GPR-SLICE v7.MT Multi-Channel

Addendum Manual

(updated November 11, 2021)

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Introduction for Multi-Channel GPR Systems

GPR-SLICE v7.0   Multi-Channel

photo courtesy of Daniela Hofmann, Entrys Group GeoRail Division, Germany **www.entrys.de**

high-frequency array STREAM 2 GHz

-16 antennas , **8 pol. H-H ,   8 pol. V-V**

-Spacing 10 cm between channels
 => equivalente to 4 cm resolution

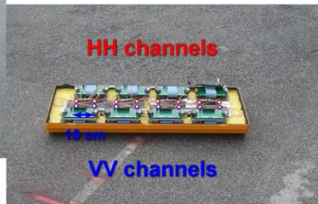- Width 91 cm, effective swath 70 cm

HH channels

VV channels

Photo courtesy of Gianfranco Morelli and Alex Novo, GeoStudi Astier (www.geoastier.com) and IDS of Italy

GPR-SLICE can process data from Multi-channel GPR systems, including:

> IDS Stream
> IDS Hi-Brite
> Mala Mira
> 3D Radar GeoScope
> Impulse Radar
> RPS Australia
> ISUNG
> GSSI SIR30

GPR-SLICE is completely integrated with all these manufacturers' proprietary GPS navigation format, including total station formats. Specialized buttons open up GPR-SLICE v7.0 software menus for users that have this additional license authorization. Fast 3D volume generation directly from processed

radargrams, as well as BlueBox Batch runs is available for multi-channel licenses.

Multi-channel GPS systems approaching 5-12 centimeter spacing between neighboring antennas and systems with smaller more manageable sizes from 4-8 antennas with dimensions on the order of a meter or less are being built by the manufacturers. To accommodate the present and future multichannel systems, GPR-SLICE has taken an unexpected evolution since the fall of 2010. The "hallmark" of GPR-SLICE software was and still is the proper interpolation of coarsely profiled datasets. However, with multi-channel systems, because the profile spacing is very narrow, the necessity for interpolation between radar lines is not necessary. **A new menu to directly compile processed radargrams to the 3D volume is now available for multichannel licenses!** The new 3D Radargram Volume Generation menu can be used to compile 3D volumes directly without having to enter the Slice/Resample menu, Grid menu or the Pixel Map menu. Some of the key changes in GPR-SLICE to accommodate the new operations included recognizing unresampled data in the compilation of the volume. Resampled data is not required and radargrams directly from \radar\ folder or from any folder processed from the \radar\ folder can be quickly compiled to the 3D binary volume.

This addendum manual is provided since there are different set of operations required. Most single channel systems are recorded with relatively coarse line spacing, and the user is relegated to use the slice/resample and gridding menus in GPR-SLICE to generate useful images. However, with multi-channel systems, because the density of lines is so fine, we can avoid slice/resample and gridding menus, and directly placed process radargrams from these GPR systems into the 3D binary volume for viewing in Open GL. The user of multi-channel systems can still use the slice/resample and gridding menus if so desired. This manual is dedicated to showing the streamlined features to obtain full resolution imaging that is provided from the native multi-channel systems that are being used. The generalized instruction set and then the specific operations for each manufacturer, IDS Stream, Mala Mira, 3D Radar Geoscope, and the Terravision are explicitly given in their own sections. The last section of this manual will introduce the new BlueBox Batch runs for all the multi-channel systems.

Multi-Channel General Operations:

The generalized operational steps for all the multi-channel systems are:

1) Import the filenames in the Create Info File menu, creating the infomain.dat (main track) and infochannels.dat (individual channels) profile information
2) Generate the navigation files in the Edit Info File menu for the main track
3) Generate the navigation files for each individual channel using the offset information from the GPS – main track
4) Extract/Convert the multi-channel radargrams
5) Set the Navigation marker type in the Navigation Menu
6) Run 0ns Editing process with the infochannels.dat
7) Using the infochannelsedit.dat file, run RSP including
    bandpass+gain
    background filter
    migration (optional filter)
    Hilbert transform (as optional/recommended filter)
8) Compile the desired processed folder into a 3D binary volume in the Radargram 3D Volume Generation menu
9) Display the data in Open GL or the Pixel 2D – multichannel menu

The specific operations up until Step 4) listed above are shown separately for each of the main multi-channel manufacturers in their own section in this manual. All the operations from Step 5) onward are then presented collectively as these are the same for all the equipment at this part of the data processing stream.

Many different system configurations have been built by the GPR manufacturers over the years containing a different number of antenna elements as well as offsets. GPR-SLICE kept all these different configurations known and previously only allowed for hardwired imports which the user was not able to adjust on import. Many of these older systems are no longer being manufactured as well. Also, should GPR users have customized their systems then the hardwired imports of navigation

were not initially flexible enough to accommodate adjustments to the system.

A new feature in the Create Info File menu allows the user to easily define the configuration of the GPR system initially by setting x,y,z offsets from main track/GPS position. After this is set the information files can be easily made. This new menu will override older operations for creating the infomain and infochannels navigation files and gives complete flexibility to easily adjust the configuration of the multichannel array in the software.
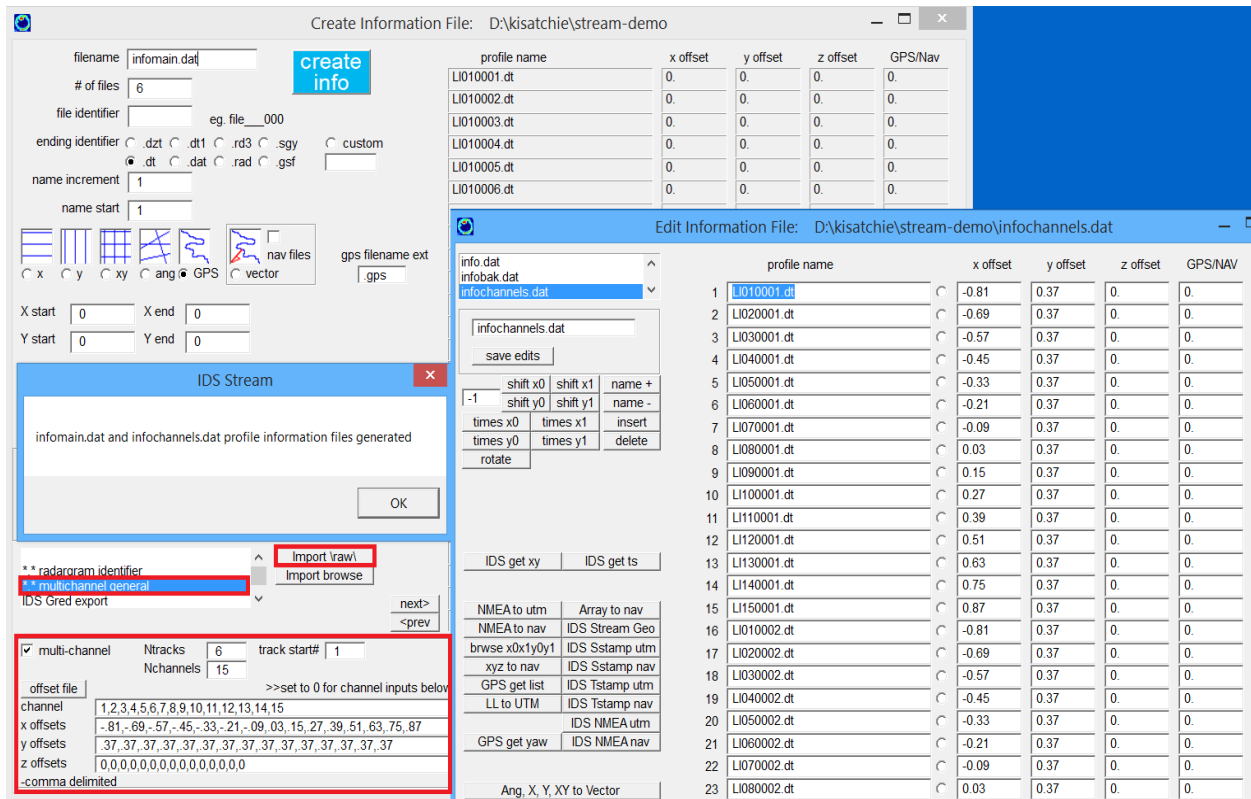
The new operations to set the system configuration and generate the navigation files infomain.dat and infochannels.dat. The *.* multichannel general text is highlighted in the listbox; the number of channels set and the number of tracks; the system configuration is defined with the channel number name followed by the x,y,z offset for each channel. This system configuration – once it is defined is translated to new GPR-SLICE projects on creation – so it only needs to be set one time. On clicking the Import \raw\ button, both the infomain.dat and the infochannels.dat files are generated. All the offsets are translated into the infochannels.dat file.

Mala Mira

The basic processes for the Mala Mira multi-channel GPR systems are:

1) Set the channel numbers and the x,y and z offsets for the Mala Array. Then click the "Import – Create Info" button in the Create Info File menu with the multichannel general highlighted in the listbox. This will automatically create 2 information files, infomain.dat which has the names of the main track radargrams, and infochannels.dat which will contains the names of the demultiplexed individual channel radargrams with all the X and Y offsets properly noted and stored.

2) The next operation is to extract all the radargrams from the main track names using the new Mira Extract button in the Edit Info File menu (shown previously). The extracted radargrams are directly placed into

the \radar\ folder with the naming convention *-N.rd3 where N is the channel number (the \raw\ folder is bypassed.)

3) After this the next operation is to click the Mira to Nav, which generates the *.rd3.gps files of the main track.   The GPS track menu can optionally be used to filter and condition the main GPS tracks should there be need error listed during track generation.
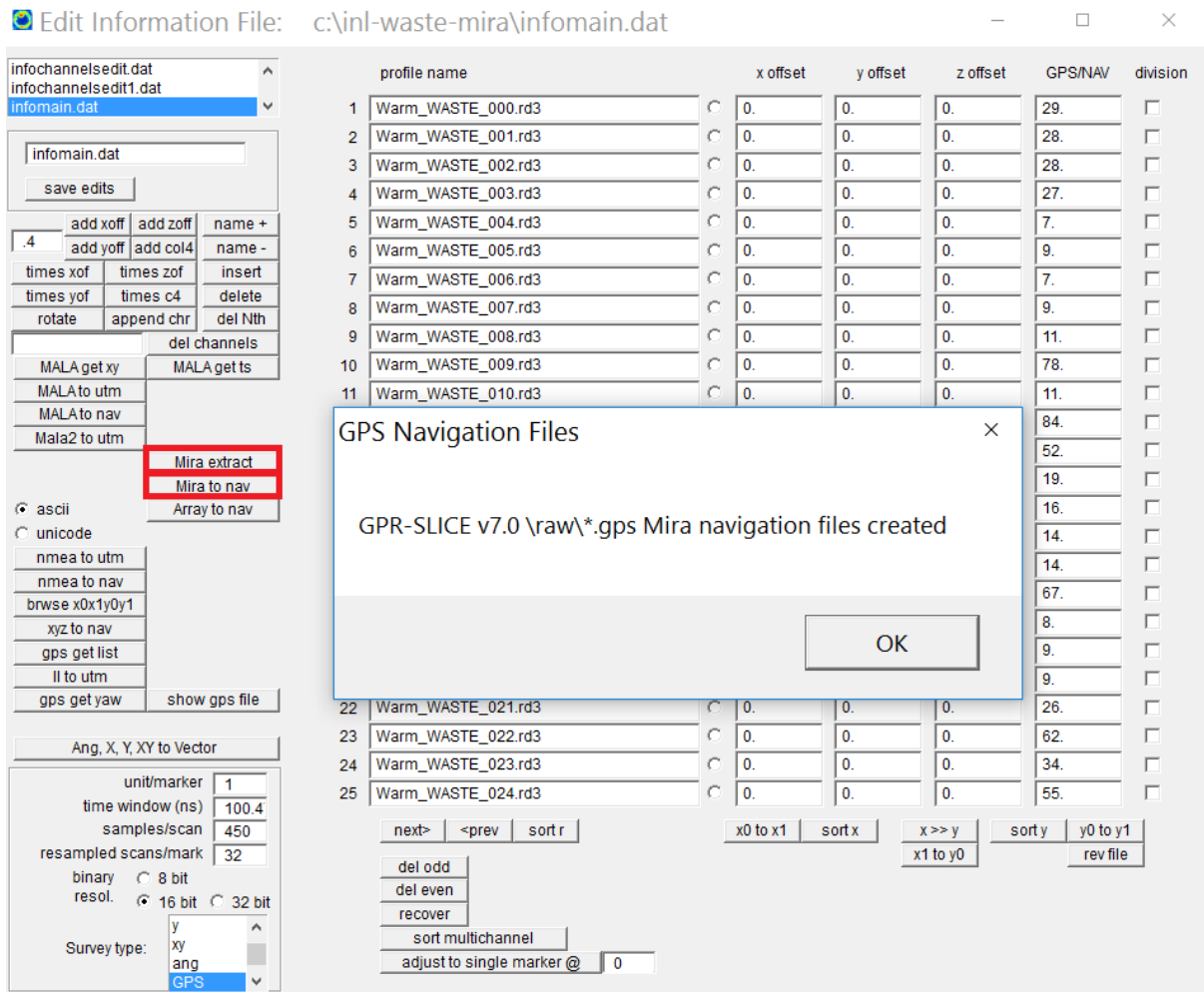
*note: The Mira Extract button will be used normally for total station projects.   For GPS projects, the user will set the GPS File Extension to the *.cor file extension (in the Create New Info menu) and will click the Mala to UTM button in the Edit Info File menu for the navigation.
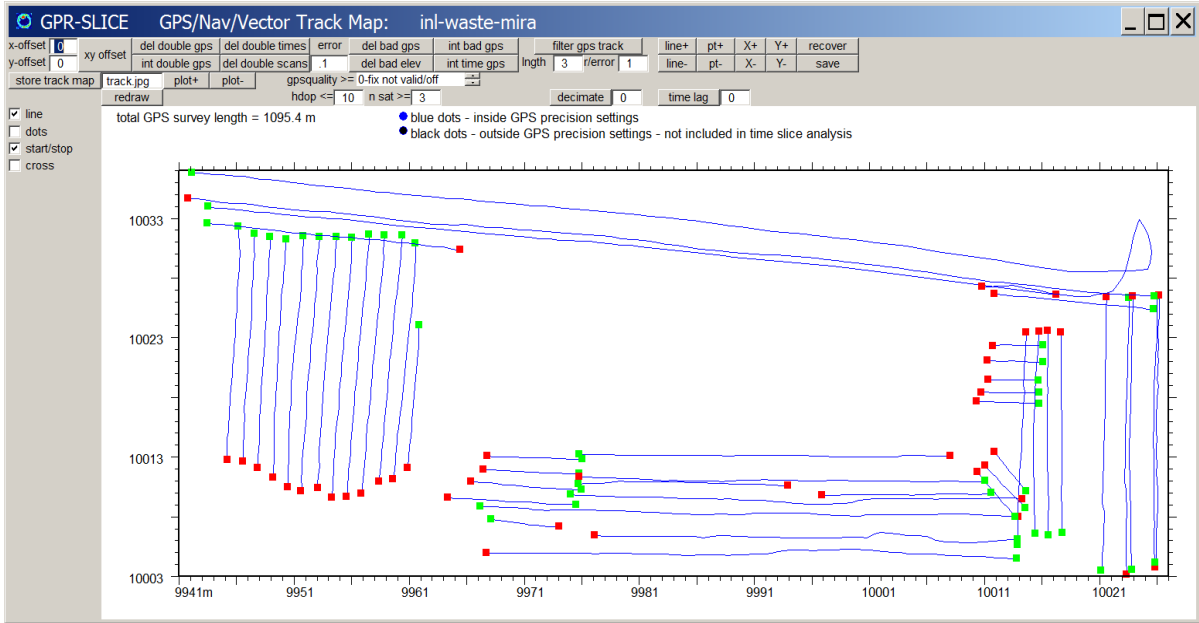
An example of the main track profile map is shown above. This particular example was made from 2 total station grids. The 2nd total station is reference to the first grid using Mala Mira tie-point log files that come with these collected datasets.

4) The next step is to highlight the infochannels.dat file back in the Edit Info File menu, and click the Array to Nav button to generate the individual channel tracks navigation (.rd3.gps files). The calculation includes the recorded offset in X and/or Y and employs monitoring the track orientation by looking at the trend between 2-3 adjacent GPS points. Note, that the X/Y offsets are stored in the first 2 columns of the information file for GPS or total station surveys.

