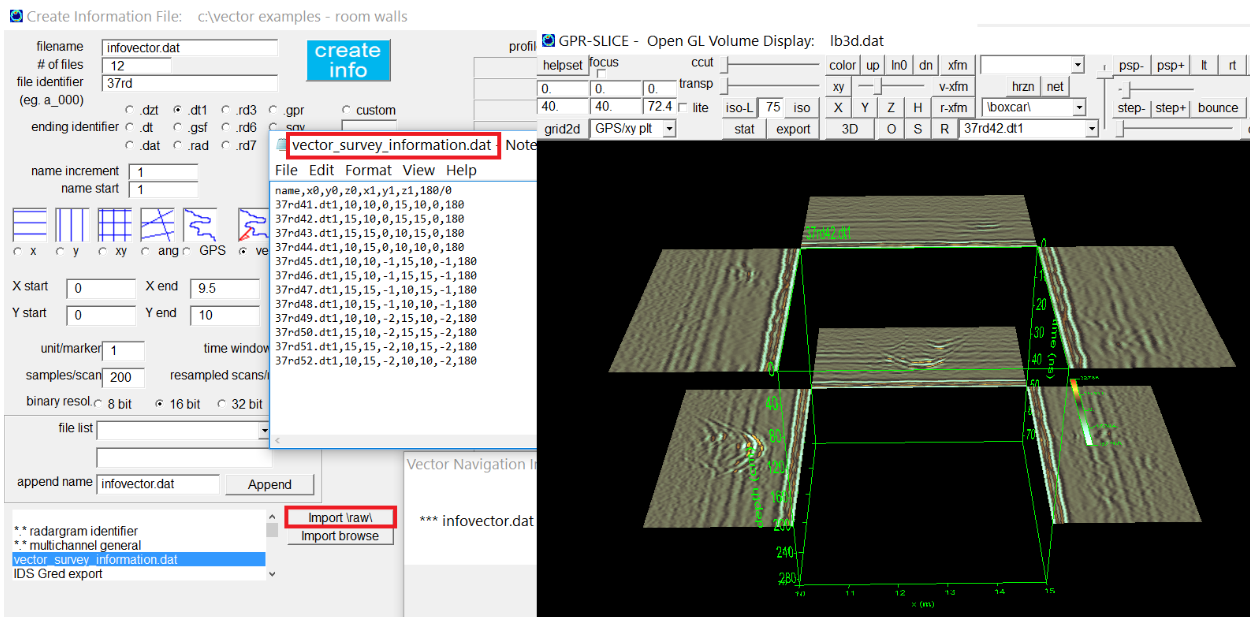


Other possibilities include a vector circular survey with each radargram progressively having smaller or larger radius… such as surveying around a circular structure or a pole. The menu is also set up for adjusting the elevation along the circular surface for looking at progressive radargrams taken at different heights on a concrete tank for instance. Many more possibilities exist for the geometric inputs provided in the Vector Circular Survey menu.

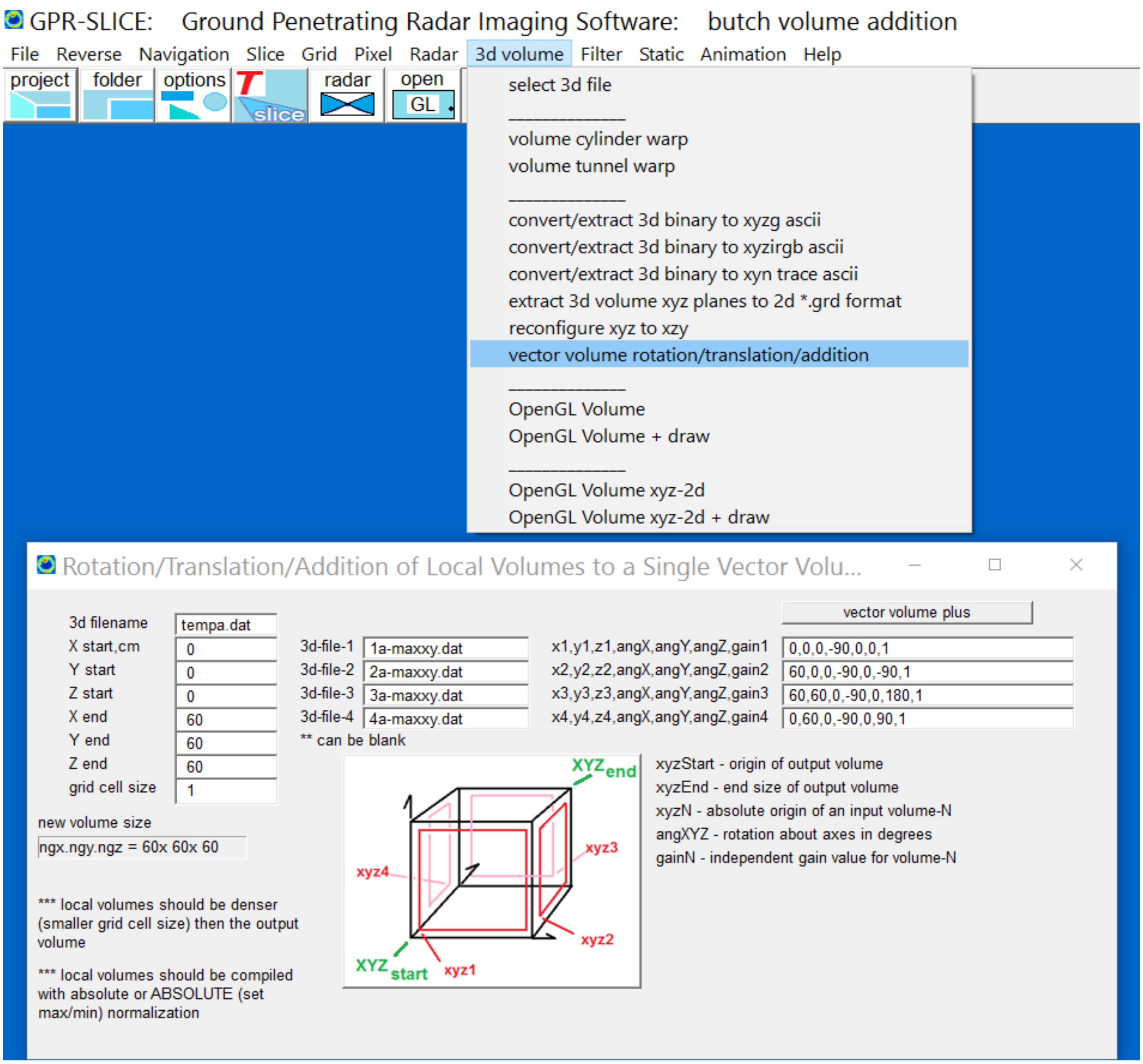
Note: GPR-SLICE provides easy set menus for these simple vector geometry, however, the software is completely flexible and the user can also generate any complicated vector geometry by modifying the *.*.gps file which contain the navigation, scan#'s and the normalized vector of the tagged scans.

Vector Imaging for Walls

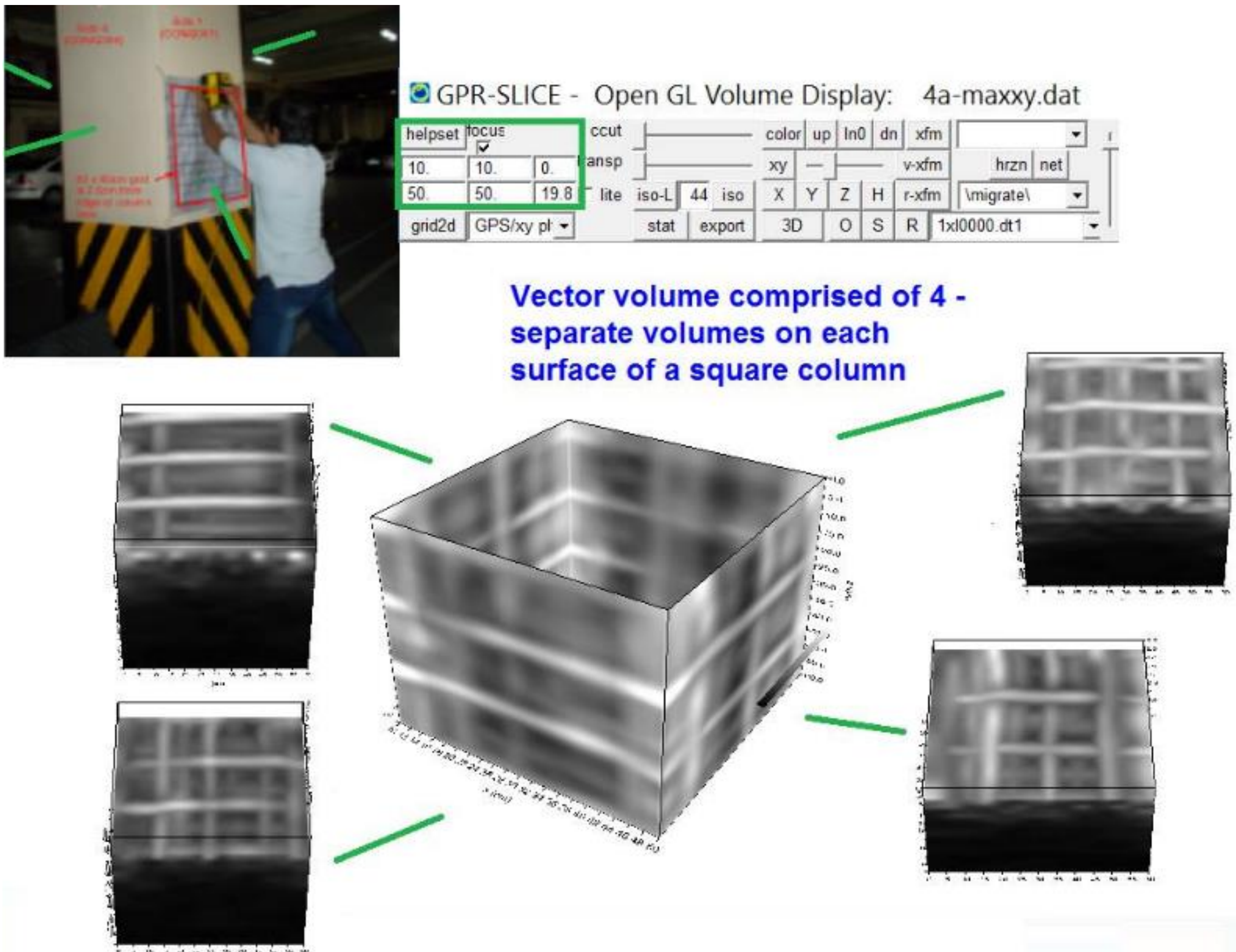
Making surveys on walls or tanks has just gotten easier inside the software. A new import in the Create Info File menu called vector_survey_information.dat will import this 8 column file for each radargram in the project that has the name, xstart, ystart, zstart, xend, yend, zend, and the angle description 180 or 0. 180 signifies a profile that is made inside a room for instance, and 0 would be outside the room and will project the radargram in the opposite direction.