An example of the GPS track generated for all the individual channels following the x and y offsets is shown above.

5) The next operation is to convert the extracted channels into the \radar\ folder without any gain, and by using the batch gain. No gain is desired yet since the 0ns offsets have yet to be edited from the different channels. **It is critical not to apply any gain**. The gain can be set to unity by clicking the Gain Reset button.
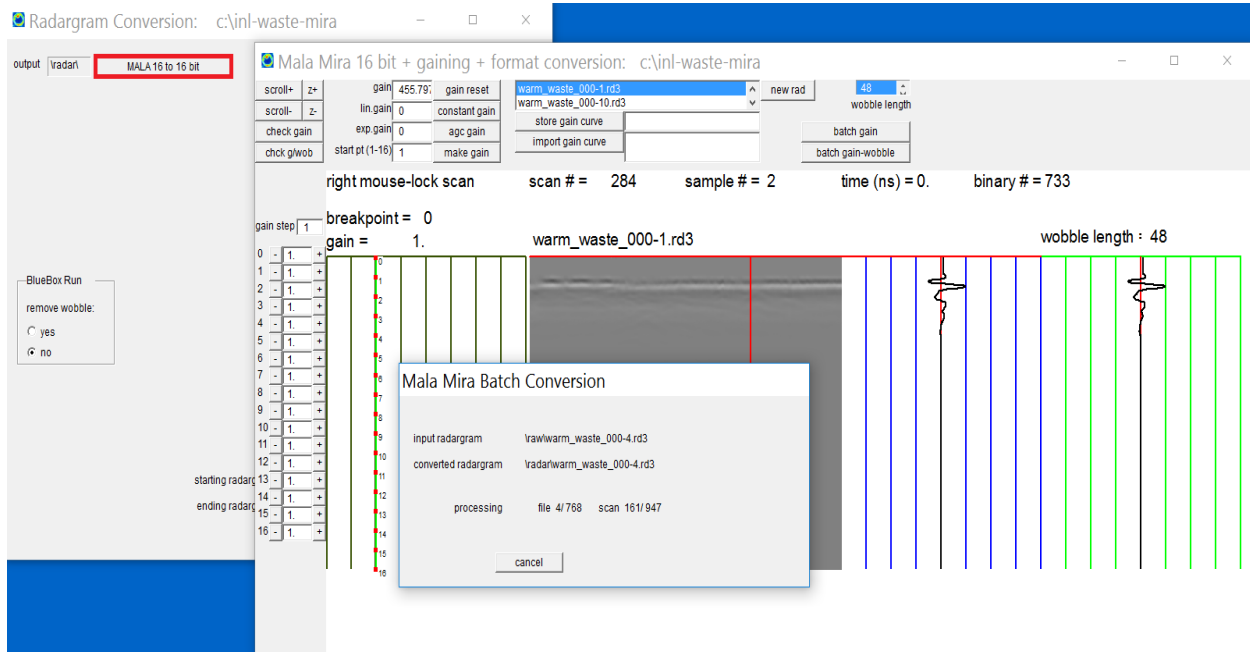
After conversion of the radargram, the navigation must be set using the option #4, GPS/Vector Trace #. This operation will extract the 5th column of the *.rd3.gps navigation files and set these scan numbers as the markers were navigation exists.

After these steps continue to the section entitled: **Processing Operations for all Multi-Channel GPR Systems.**   This will show the steps for signal processing for multichannel GPR and how to compile these data to a 3D volume.

3D Radar Geoscope – VOL format

1) Set the survey type to GPS or X or Y, the number of channels, and the antenna separation and offsets. Click the "Import – Create Info" button. This will automatically create 2 information files, infomain.dat which has the names of the main track radargrams, and infochannels.dat which contains the names of the extracted individual channel radargrams with all the X and Y offsets, antenna separation, properly noted and stored.

2) The next step the individual channels are extracted from the multiplexed radargrams listed in the infomain.dat file in the Edit Info File menu.
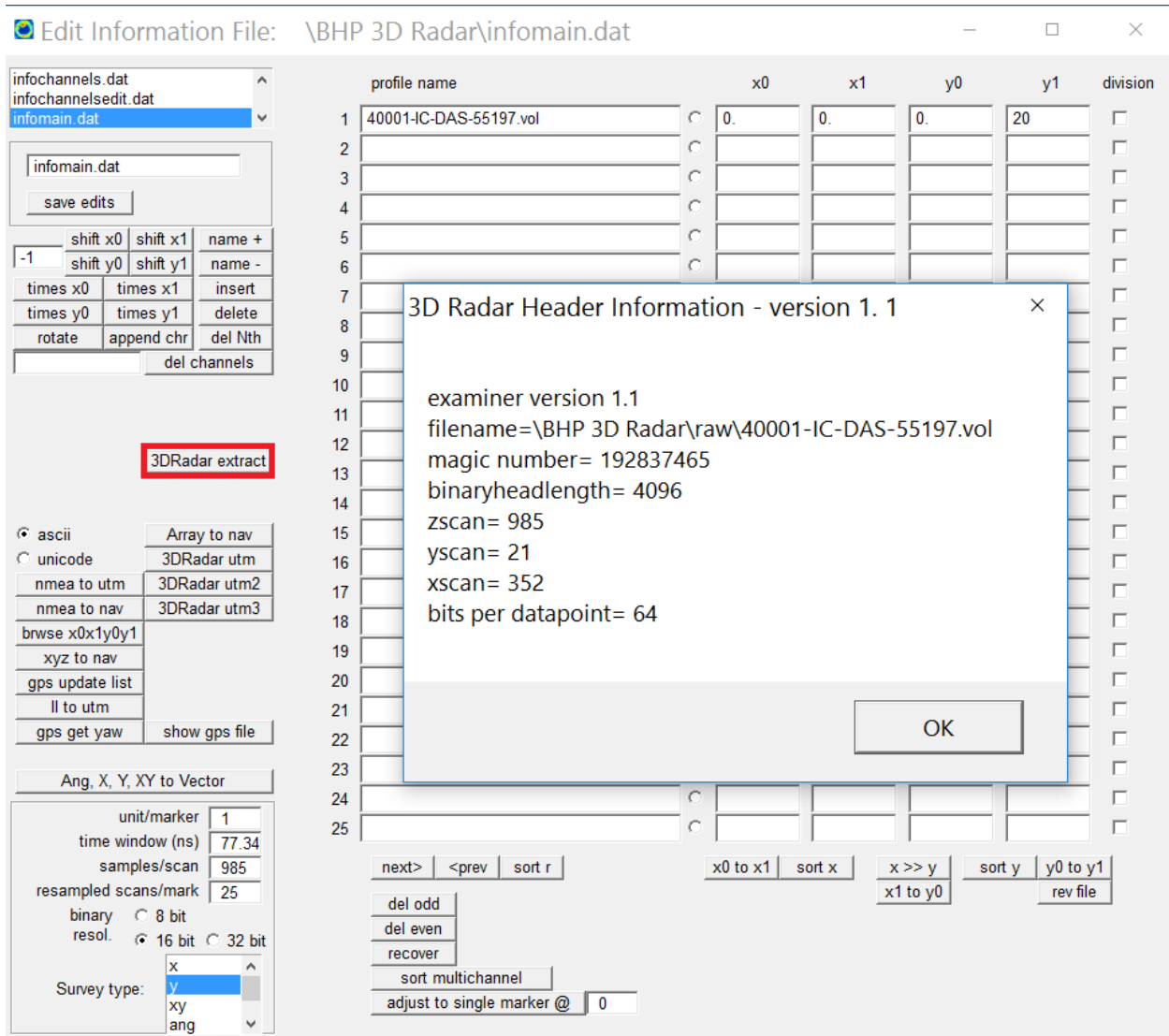
3) The next step is to make sure the infomain.dat file is highlighted in the Edit Info File menu. Then click the 3DRadar to UTM, which generates the *.rd3.gps files of the main track and updates the number of GPS listings in the 4th column of the information file.   The user can use the GPS track menu optionally to filter and condition the main GPS tracks should there be any need to or track warning messages come up.   (For non-GPS

surveys these buttons are not used and just the x0,x1,y0,y1 columns are used as the navigation).

Optionally for newer versions of 3D Radar *.txt files are provided as the navigation formats. For these datasets the XYZtoNAV menu is needed to read the navigation and create the GPS files:
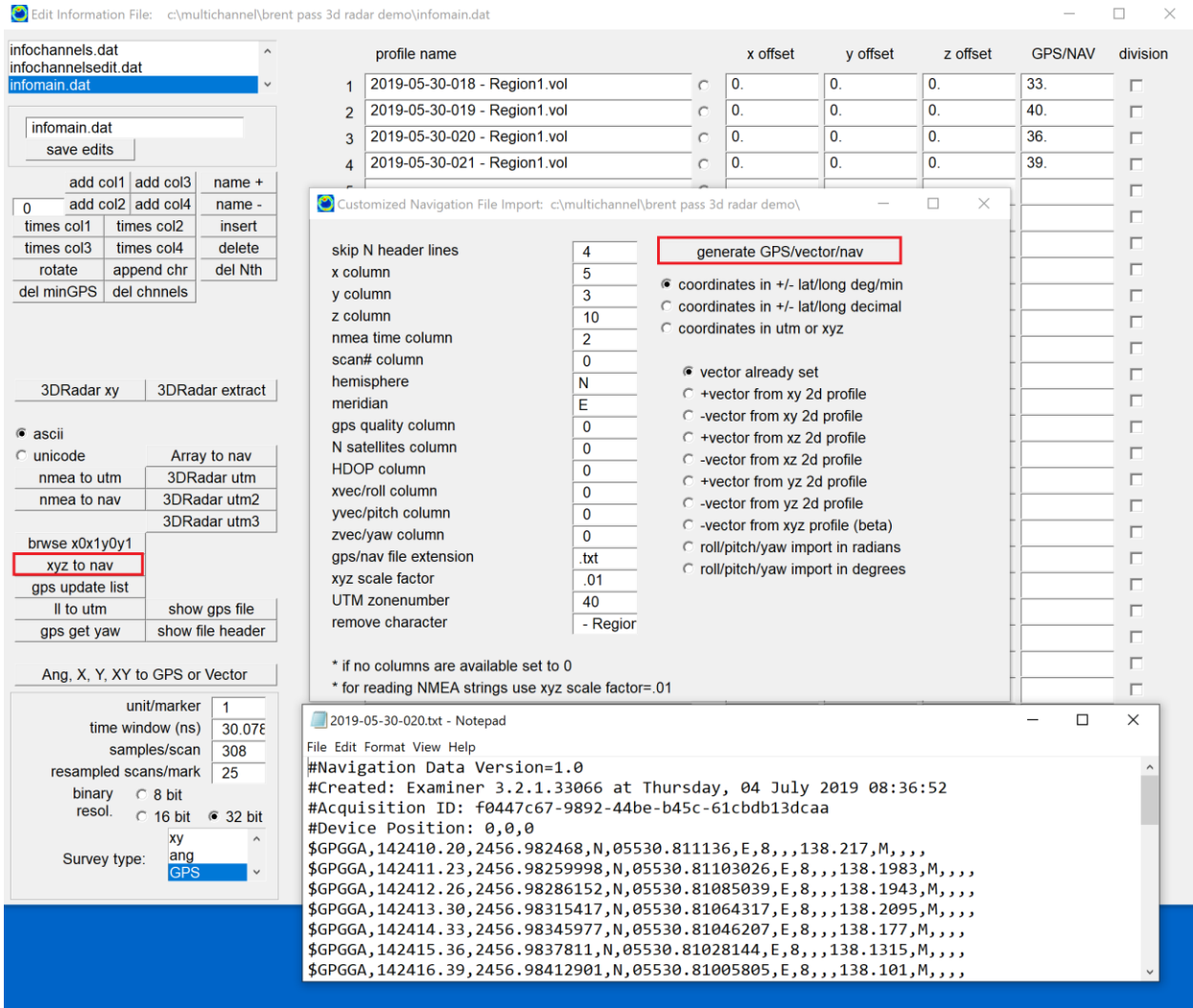
4) The next step is to highlight the infochannels.dat file back in the Edit Info File menu, and click the Array to Nav button to generate the individual channel tracks navigation (.vol.gps files). The calculation includes the recorded offset in X and/or Y and employs monitoring the track orientation by looking at the trend between 2-3 adjacent GPS points.

Edit Information File: C:\3DRadar GPS test\infochannels.dat

infobak.dat
infochannels.dat
infochannelsedit.dat

infochannels.dat

save edits

shift x0	shift x1	name +
shift y0	shift y1	name -
times x0	times x1	insert
times y0	times y1	delete
rotate		

0

3D Radar xy   3D Radar ts

NMEA to utm   Array to nav
NMEA to nav   3DRadar utm
brwse x0x1y0y1   3DRadar utm2
xyz to nav
GPS get list
LL to UTM

GPS get yaw

Ang, X, Y, XY to Vector

unit/marker   1
time window ns   35
samples/scan   216
resampled scans/mark   32

resampled resol. ○ 8 bit ● 16 bit

Survey type: xy / ang / **GPS**

	profile name		x offset	y offset	z offset	GPS/NAV	division
1	2013-04-11-003-Region1-00u-1.vol	○	0.	0.	0.	1064.	☐
2	2013-04-11-003-Region1-00u-2.vol	○	0.12	0.	0.	1064.	☐
3	2013-04-11-003-Region1-00u-3.vol	○	0.24	0.	0.	1064.	☐
4	2013-04-11-003-Region1-00u-4.vol	○	0.36	0.	0.	1064.	☐
5	2013-04-11-003-Region1-00u-5.vol	○	0.48	0.	0.	1064.	☐
6	2013-04-11-003-Region1-00u-6.vol	○	0.6	0.	0.	1064.	☐
7	2013-04-11-003-Region1-00u-7.vol	○	0.72	0.	0.	1064.	☐
8	2013-04-11-003-Region1-00u-8.vol	○	0.84	0.	0.	1064.	☐
9	2013-04-11-003-Region1-00u-9.vol	○	0.96	0.	0.	1064.	☐
10	2013-04-11-003-Region1-00u-10.vol	○	1.08	0.	0.	1064.	☐
11	2013-04-11-003-Region						
12	2013-04-11-003-Region						
13	2013-04-11-003-Region						
14	2013-04-11-003-Region						
15	2013-04-11-003-Region						
16	2013-04-11-003-Region						
17	2013-04-11-003-Region						
18	2013-04-11-003-Region						
19	2013-04-11-003-Region1-00u-19.vol	○	2.2	0.	0.	1064.	☐
20	2013-04-11-003-Region1-00u-20.vol	○	2.32	0.	0.	1064.	☐
21	2013-04-11-003-Region1-00u-21.vol	○	2.44	0.	0.	1064.	☐
22		○					☐
23		○					☐
24		○					☐
25		○					☐

GPS Filtering

21 files were found containing double GPS points:
**** recommend using Del Double GPS operation in the GPS track menu

OK

next>	<prev	sort r		x0 to x1	sort x	x >> y	sort y	y0 to y1
del odd						x1 to y0		rev file
del even								
recover								
sort multichannel								

5) The conversion menu is then entered and the 3D radar data are converted with batch gain-wobble (or alternatively batch gain where later bandpass filtering will be applied). If the time 0 is stable a gain curve can be applied at this point, but if time 0 varies, it should be applied after time 0 correction.
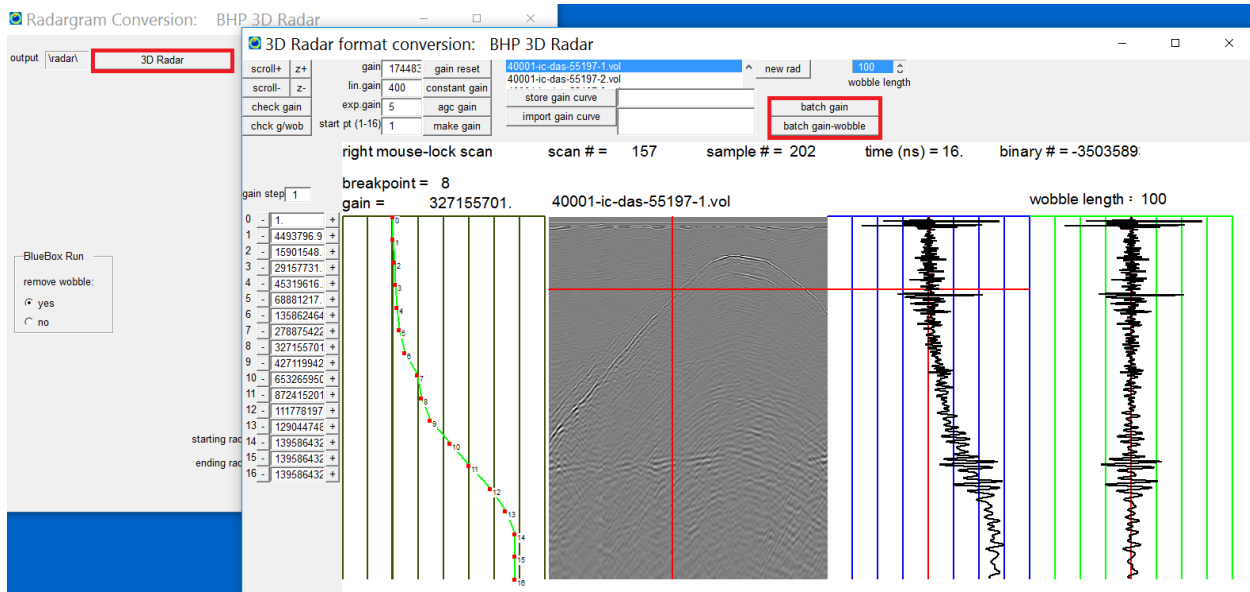
The conversion menu will automatically pop up and the user must generate a gain curve at the end of the extraction process to visualize the pulses and bring them within range before running Batch Gain. If the data are pre-processed in Examiner software from 3D Radar then use a gain curve. If the data are unprocessed, then do NOT use a gain curve!

An example GPS track map for all the individual channels for this Geoscope dataset is shown below:
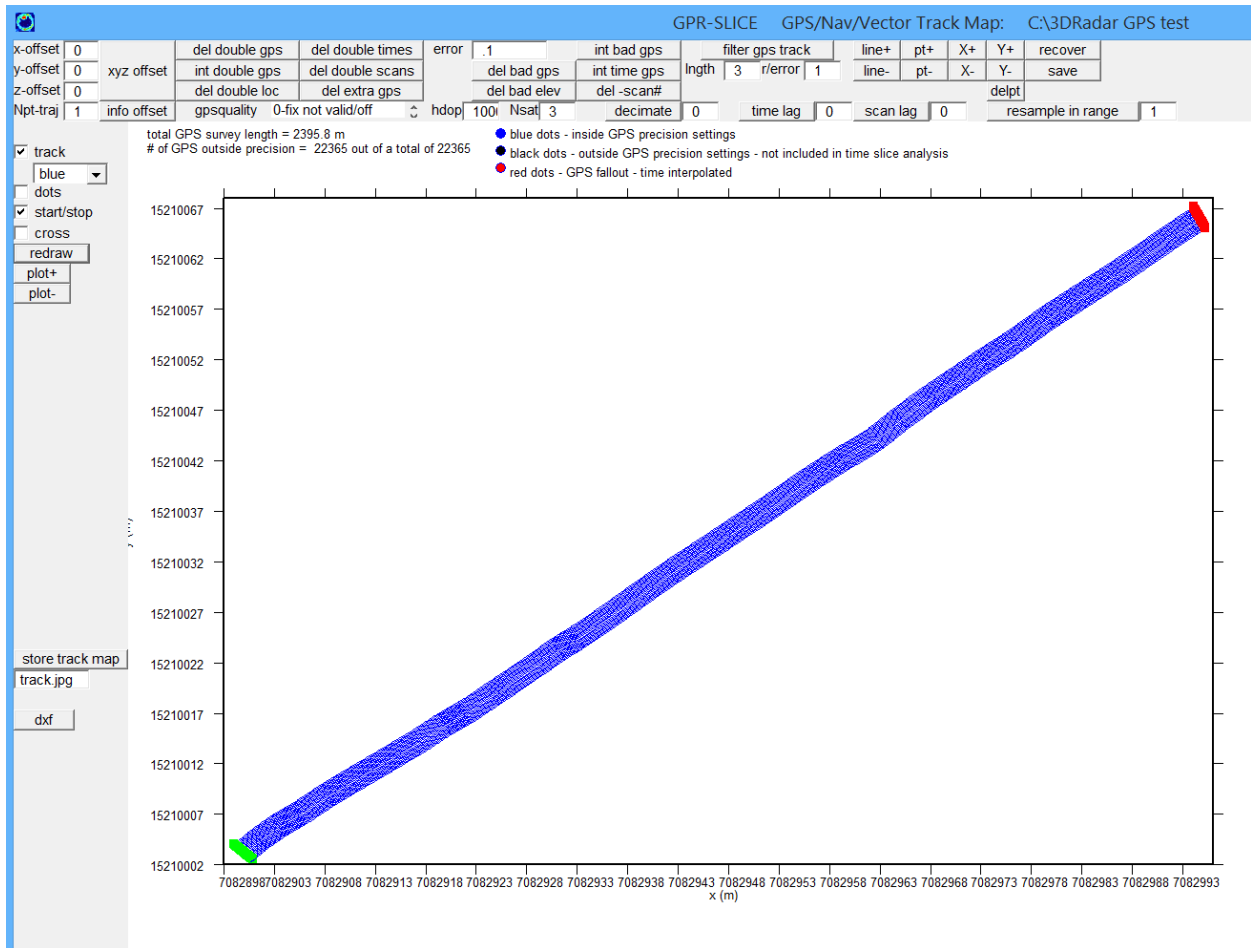
6) Set the navigation for the 3D Radar Geoscope using the Artificial Marker operation in the Navigation menu. The Geoscope navigation files normally contain GPS or total station information on every scan. For this reason, and also because the 5th column is not assigned scan number (which is mute), the Artificial Marker process is the complete navigation and accurate solutions.

3D Radar Geoscope – SEGY format

1)   An alternate 3D Radar format available in late 2020 is a SEGY format. Each swath of data is written into a single SEGY file. The equipment format chosen is SEGY Multichannel Multipex.
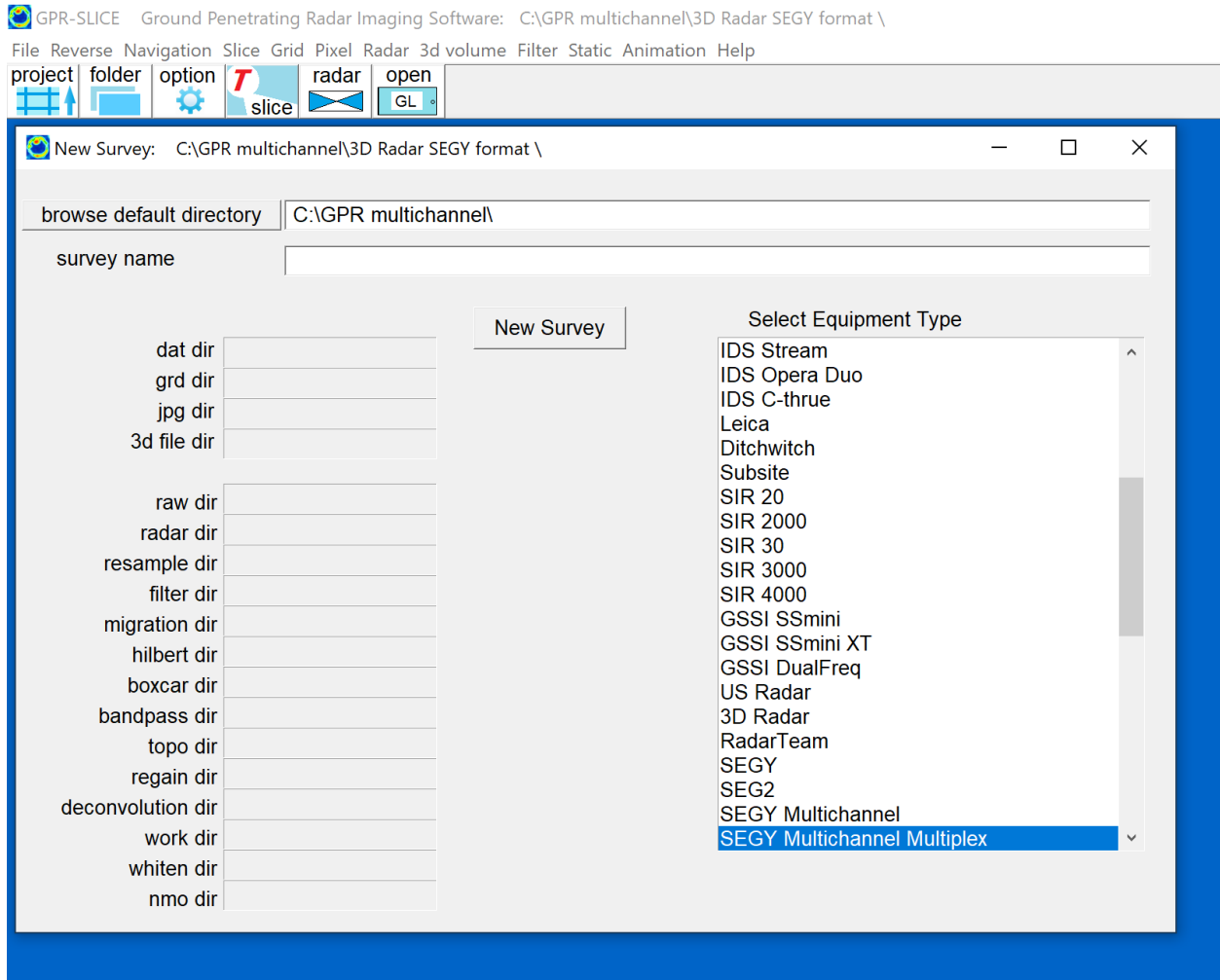
2) With this equipment type, the infomain and infochannels are generated in the Create New Info menu:

3) With infomain active, the SEGY Demultiplex button is clicked which will separate each channel into its own SEGY file in the \raw\ folder:

4) With infochannels.dat active the SEGY to NAV button is clicked to write the GPS navigation files from the SEGY trace headers:

** After these steps, the identical processing as in the 3D Radar section for *.vol format is followed

IDS Stream

The basic processes for the IDS Stream and their family of different multi-channel GPR systems (including the EM, MT and Hi-Brite, and C system) are:

1) Click the "Import – Create Info" button in the Create Info File menu with the multichannel general highlighted in the navigation listbox. This will automatically create 2 information files, infomain.dat which has the names of the main track radargrams, and infochannels.dat which contains the names of the individual channel radargrams with all the X and Y offsets properly noted and stored. Different X and Y offset may be needed for different IDS systems not listed here. Shown below is for a 15 channel system Stream EM. Configurations for IDS Stream C HH and VV channels are also given in the next few screen shots as well.

IDS Stream C VV configuration: For a IDS Stream C there are 23 channels of VV polarization at approximately 4.4 cm separation between channels.

IDS Stream C HH configuration: For a IDS Stream C there are 9 channels of HH polarization at approximately 9.6cm separation between channels.

2) The next step is to work directly on the infochannels.dat file in the Edit Info File menu. Recent IDS Stream operation now generate *.geox files with every radargram. Clicking the IDS Stream Geox button will read these files and place into *.dt.gps format using this systems array navigation. (The GEOX files are the manufacturers navigation solution.

2a) Optional method for generating GPS navigation files is to click the IDS Gec button with infomain.dat highlighted. This will generate the navigation on the main track – channel 1 file.

2b) After generating the main track, which can be edited if necessary in the GPS Track menu, the button Array to Nav is clicked with infochannels.dat file highlighted in the Edit Info File menu:

*** Note: For IDS Stream EM equipment, channels 1-8 the VV channels will have often twice as many recorded scans as the HH channels 9-38. Because the IDS navigation for GPS is tied to channel 1, the master navigation file has scan numbers for NMEA strings that are twice as many scan positions as that in the HH channels. The button Fix Stream Nav should be clicked to correct for the navigation for the HH channels – which divides the scan number in the master navigation files by 2. It is unusual application in any multichannel equipment, but necessary since this manufacturer records different scan lengths for different channels.

3) After generating the infochannels.dat navigation file, the next step is to convert the IDS individual channels – which come naturally extracted from the IDS stream system – using the Batch Gain-Wobble operation. Note that the conversion is done **WITHOUT** any gain set. This is critical as the 0ns offsets have not yet been corrected for. The batch gain-wobble operation will insure that the drift on the bottom of the radargram is properly brought back to the 0 line. (This will also enable directly using the Regain operation after 0ns editing is done whereas without the batch gain – wobble operation, bandpass filtering would have to first be applied before regaining).
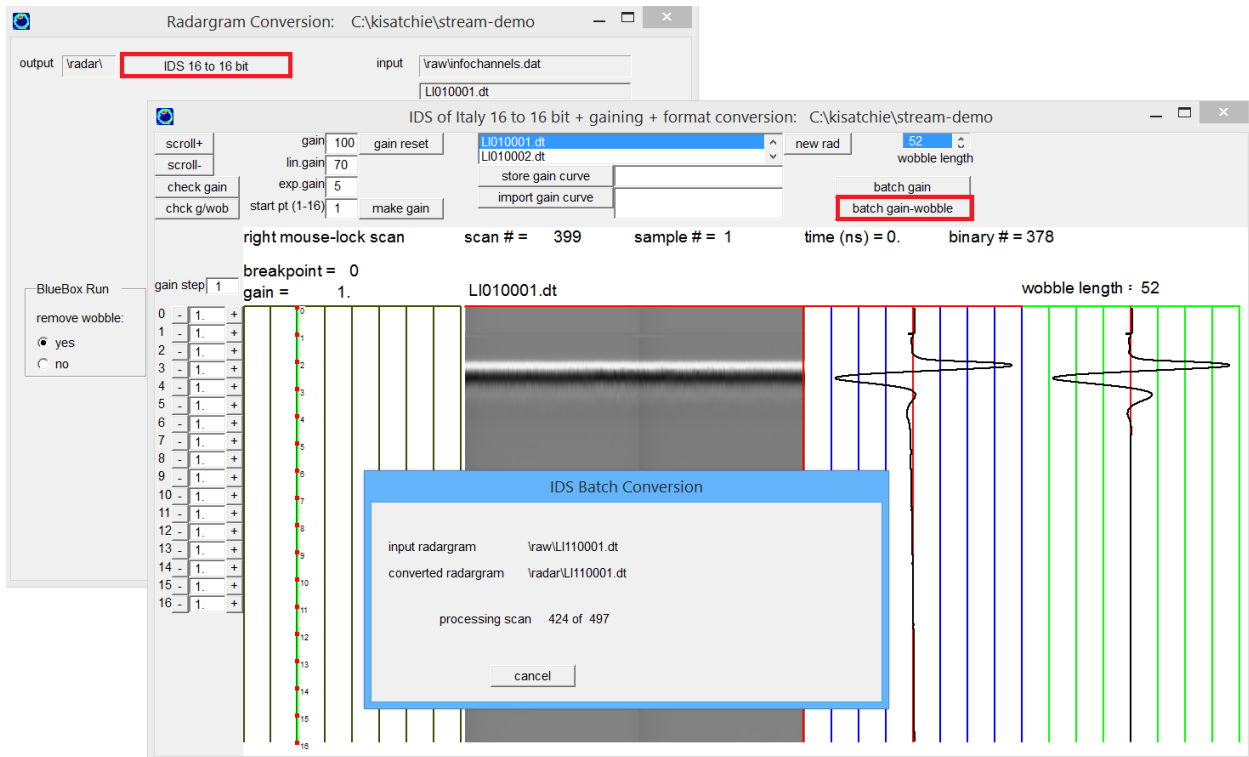
Impulse Radar - Raptor

The basic processes for the 16 channel Impulse Radar Raptor multichannel system are:

1) Use the "help set" with the channel descriptions including, Nchannels, xoffset, xstart set to the appropriate values.   This will create the channel names and their offsets.   Note, these values can be customized and edited manually should the channel separations or naming convention be different.