Vector Volume Addition – example imaging of a 4-sided square column



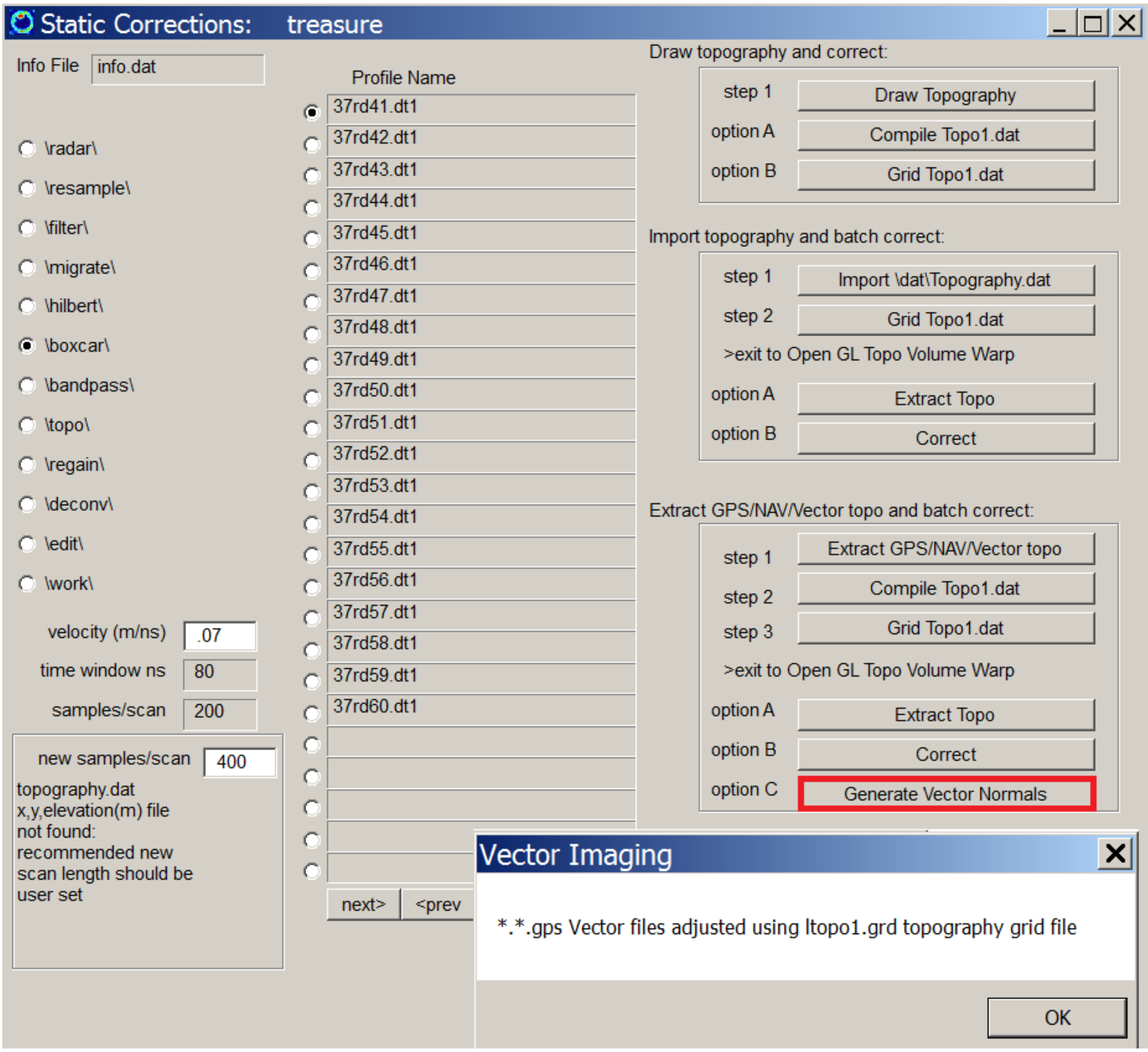
GPR-SLICE has a new menu to synthesize a vector volume from separate localized volume (see screen shot above). This menu can be used for instance to combine all the surface surveys and their separate volumes taken on a 4-sided square column and generate a single vector volume! The new menu on the 3D volume pull down menu has slots to set the absolute origin that each volume is recorded on, along with their corresponding axes rotation needed to place the new volumes in their vector location. There are also separate gain values that can be applied during the addition process for each individual volume.



Some of the requirements and recommendations for this new vector operation are to: 1) make individual volumes that have more density then the output volume to insure that there are no empty cells during rotation and translation into the output vector volume, and 2) we highly recommend that absolute or ABSOLUTE (user defined set min/man) normalization be used to generate the volumes. With absolute normalization, keeping the gains lower at depth in each individual volume will help to ensure that volume elements that are overlapped - as will occur on the corners of the new volume - do no overwhelm the imagery - and only the true amplitudes are being added and not normalized amplitudes at each level from the time slice dataset. An example of a column concrete/rebar survey made with a Sensors and Software Conquest GPR system by Butch Federizon at Geomaster Corp in Quezon City in the Philippines is shown in the example imagery.

This new option is not limited to just 4 volumes. The menu can be run several times with the output volumes as input volume to comprise many more locations into a single vector volume. The size of the output volume if areas are separate by large distances can become "intolerable" for volume memory and it is recommended that adjacent areas be used to keep the output volume manageable. The vector volumes are distinguished from our typical volumes in that the z axis is no longer measured in time and the volume is a depth volume. Time axes will not appear in OpenGL for these new vector volume displays.

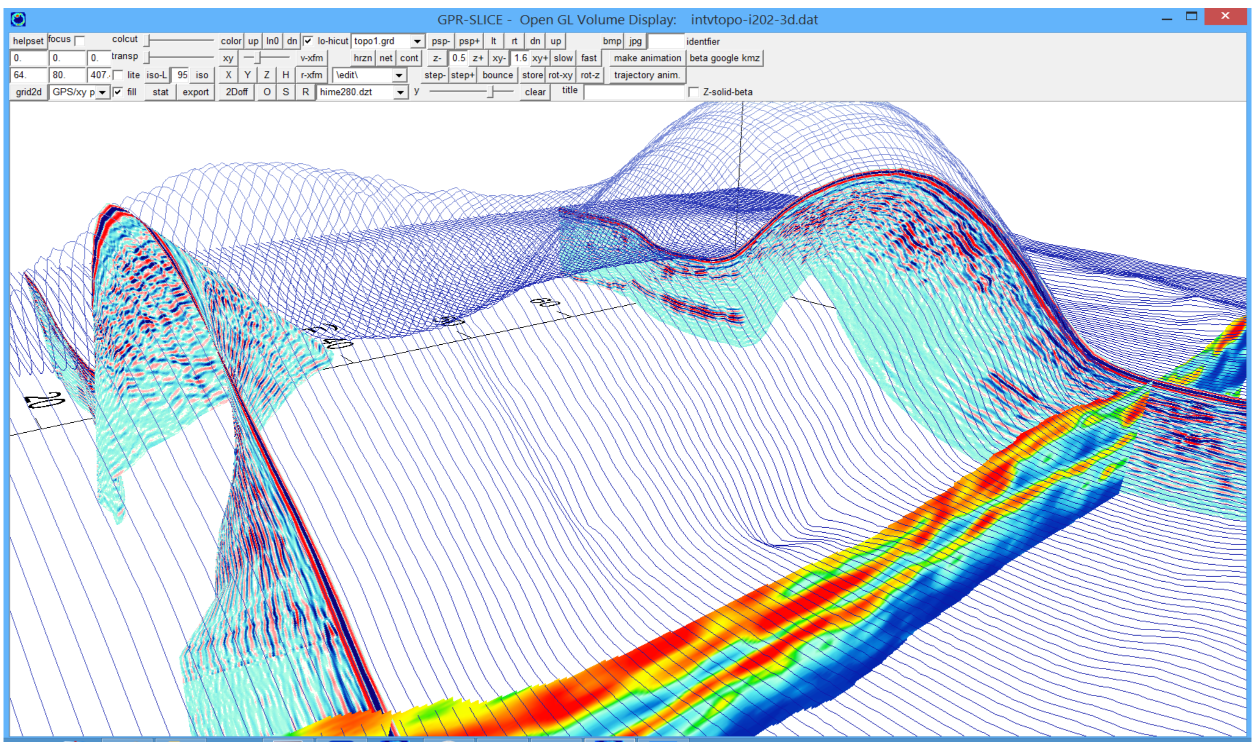
Automatic Vector Imaging Over Sites with Topography



GPR-SLICE v7.0 has an option to calculate the surface normals automatically across a topography grid file and place these vector components into columns 9-11 in the *.*.gps files. The button called Generate Vector Normals, will read the active topography grid file and compute the surface normal to the topography. The surface normal is in the direction that the GPR scan will be projected into the ground. The surface normal is computed looking at 2 vectors on the topography grid file, e.g. looking at 3 points on the topography file and generating 2 vectors of elevation differences between two of the points, leaving one point as the origin of the vectors. The cross product between the two vectors provides the surface normal to the vector.

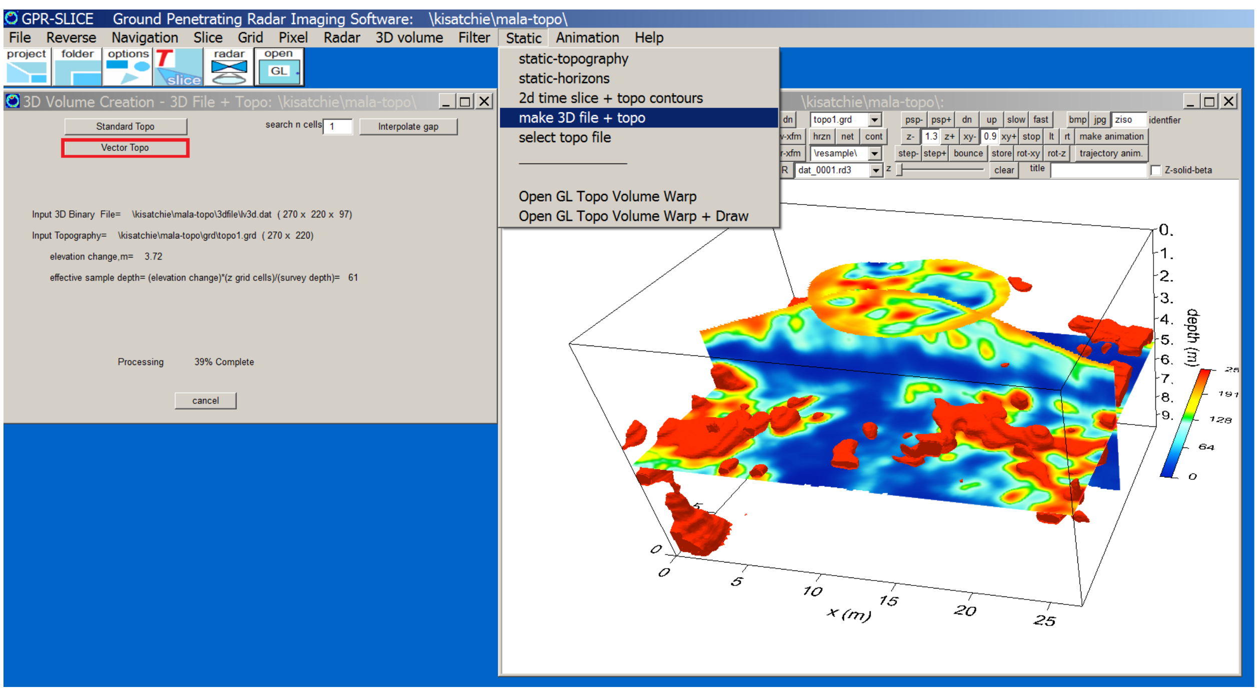
Currently in GPR-SLICE v7.0, a distance of 5 grid cells is examined in order to give a local surface normal without too much rapid change that would occur in looking at adjacent grid cells and topography. This provides for a touch of smoothing in generating the vector columns. In the future, options for adjusting this value by the user and/or vector smoothing will be provided.

An example of what can be achieved with the automatic vector imaging options, is that a 2D radargram collected over a site with topography, gets projected as a 3D radargram when the orientation (pitch, roll and yaw) of the antenna is included. Shown below are example 3D radargrams collected over a site with topography.



Vector Volume

GPR-SLICE Static corrections now incorporate vector topography. Using the Vector Topo button in the Static corrections menu, flat rectangular volumes will be warped into their vector space using the surface normals of the digital elevation model. The topography grid file - topo1.grd - is used to position the grid cells into their vector space assuming the antenna was perfectly parallel with the surface of the topographic site. The repositioning and warping of the cells into their correct 3D space can create voxel gaps in the newly created binary 3D volume. A button to conveniently interpolate the gap using nearest neighbors can be applied clicked in the menu. The user should first look at the raw converted file to see if gaps are significant. If not, then a simple gap interpolation with a x, y interpolates grid cell length of 1 should suffice. An example of vector warped volume is shown in the next figure. The vector volume is written with the append identifier "topo-" added onto the flat rectangular volume. If this volume is subsequently interpolated the identifier "int" will be further added onto the volume naming automatically. From this menu standard topographically adjusted volumes which simply shift the grid cells vertically can also be made using the Standard Topo button.