2) Click the "Import – Create Info" button in the Create Info File menu with the *.* multichannel general highlighted.   This will create the infomain and infochannel information files.
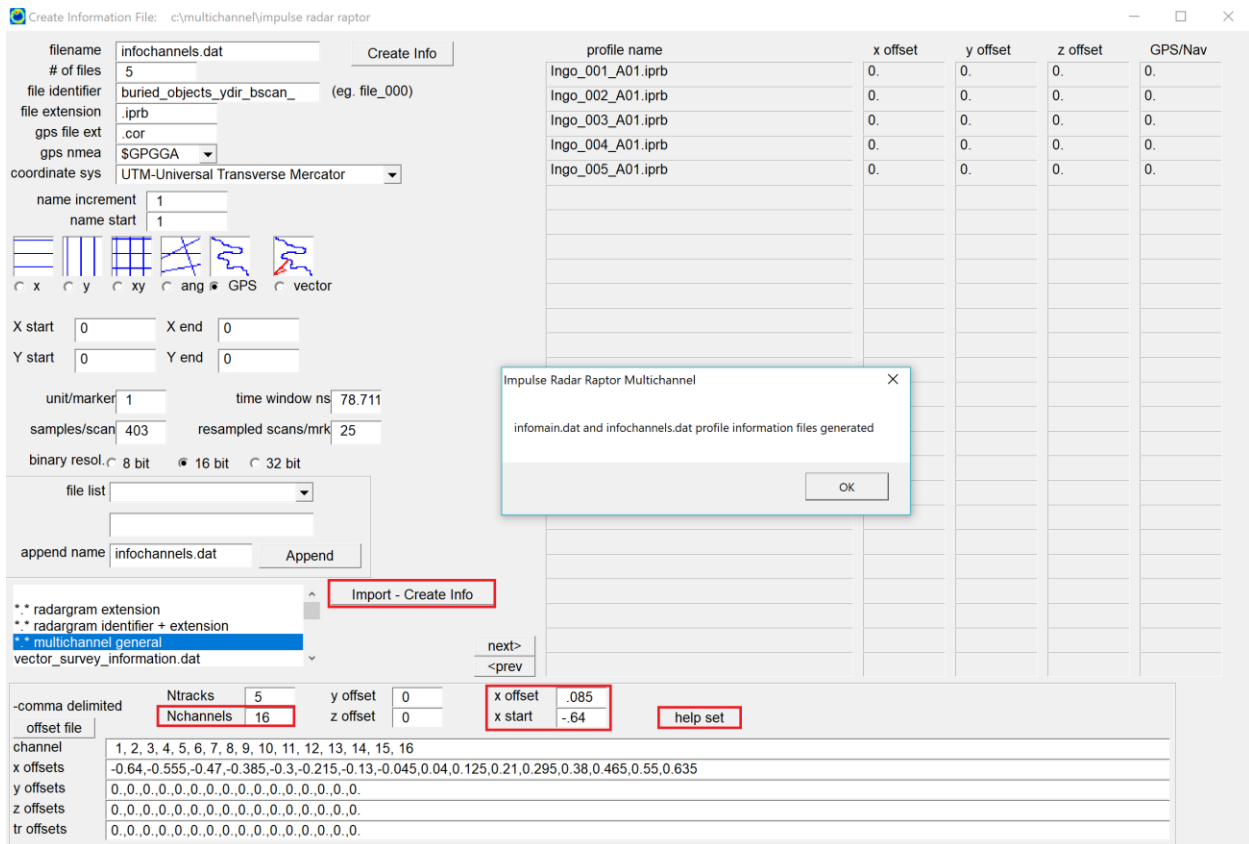
3) In the Edit Info File menu, click the "Raptor to utm" button with infomain.dat active to create the main track navigation. If navigation errors are reported those can be fixed in the GPS track first.

4) With infochannels.dat active, the user will then click the "Array to Nav" button to calculate the individual track for each channel based on the x-offset (and y-offset if set) in the information file.

5) In the GPS track menu the complete Raptor navigation can be seen. For this particular data during computation of the navigation the software indicated that the number of GPS was double in some locations requiring the user to click the "Del Double GPS" button. Note, sometimes other navigation errors can exist which may require clicking the "Del Double Scans" (or even the "Del Extra GPS" button. The "Del Extra GPS" button requires that all the scans be converted before testing this navigation issue).   After these operations the user can continue on to the section entitled "Processing Operations for all Multichannel GPR Systems" in this manual.
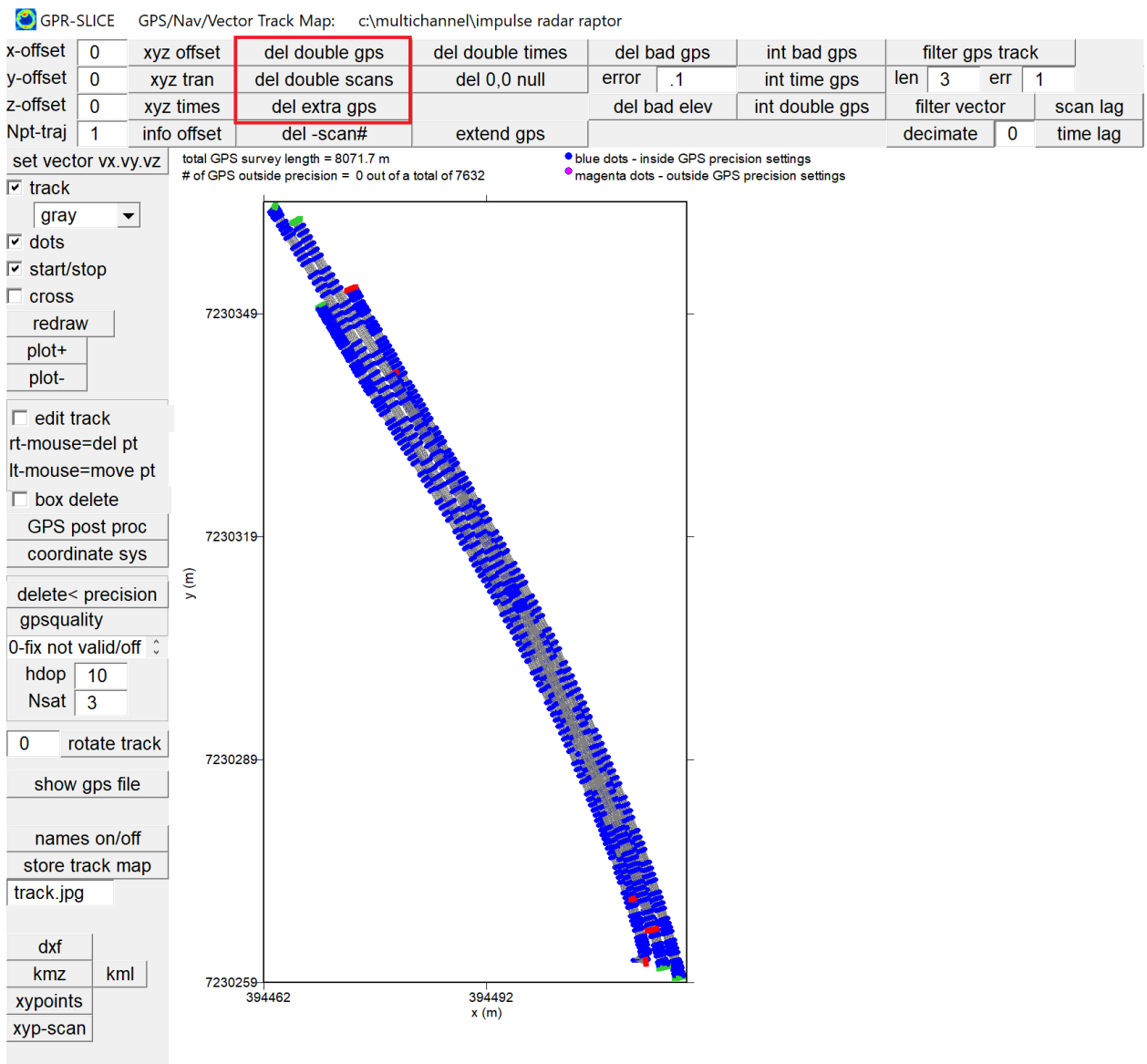
GSSI SIR 30

The basic processes for the 1-4 channel GSSI SIR 30 multichannel system are:

Create New Info menu:

1) Use the "help set" with the channel descriptions including, Nchannels, xoffset, xstart set to the appropriate values. This will create the channel names and their offsets. Note, these values can be customized and edited manually should the channel separations or naming convention be different.

2) Click the "Import – Create Info" button in the Create Info File menu with the *.* multichannel general highlighted. This will create the infomain and infochannel information files.
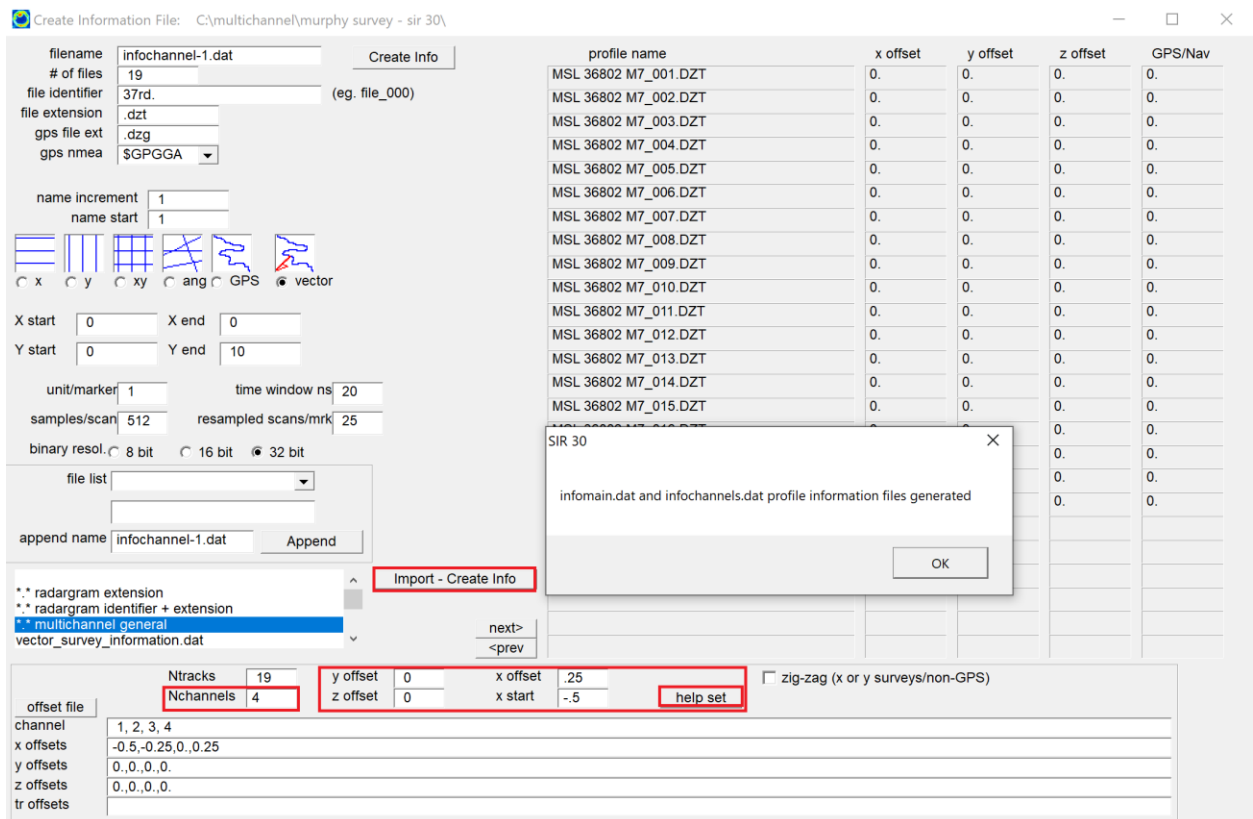
infomain.dat: contains the name of the main track 32 bit multiplexed radargrams
infochannels.dat: contains the extract channels with -N.dat designation

Edit Info File menu:

3) highlight the infomain.dat file

4) click the GSSI to UTM button to generate the GPS on the main

5) click the Separate SIR30 button to extract the individual channels

6) set the information file to infochannels.dat

7) click the Array to Nav button to generate the individual GPS tracks for each extracted channel based on the xy offsets.

8) click on the infochannel-1.dat (or -2,-3,-4.dat) and begin standard processing….

RPS Multichannel

The basic processes for RPS Multichannel systems from Australia are after the infomain.dat and infochannels.dat are made in the Create New Info menu :

1) Create the infomain and infochannels.dat file in the Create New Info menu.
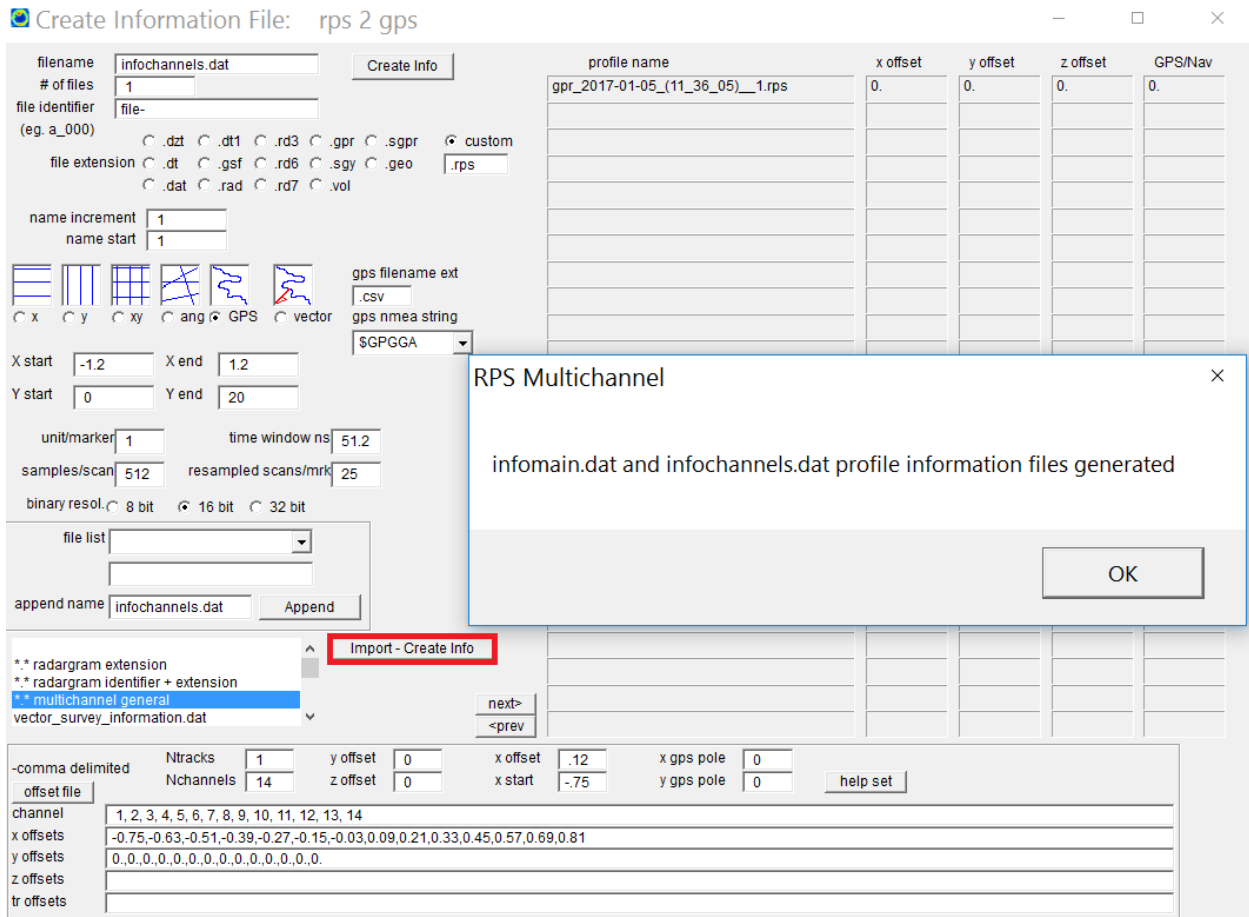
2) Create the navigation using the RPS to UTM button. As of 4/13/17 RPS is still developing their file conventions, but there current *.csv navigation files needs to have the same name as the main track names in the infomain.dat, but just with the *.csv extention.   Clicking RPS to UTM will generate the navigation files and do all the UTM conversions.

3) Extract RPS will demultiplex the main radargram and make individual radargram files names with the -1,-2, … -N.rps extensions

4) The next step is to generate the individual channel navigation using the Array to Nav button

5) The next operation is to convert   the raw radargrams in the Conversion menu. No range gain is applied yet as time 0 corrections need to be done first.   After this, standard operations detailed in the next section can be followed.

6) After conversion, the next step is to run the GPS vector trace# navigation in the Marker menu. After this operation some standard processing operations can be run, as detailed in the next section for all multichannel radar systems.

RPS BlueBox Operation are also available in a convenient menu show below. Bandpass and background filtering are set as the RSP batch operation. The new Bandpass menu can have a simultaneous gain curve applied and set in the Spectra+Gain menu. This Bluebox will go all the way to a final 3D volume.

GPR-SLICE   Ground Penetrating Radar Imaging Software: rps 2 gps

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 + editing
BlueBox: basic + editing + RSP
BlueBox: xy decoupled gridding + RSP
BlueBox: xy decoupled gridding + editing + RSP

BlueBox: xy decoupled volume + RSP
BlueBox: xy decoupled volume + editing + RSP

_____BlueBox multichannel batch processing_____

BlueBox: RPS Multichannel - customized RSP

BlueBox ...   —   □   ×

infomain.dat   ☑ processing graphics
number of channels = 14

BlueBox Run: RPS Multichannel

user step 1: import \raw\ in Create Info File menu

user step 2: click RPS to Nav with infomain.dat in Edit Info File menu

user step 3: click Array to Nav with infochannels.dat in Edit Info File menu

user step 4: start the BlueBox Run

blue 1: Extraction   ☑

blue 2: Conversion   ☑
      (wobble off)
blue 3: Navigation   ☑

blue 4: Radargram Editing   ☑
    (threshold=.5 Nsamp back=0)
blue 5: RSP Batch   ☑
      ☑ bandpass
         background (nlen=99000 n1=3 n2=512)
blue 5: Radargram 3DVolume - prompt   ☑
      ☑ help set   (xy gridcellsize=.08)
      ☑ interpolate gap   (intx=2 inty=2)
         compiled folder=background
blue 6: Open GL   ☑

set all
terminate

ISUNG Multichannel

The basic processes for ISUNG Multichannel systems from Korea are after the infomain.dat and infochannels.dat are made in the Create New Info menu:

1) Create the infomain and infochannels.dat file in the Create New Info menu. One will need to set the Xoffset between channels and the Xstart value for channel. Also, the number of channels are set before the button Help Set is clicked.

2) Next step is to extract the individual channels from the multiplexed radargrams from the infomain.dat file. The extracted channels are written to the \radar\ folder of the project.
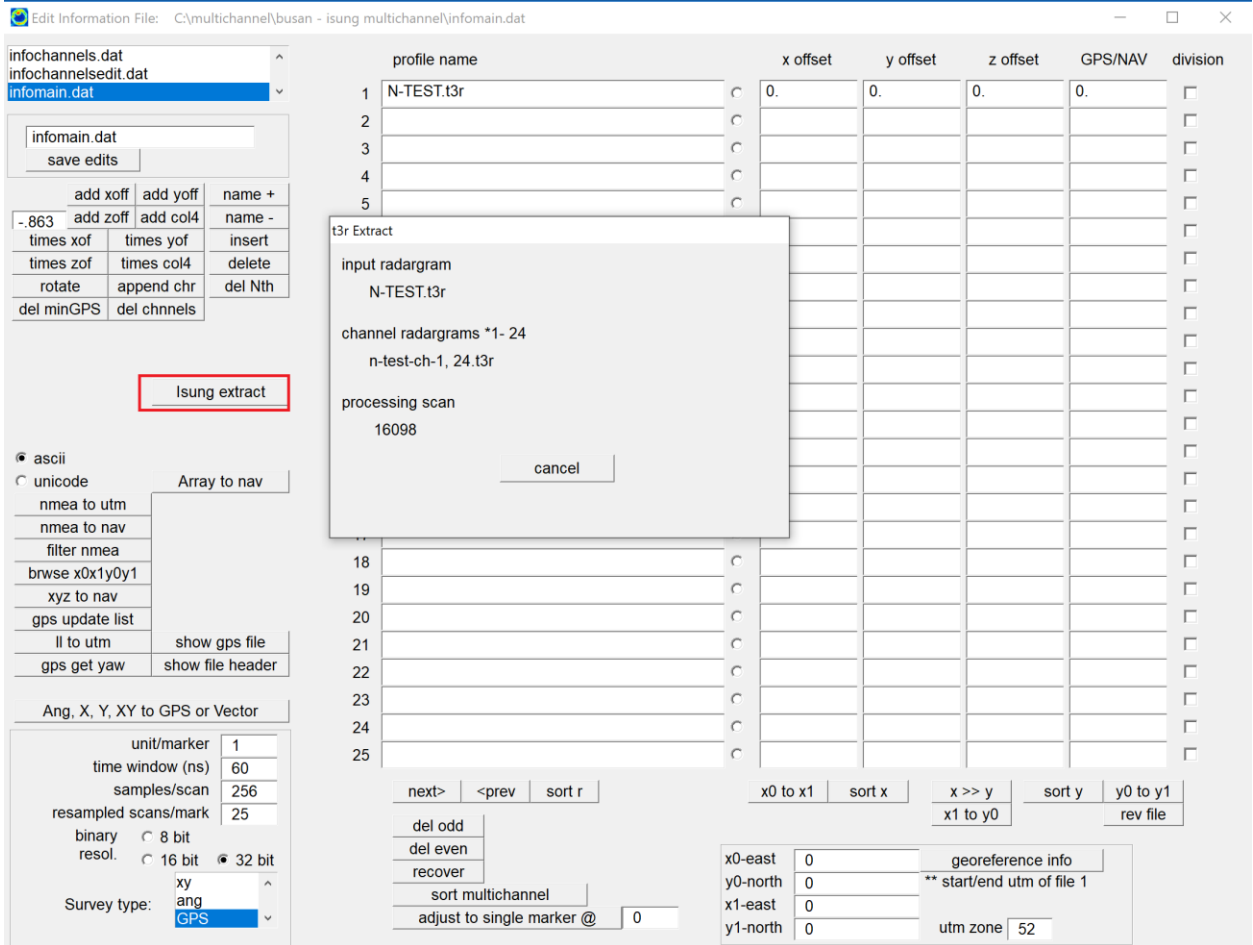
3) Create the navigation using the XYZ to NAV button with the all the settings shown in the menu.   This reads the *.csv file containing all the information on the GPS navigation and will convert to GPR-SLICE format and make all the UTM conversions.

4) The next step is to generate the individual channel navigation using the Array to Nav button which reads all the offsets for each channel and computes the navigation.

5) The next operation is to convert the raw radargrams in the Conversion menu. No range gain is applied yet as time 0 corrections need to be done first. However, one needs to apply a constant gain. The user should experiment with different gain values till the initial ground wave pulse appears and is not clipped. This particularly data requires a constant gain of about 50000 to be applied. After this gain is applied the user can begin data processing by clicking the Batch Gain button or the Batch Gain-Wobble button should they want to remove low frequency noise if it exists.
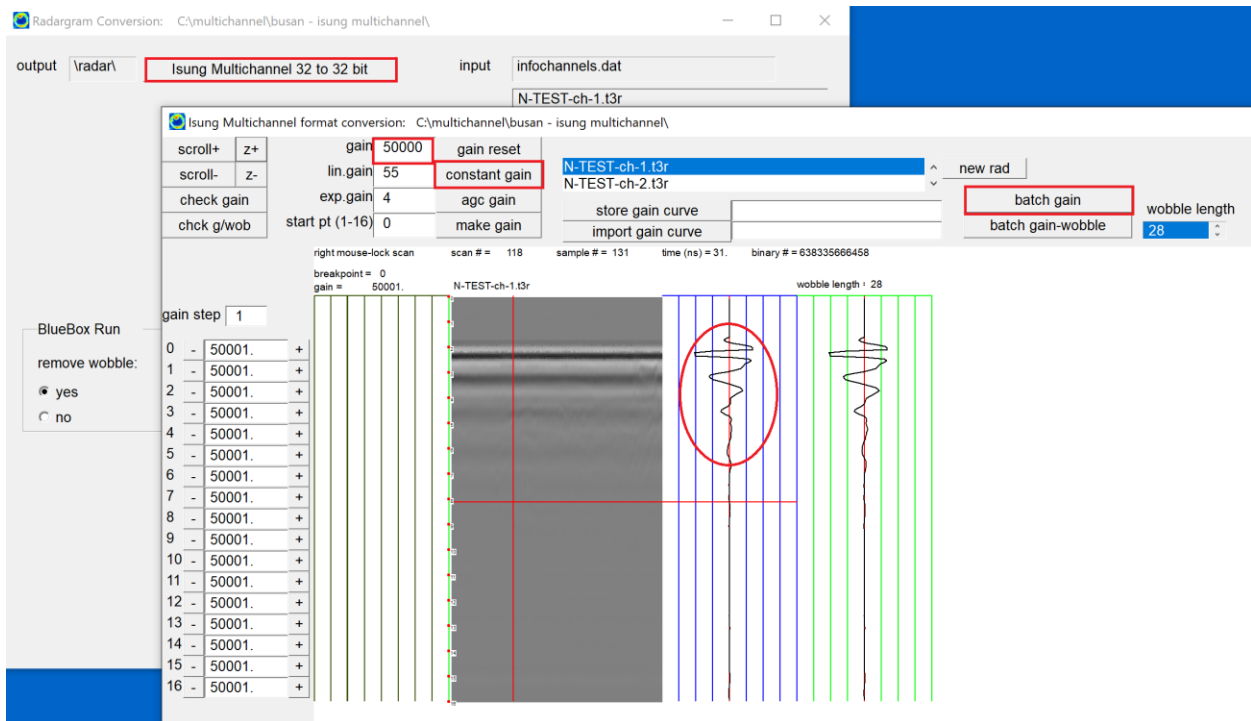
6) After conversion, the next step is to run the GPS vector trace# navigation in the Marker menu. After this operation some standard processing operations can be run, as detailed in the next section for all multichannel radar systems.
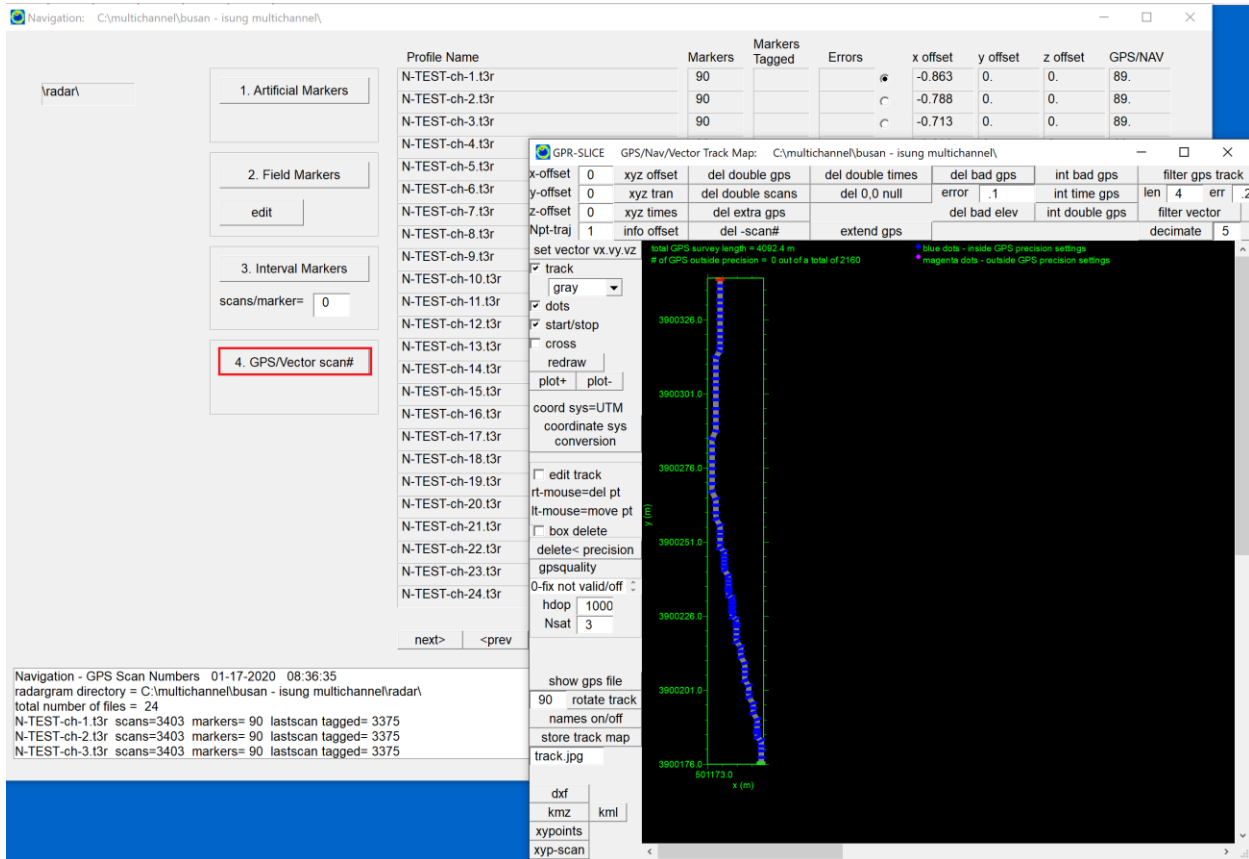
After Navigation the user can run BlueBox operations or continue to do processing manual as shown in the next section for all multichannel manufacturers.

Processing Operations for all Multi-Channel GPR Systems

The multi-channel data all require several radargram signal processes normally to get the best images. The user will want to apply standard signal processing such as scenarios. The most commonly recommend filters are:

- 0ns radargram editing
- Spectra+Gain
- Bandpass filtering
- Background removal
- Migration (as an optional filter)
- Hilbert transform (as an option)
- 3D radargram volume generation
- Interpolate empty voxel cells in 3D volume

The first 4 processes should always be implemented on the multichannel dataset as recommended. A new Spectral + Gain menu can also combine bandpass with real time gaining

0ns Radargram Editing

The 0ns editing is a critical step. The user should experiment and view the 0ns edited radargrams of the extracted channels to make sure their settings for the 0ns triggering and detection look reasonably good. In this example above, a threshold of .2 on the peak response is set. If there is digital noise before the ground wave, the a few samples can be skipped on the radargram pulse to start the detection. In the example this value is currently set to 0 which means that detection will start on the top of the pulse at sample 1. The digital noise before the ground wave may vary from dataset or manufacturer to manufacturer. The triggering can also be brought back a few samples if desired using the backup N samples option in the menu to give a better estimate of the first recorded ground wave pulse. The settings for any particular dataset may need to be adjusted for the best results.   There are several methods to detect the ground wave:

Method 1 – calculates a moving average on the pulse and the next sample value is N threshold higher then a the detection is made.

Method 2 – finds the first peak pulse above the threshold. If one wants to define the rise before or after the first peak, then the N backup should be set to an appropriate value.

Method 3 – finds the first zero crossing after the peak response is detected.

   After the 0ns editing is done, a new information file, infochannelsedit.dat is automatically generated which will have the new samples/scan of the 0ns edited radargrams which are written to the \edit\ folder of the project. After completing the 0ns editing process, the user needs to go back to the Edit Info File menu and click on the **infochannelsedit.dat** file as the active information file**.** A new option exists for the radargrams to be resampled to their original digitization as well.

Spectra+Gain

The first step after radargram editing is to regain the individual channel radargrams by first entering the Spectra+Gain menu. IDS Stream and Mala Mira will normally have been collected as 16 bit ungained radargrams, so post processing gain is always required. 3D Radar Geoscope may have had gain applied depending if the data were pre-processed or not. GSSI Terravision is recorded with gain in the field. However, sometimes these data are not characteristically gained very well since the GPR systems here only have a limited number of gain points to generated gain during the recording. Normally, this data will need some slight adjustments, particularly below the ground wave to make better gaining on the data.

In the Spectra+Gain menu the first operation the user will do is click the AGC Gain button. After this they will then set the lo-cut and hi-cut bandpass

thresholds using the left and right mouse button on the power spectra plot. They will need to experiment what a good bandpass setting is needed for any given data. (This data in the example required a very narrow bandpass to throw away a lot of the low end noise. Typical data may not need such a drastic-narrow bandpass filtering). After they set the lo-cut and hi-cut thresholds, then clicking the Help Set button will design the bandpass curve to match the half power points of the desired bandpass settings.