ANG, X, Y or XY Survey Conversion to Vector

Among the miscellaneous improvements which are useful for further discussion is the conversion of ANG surveys to Vector. Not only can ANG surveys be converted, but X, Y, or XY surveys can also be converted using the new button option in the Edit Info File menu. What does this mean? Well, for ANG surveys, it allows for 3 labeled reporting on radargrams, e.g., x, y, and the integrated range. ANG surveys are treated just like GPS/Vector surveys with random tracks. Our vector survey navigation format as stated in a previous newsletter is a generalized navigation format which is inclusive of all known navigation methods that are presently done with GPR. Having a standardized navigation formation will alleviate the confusion of different survey formats. Providing the conversion button for ANG, or X, Y, or XY surveys to Vector is a first step in migrating to this single standardized navigation format. (The Vector formats - just like GPS formats which it is inclusive of - keep the number of GPS listings in the Y1 column of the profile information file after making the 20 column vector navigation files *.*.gps associated with each radargram.)

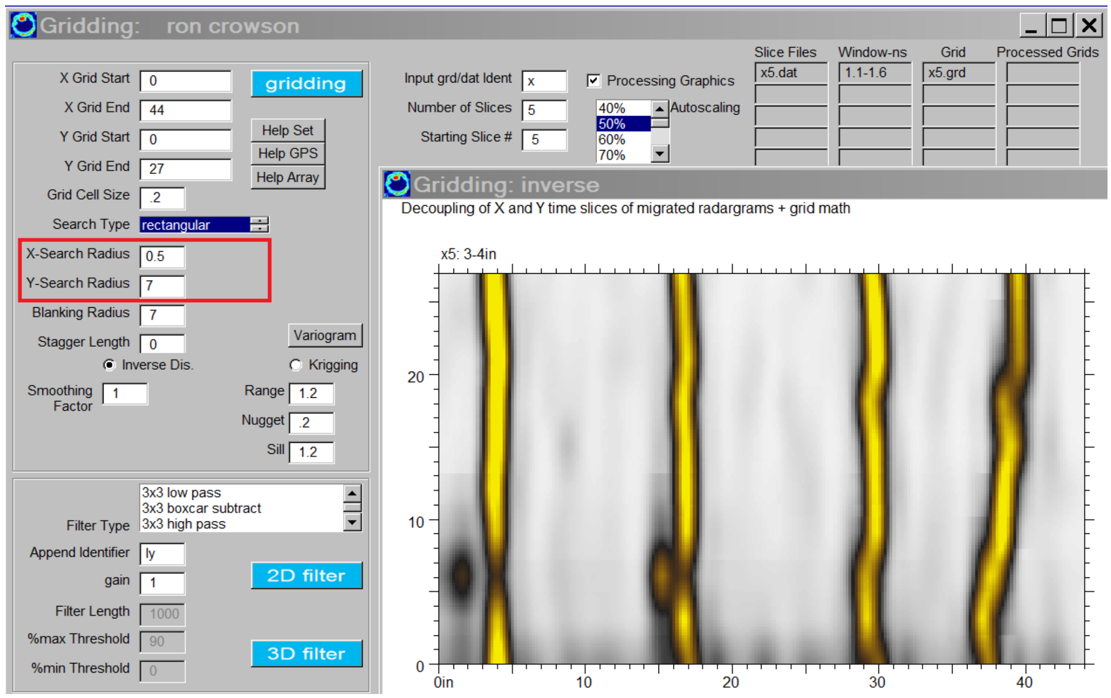
In addition, features available to X, Y, XY or GPS surveys were never programmed into the specific ANG survey definition such as TSPoints or Time Slice/Radargram split screen displays. Converting your surveys to the generic Vector survey will give one full capabilities of all the imaging options in GPR-SLICE v7.0. (Future versions may simply eliminate all the different survey types and require the generalized Vector definition).

Concrete Imaging and Enhancing Linear Features From Cross XY Surveys (e.g. rebar in concrete)

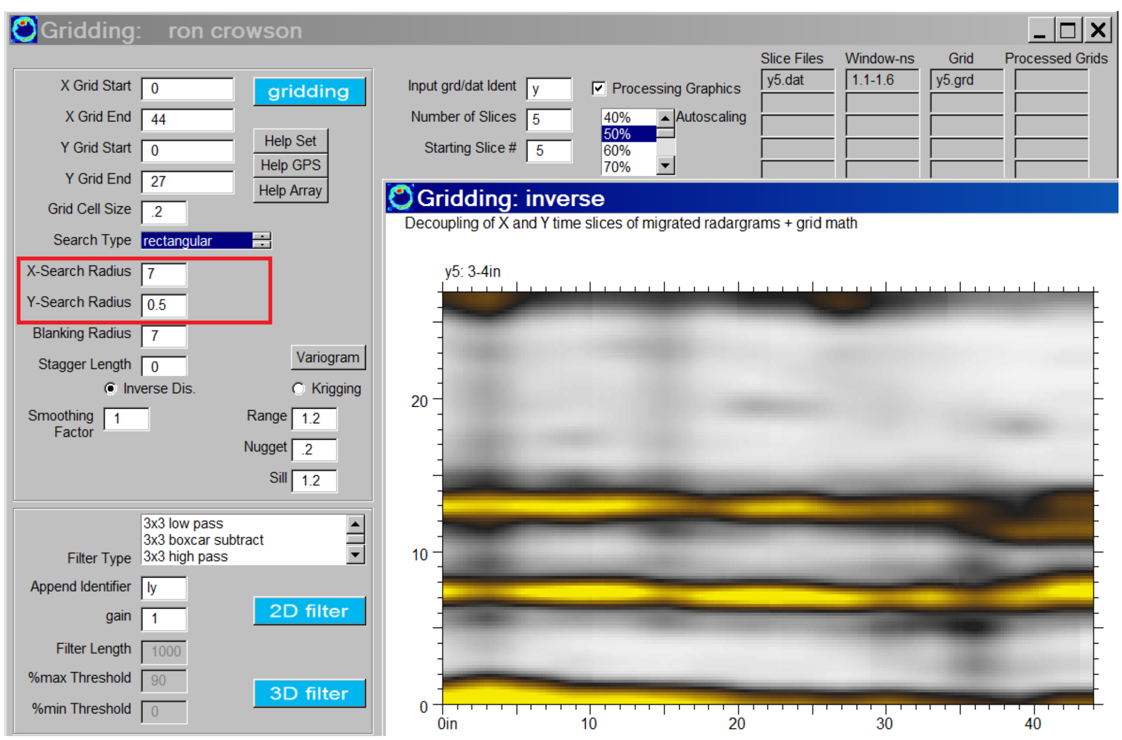
As many new users of GPR-SLICE are doing geotechnical surveys, it is useful to show how rebar and concrete mapping options in the software can be used to enhance linear features. For those doing XY surveys on concrete, it is possible to decouple the X and Y lines, generate separate grid maps with directional weighting, and then use grid math to add the decoupled grid maps back to enhance linear features. Shown in the first diagram on the next page is one-time slice made from lines parallel to X axis of a grid. To enhance linear features transverse to the X lines (or better said, to "bleed" anomalies across to adjacent lines) one can use x and y search radius which are unequal. In this example the X search radius is minimized (to a value of 0.5 distance unit) and the Y search radius is expanded (to a value of 7 distance units). The net effect on gridding is to better connect linear anomalies going across the lines. Similar operations are made for the Y lines of the grid (shown in the bottom figure on the next page) with X search radius set to 7 and the length of the Y search radius which is minimized to 0.5. After the decoupled grids are made, Grid Math is used to add the grids back together (shown on page 288). Rebar mapping in concrete is shown to be significantly enhanced.

Comparisons can also be made using combined XY gridding which show the linear features but not quite as well as the decoupled grids. Users can practice on this dataset given in the Advanced Users Workshop folders on the ftp site (\Kisatchie\concrete2\). In general, XY combined gridding is better when there is no prior knowledge of what kind of structures are in the ground. However, having prior knowledge can allow you to enhance these features, particularly for linear structures that are primarily parallel to the x or y directions

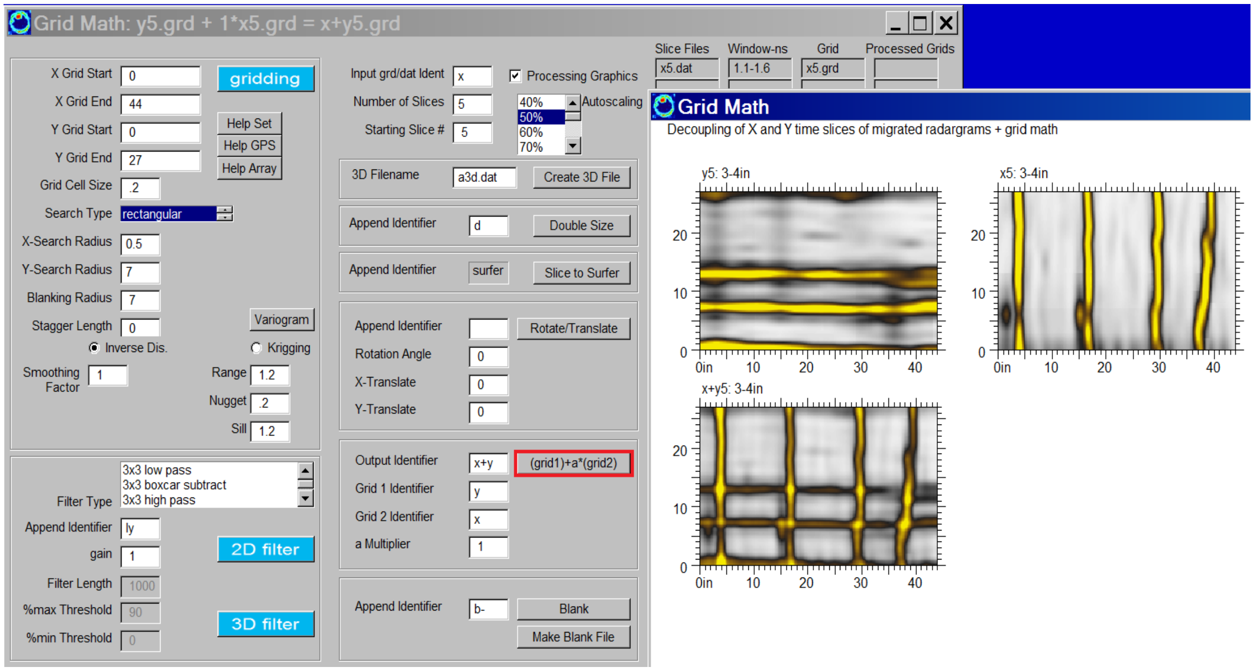
Note: A high cuts-per-mark setting of 10 in the Slice/Resample menu was used in generating the spatial bins for the time slice ASCII datasets. This will insure that a high density of bins is generated along the radargram. The search radius along the radargrams was set to about 2.5 times the bin width or 0.5 distance units (for enhancing the linear features transverse to the radargram direction).



Grid settings used for making time slices of just the X line data.



Grid settings used for making time slices of just the Y line data.