Bandpass

Once the Spectra+Gain are set the user will then run the Bandpass operation in the Filter menu. The operation will run and batch and the user can view the original ungained radargram with the bandpass and simultaneous gain application during the processing. To save time the Processing Graphics checkbox in the Filter menu can be shut off to stop the graphic display…This checkbox can also be turned on at anytime to start/stop graphic previews during and run operation.
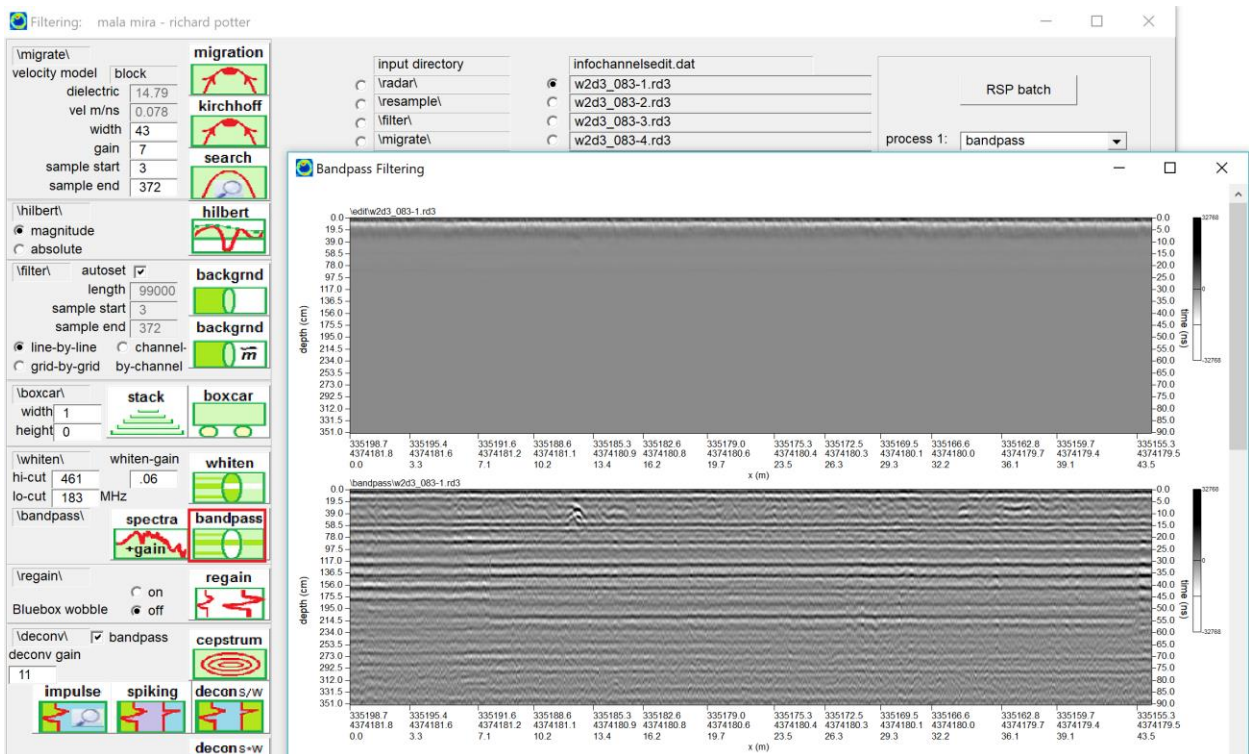
Background Filtering

    Background filtering is usually necessary for multi-channel systems to better balance the channels and to remove banding noises. The background filtering process is run on the \bandpass\ folder. Note, a long filter length – greater than the total length of the radargram – should normally be set here to insure that average scan removal across the entire radargram is calculated.   With autoset engaged in the Filter menu (see the screen shot in the following diagram) for background filtering, an artificially high number of scans will be used to calculate the average scan across the entire radargram.

    For multichannel processing, the average scan across the each individual radargram, or across all the individual channels in the whole project can be computed. Radio button options for setting the desired background calculation: line-by-line, or channel-by-channel can be defined.   (Grid-by-grid is usually used for single channel surveys and computes the average scan across the whole grid. This operation is not recommended for multichannel datasets. Channel-by-channel background filtering may have advantages in preserving linear features.)
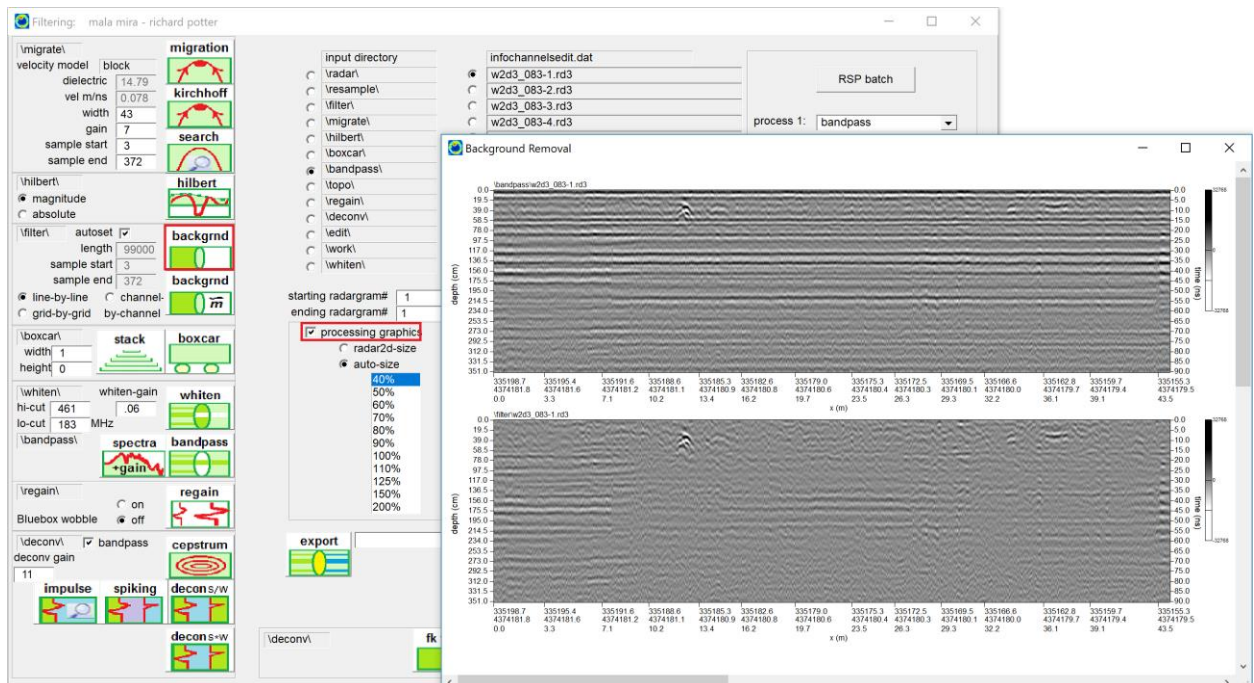
3D Radargram Volume Generation

After all the RSP including regaining, spectral whitening, and background filtering are completed and if migration and Hilbert transforms are used, 3D Radargram Volume Generation can commence. In this example the grid X,Y cells is set so that the effective grid cell size is slightly larger than the crossline separation of the antennas. Because of this, the initial 3D volume that is created will not have any gaps in the volume (unless the density of the radar pulses on the ground in the in-line direction). The menu wants the user to also set the total number of grid cells in Z direction. The full radargram pulse or some decimated sampling of the pulse can be used to generate the 3D volume.

The XY grid cells are normally set to closely match the cross line separation of the antennas in the multichannel system or slightly larger. However, cells sizes which are even smaller than the antenna separation can be used. In this instance, when the volume is initially made, there can be cells with no information written. A button called Interpolate GAP can be used in the menu to quickly interpolate nearest neighbors using an inverse distance algorithm at these cells to fill in the gap. A value of x search cells=1, y search cells=1 setting for interpolating the gap will look out 1 cell in each x and y directions to take an average of all cells found nearby with data. Values higher than one in either search direction can also be used in filling the gaps, particularly if grid cells smaller than the cross line separation is desired. The interpolated volume will have an append identifier of "int" automatically placed onto the new 3D volume name. There is also a button to smooth the compile 3D volume using a new 3x3x1 volume filter provided in the menu which will automatically add a "l" appended identifier onto the smoothed volume.

Optionally, the user can set the focus checkbox option on and generate a 3D volume with just a portion of the total area and depth of the volume. Often, if deeper data is noisy or the signal strength is attenuated, the sample end can be set to a value much shallower in depth. This can also help to make the 3D volume size more manageable if a good graphics card with a lot of memory is not available. In this example only 100 grid cells in Z are desired – which corresponds to about every 2nd sample of the digitized radar pulse which is 235 samples long after editing. The number

of Z grid cells can be set to the exact sample length as well – generating a volume that is exactly the total resolution of the recorded pulse. Heavy volumes though, may sometimes have limits in Open GL if a good hi-memory graphics card is not be used.
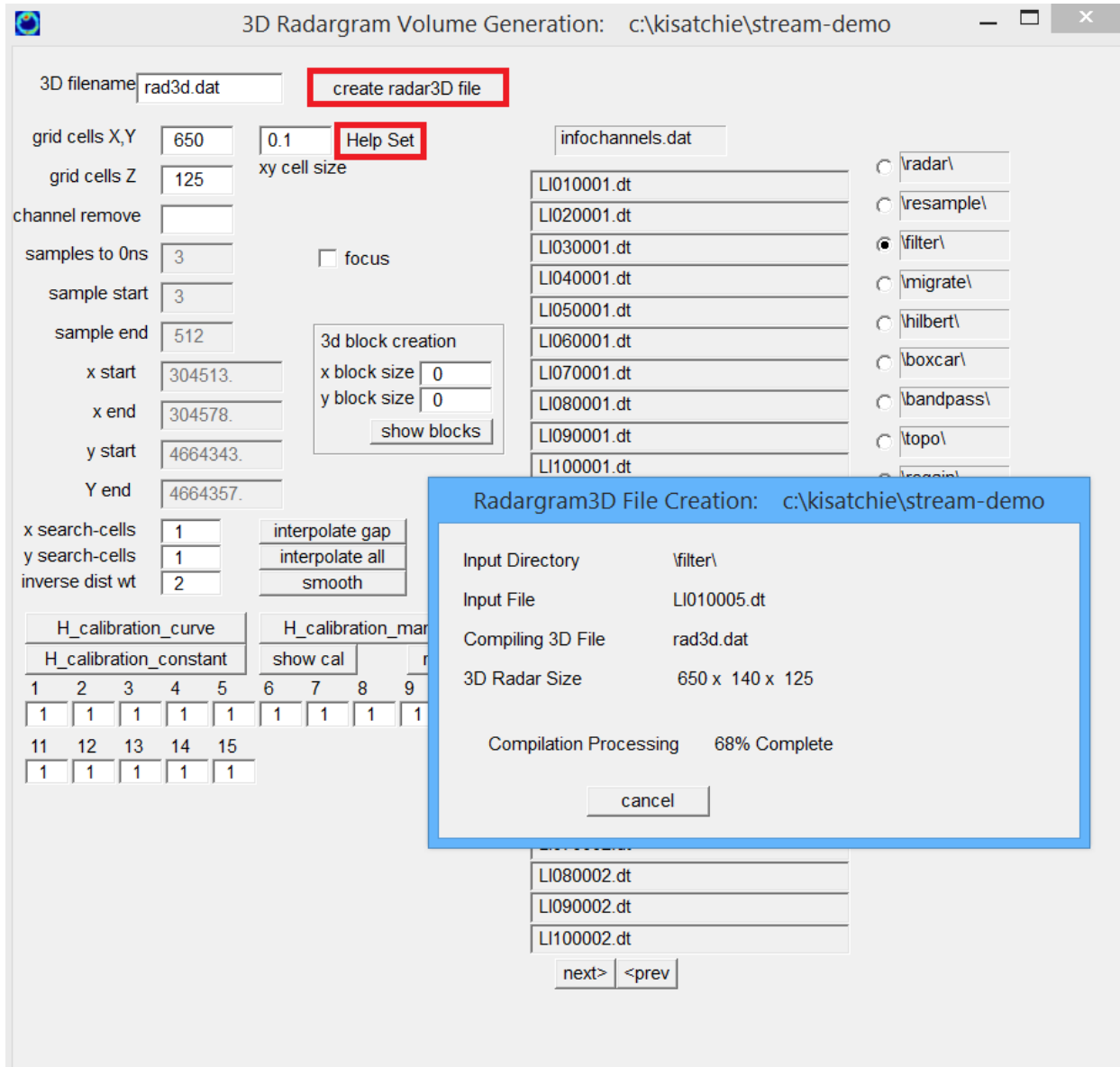
Interpolate Gap

The compilation of the 3D volume can also generate volume with a lot of missing cells. This can happen if the crossline spacing of the antennas in the array are larger than the grid cell size. However, it can also happen if the density of recording along the array track is less dense then the grid cell size in XY. An example of a volume that can be generated if some cells are empty is shown below. This is examined in the Open GL Volume – Texture Method menu. In regular Open GL menu the look can be different. The reason being is that the blending between cells with data is handled slightly different. For example, if a volume were generated with no location in the volume where adjacent cells had data, Open GL Volume might show the entire volume as blank – whereas Open GL Volume – Texture Method may show some of the cells that were filled.

In any event, the data at the desired cell density needs to be interpolated to fill the gap. An inverse distance algorithm is used to only examine empty cells and to interpolate into that cell using the surrounding cells. A search search size of 1 cell in x and y instructs the operation to look out 1 cell in each direction from the empty cell to locate cells with data. Only 1 additional cell needs to be detected for the empty cell to get filled.
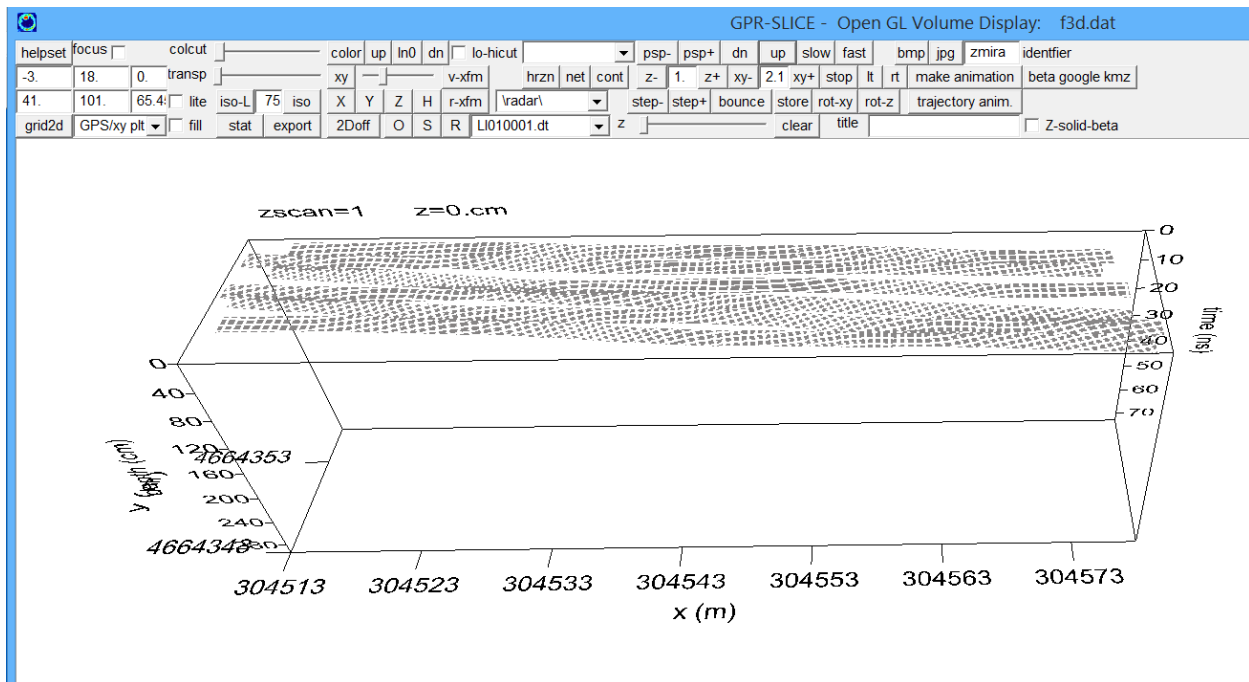
To fill in the gaps in the 3D volume, the Interpolate Gap operation is run. In this example, the x and y search-cells is set 1. The searching looks an equal distance in all directions to fine nearby cells that have data for the inverse distance interpolation. (Optionally, a button called Interpolate All can be used to recalculate all grid cells using nearest neighbor search and inverse distance). The inverse distance weighting exponent (same as in the Grid menu) can be set prior to interpolation. Lower exponents – e.g. 1 will give nearly equal weighting to all cells included whereas 2 or higher will weigh the closest cells higher.
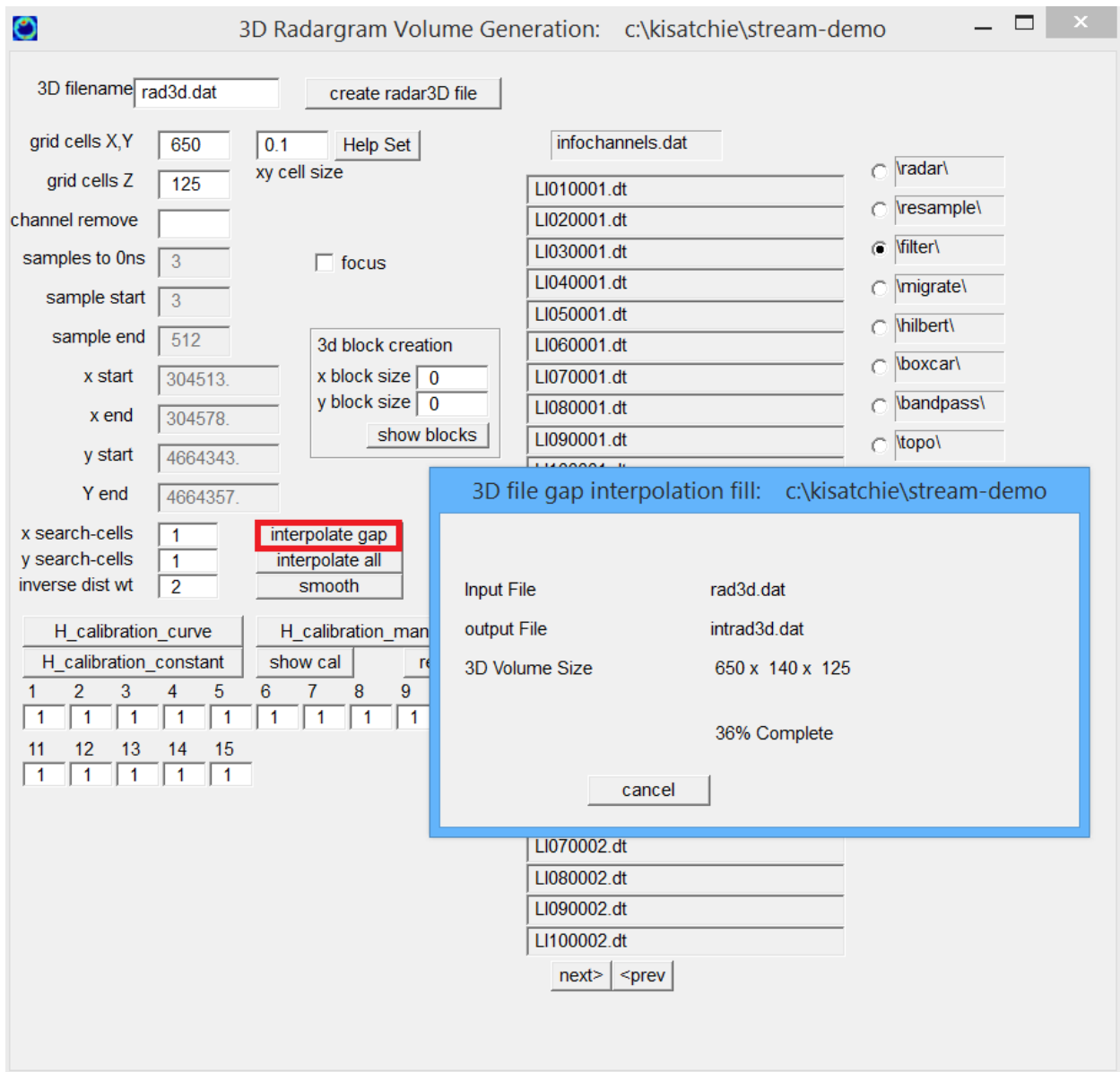
The hardwired identifier "int" gets appended onto the new interpolated 3D filename. This new filename must be selected in the Open GL Volume select 3D volume menu, as it is not automatically set to be the 3D volume for viewing.

An example of the previous dataset with interpolation is shown in the next figure:
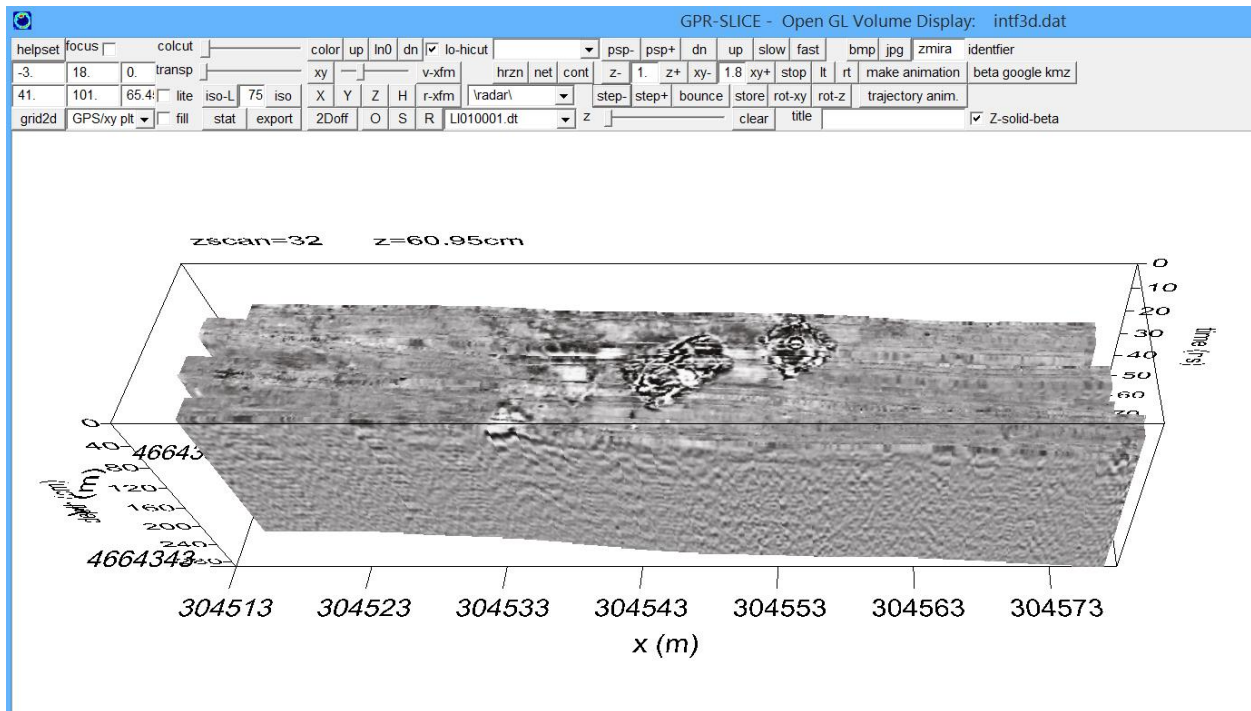
3D Volume Smoothing

The Grid menu in GPR-SLICE has had volume smoothing operations since 2008. All of these filters were originally made to smooth out the volume following a 3x3x3 or 5x5x5 or 9x9x9 or 17x17x17 size. These smoothing operations also contained the z grid cells. However, with the new hi-density multi-channel data, the smoothing in the Z direction is now not as necessary to make appealing volumes. 3x3x1, 5x5x1, 9x9x1 or 17x17x1 smoothing is now done on the volume at single z levels. (Note: It would be a mistake to do smoothing on a high density pulse volume including other z levels, since the data would tend to 0 as the interpolation radius increased in this

direction. A Hilbert transformed volume on the other hand would not tend to 0 since this is a completely rectified volume).

Single plane smoothing operations can be accessed directly in the Grid menu.   For a convenience the more common 3x3x1 filter can be expedited in the 3D Radargram Volume Generation menu as shown in the next menu screen shot.   The letter "l" is appended onto the input 3D filename.
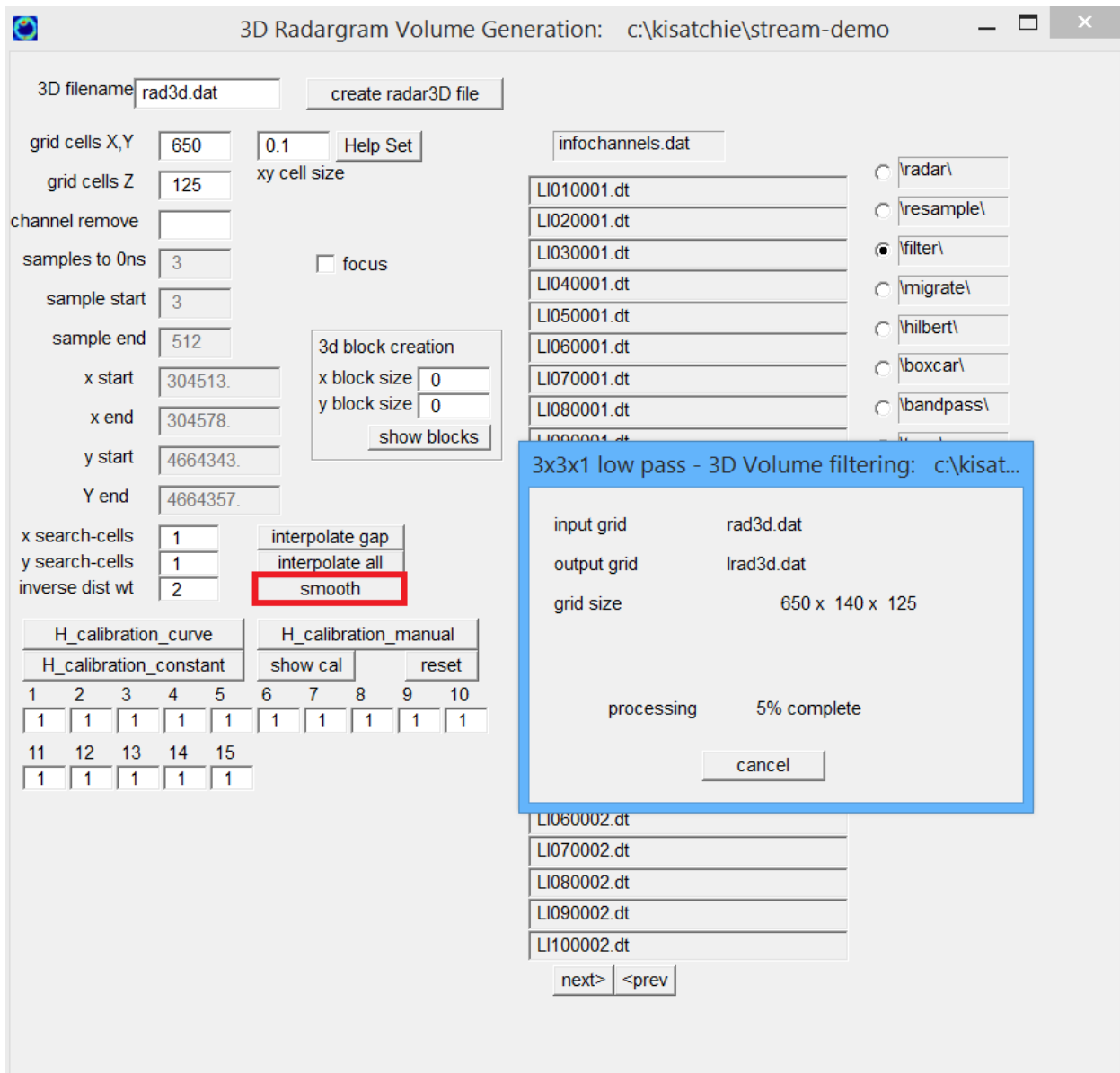
Multichannel Calibration Gain Curves

Multichannel systems that are being manufactured can suffer from channel imbalances. Even identically manufactured antenna that appears to be identical can have varying gain and frequency responses as well as differences in directional responses. In an attempt to improve the gain balancing between multichannel systems, a new H-Calibration Curve operation is available in the 3D Radargram Volume Generation menu. The calibration gain curves should normally be generated from Hilbert transformed radargrams. This allows for the easiest gain comparison between the different channels. The calibration curves are normalized between the strongest channel at each sample in the digitized radar scan. An example of a 7 channel multichannel system and the calibration gain curves calculated between all the channels is shown in next figure. For this equipment it can be seen that channel 1 appears to be the strongest channel except at the top portions of the radar scan, where channel 3 is the strongest. In the generation of the 3D radargram volume, these gain curves will be applied to the corresponding channel during compilation. Should the user want to shut off using the calibration gain curves there is a Reset button which will set all the gain curves to 1 across the scan. A button called H-Calibration Manual allows the user to manually set variable constant gains across the gain curves and this will read the single channel slots in the menu to insert these values.
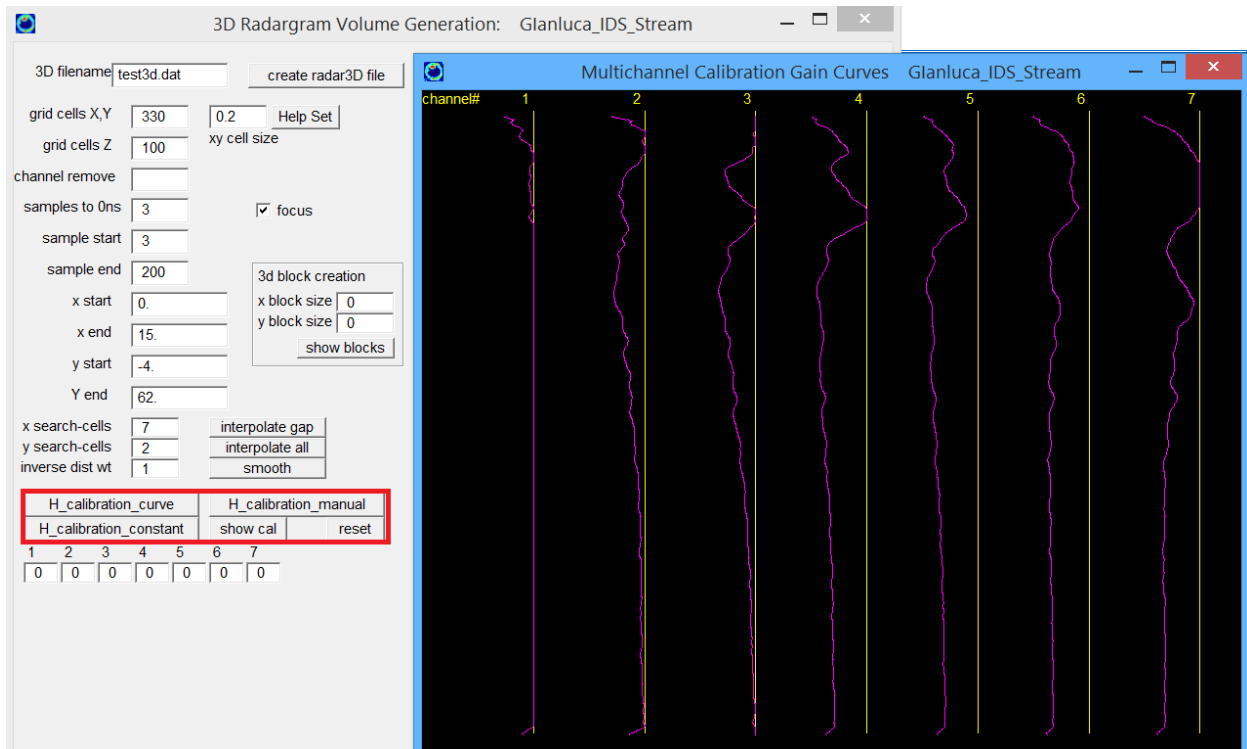
Examples of Multi-Channel Imaging

Examples of 3 manufacturers, the IDS Stream, Mala Mira, and the 3D Radar Geoscope and images generated from these multichannel systems are shown in Figures 2-4. The quality and resolution seen with the new capabilities in GPR-SLICE without slice/resample and gridding menu is now showing the true capabilities from these state-of-the-art multichannel systems. The manufacturers have solved a lot of engineering issues in the last 18 months which have significantly enhanced the balancing of individual antenna elements which has also greatly improved the image quality.