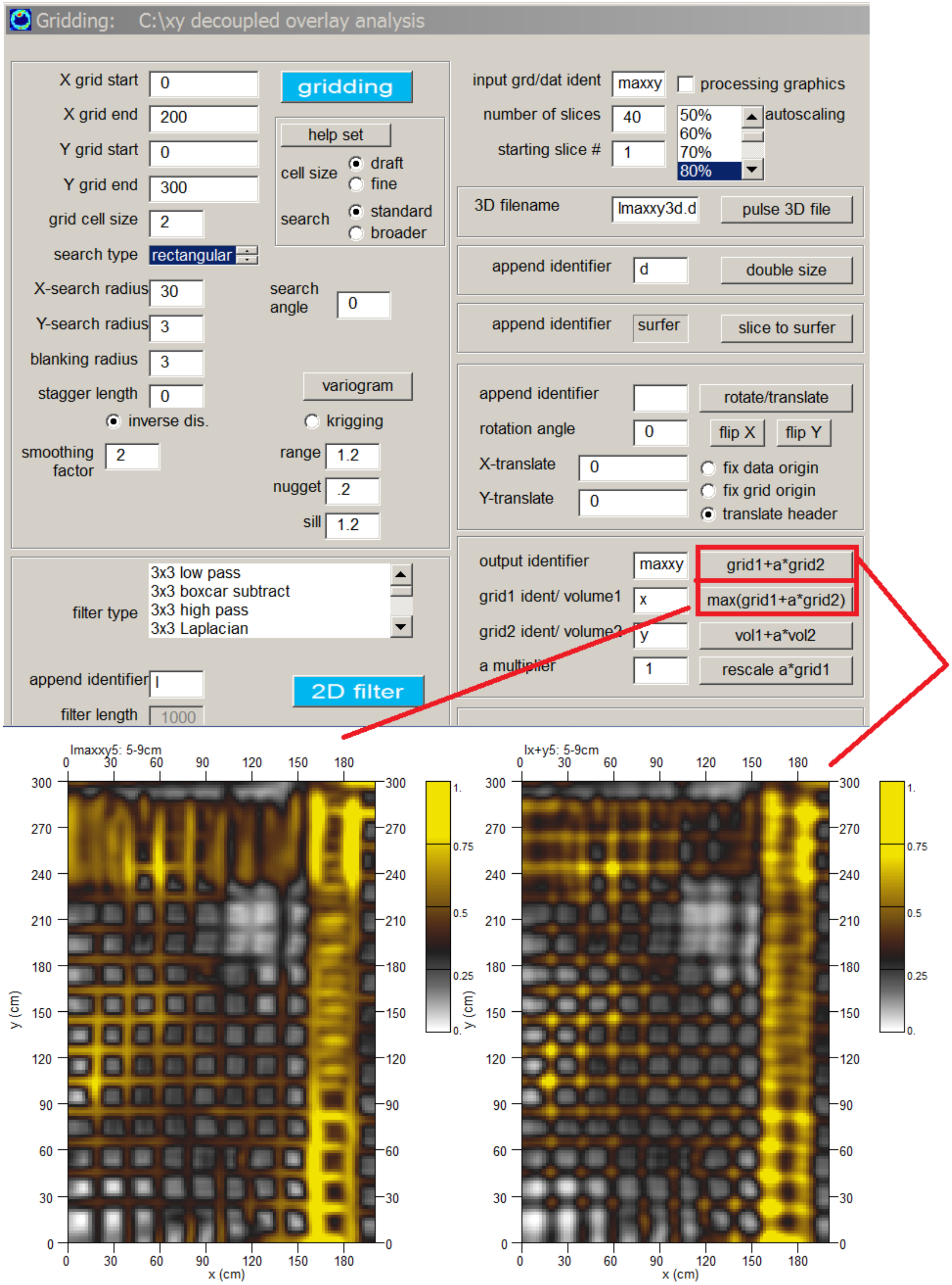


Grid math operation to add time slices made from decoupled X and Y lines to generate X+Y time slices are easily accomplished in the Grid menu. The weight between the grids is usually set to 1 but it can be changed to decimal values other than one. Negative values can also be used which in essence represents grid subtraction.

Note: A BlueBox Batch process to completely run the XY decoupled gridding operation from start to finish is available. See this section in the manual.

Max(X,Y) Grid Math

XY decoupled gridding for enhancing linear features from cross surveys has a new option for further enhancements. Overlay analysis is implemented using a new option called Max(X,Y) in the Grid menu. The procedure in the Grid menu will chose the maximum value of the X and Y decoupled grids and place into the output grid. Comparison of the traditional grid math and the Max(X,Y) option is shown in next figure. Traditional addition of the independently gridded X and Y datasets which were completed with elliptical searching, shows simple addition to have more “dotty” amplitudes at the crossovers between rebar in the image. The Max(X,Y) procedure because it only takes the peak response between the two grids shows more even amplitudes. These observations can be understood in that the addition will double the amplitudes over the



xy decoupled gridding - comparison of Max(X,Y) vs (X+Y)

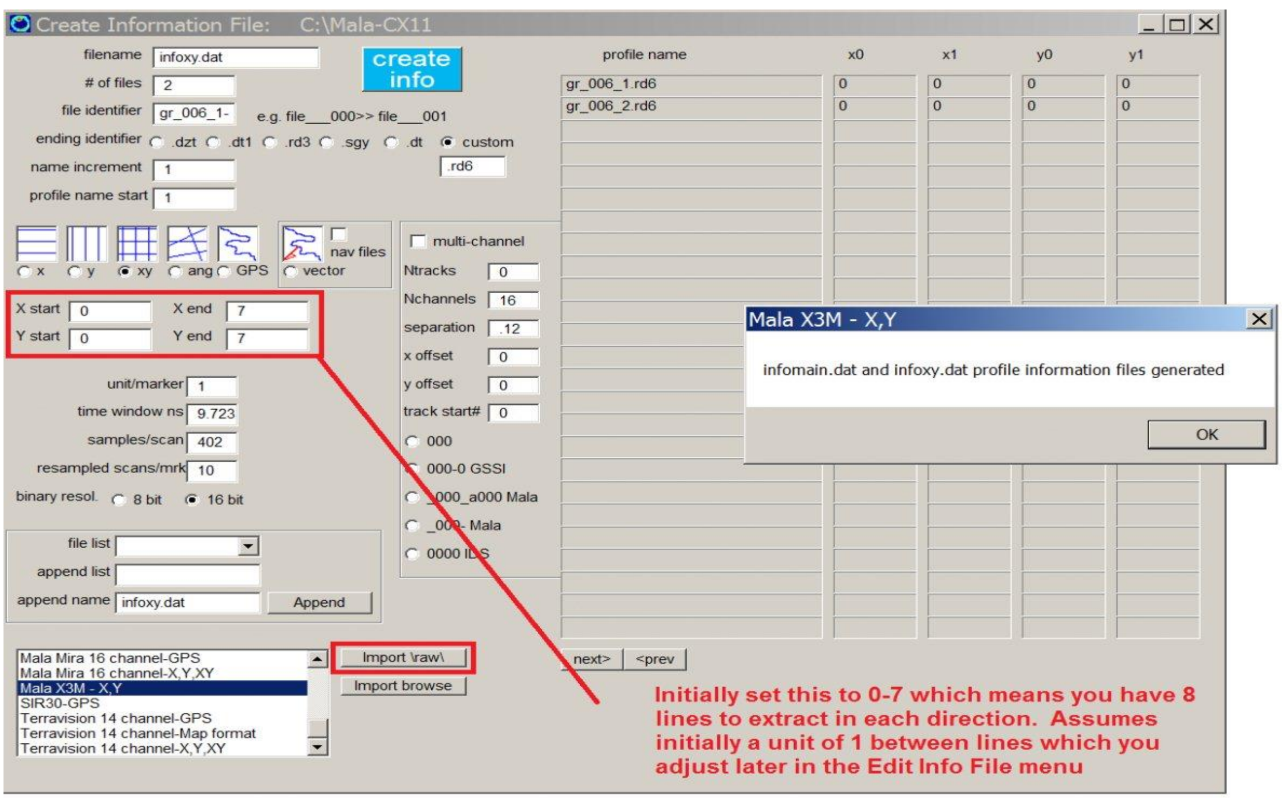
intersections (particularly when the profile spacing is equivalent to the rebar spacing). Choosing the Max(X,Y) between the two grids will not overweight the rebar intersections. Max(X,Y) is essentially overlay analysis however the individual transforms are not being applied - simply the binary process of using the peak value between the two decoupled grids. Max(X,Y) shows better constant amplitude mapping along the rebar.

Because the Max(X,Y) is a very useful operation for concrete imaging or for sites with linear features parallel to the profiled lines is so valuable, it is now also included as a setting in BlueBox Batch operation: **XY Decoupled Gridding + Edit + RSP.**

Equipment Specific Operations

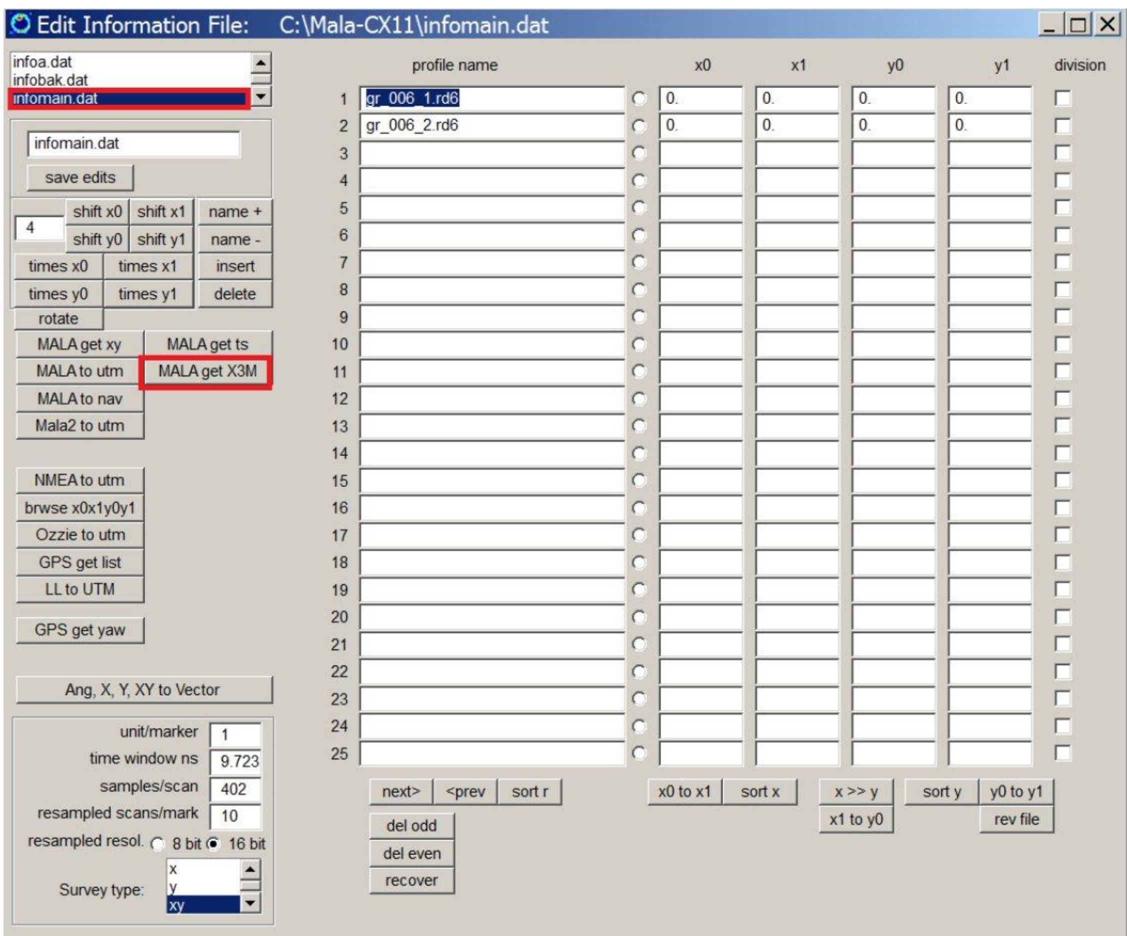
Mala X3M, CX11, CX12

GPR-SLICE was integrated for the Mala X3M, CX11 and CX12 equipment in 2011. These data can have a unique data format for cross gridded surveys. The extra operation in GPR-SLICE is to extract the multiplex radargrams into individual radargrams. The initial radargrams collected with this equipment are the multiplexed *.rd6 data which are extracted to create individual lines with the *.rd3 extension. Screen shots and step by step instructions are given as follows:



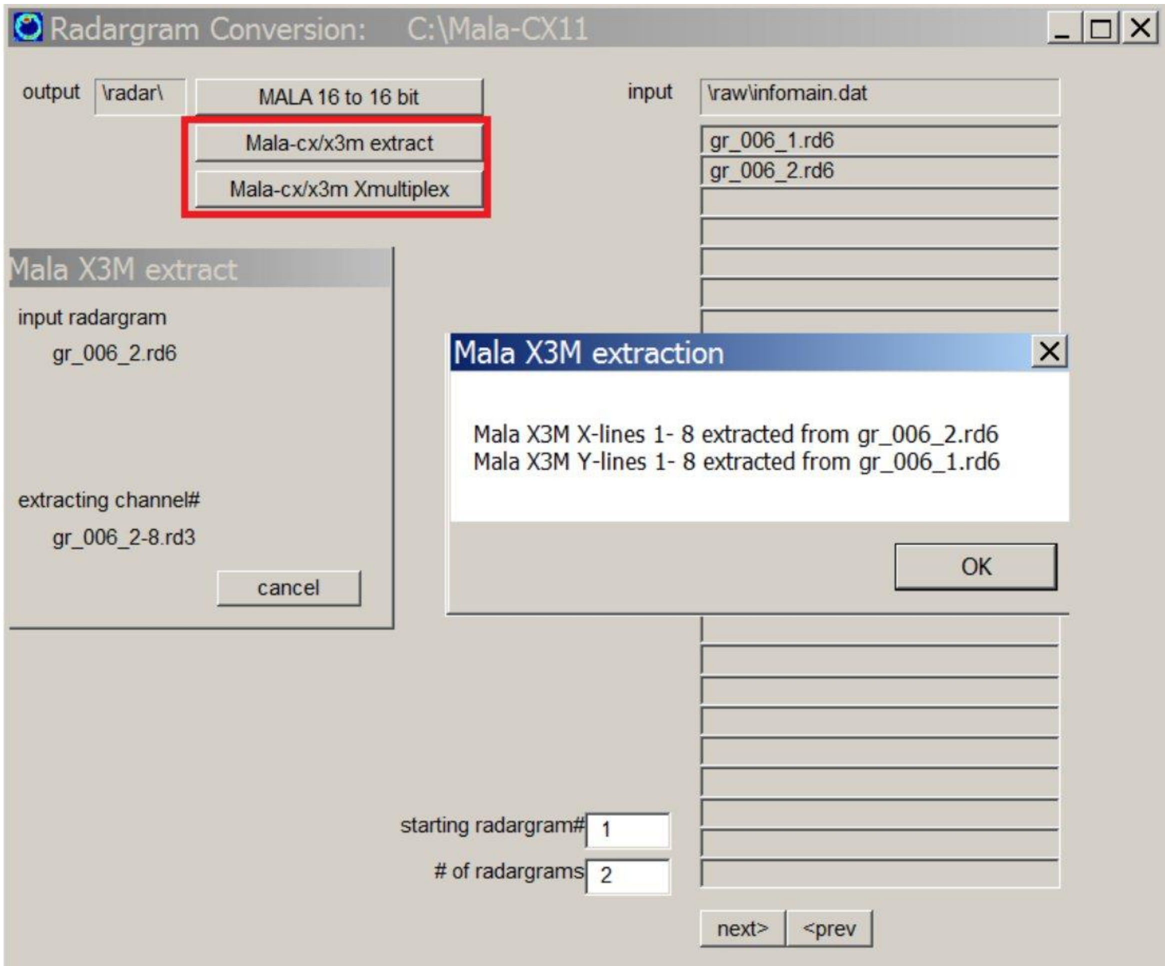
1) Create Info File menu:

step 0) set the recording unit, m, inches, ft etc in the Options menu
step 1) set the xstart/xend ystart/yend to 0-7 if you have 8 profiles in each direction, or to 0-(N-1) profiles if you have a variable N number of profiles in each direction. (If *.rhd or *.3dq Log files are in the folder GPR-SLICE will automatically set these in the latest version from March 2014 and these do not have to be set manually)
step 2) set the import listbox to Mala X3M - X,Y or Mala CX11 or Mala CX12
step 3) click the Import \raw\ - this creates the infomain.dat and infoxy.dat -
infomain.dat is the main info file with the multiplexed radargrams
infoxy.dat is the complete individual extracted cross grid information file



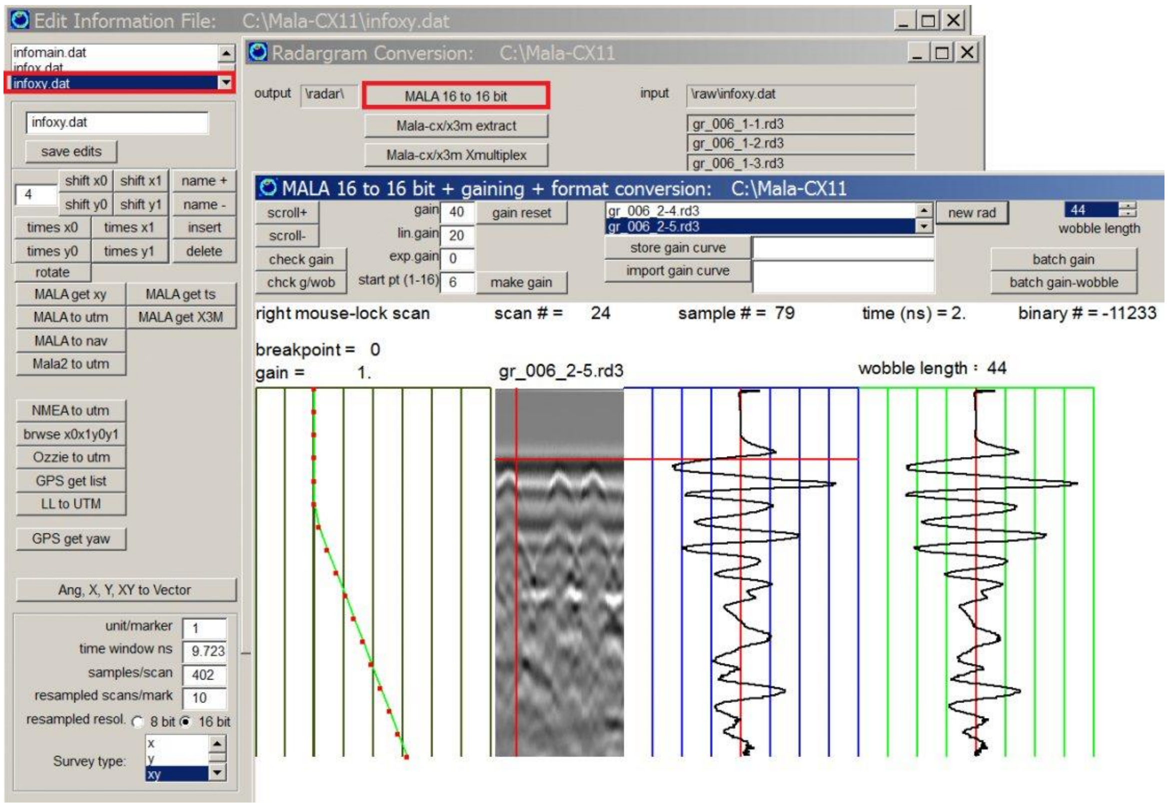
2) Edit Info File menu:

step 1) highlight the infomain.dat file
step 2) click the Mala get X3M button to insert samples/scan and time window if needed



3) Convert menu:

step 1) click the Mala X3M/CX extract or the Mala X3M/CX Xmulitplex button - you will need to test which button your equipment has since some older CX11 do not multiplex the data in the y/*_2.rd6 - in that case click the Extract button instead etc.



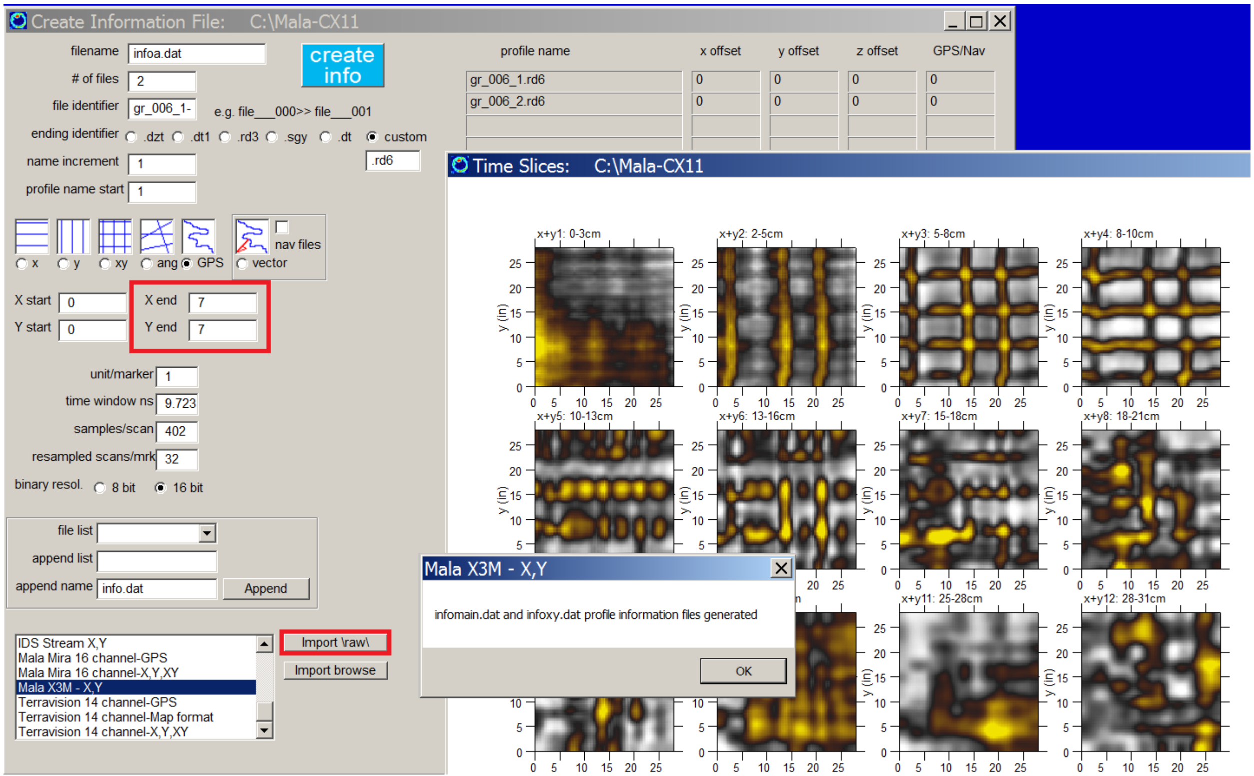
4) Edit Info File menu:

step 1) highlight the infoxy.dat file

step 2) adjust the line length start or end locations to the correct values by using the Shift/Times buttons if needed (Note the *.rhd or *.3dq files are automatically read if they exist to generate the infoxy.dat line length in the unit chosen in the Options menu)

step 3) proceed as usual to the Convert menu and use the Mala 16 to 16
(check the *_2.rd3 data to make sure they were properly extracted or demultiplexed - if incorrect start back from the Convert menu with the infomain.dat and use the other button operation)

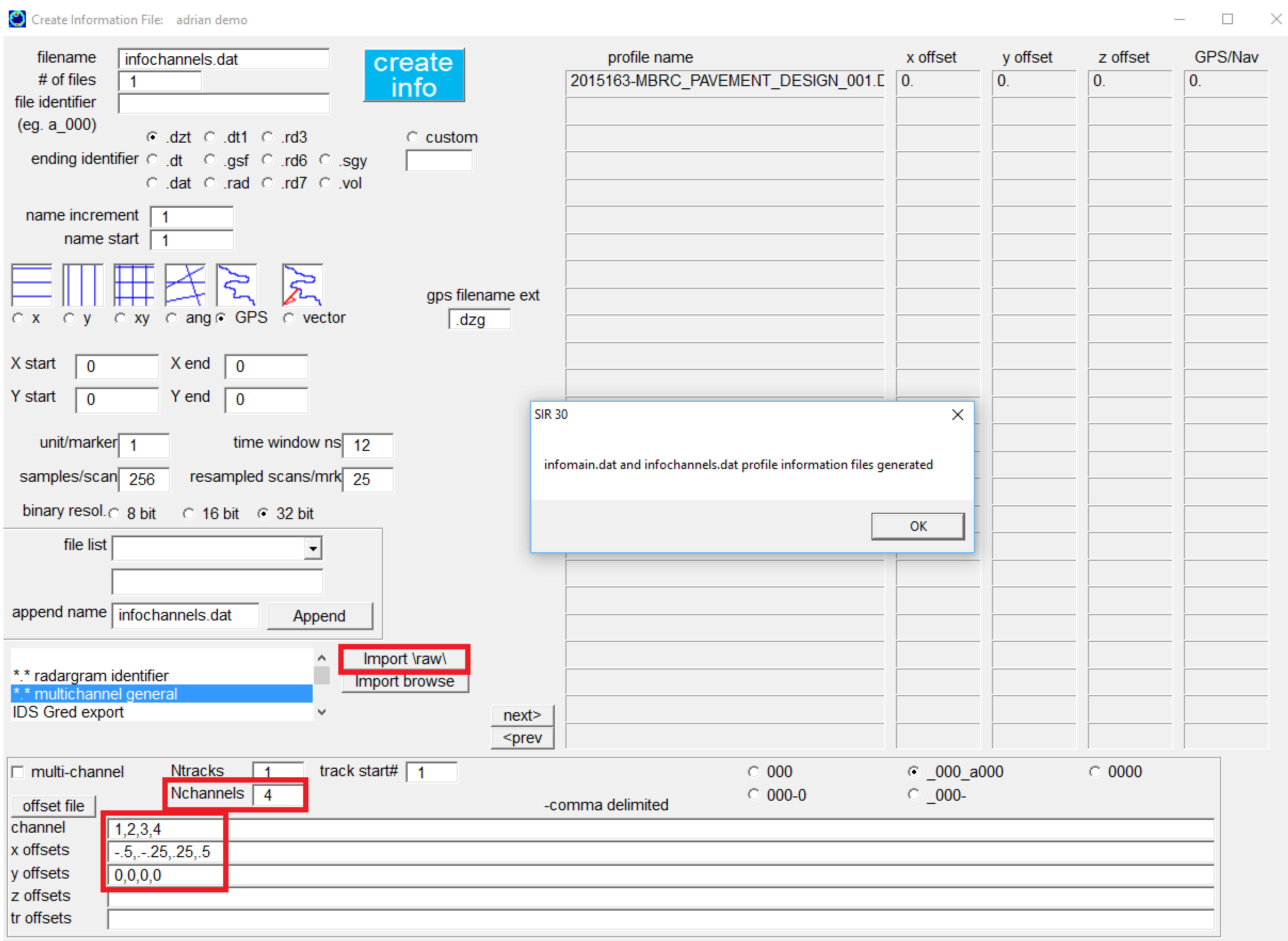
An example of a Mala CX12 dataset is shown in the next figure. The site is a concrete survey collected in X and Y directions. A total of 8 lines in each direction were recorded for the survey.



(Data courtesy Shawn Williams, Idaho National Labs).

GSSI SIR 30

GPR-SLICE was outfitted to read GSSI SIR 30 datasets first in 2012 and in 2014 the software was enhanced to include complete 32bit processing. In 2016 buttons to automatically extract the individual channels from SIR 30 multiplexed radargrams was added. The menu screen shots and basic instructions are given as follows:



Create New Info menu:

step 1) set the number channels, channel numbering, x-offset, y-offset in the multi-channel box (multi-channel license required)

step 2) click the import \raw\ button generating the infomain.dat and the infochannels.dat files

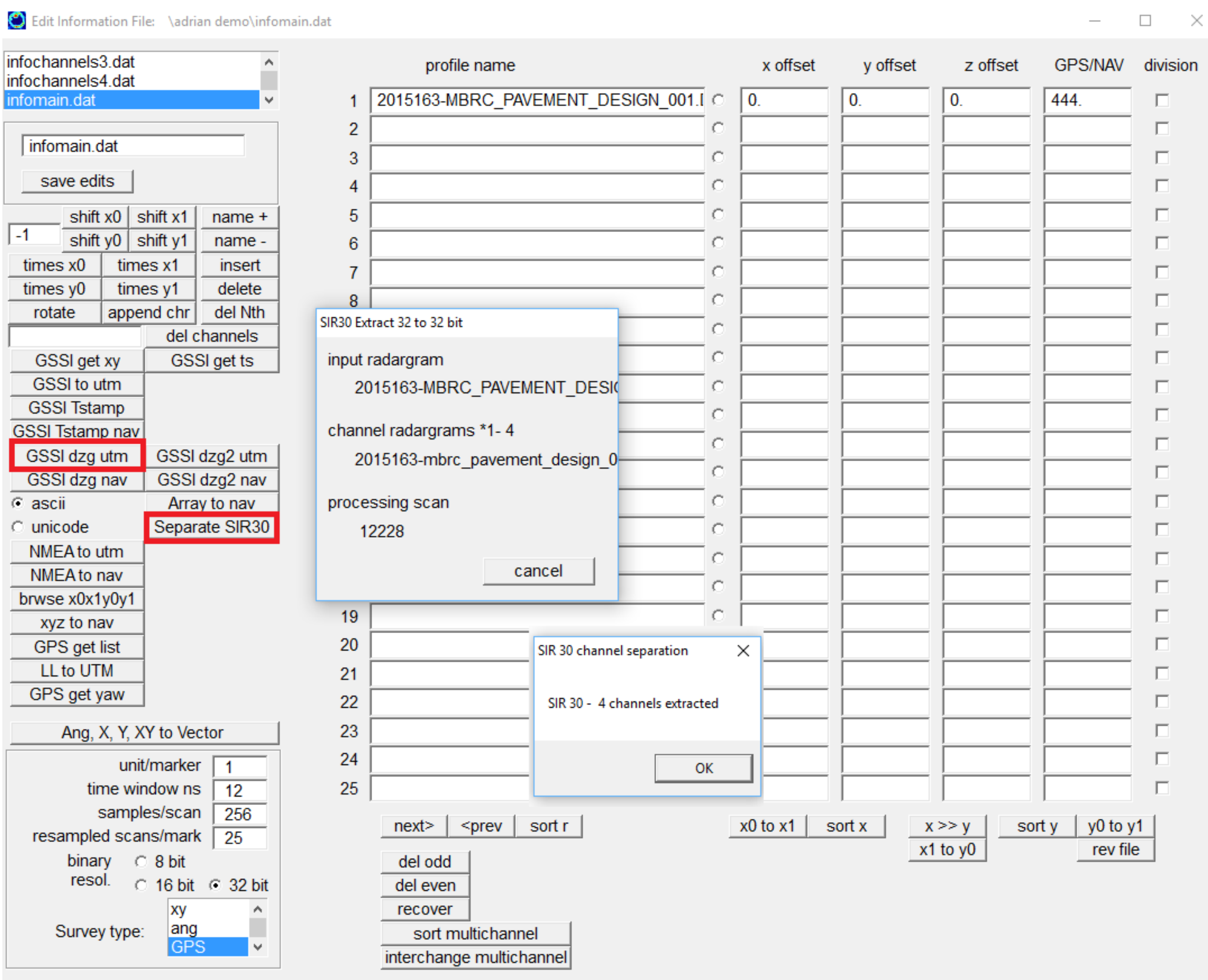
infomain.dat: contains the name of the main track 32 bit radargrams
infochannels.dat: contains the extract channels with -N.dat designation

Edit Info File menu:

step 1) highlight the infomain.dat file

step 2) click the GSSI dzt utm button to generate the GPS on the main

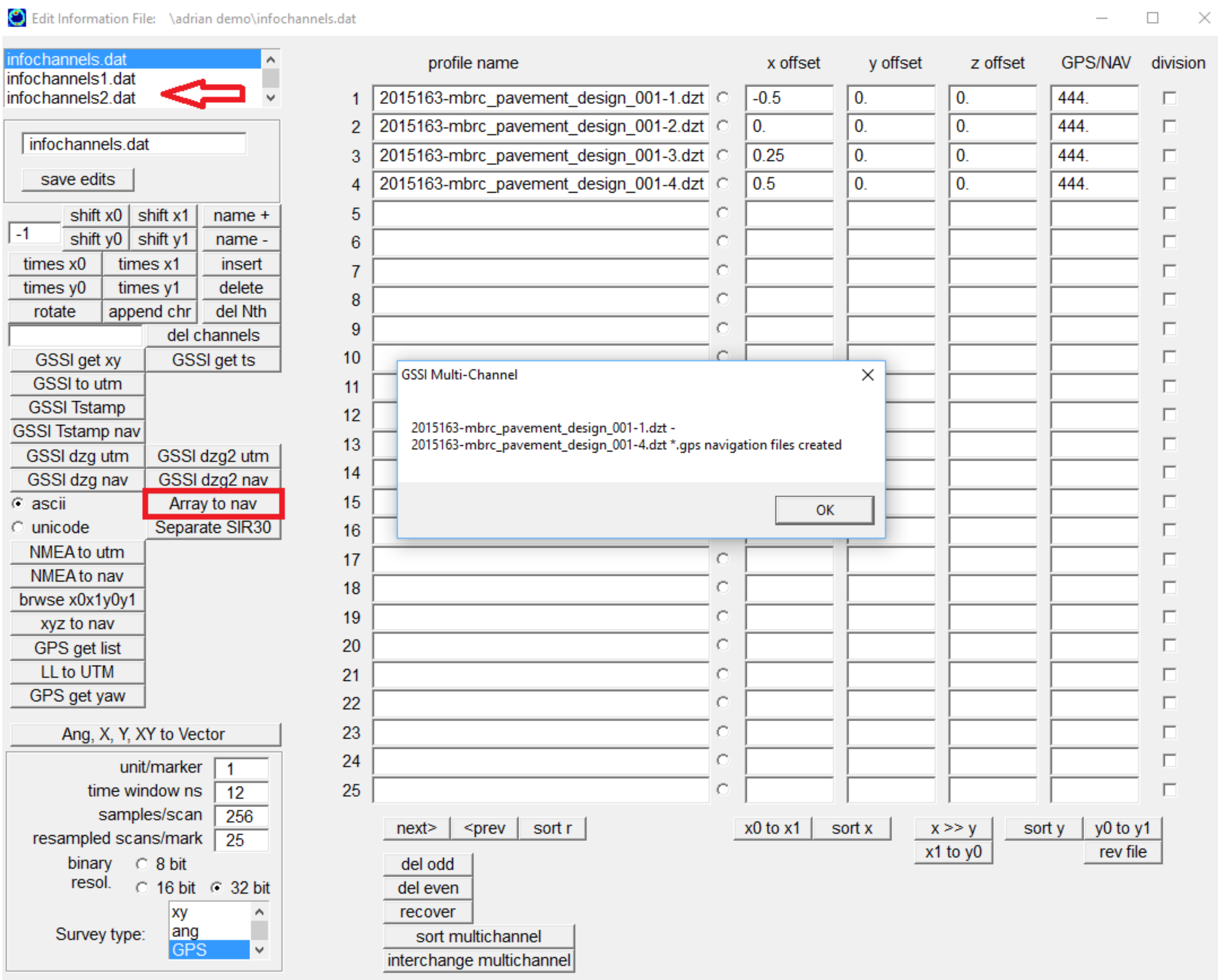
step 3) click the Separate SIR30 button to extract the individual channels



step 4) set the information file to infochannels.dat

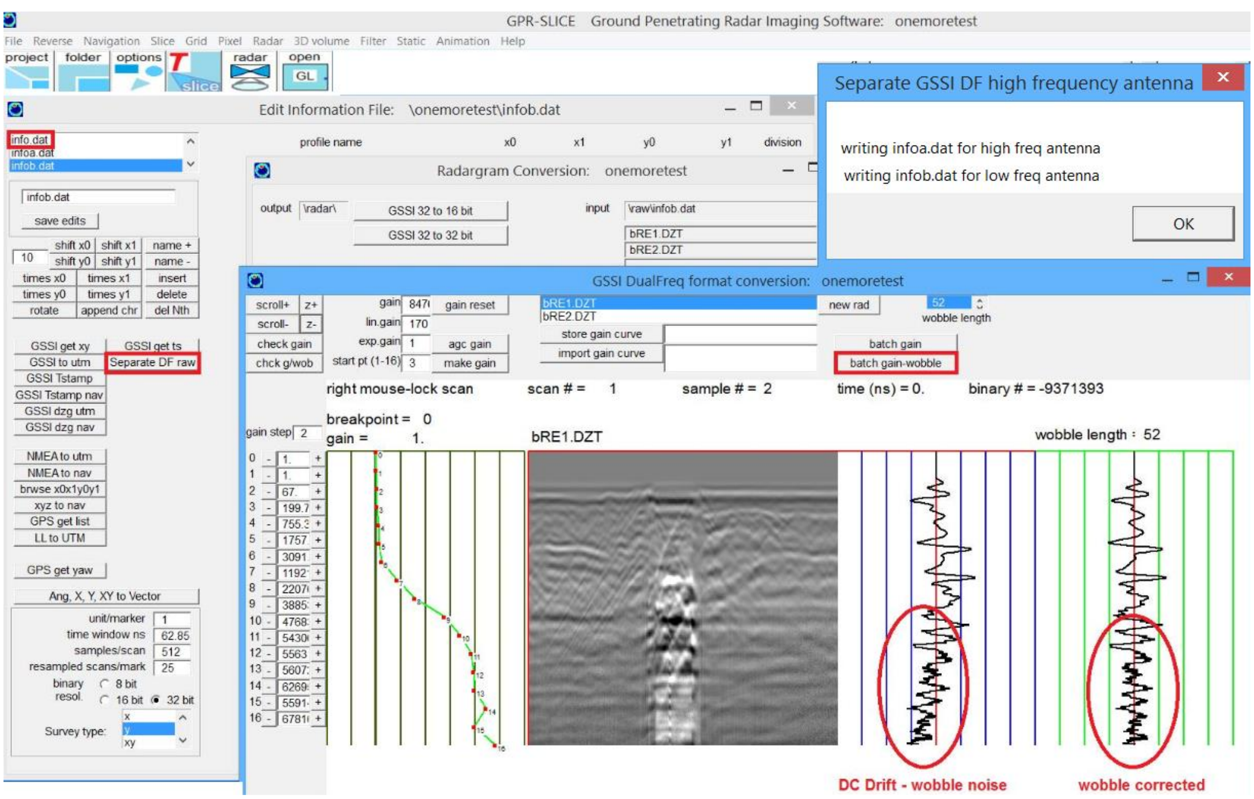
step 5) click the Array to Nav button to generate the individual GPS tracks for each extracted channel based on the xy offsets

optional: If channels 1, 2, 3, 4 do not have the same time window, currently the user will need to edit the infochannel.dat file and make manually infochannel1-4.dat separately. Use the GSSI Get TS button for each information file to assign the unique time windows. Infochannels1-4.dat can be made by using the delete or the del channels options in the Edit Info File menu.



GSSI Dual Frequency Equipment Channel Separation

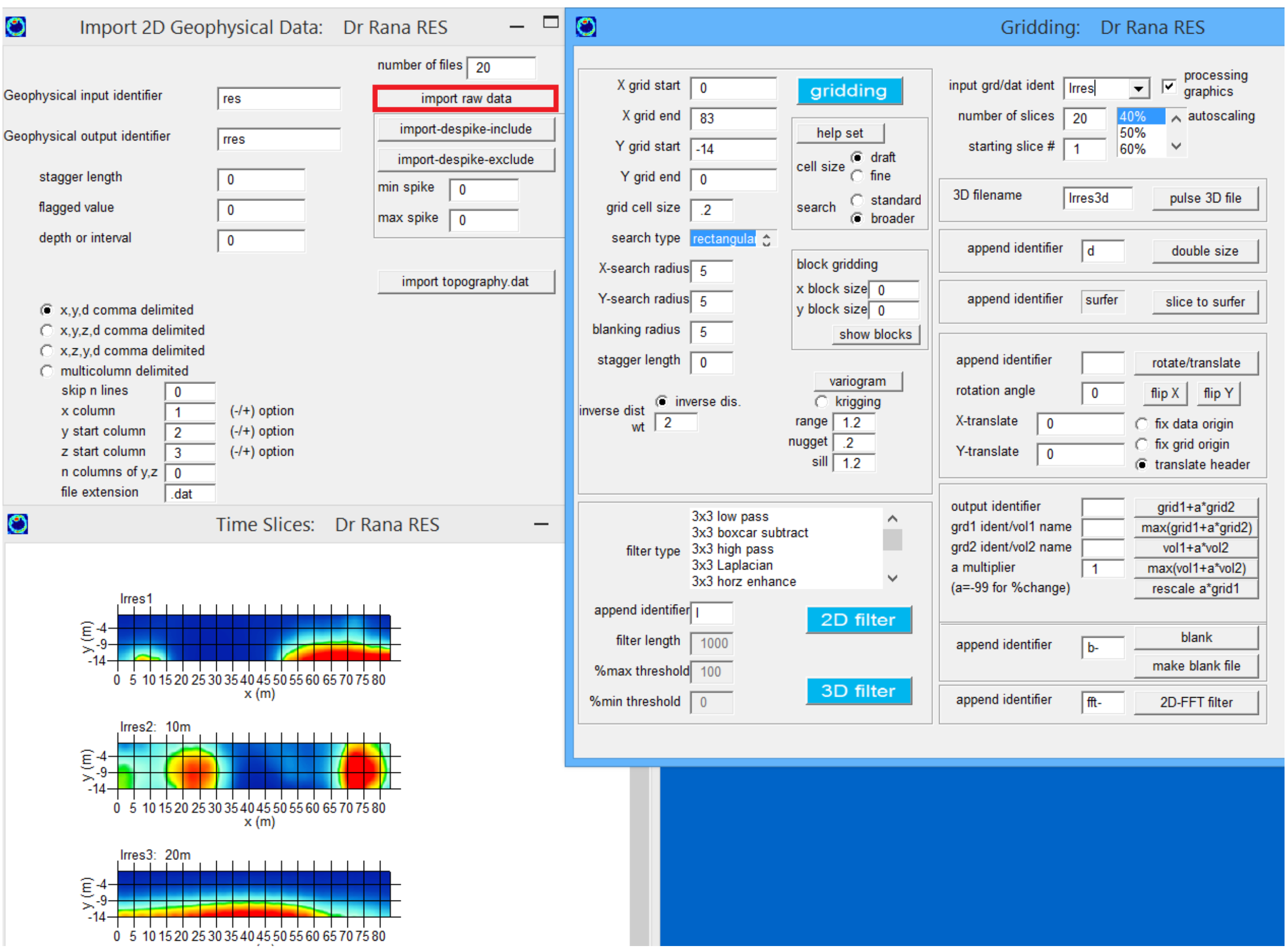
In the Edit Info File menu there is a button operation to separate the dual frequency GSSI radargrams. The raw radargram are written as a two tier multiplex radargram. For operations in GPR-SLICE this multiplexed radargram can first be separated. The GSSI dual frequency channel separation will extract the high and low frequency channels from the multiplex raw radargrams and place these directly into the \raw\ folder. For the high frequency channel, the letter a is appended onto all the names of the extracted radargrams, and the letter b for the low frequency channel radargram names. After the extraction processes is completed two separate information files infoa.dat infob.dat are also automatically made. Because the extracted channels are made to the \raw\ folder, additional pre-conditioning of the radargrams to remove low frequency drift – wobble – in the pulses can be applied. Several of the DF radargrams are shown to have drift, indicating that wobble filtering or bandpass filtering can be applied to the raw recorded data and will be needed in processing for this dataset.



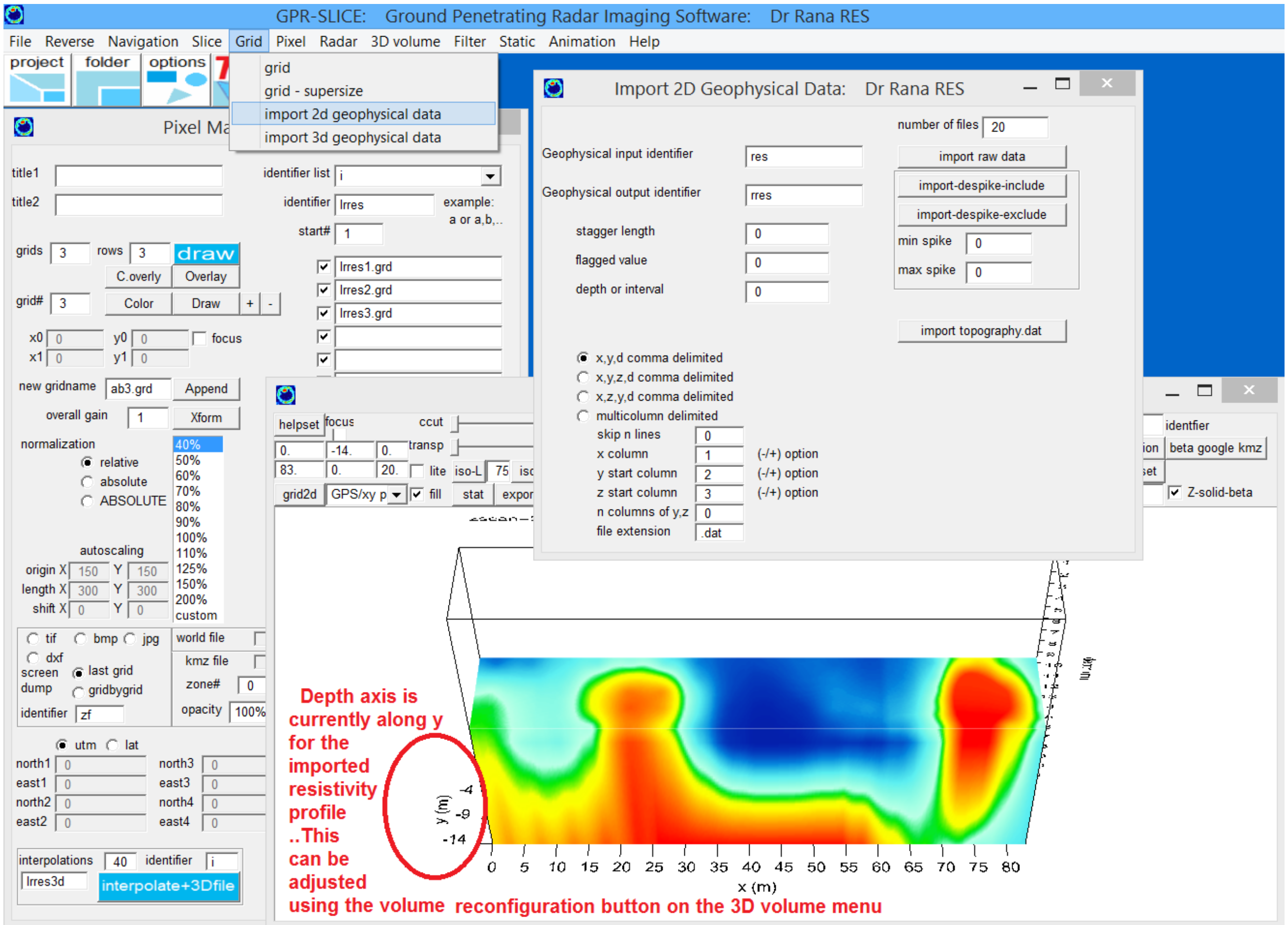
3D Visualization with Imported Geophysical Data (Resistivity, ERT, Seismic)

GPR-SLICE v7.0 has the capability to display any 3D dataset. Although signal processing of imported datasets is limited to GPR processing, many useful operations can be used. Electrical Resistivity Tomography as well as traditional seismic data can be visualized in GPR-SLICE. A special example of importing 2D resistivity profiles and creating a 3D volume is detailed

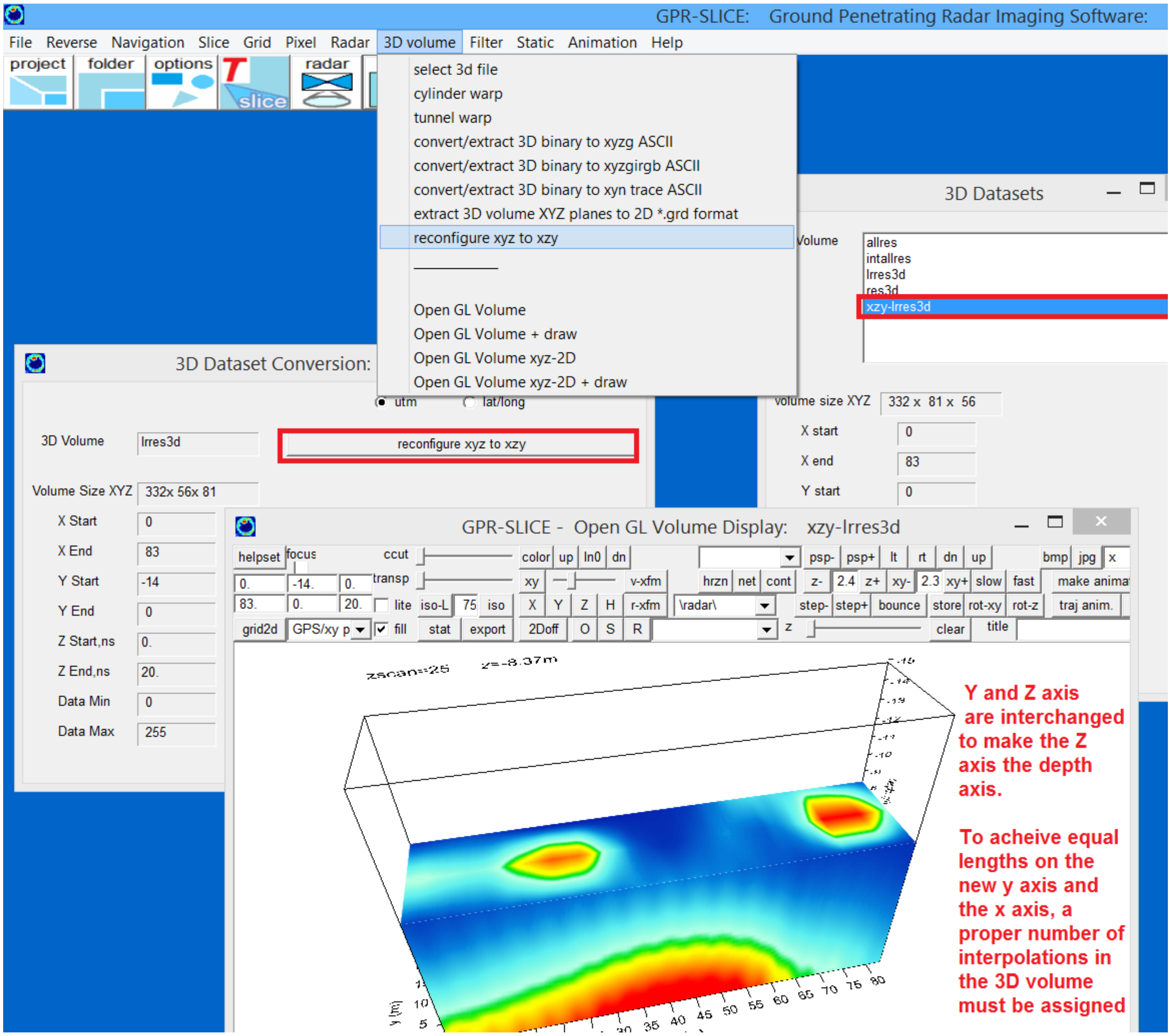
1) 2D resistivity profiles are imported and gridded



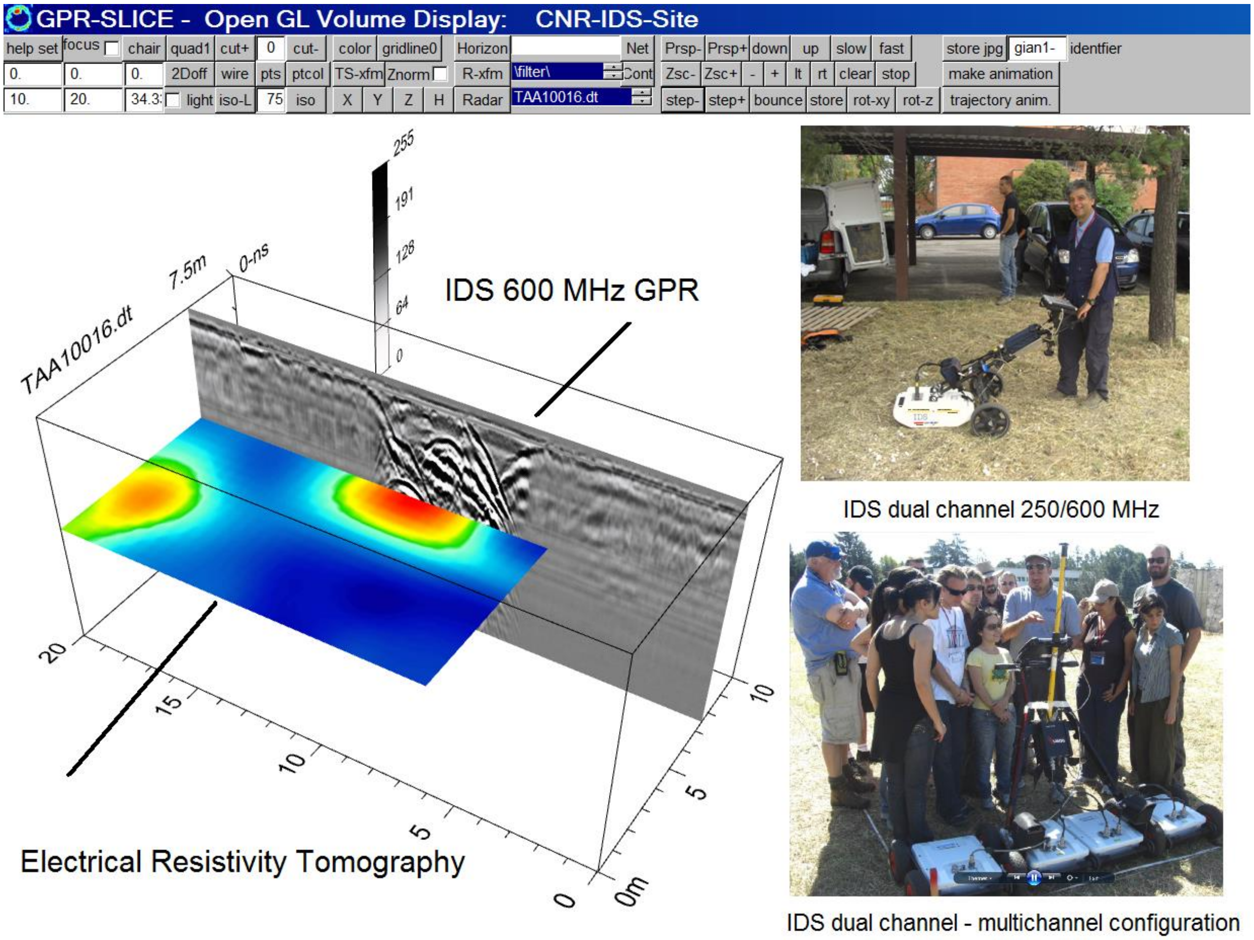
2) A 3D volume is generated by interpolating the resistivity profiles. The one problem now is that the y axis contains the actual depth axis depth axis.



3)Using a 3D volume pulldown menu and running the reconfigure XZY to XYZ button will write a new volume interchanging the Y and Z axes in the volume. To get an equivalent number of grid cells in the new Y and X axis the user must set an appropriate number of interpolations in generating the 3D volume. In this example an interpolation of 40 grids to be interpolated between resistivity profiles was required.



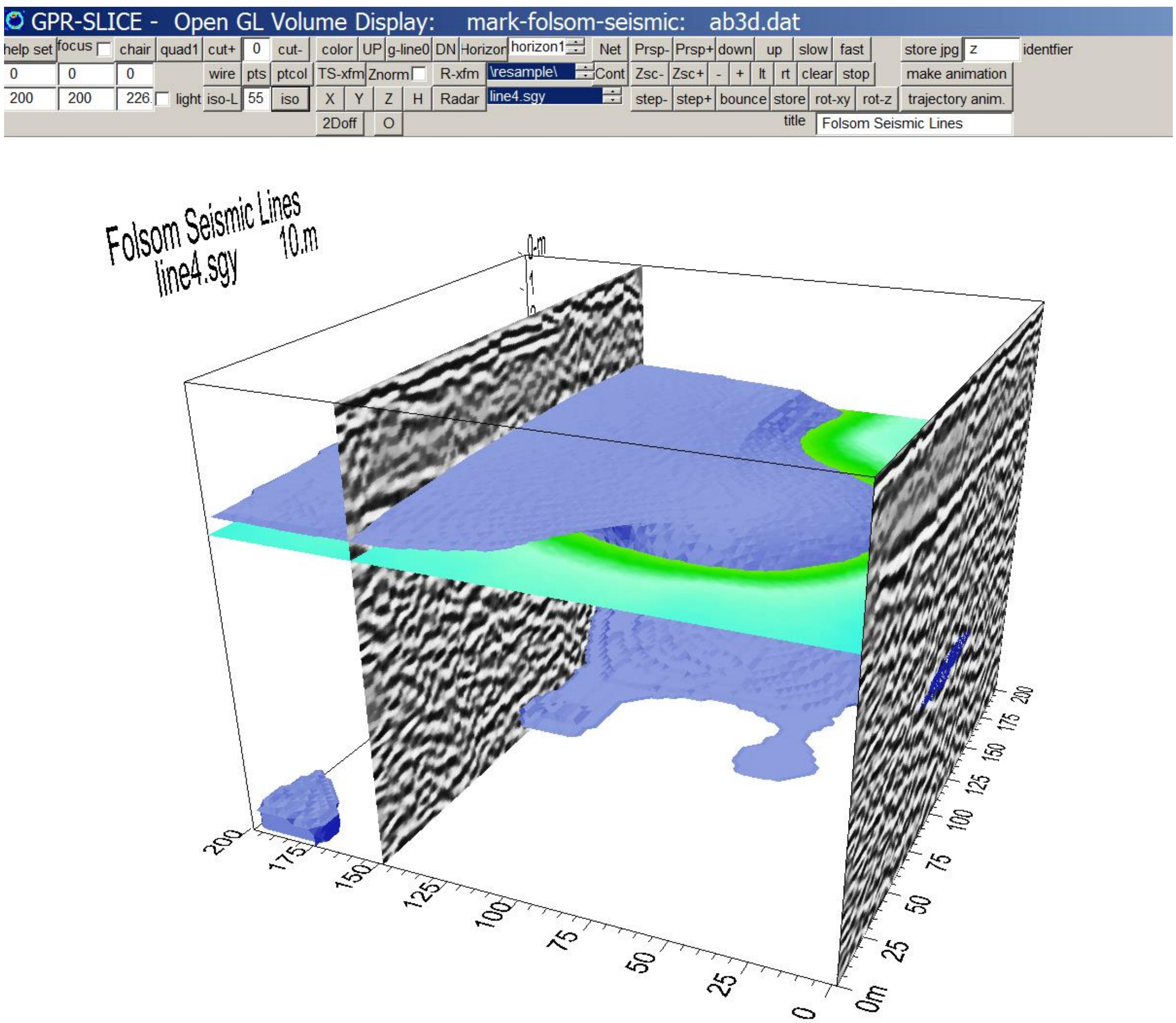
The archaeological geophysics field school offered by Consiglio Nacionale delle Ricerche in Rome was sponsored by Salvatore Piro of the Institute of Technologies Applied to Cultural Heritage at CNR and Stefano Campana of the University of Siena. In this workshop we had an opportunity to use the new IDS dual channel GPR systems which performed very well in the field. Electrical Resistivity Tomography (ERT) was also collected on a test site with GPR and we were able to process this data and incorporate these results side-by-side in the Open GL Volume. Shown in following figure is a Z fence showing a portion of the



test site imaged with ERT along with a GPR radargram from the IDS dual channel system. ERT visualization is GPR-SLICE can be done easily by simply importing XYZ-N.dat depth slices of ERT data (from the GPR-SLICE Grid pull down menu), then gridding and interpolating these to generate 3D volumes. This particular example was made with just 8 ERT inversions in depth. (There is currently one inconvenience in importing ERT data in that the depth scale requires editing the 3D header *.hed file associated with 3D volume to place a "fake" time window to give the same apparent depth of the radargrams). Jessica Ogden of the British School in Rome has recently been importing ERT data into GPR-SLICE to make 3D images of the Portus Roman site.

The beauty of the ERT method at the test site was that the resistivity probes were placed only on the boundaries of the site. This powerful inversion technique of electrical waves allows for developing tomographic models of areas within the perimeter of the resistivity probes. (ERT data was collected and provided by Gianfranco Morelli of GeoStudi, Italy). The large anomalies are rock filled test pits containing cylindrical pipe.

GPR-SLICE Open GL Volume can also be used to visualize 3D seismic data. Shown in an example in the following page is a seismic reflection survey conducted by Mark Olson of Advanced GeoScience from Palos Verdes. The preprocessed SEGY lines were converted in the Convert menu using and then processed normally as GPR radargrams. The data imported although it was already pre-processed, the GPR-SLICE filtering menu is equally capable of producing signal processed seismic lines of single fold data.



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