A recent survey done for a 1.5 hectare section of the Carnuntum site in Austria with 1232 radargrams was compiled to a 3D volume in just 75 seconds - after which viewing in Open GL Volume Texture Method menu could be easily accessed!

Here is a GPR-SLICE image of the data collected at Dr. Salvatore Piro's CNR Workshop ITABC in Rome made from the IDS Stream 15 channel/12 cm configured GPR system:
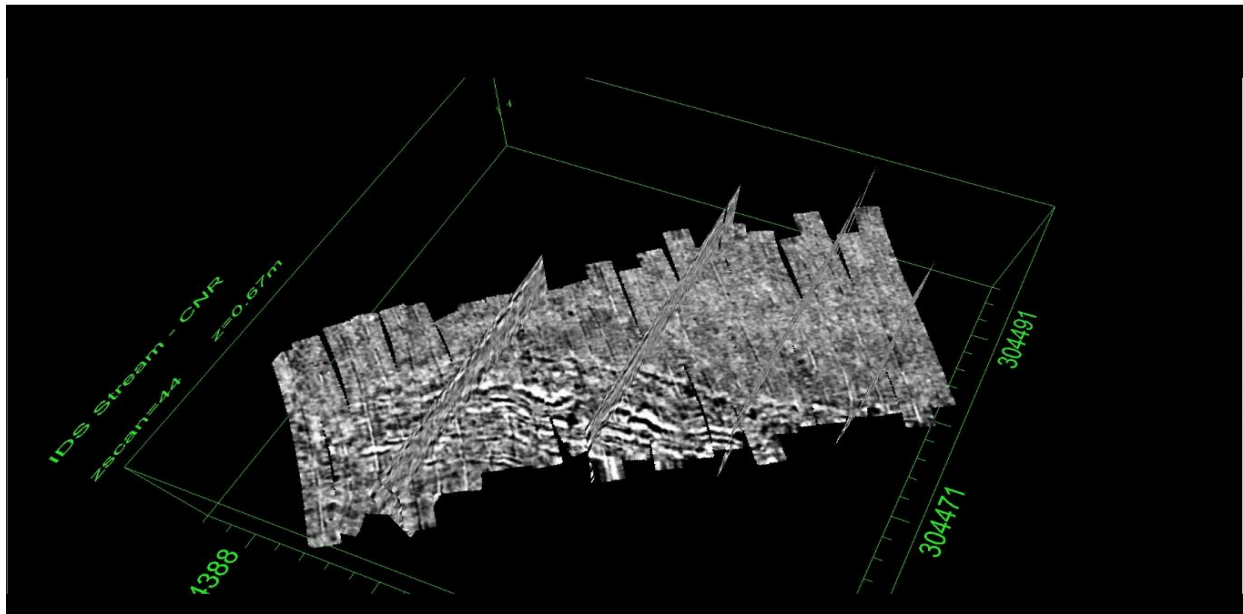
(Data courtesy Gianfranco Morelli of Geostudi Astier, Italy, www.geostudiastier.com)

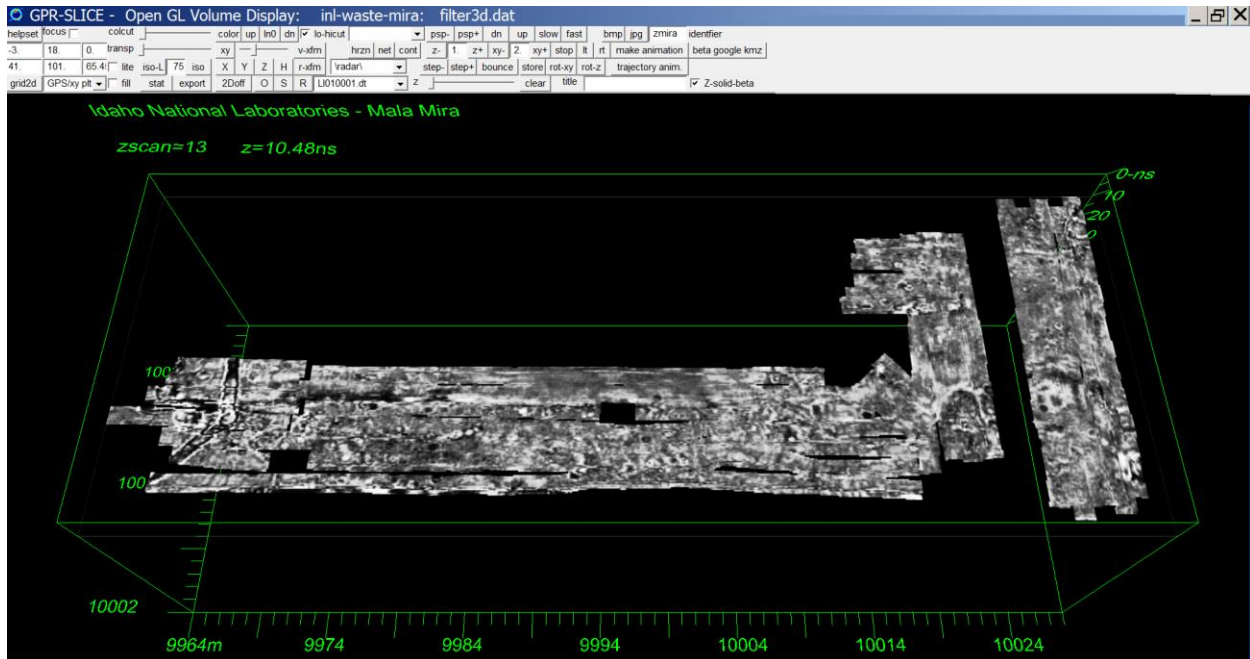A GPR-SLICE image was generated from data collected at Idaho National Laboratories using the Mala Mira multichannel GPR system. This equipment was used in a 16channel/8cm antenna separation configuration:

(Data is courtesy of Shawn Williams, Idaho National Laboratories.)

A GPR-SLICE image made from data collected at an archaeological site in Norway and using the 3D Radar Geoscope multichannel system is shown in the next screen shot. The equipment was configured in a 31 channel configuration with 5 cm separation between antenna. The image shown used only half the channels with similar frequency responses.   (The data was collected by Kevin Barton of Landscape and Geophysical Services in Ireland and courtesy of 3D Radar Norway).
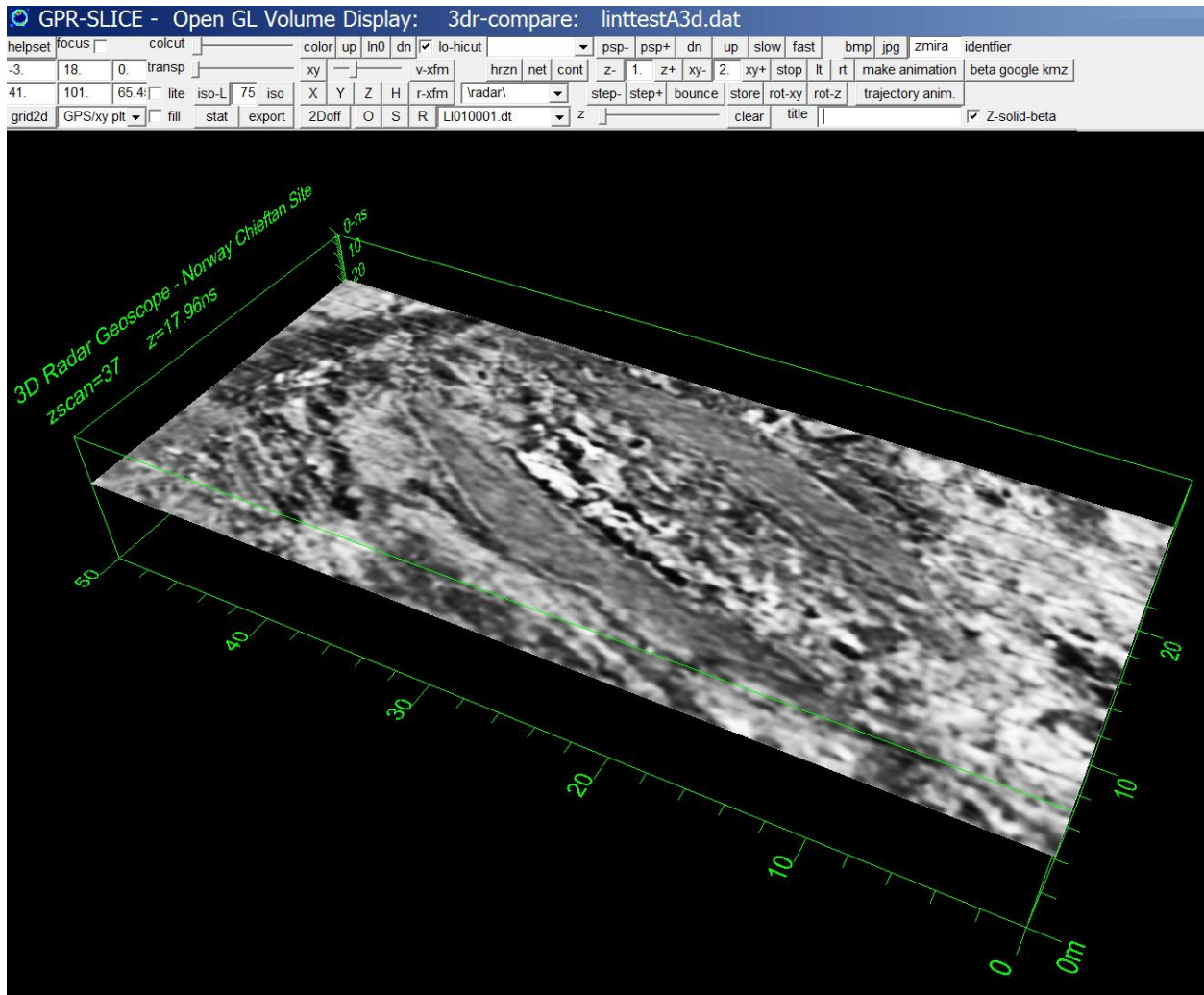
3D Transform Setting in Open GL

With the new 3D Radargram Volume Generation menu, it will be more common to also generate volumes of the processed pulses. For this reason, it was useful for GPR-SLICE to have additional transforms to optimize the colorization of pulse 3D volumes. Bipolar transforms 1-4 are now included in the 3D and 2D transform controls (see next screenshot). The bipolar settings are necessary to adequately colorized both positive and negative parts of the radar pulses. The quick bipolar buttons create a series of gradual to steep transform changes across the zero of the +/- pulse data.

In addition, there is a flag to engage or disengage the lo-cut/hi-cut threshold settings for N standard deviation from the histogram mean. This checkbox can be set directly within the 3D Transform menu, or it can be engaged/disengaged directly in the Open GL Volume menus. Each time the transform menu is exited or the lo-cut/hi-cut threshold is checked on or off directly in the Open GL menu, the transformed data volume needs to be re-read into memory.
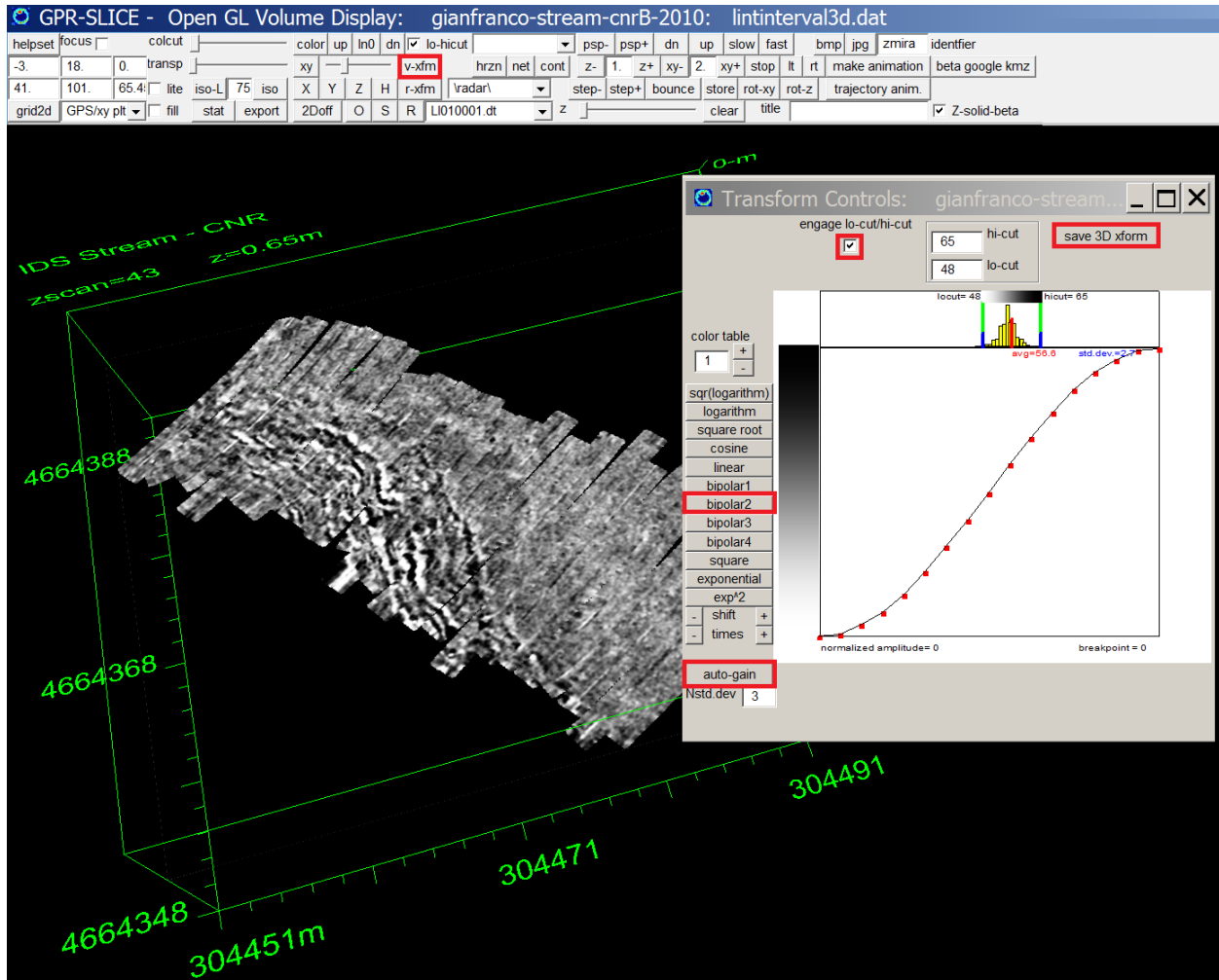
Multi-Channel BlueBox Batch Processing

Complete batch processing for all the multi-channel radar systems are available using BlueBox(c) Batch processing menu in the GPR-SLICE. The BlueBox – Customized RSP menu will handle the data processing from raw conversion all the way through signal processing and to compilation of a 3D volume. The BlueBox Batch runs can be launched with a single click of the mouse. The BlueBox Batch runs can include:

- o multichannel extract (for Mala, 3D Radar, Isung systems)
- o raw data conversion
- o navigation
- o 0ns radargram editing
- o Typical radargram signal processes are set in the Filter menu (see screen shot)
    - ▪ bandpass + simultaneous gain
    - ▪ background filtering
    - ▪ (Kirchoff migration – optional)
    - ▪ Hilbert transform,
- o radargram volume generation
- o >> Open GL

During the BlueBox Batch runs the user can prompt the software to show a menu to place in appropriate setting before batch operations are continued.   In particular, the Bandpass filtering + simultaneous gain the user can click the checkbox in front of bandpass to set a proper gain curve and lo-cut and hi-cut frequency thresholds during the batch operations.

A typical BlueBox menu detailing all the steps for complete automatic processing from start to finish for a project is shown below: