GPR-SLICE v7.MT Multichannel

Addendum Manual

(updated June 8, 2024)

Table of Contents

Introduction for Multi-Channel GPR Systems 3

Multi-Channel General Operations: 5

Proceq GS9000 6

Mala Mira 12

3D Radar Geoscope/Kontur – VOL format 17

3D Radar Geoscope/Kontur – SEGY format 24

IDS Stream X, C, UP and DP 27

Impulse Radar - Raptor 38

GSSI SIR 30 42

RPS Multichannel 45

ISUNG Multichannel 49

Processing Operations for all Multi-Channel GPR Systems 54

Multichannel Calibration Gain Curves 63

Examples of Multi-Channel Imaging 65

3D Transform Setting in Open GL 68

Gridblock Operations 69

Multi-Channel BlueBox Batch Processing 72

Introduction for Multi-Channel GPR Systems

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

Proceq
IDS
Mala
3D Radar
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.MT 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.

This addendum manual is provided since there are different set of operations required for each multichannel system. 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 place processed radargrams from into a 3D volume for viewing in Open GL. The user of multi-channel systems can still use the slice/resample and gridding menus if so desired.

The last section of this manual will introduce the BlueBox Batch runs for the multi-channel systems.

Multi-Channel General Operations:

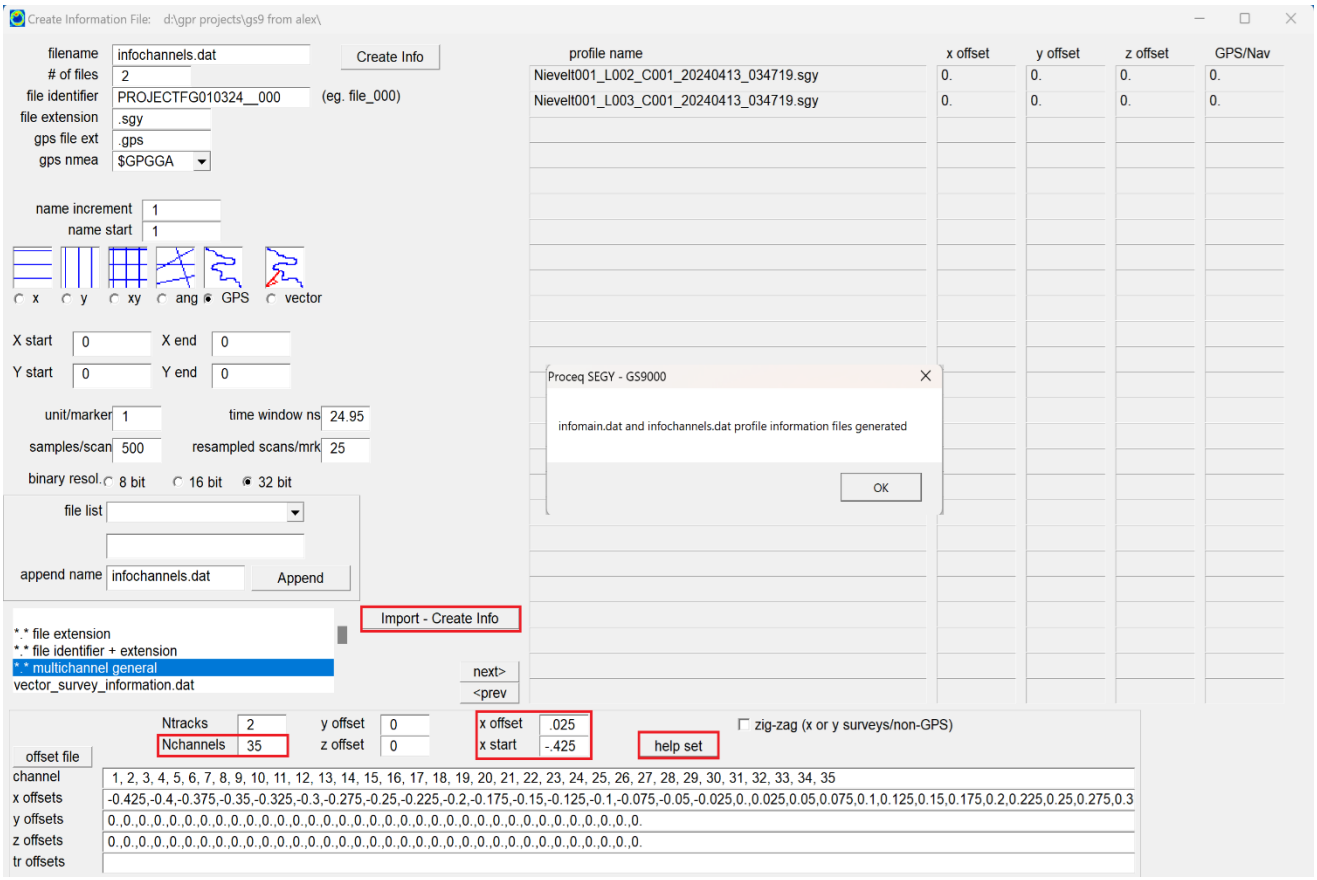
The generalized operational steps for all the multi-channel systems are:

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 background filtering, bandpass+gain, Kirchoff migration and Hilbert transform
8) Compile the desired processed folder into a 3D binary volume in the Radargram 3D Volume Generation menu. For super large sites block gridding operations are used to set individual blocks to a convenient size, e.g. 50x50m depending on the channel density and the ultimate xy volume resolution desired.
9) Display the data in Open GL or the Pixel 2D – multichannel menu, or for super large datasets using the Gridblock menus.

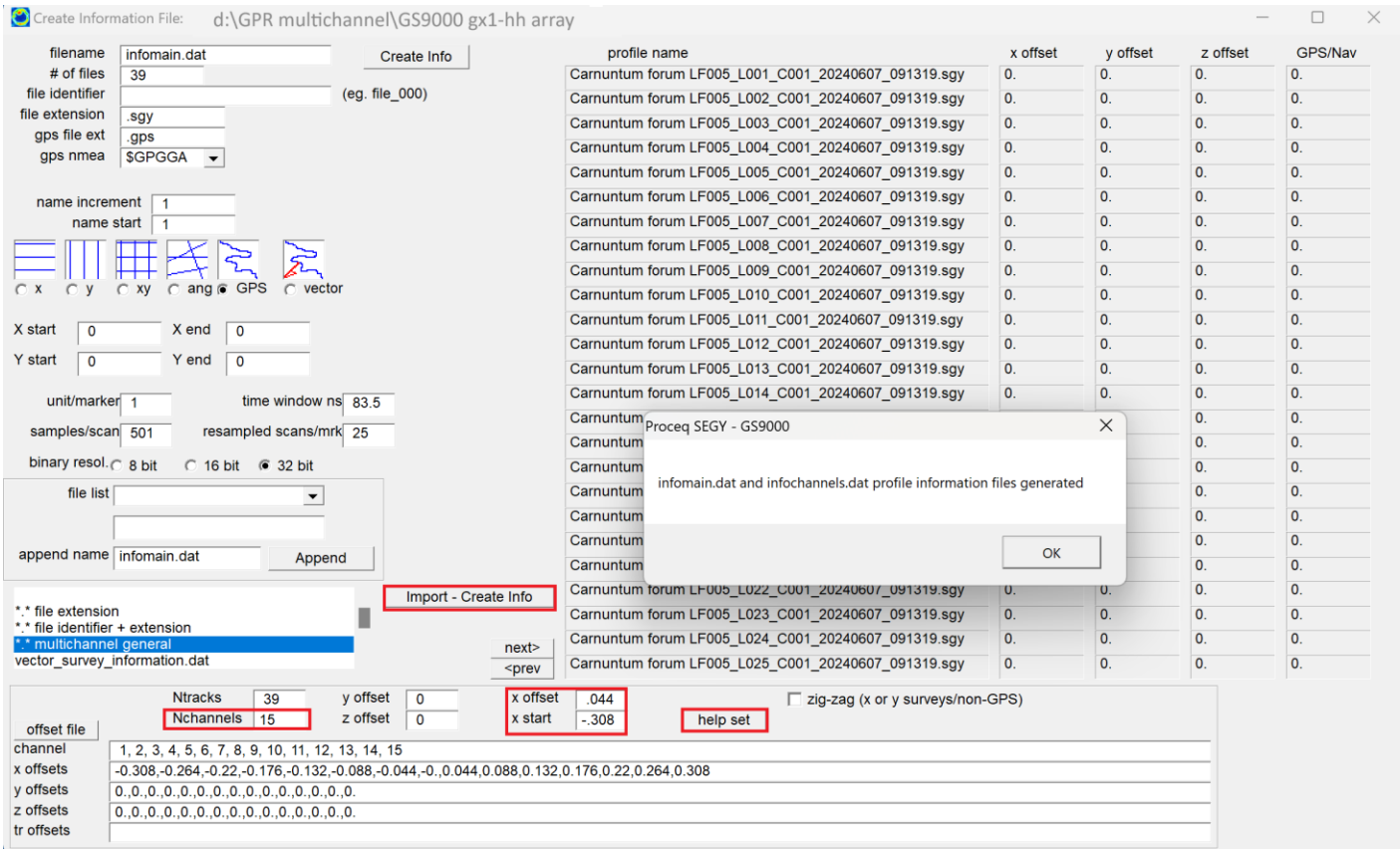
Proceq GS9000

The basic process for setting up the navigation for the Proceq GS9000 multichannel system for the GX1 vv and hh channels and the GX2 vv arrays are shown:

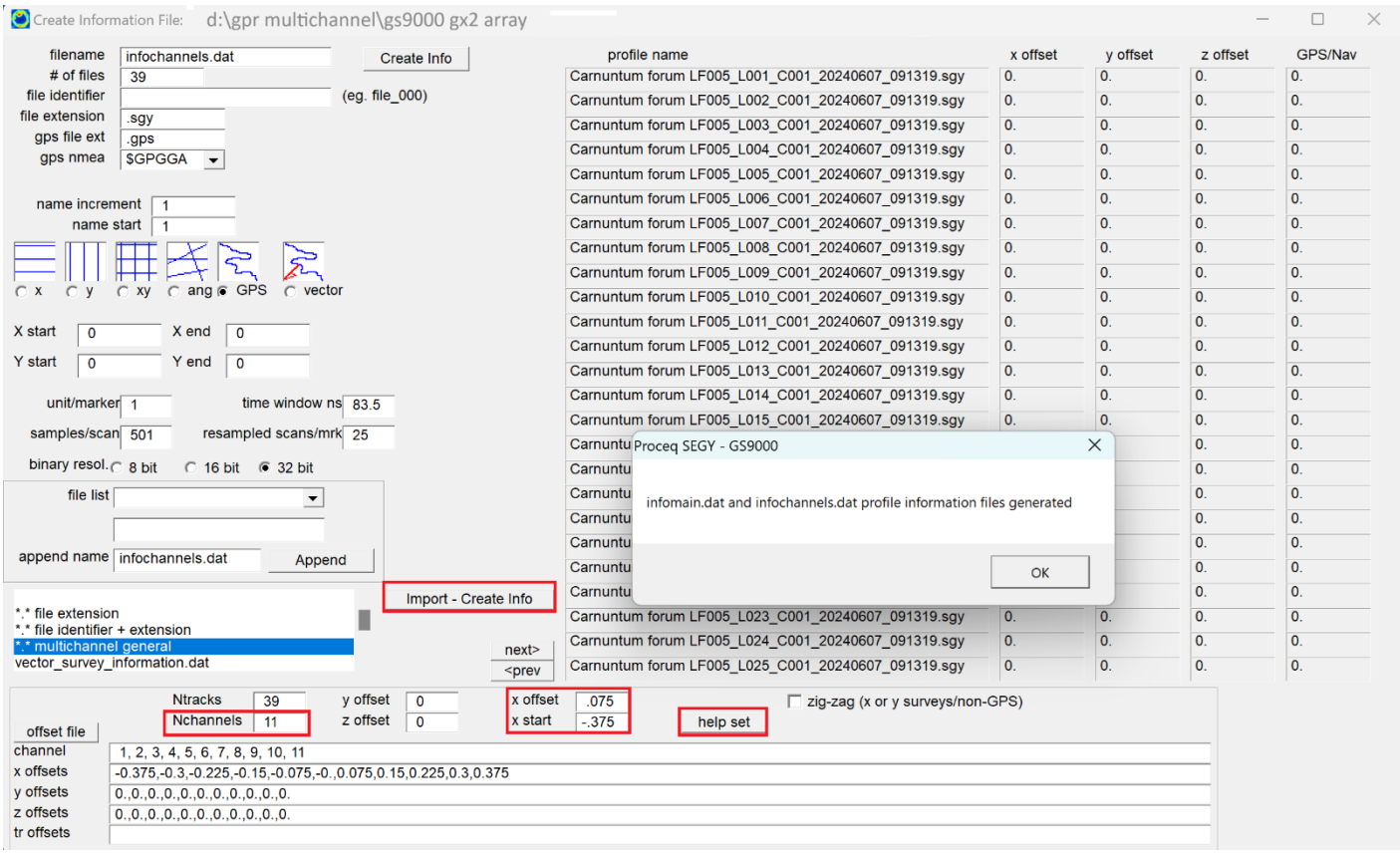
1a) GX1 vv Array – 35 channels at 0.025cm spacing. Set the number of channels and the x, y and z offsets for the array and click the Help Set button in the Create New Info menu. After that clicking the Import – Create Info button with the multichannel general highlighted in the listbox. This will automatically create 2 information files infomain.dat which has the names of the channel 1 main track radargrams and infochannels which will contain the names of the individual channel radargrams.



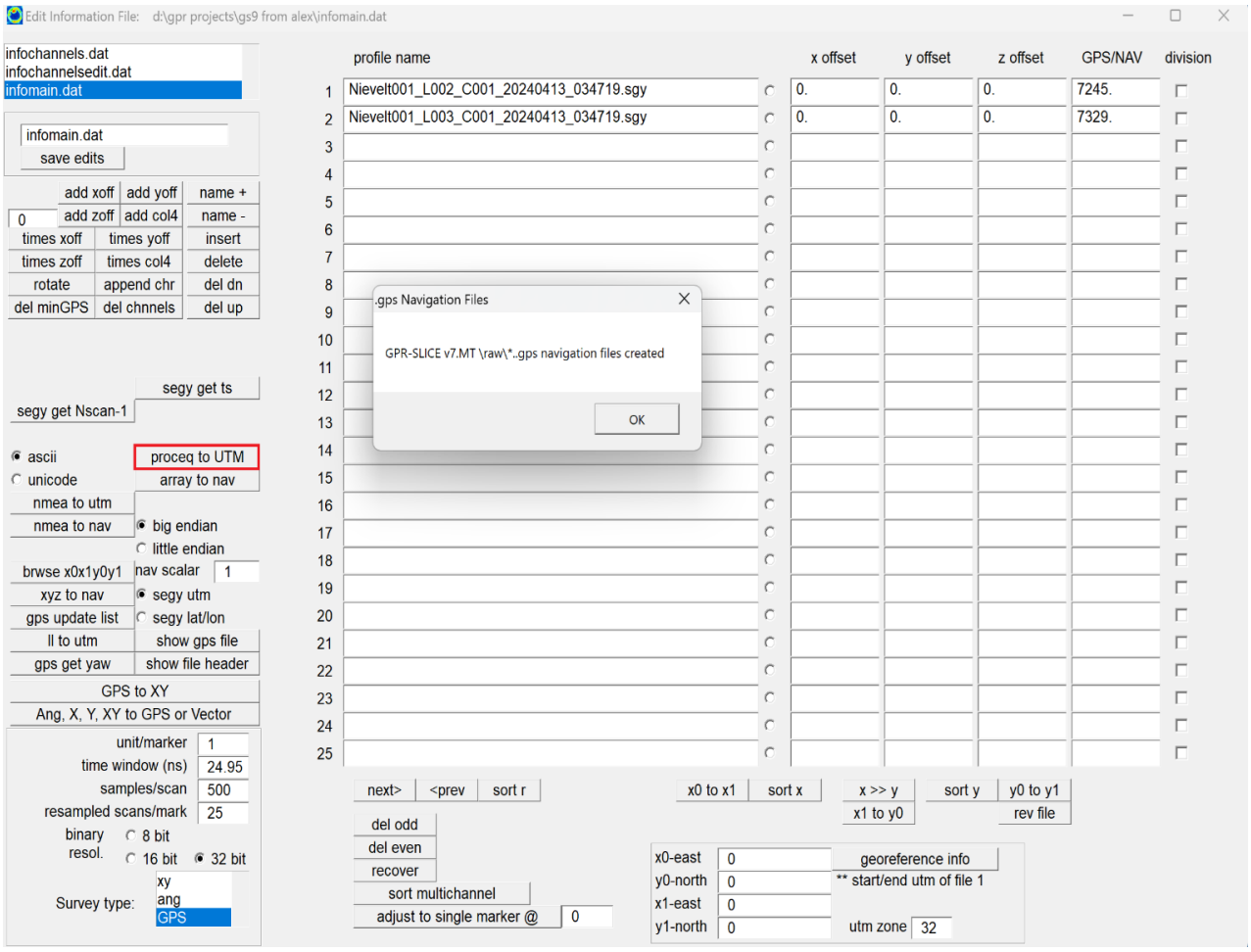
1b) GX2 hh array – 15 channels at 4.4cm separation



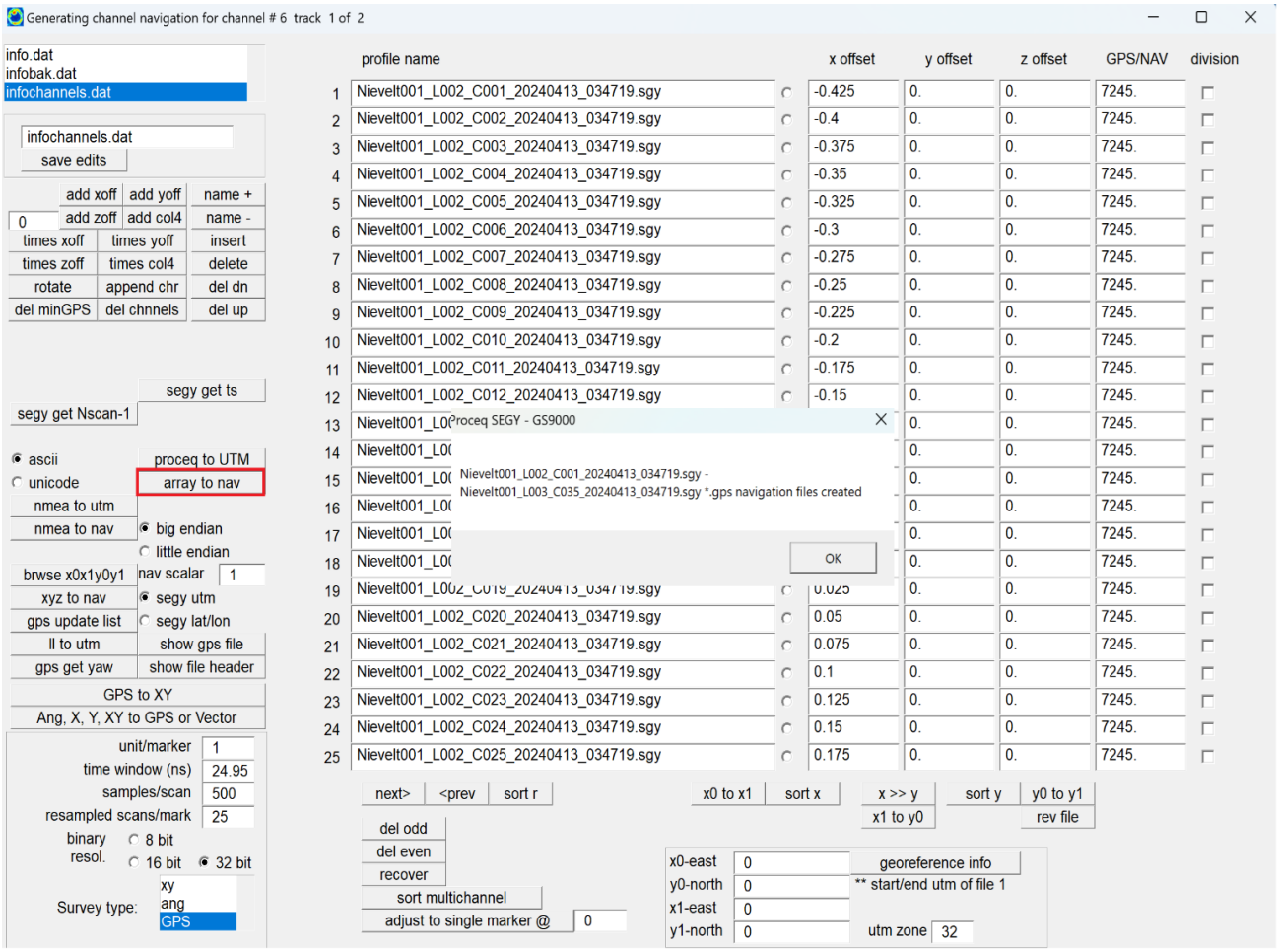
1c) GX2 vv array – 11 channels at 0.075cm spacing



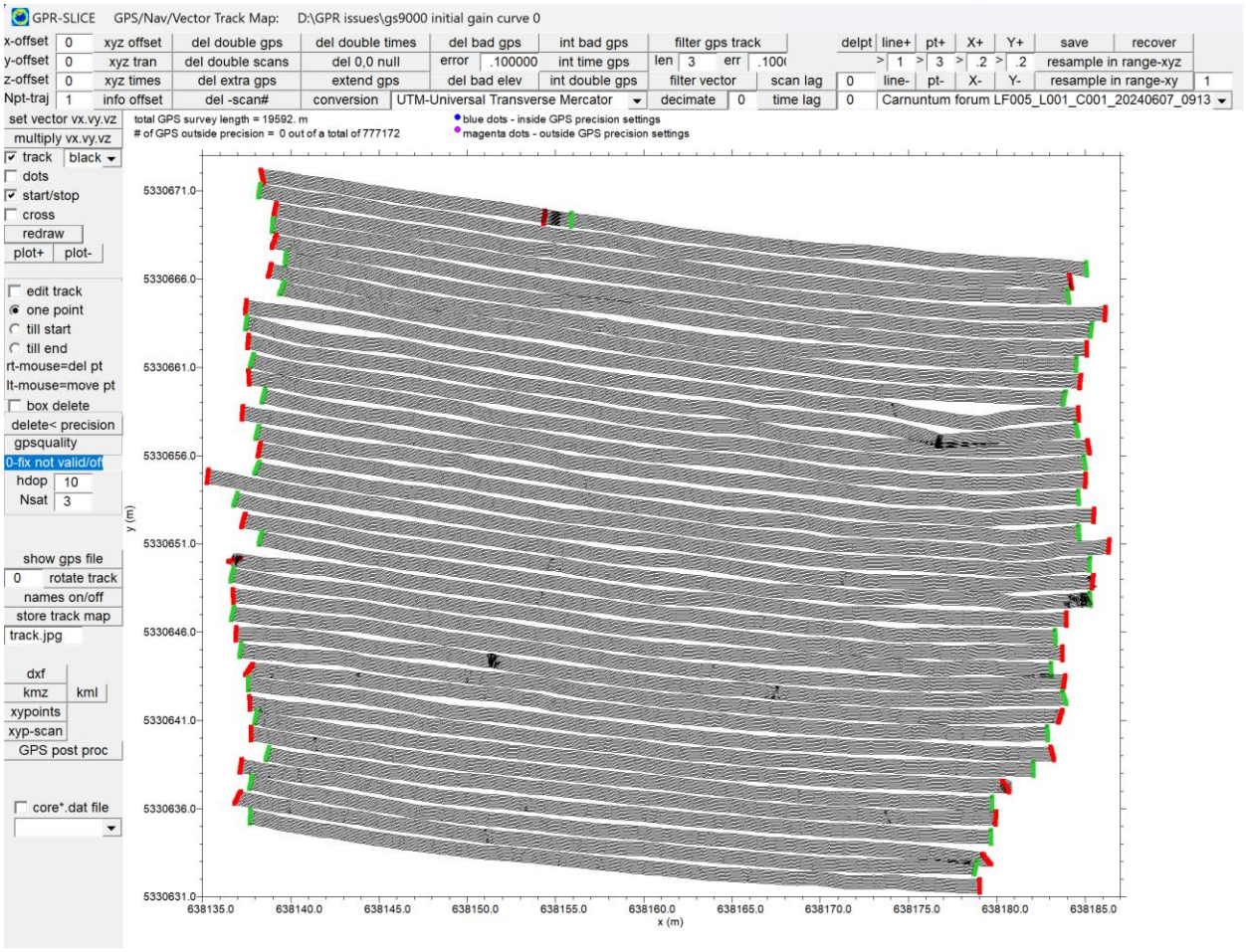
2) The next step is to generate the navigation with infomain.dat active in the Edit Info File menu. Clicking the Proceq to UTM will create the navigation for each swath.



3) Changing the information file to infochannels.dat and clicking the button Array to Nav will generate the individual channel navigation files based on the assigned X and Y offsets in the file.



An example of a GS9000 GX2 array GPS track is shown in the following figure:

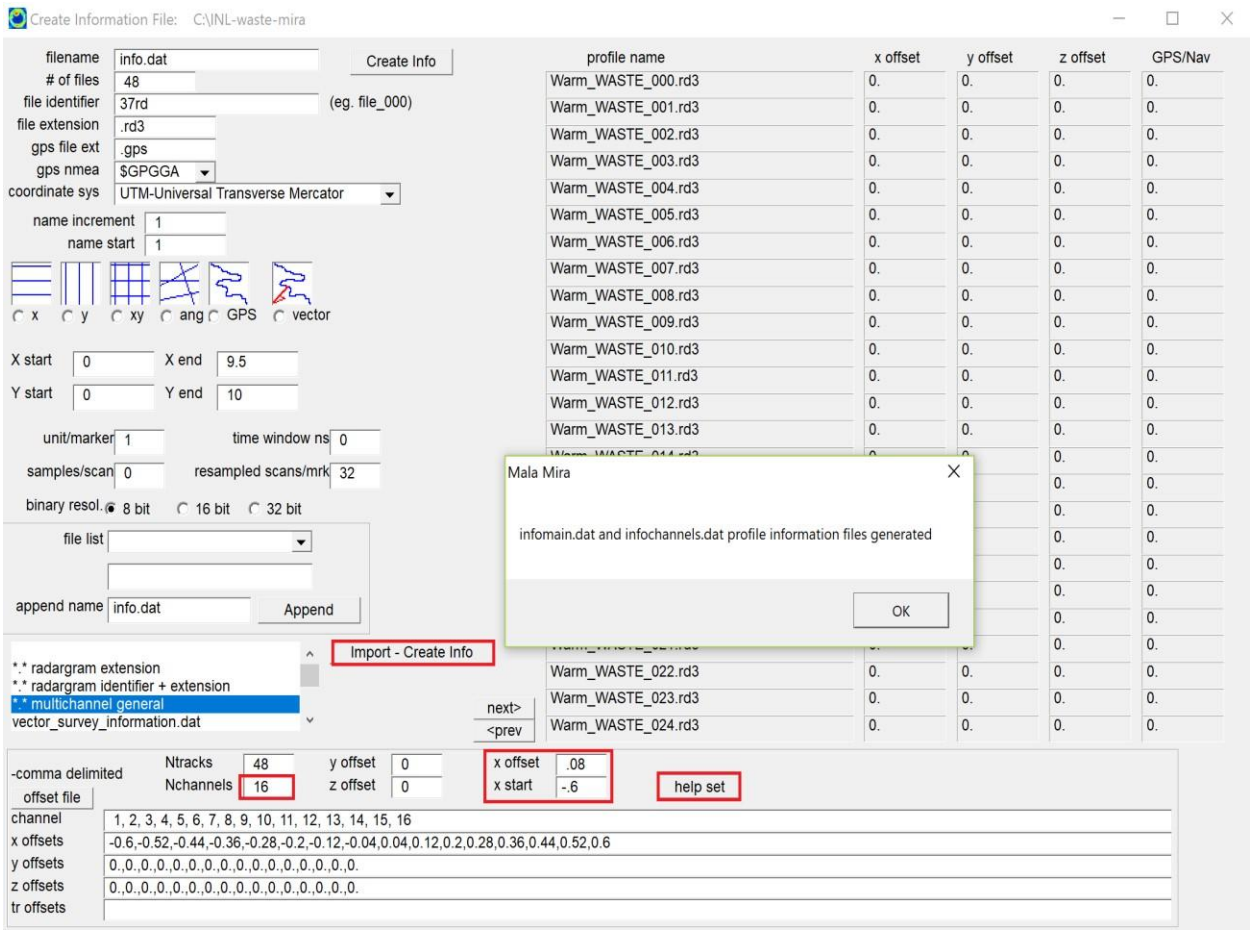


After these steps continue to the section entitled: **Processing Operations for all Multi-Channel GPR Systems.** This will show the steps for generalized signal processing for all multichannel GPR and how to compile these data to a 3D volume.

Mala Mira

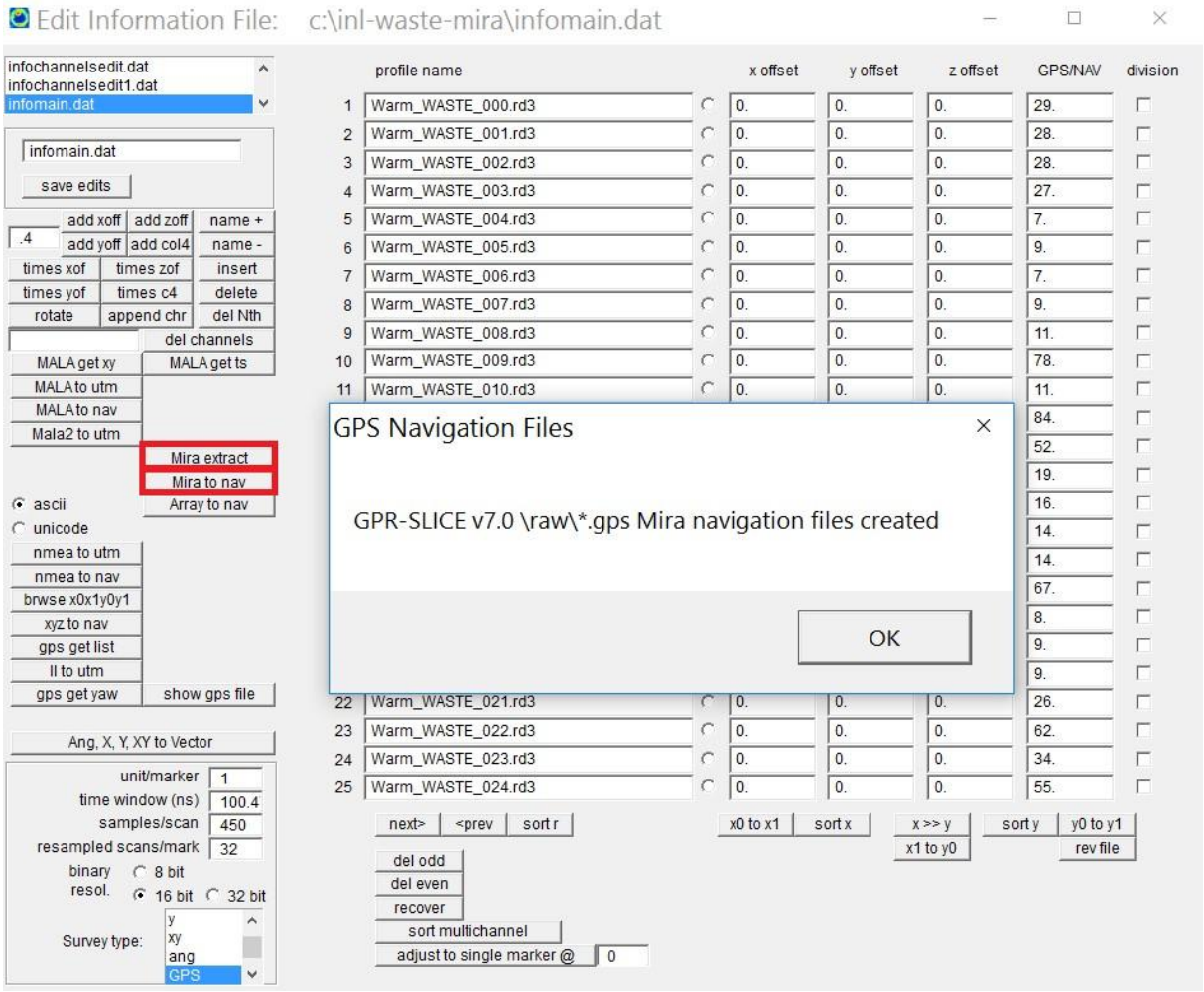
The basic processes for the Mala Mira multi-channel GPR systems are:

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.

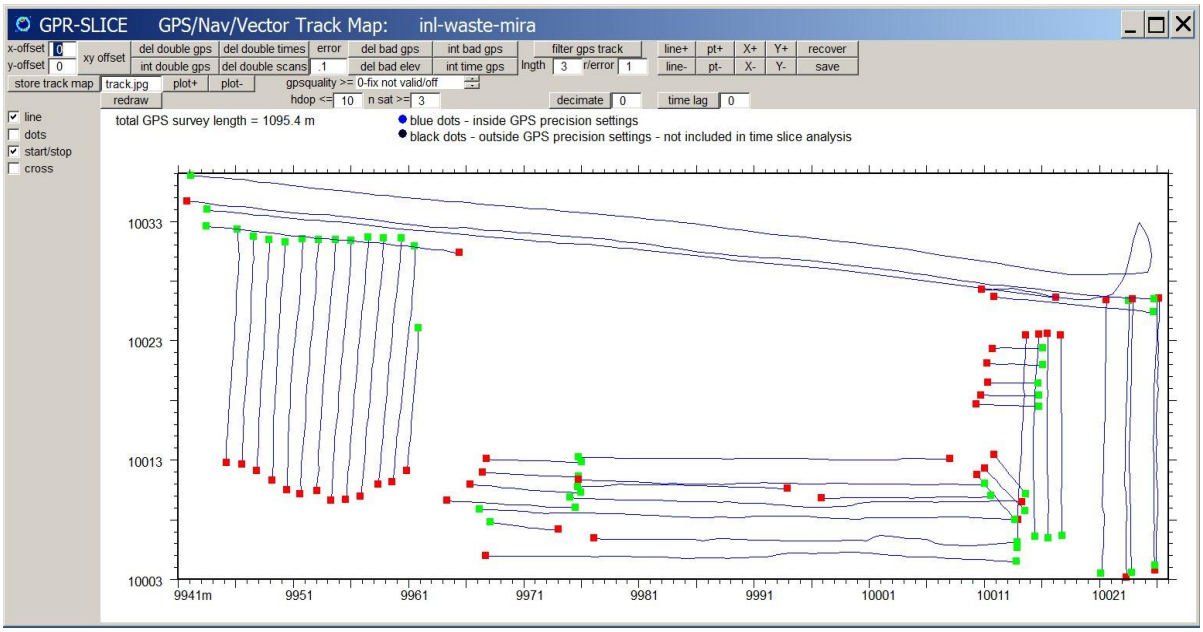


2) The next operation is to extract all the radargrams from the main track names using the new Mira Extract button in the Edit Info File menu (shown previously). The extracted radargrams are directly placed into the \radar\ folder with the naming convention *-N.rd3 where N is the channel number (the \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.

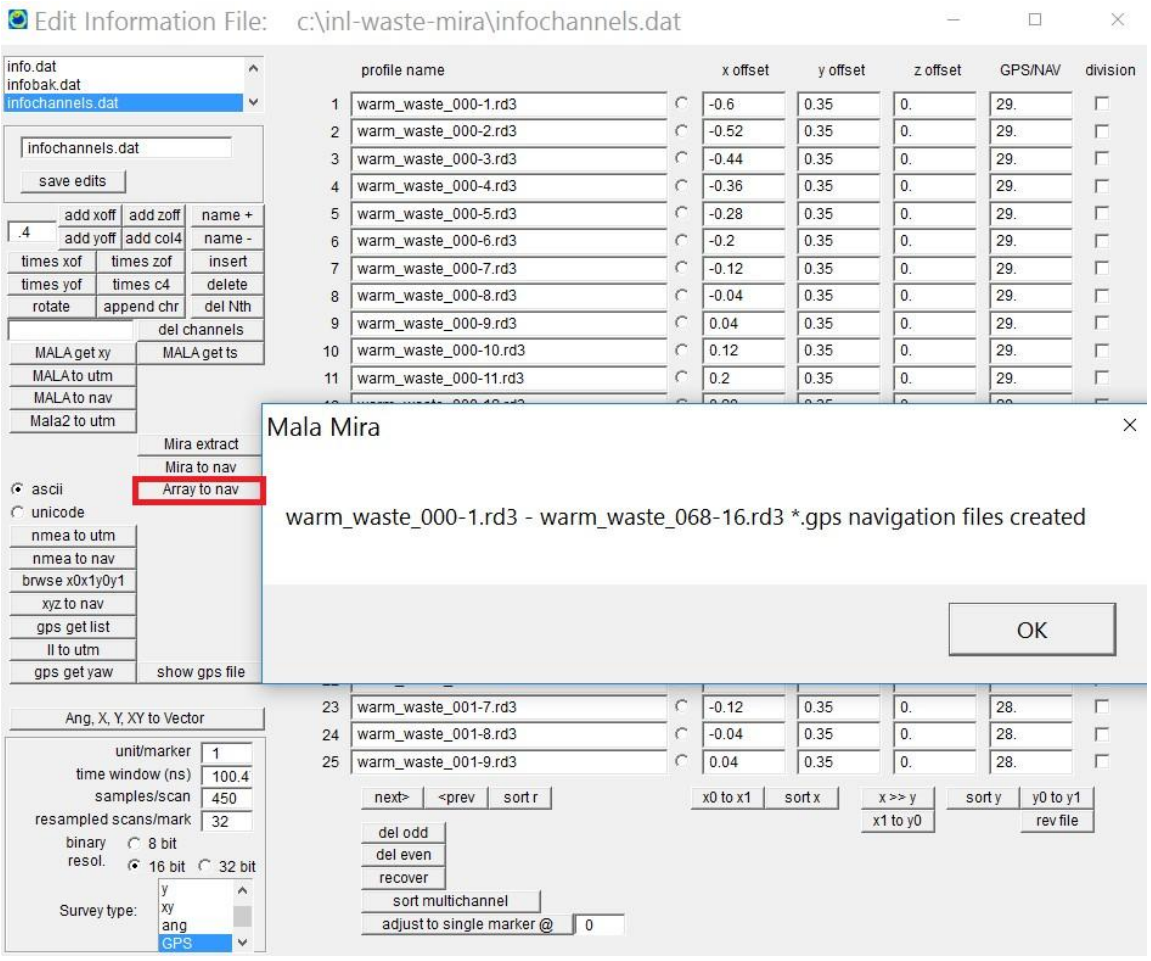


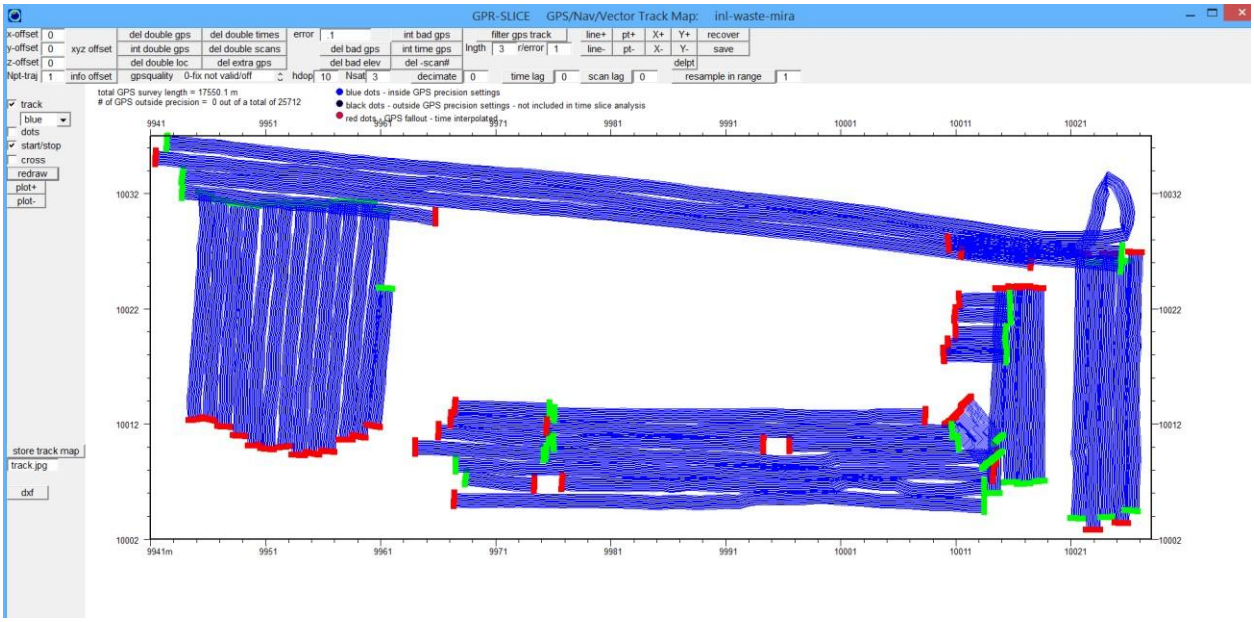
*note: The Mira Extract button will be used normally for total station projects. For GPS projects, the user will set the GPS File Extension to the *.cor file extension (in the Create New Info menu) and will click the Mala to UTM button in the Edit Info File menu for the navigation.



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.



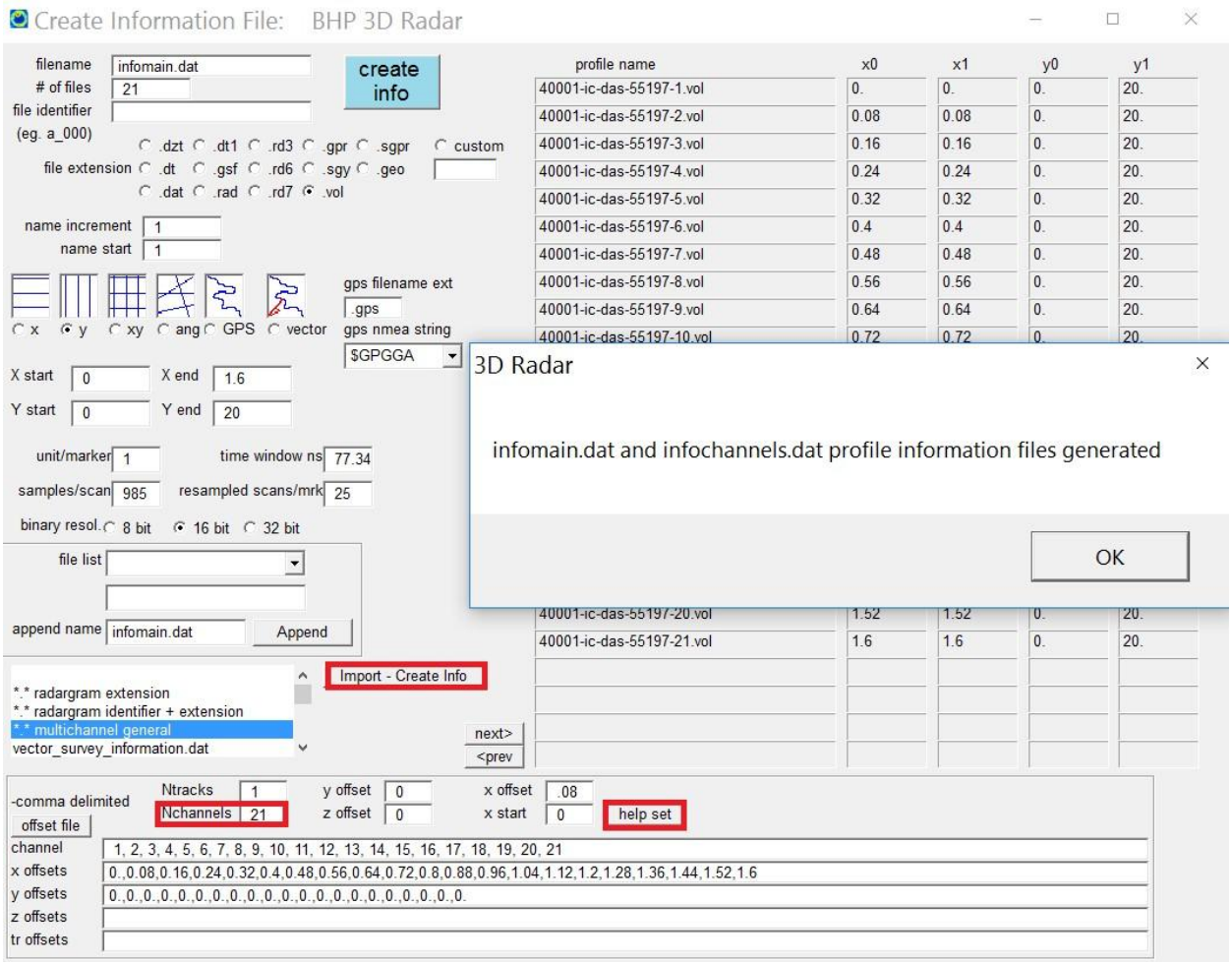


An example of the GPS track generated for all the individual channels following the x and y offsets is shown above.

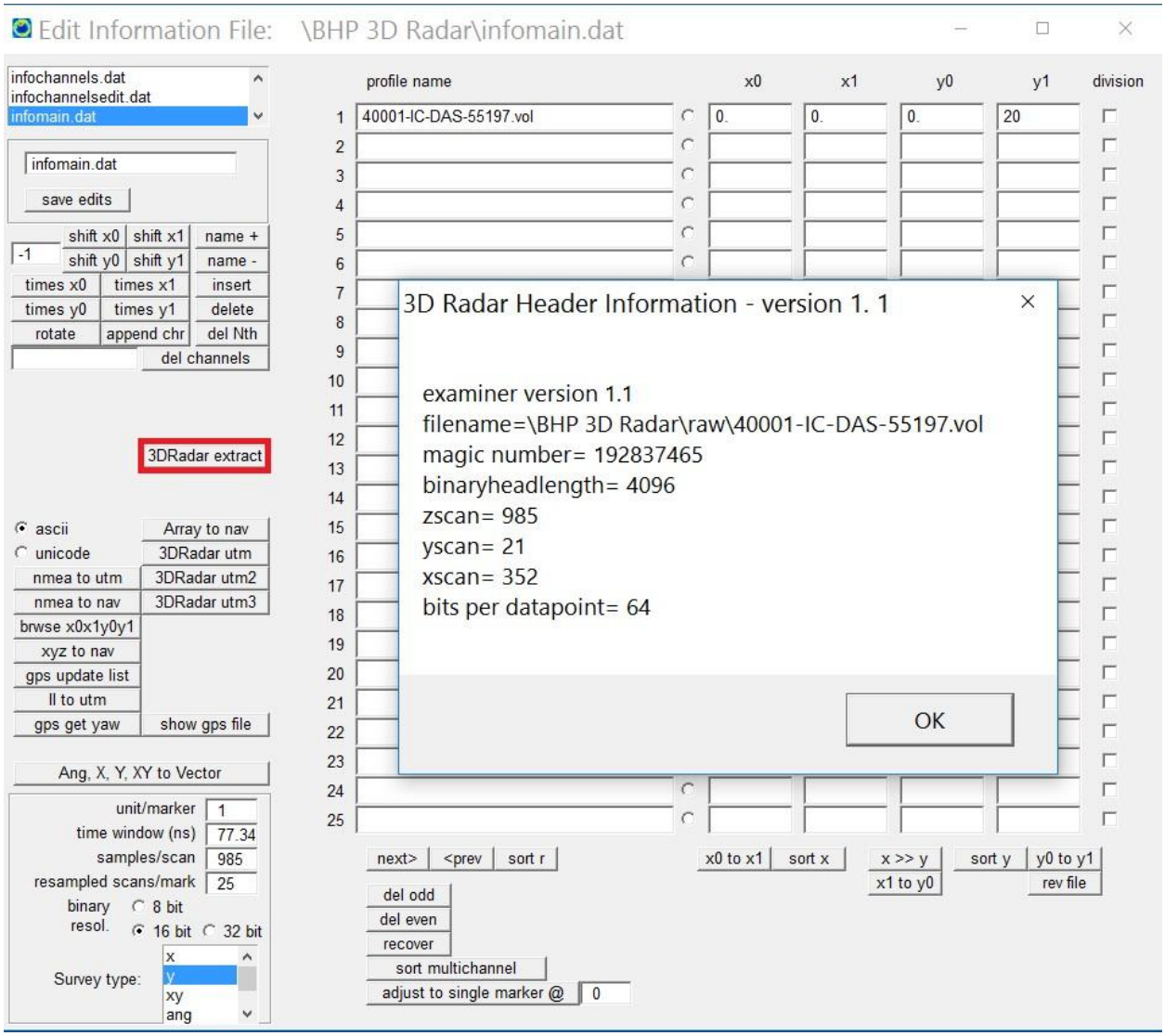
After these steps continue to the section entitled: **Processing Operations for all Multi-Channel GPR Systems.** This will show the steps for signal processing for multichannel GPR and how to compile these data to a 3D volume.

3D Radar Geoscope/Kontur – VOL format

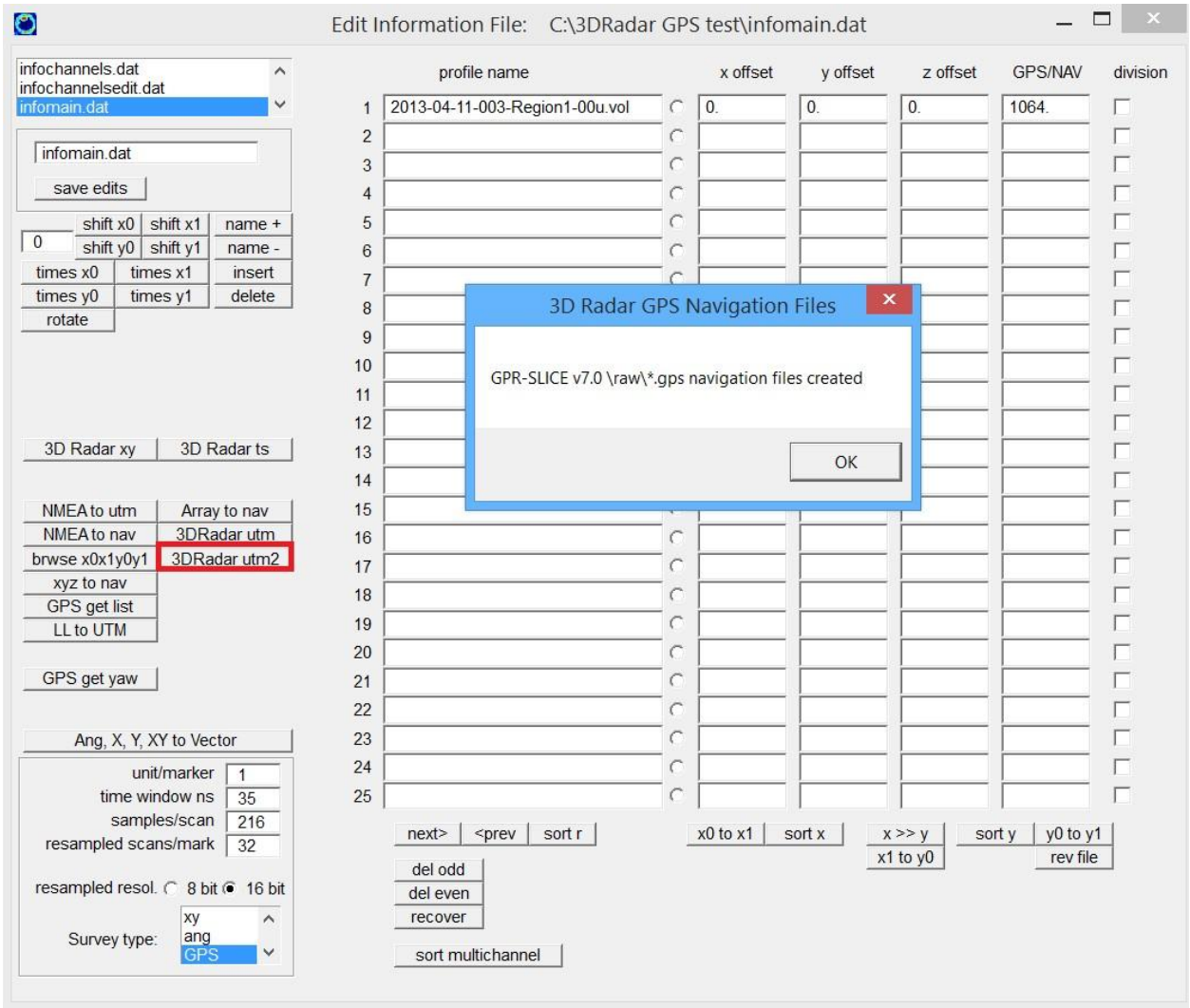
1) Set the survey type to GPS or X or Y, the number of channels, and the antenna separation and offsets. Click the "Import – Create Info" button. This will automatically create 2 information files, infomain.dat which has the names of the main track radargrams, and infochannels.dat which contains the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

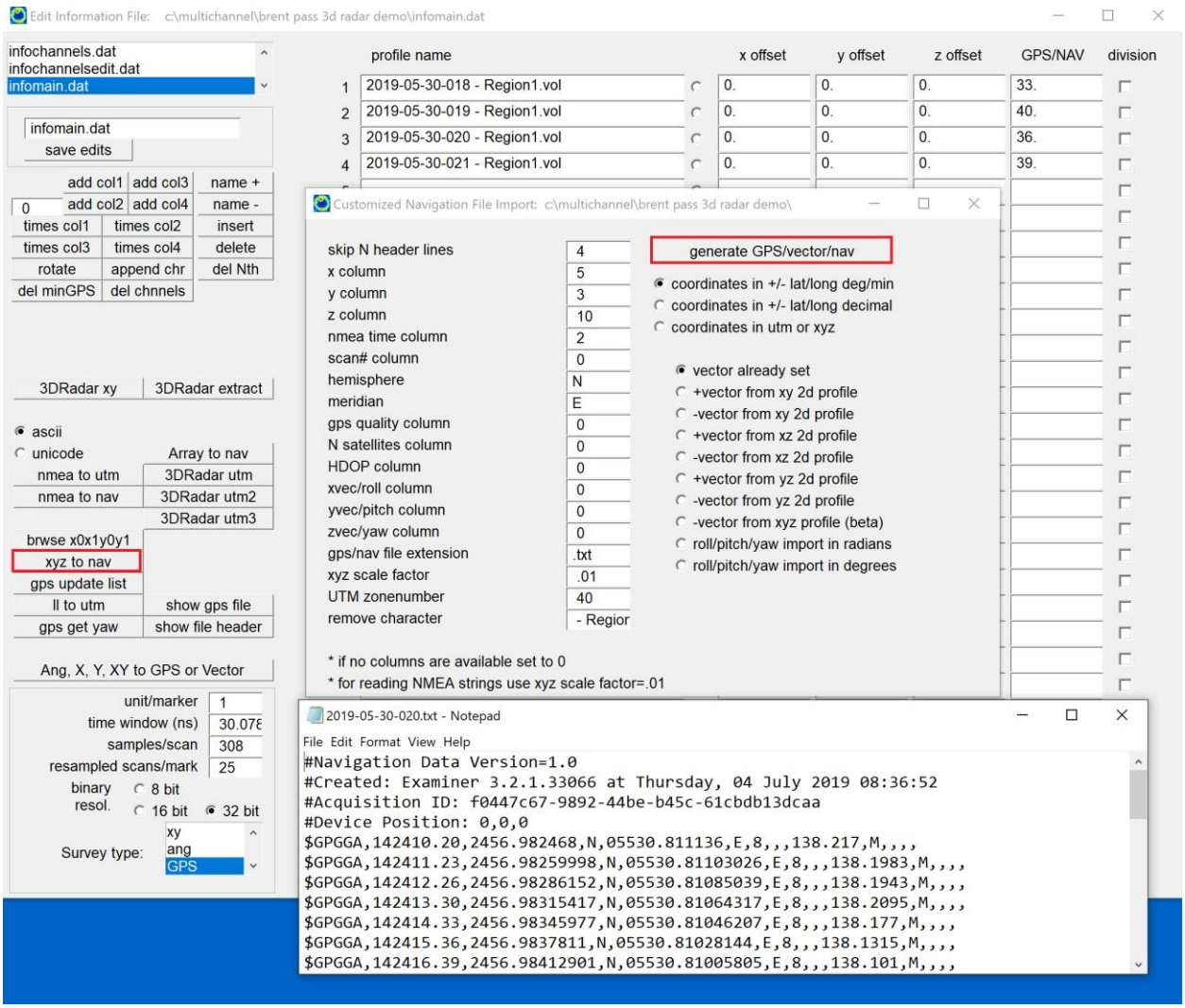


3) The next step is to make sure the infomain.dat file is highlighted in the Edit Info File menu. Then click the 3DRadar to UTM, which generates the *.rd3.gps files of the main track and updates the number of GPS listings in the 4th column of the information file. The user can use the GPS track menu 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).

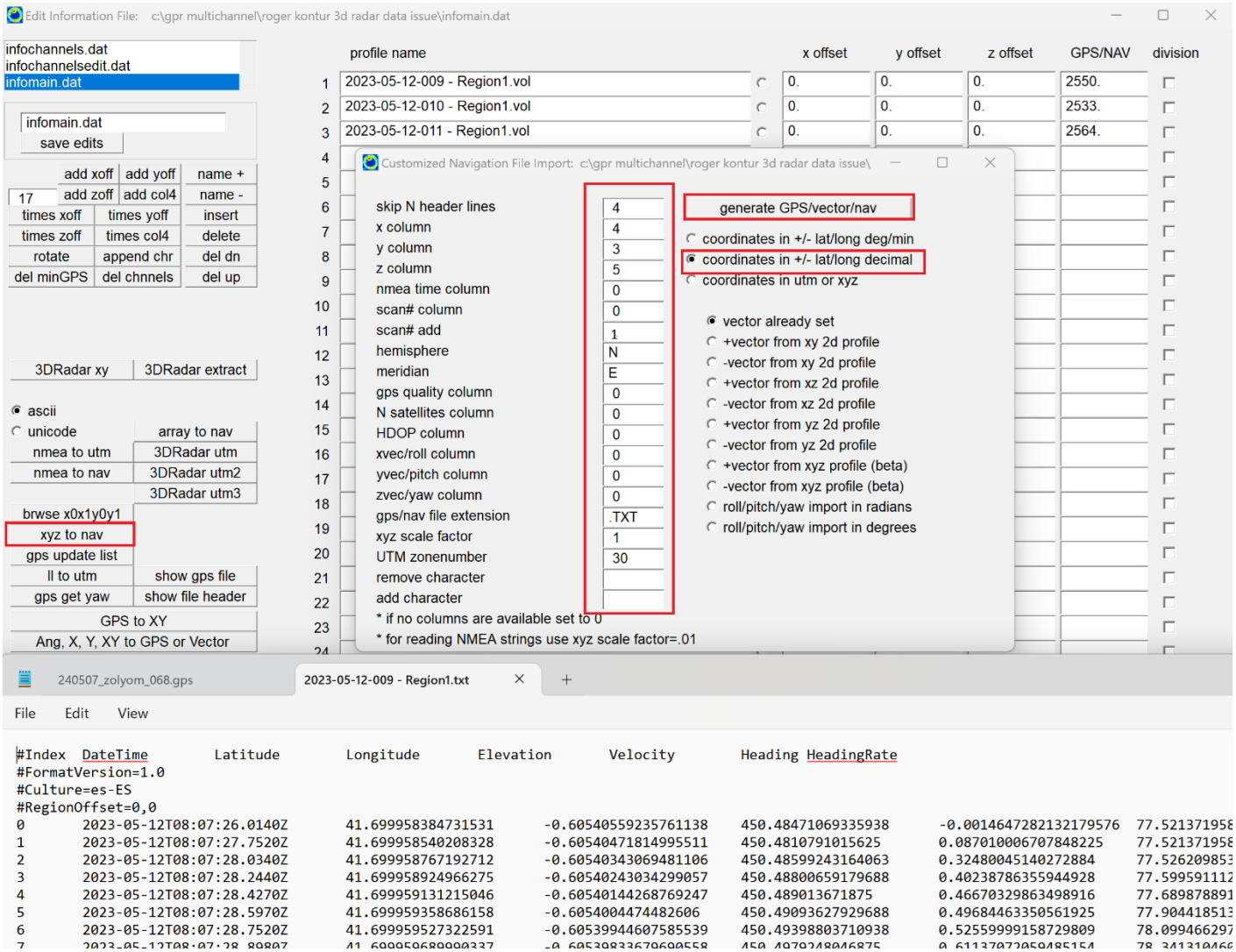


Optionally for newer versions of 3D Radar *.txt files are provided as the navigation formats. For these datasets the XYZtoNAV menu is needed to read the navigation and create the GPS files. In some case the full NMEA string is present and in other cases extracted NMEA components

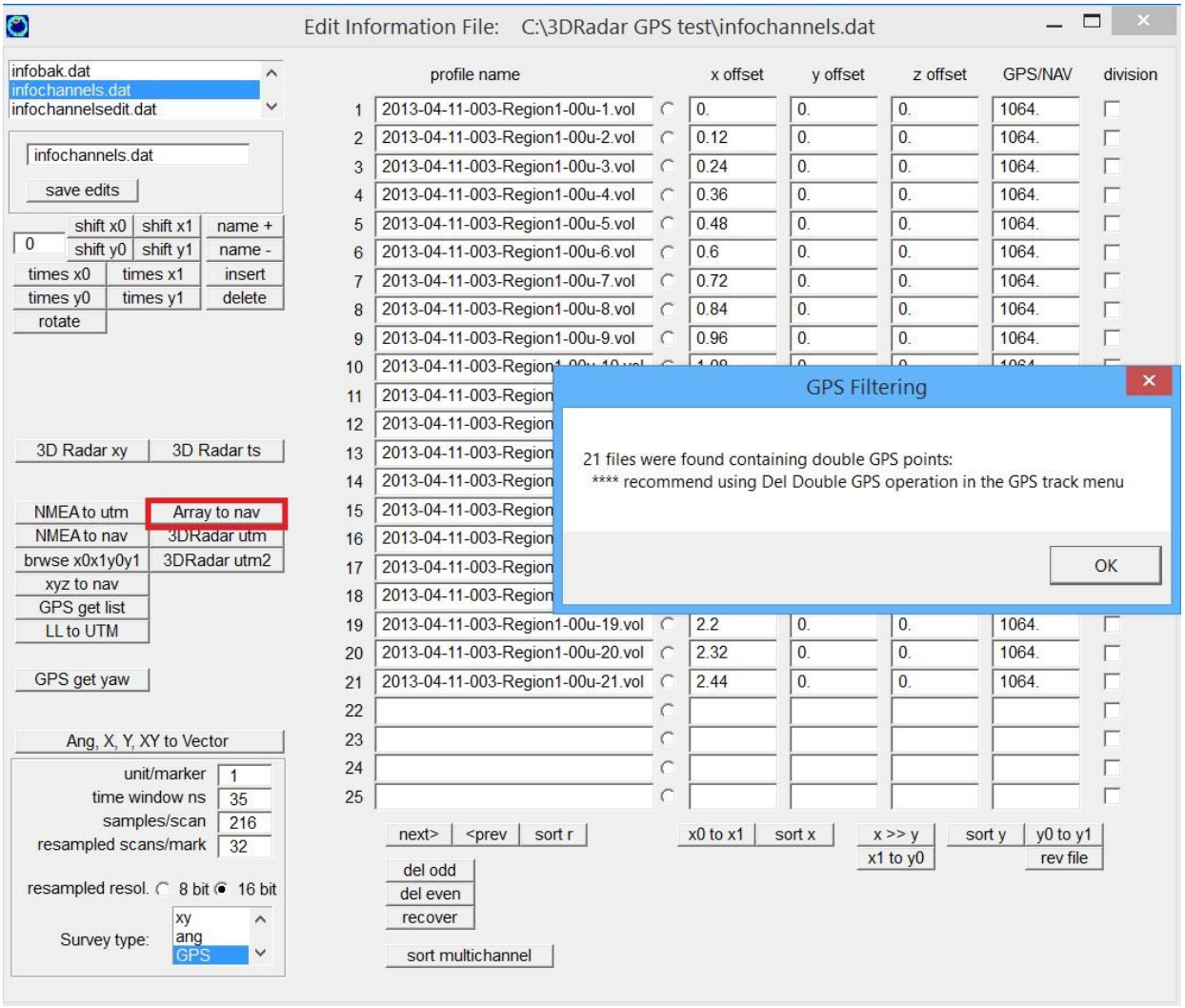
3a) Full NMEA string *.txt Kontur navigation files and how to generate *.gps files using the XYZ to NAV operation:



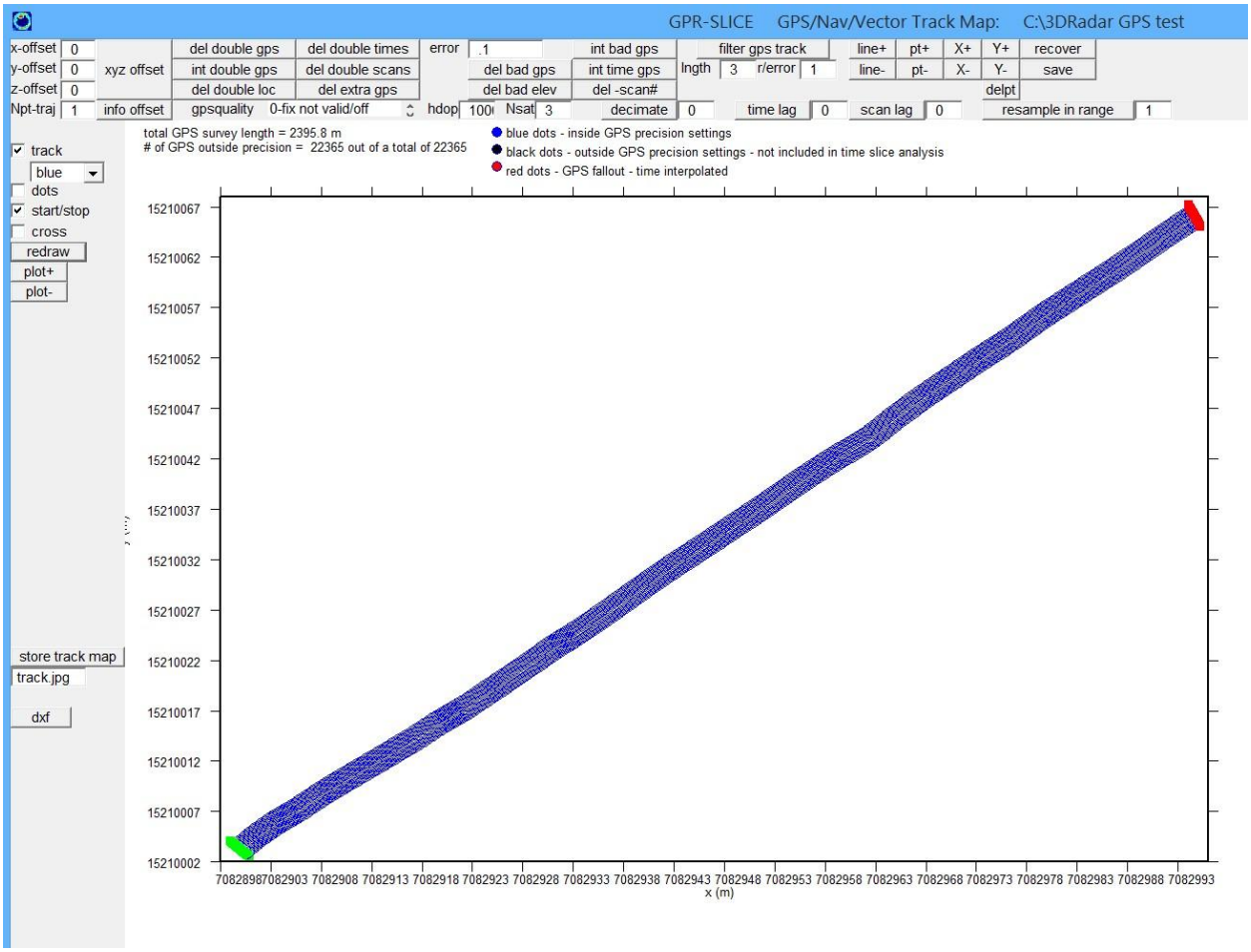
3b) Extracted NMEA components in the *.txt Kontur Navigation files and how to generate *.gps files using the XYZ to NAV operation:



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.



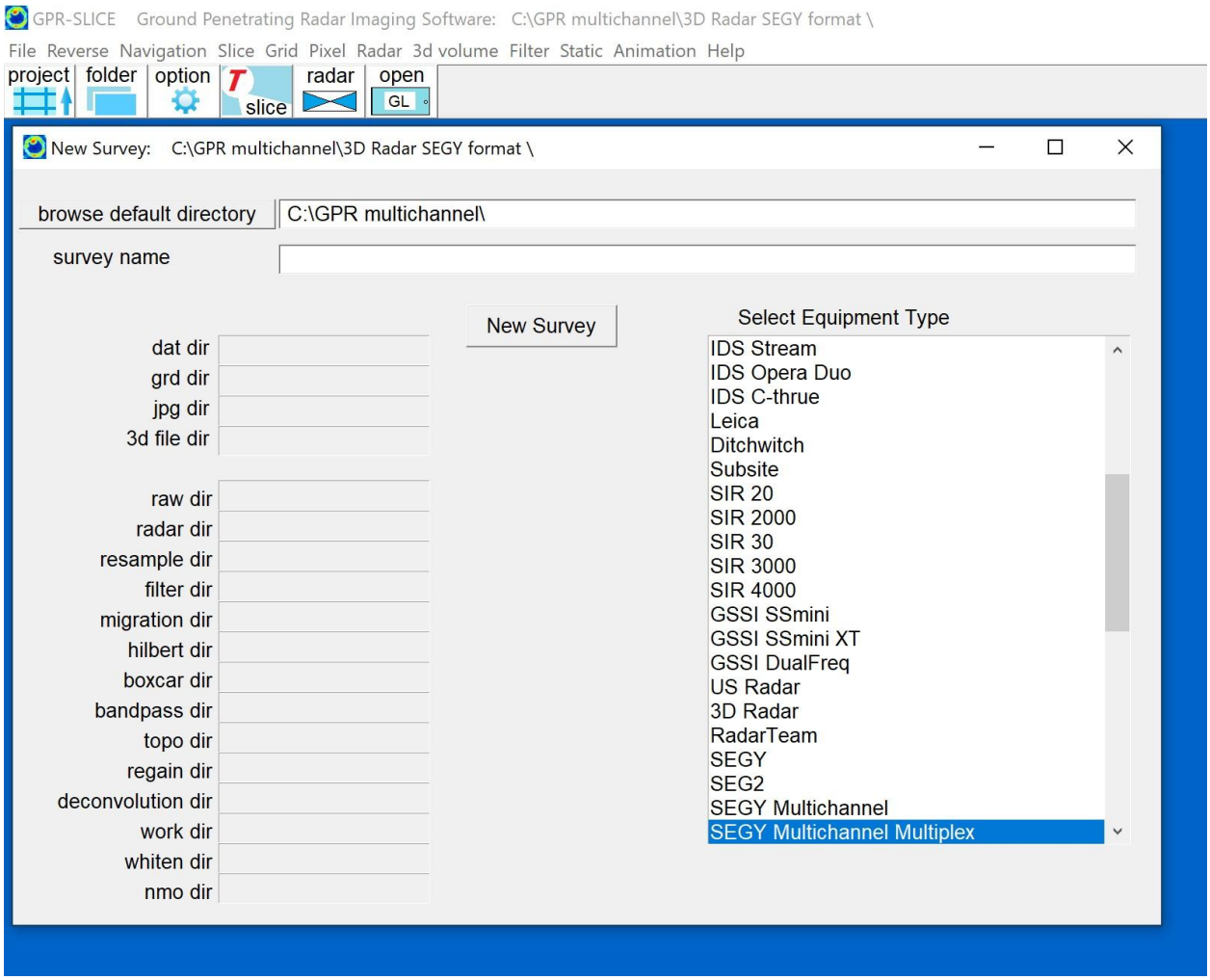
An example GPS track map for all the individual channels for this Geoscope dataset is shown below:



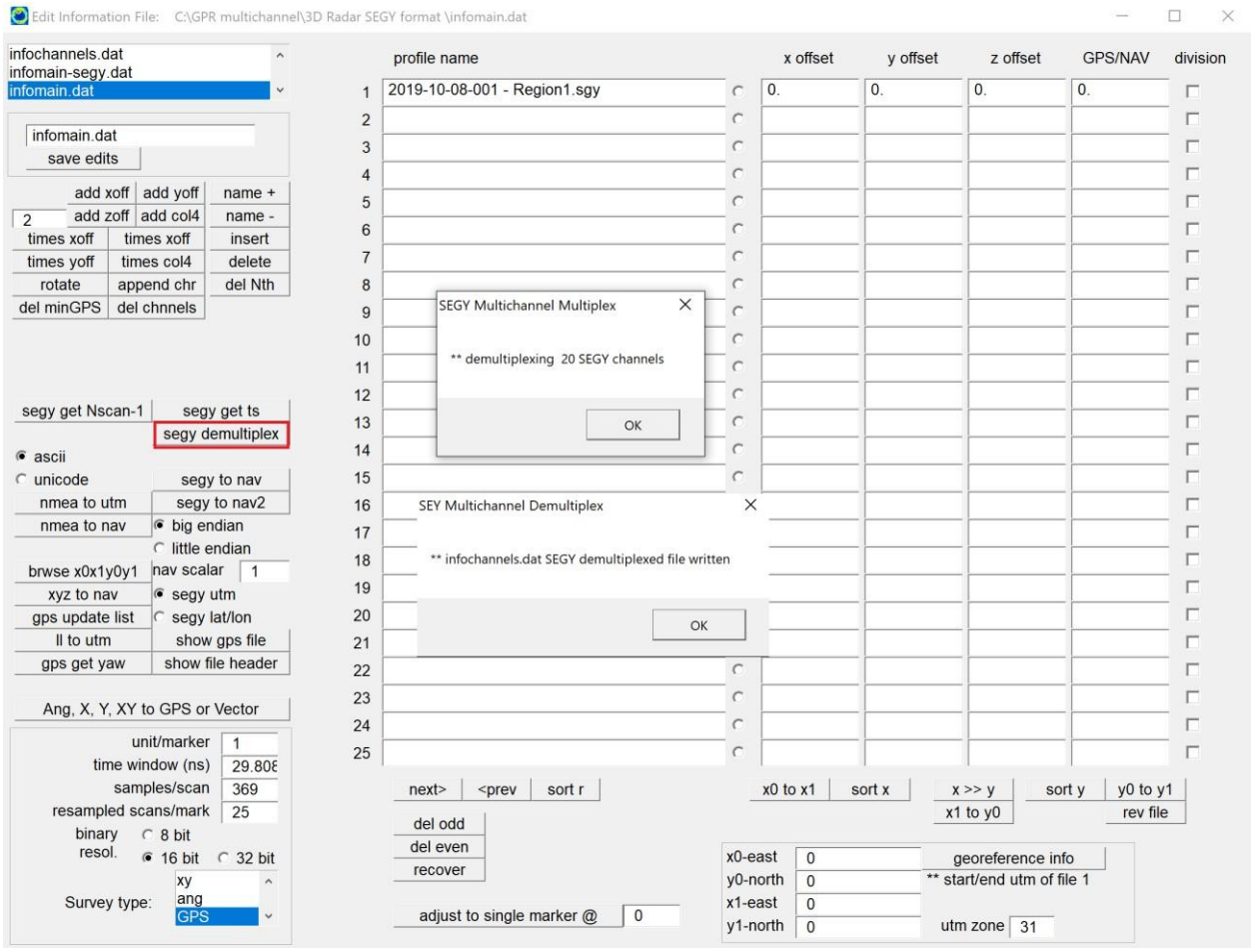
After these steps continue to the section entitled: **Processing Operations for all Multi-Channel GPR Systems.** This will show the steps for signal processing for multichannel GPR and how to compile these data to a 3D volume.

3D Radar Geoscope/Kontur – SEGY format

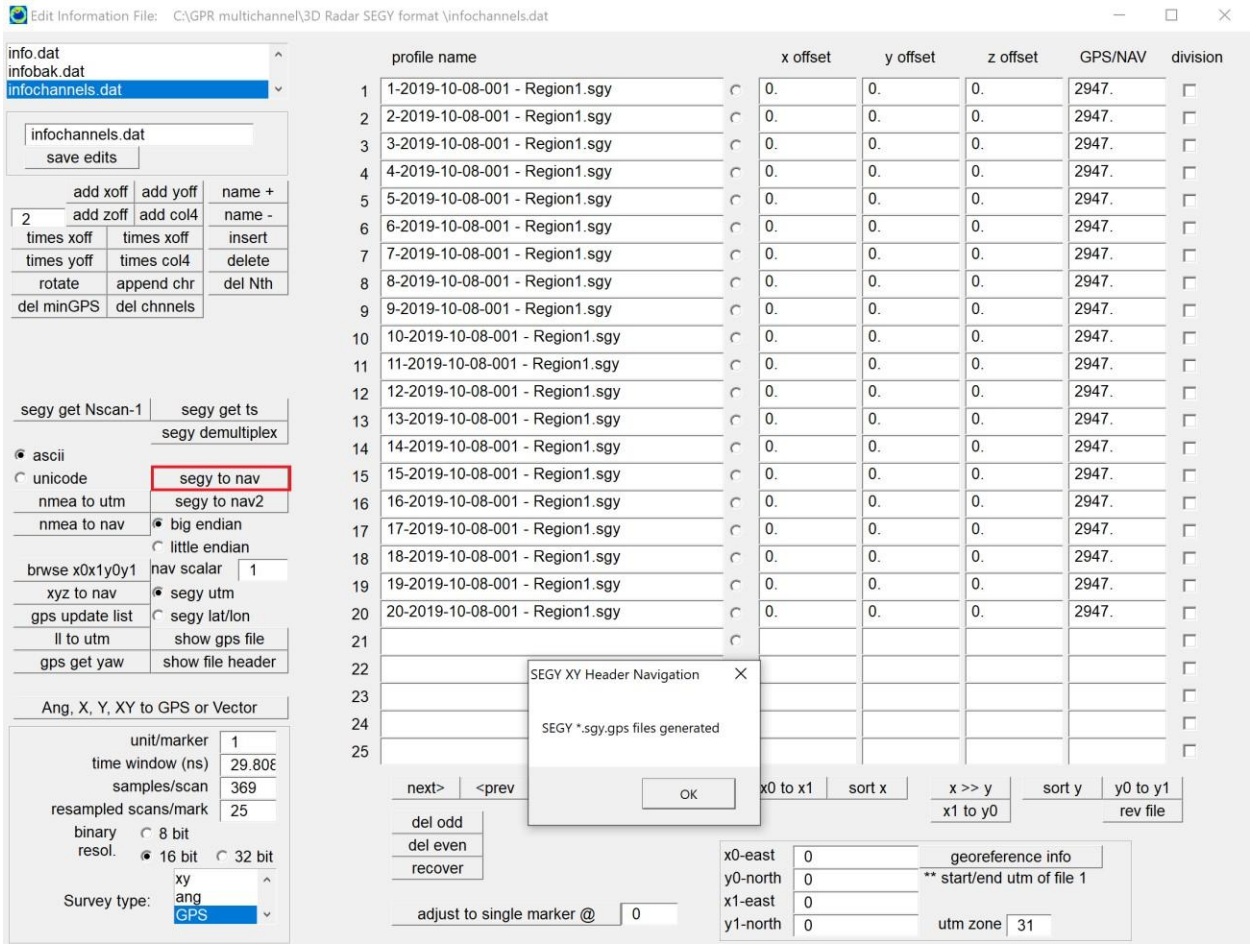
1) An alternate 3D Radar format available in late 2020 is a SEGY format. Each swath of data is written into a single SEGY file. The equipment format chosen is SEGY Multichannel Multipex.



2) The infomain.dat and infochannels.dat are made similarly to the 3D Radar non-SEGY data. With infomain.dat active, the SEGY Demultiplex button is clicked which will separate each channel into its own SEGY file in the \raw\ folder:



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

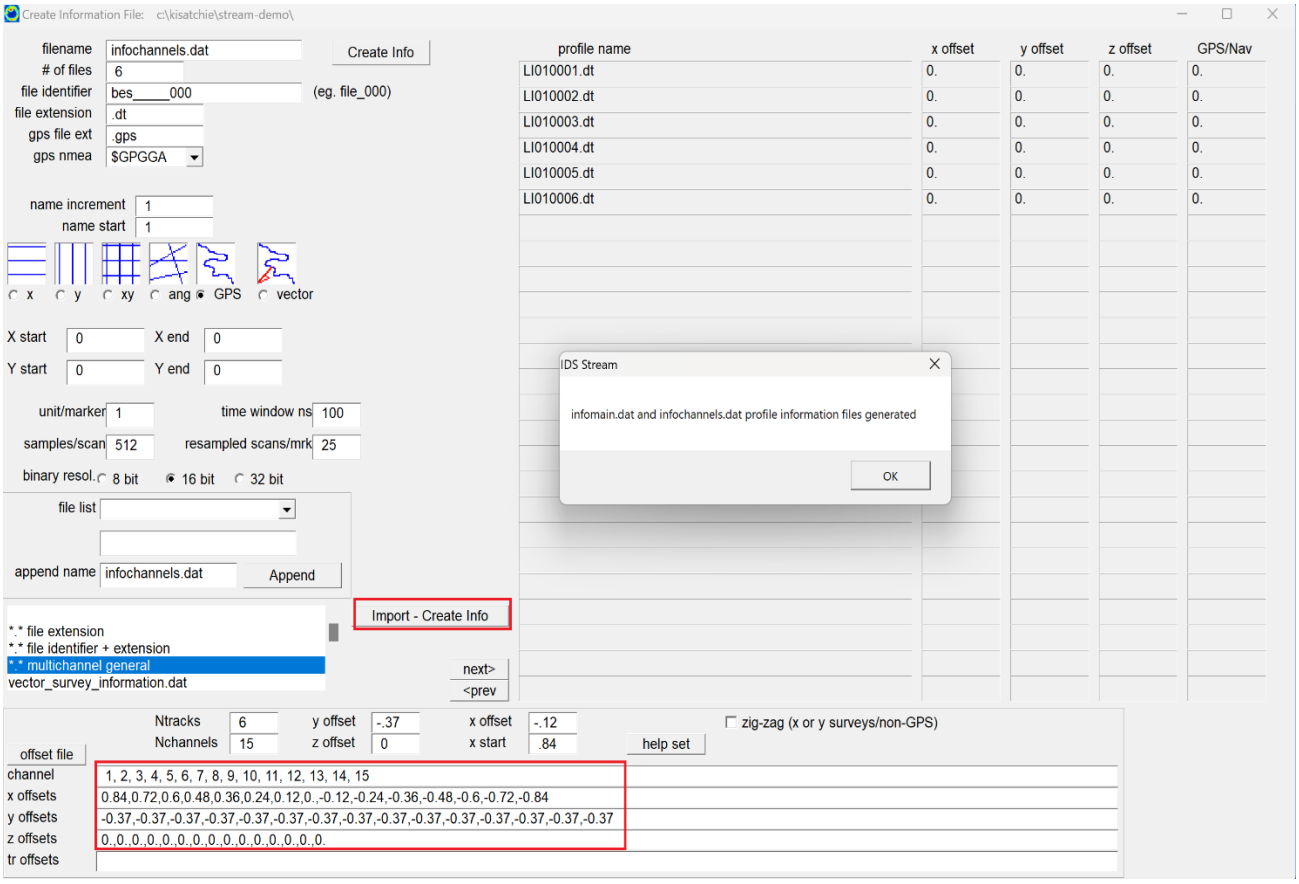


IDS Stream X, C, UP and DP

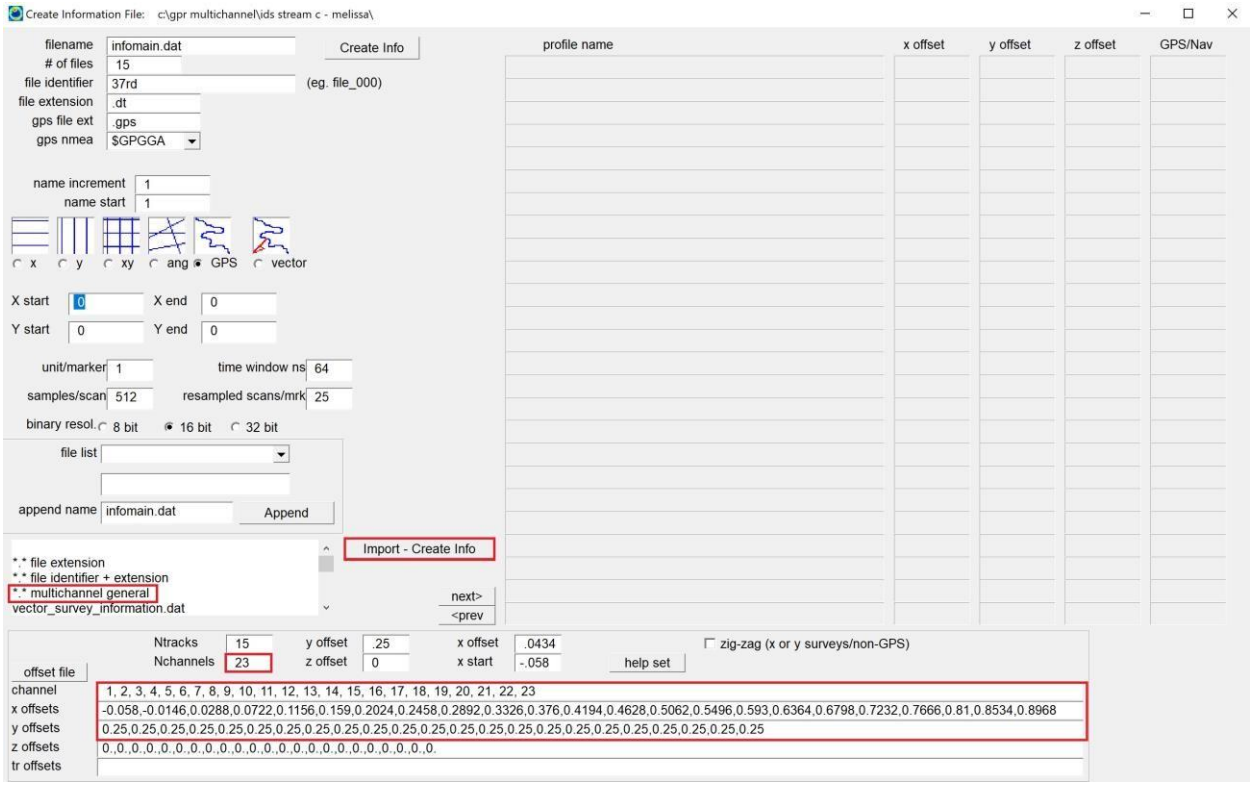
The basic processes for the IDS Stream and their family of different multi-channel GPR systems (including the X, C, UP and DP systems) are:

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. Configurations for IDS Stream X, C, UP and DP and the HH and VV channels are also given in the next few screen shots as well.

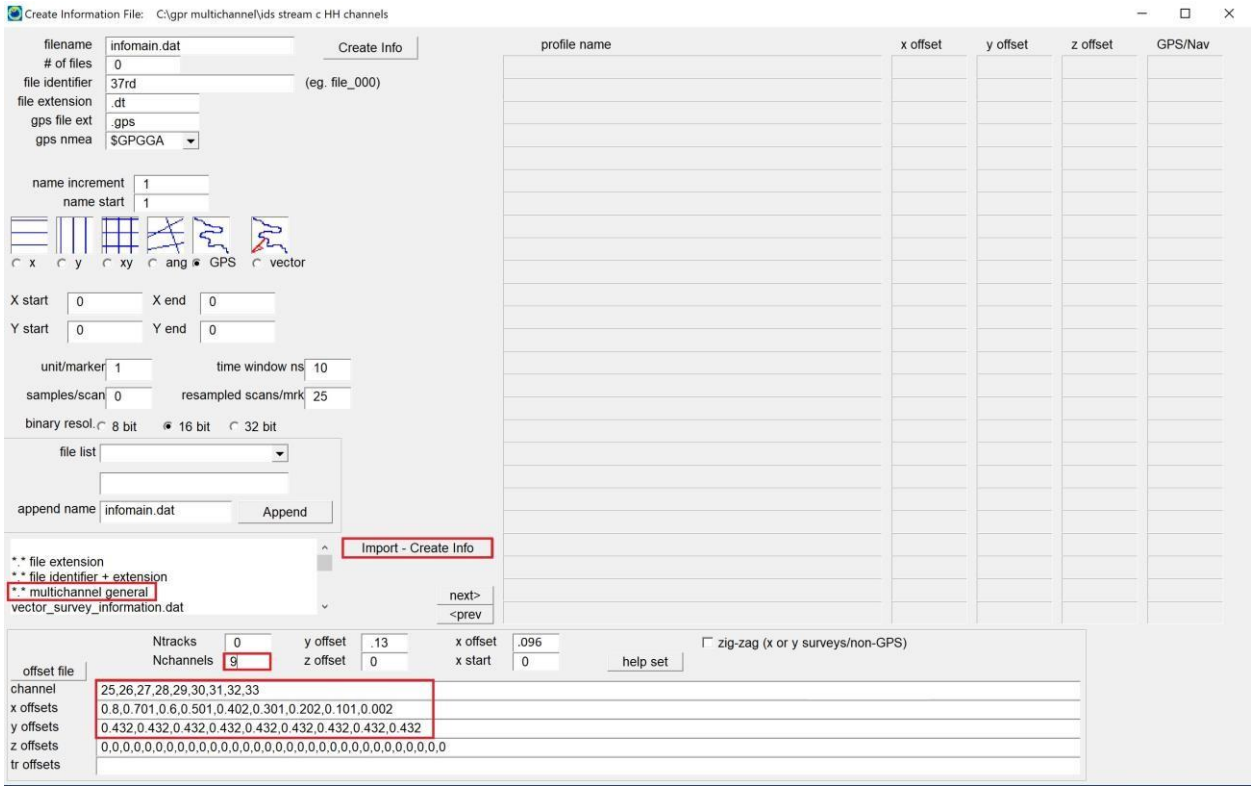
IDS Stream X configuration: For a IDS Stream X there are 15 channels at approximately 12 cm separation between channels.



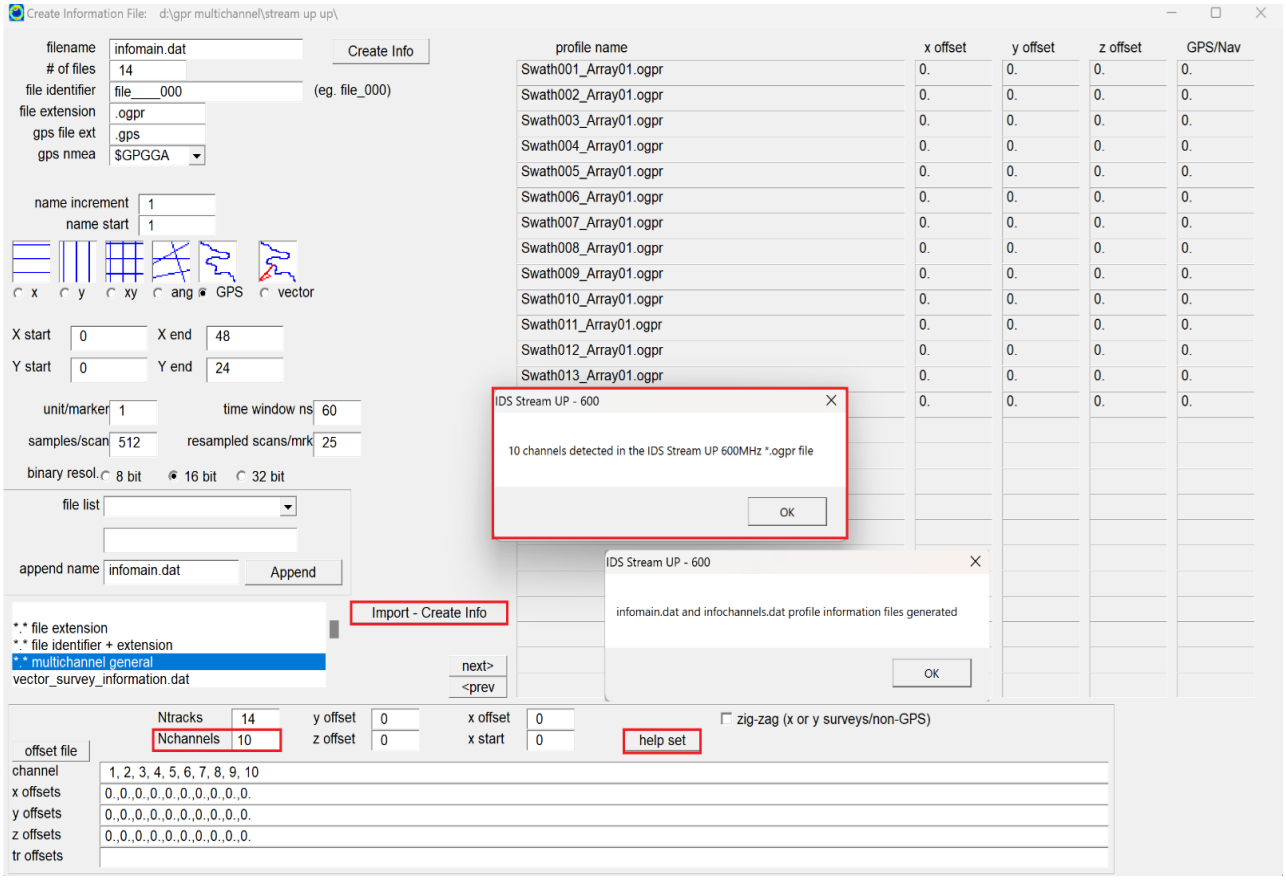
IDS Stream C - VV configuration: For a IDS Stream C there are 23 channels of VV polarization at approximately 4.4 cm separation between channels.



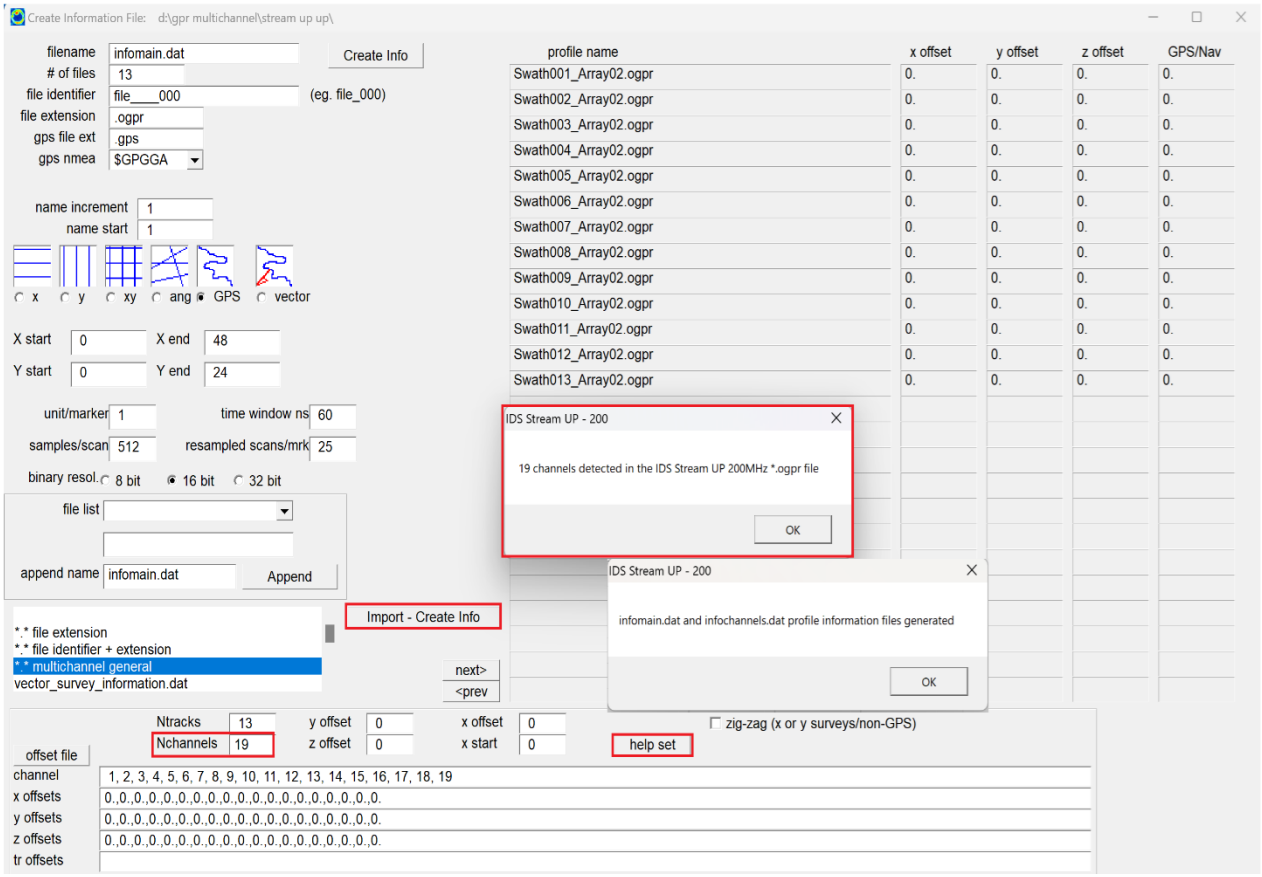
IDS Stream C HH configuration: For a IDS Stream C there are 9 channels of HH polarization at approximately 9.6cm separation between channels.



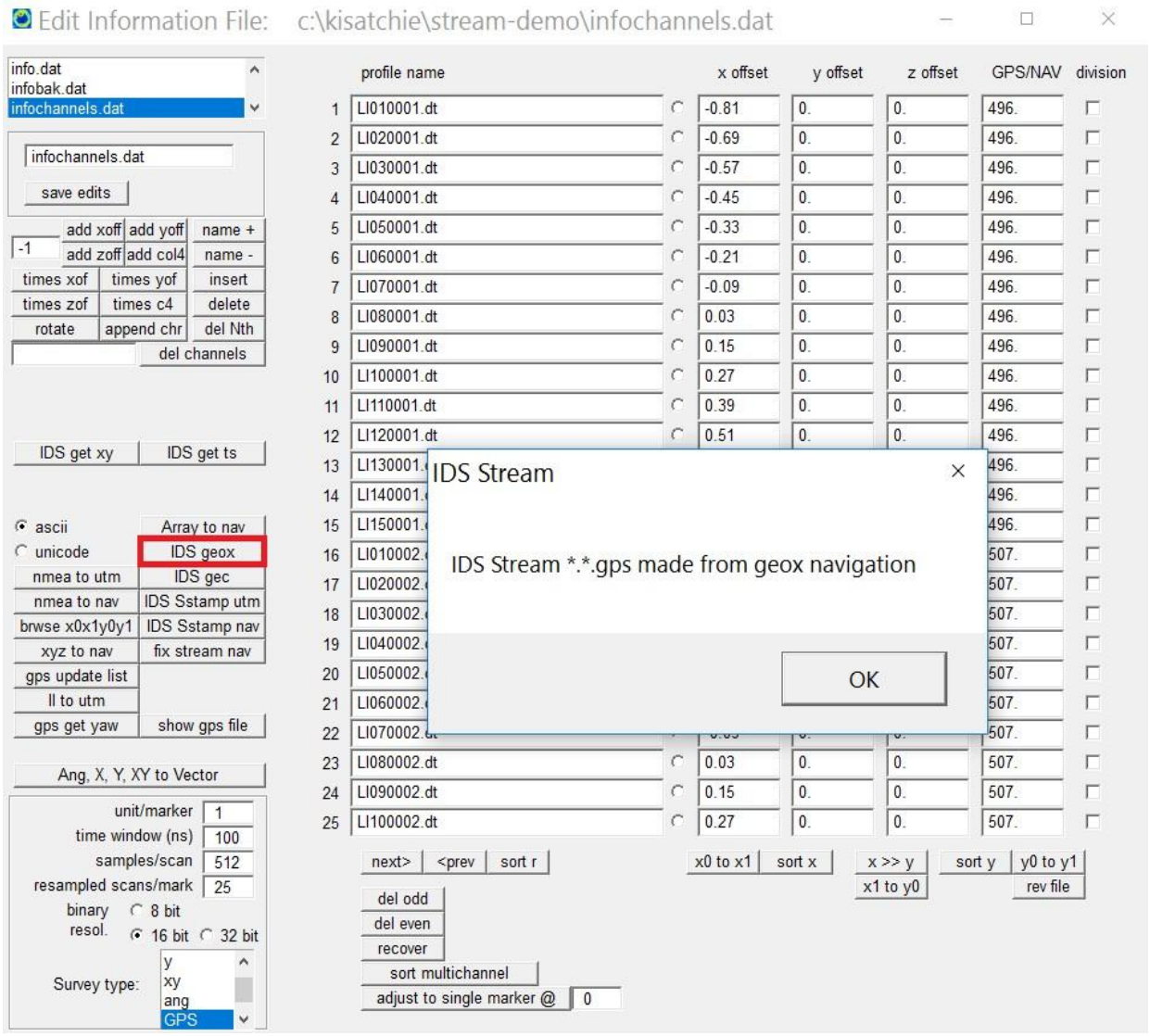
IDS Stream UP – 200MHz/IDS Stream DP - HH configuration: For a IDS Stream UP with 200 MHz antennae there are 10 channels in this example. On clicking the Import – Create Info button the software will indicate how many channels are contained in the *.ogpr format. (Note, Stream UP and Stream DP have a self contained format with navigation and radargrams included in the *.ogpr format. IDS Stream – HH configuration should use the IDS Stream UP – 200MHz equipment type)



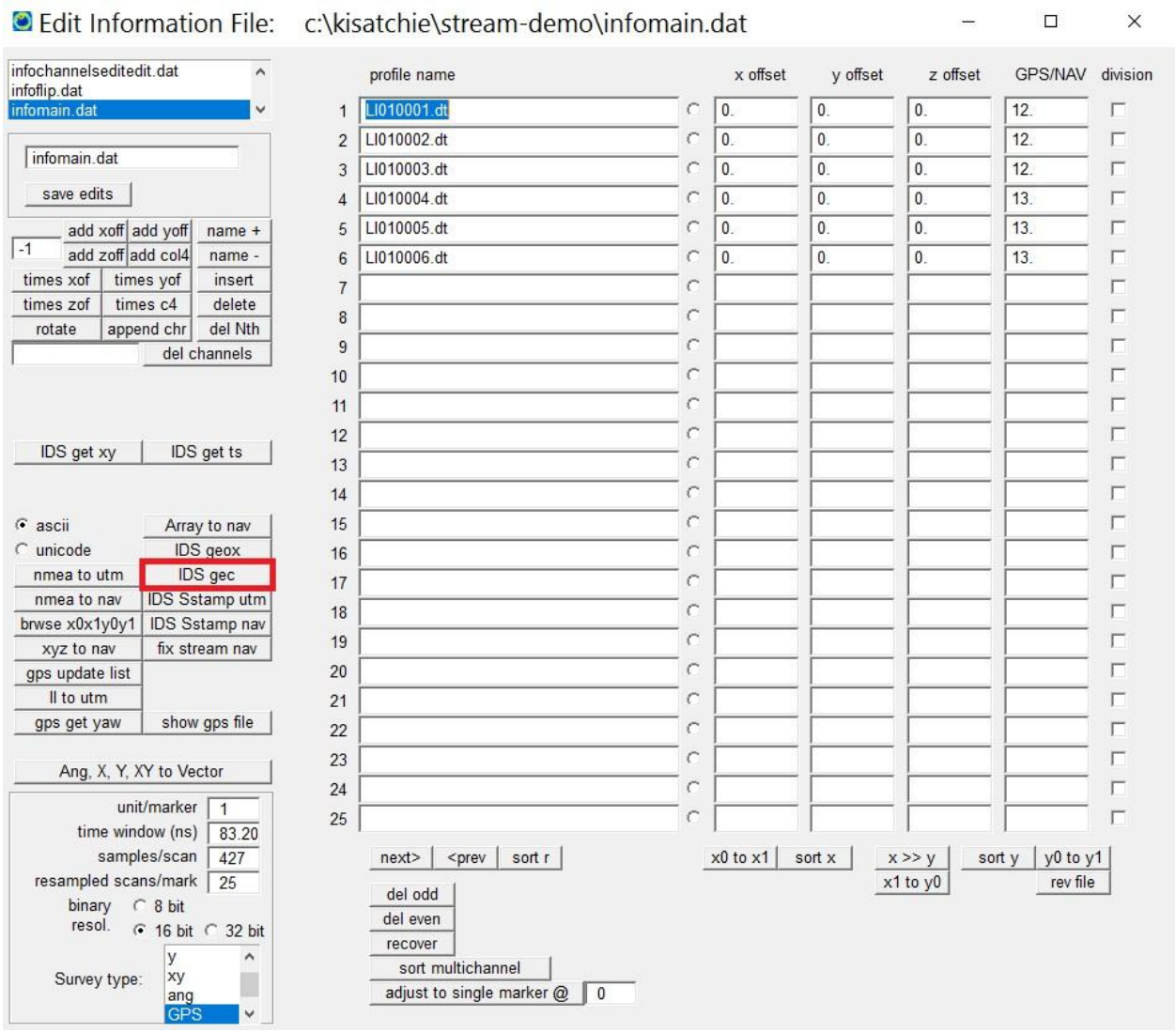
IDS Stream UP – 600MHz/IDS Stream DP - VV configuration: For a IDS Stream UP with 200 MHz antennae there are 19 channels in this example. On clicking the Import – Create Info button the software will indicate how many channels are contained in the *.ogpr format. The IDS Stream DP VV (Note, Stream UP and Stream DP have a self contained format with navigation and radargrams included in the *.ogpr format. IDS Stream DP – VV configuration should use the IDS Stream UP – 600MHz equipment type)



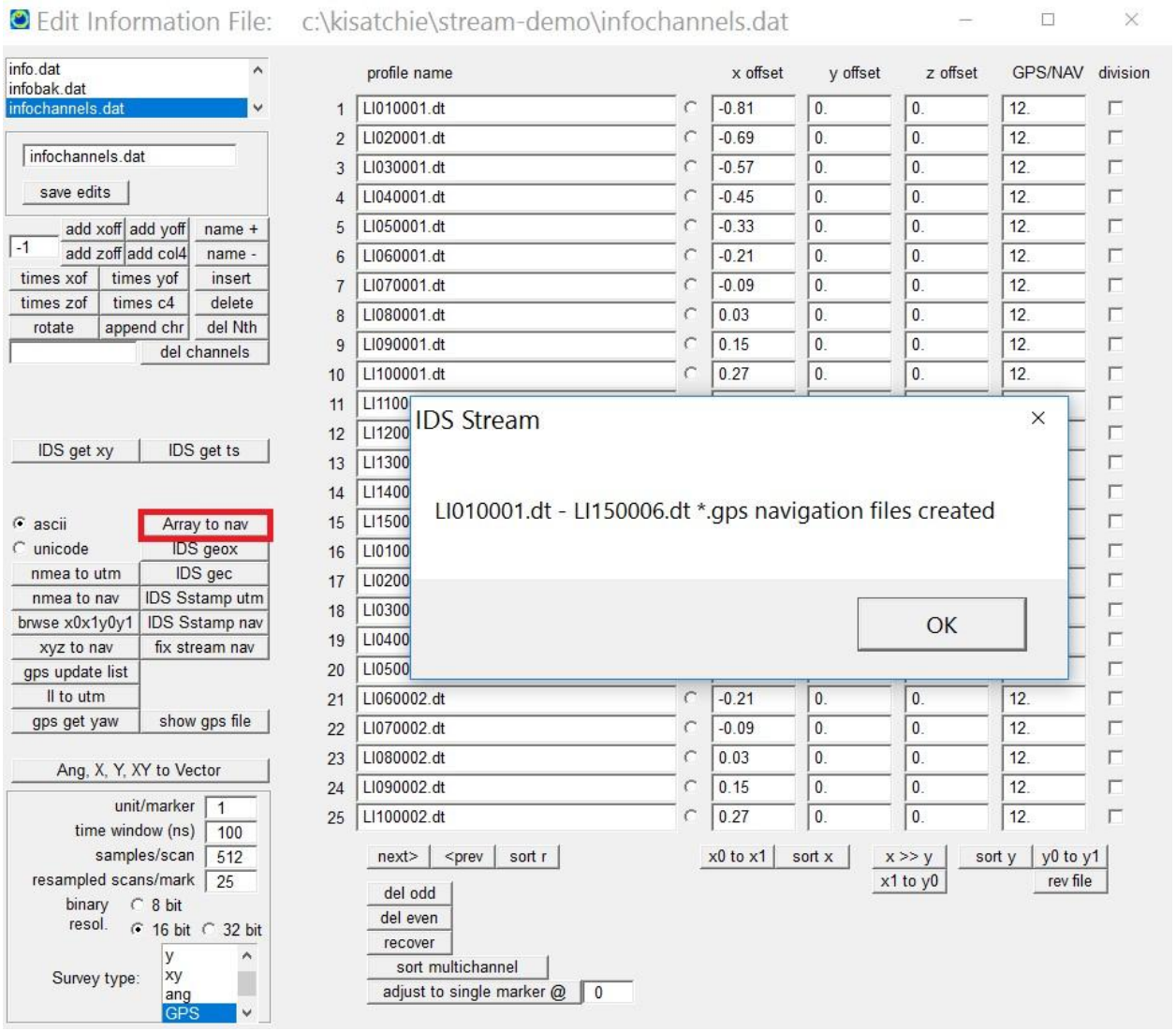
2) For IDS Stream X and C: The next step is to work directly on the infochannels.dat file in the Edit Info File menu. Recent IDS Stream operation now generate *.geox files with every radargram. Clicking the IDS Stream Geox button will read these files and place into *.dt.gps format using this systems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



2a) For IDS Stream X and C: 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.



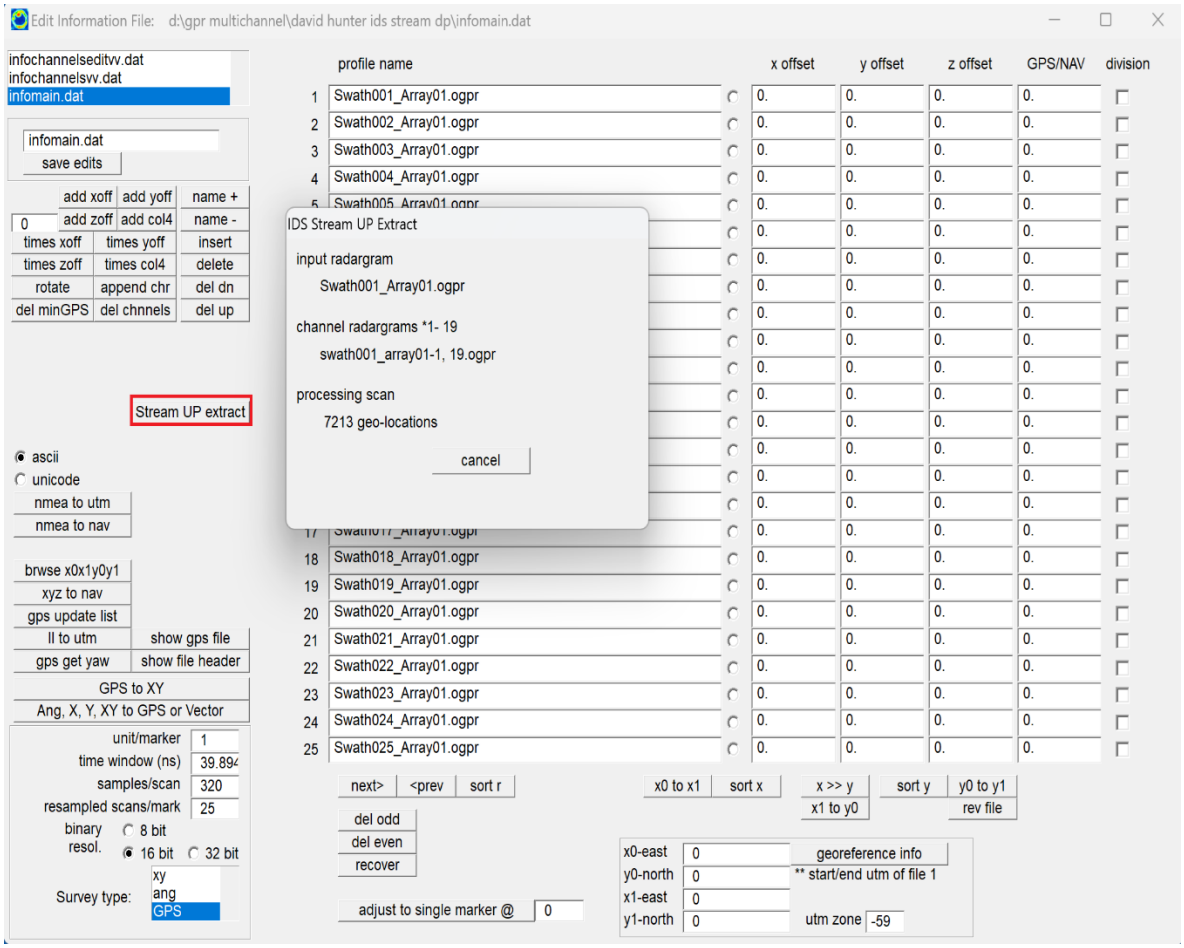
2b) IDS Stream X and C: After generating the main track, which can be edited if necessary in the GPS Track menu, the button Array to Nav is clicked with infochannels.dat file highlighted in the Edit Info File menu:



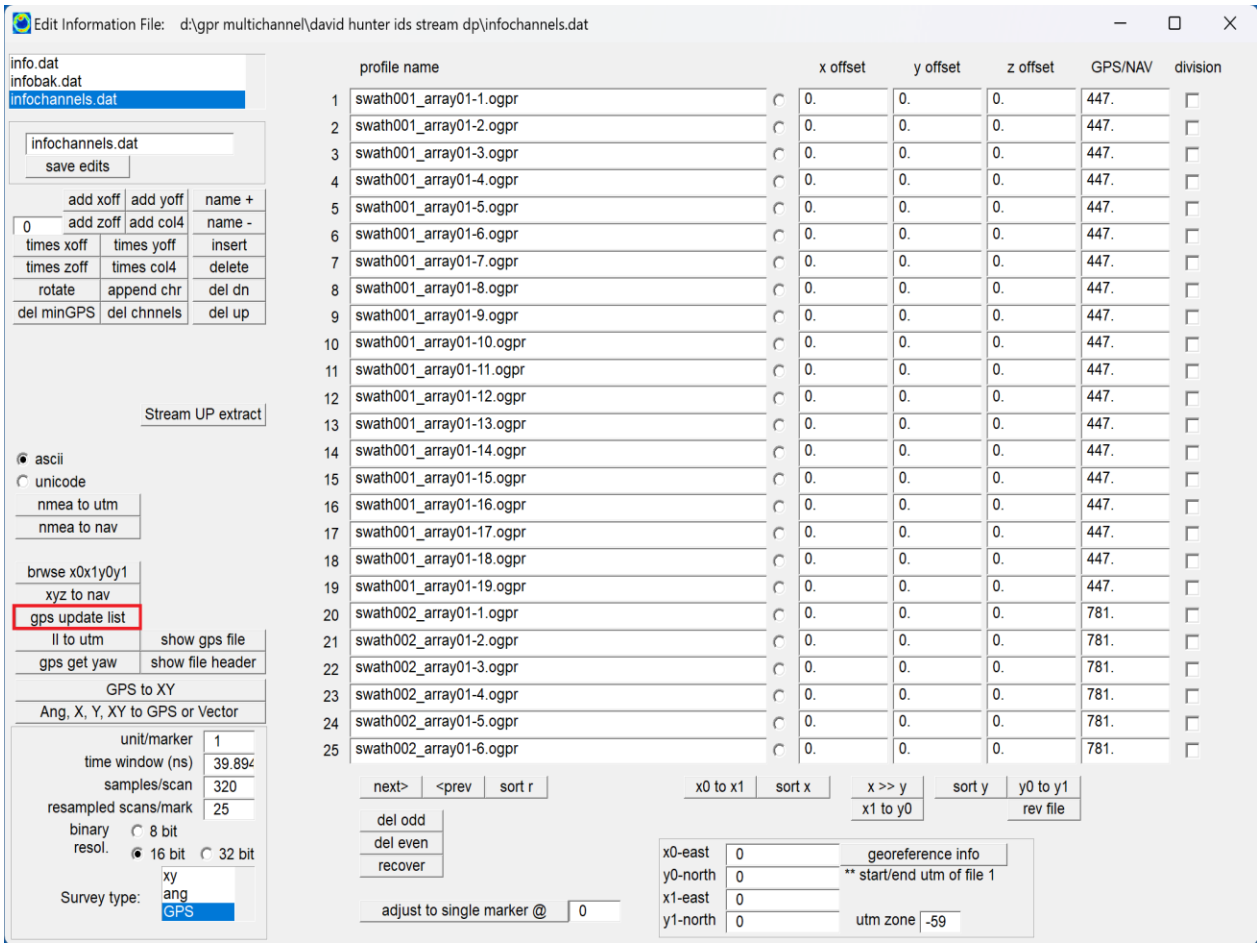
*** Note: For IDS Stream C equipment, channels VV channels will have often twice as many recorded scans as the HH channels. Because the IDS navigation for GPS is tied to channel 1, the master navigation file has scan numbers for NMEA strings that are twice as many scan positions as that in the HH channels.

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.

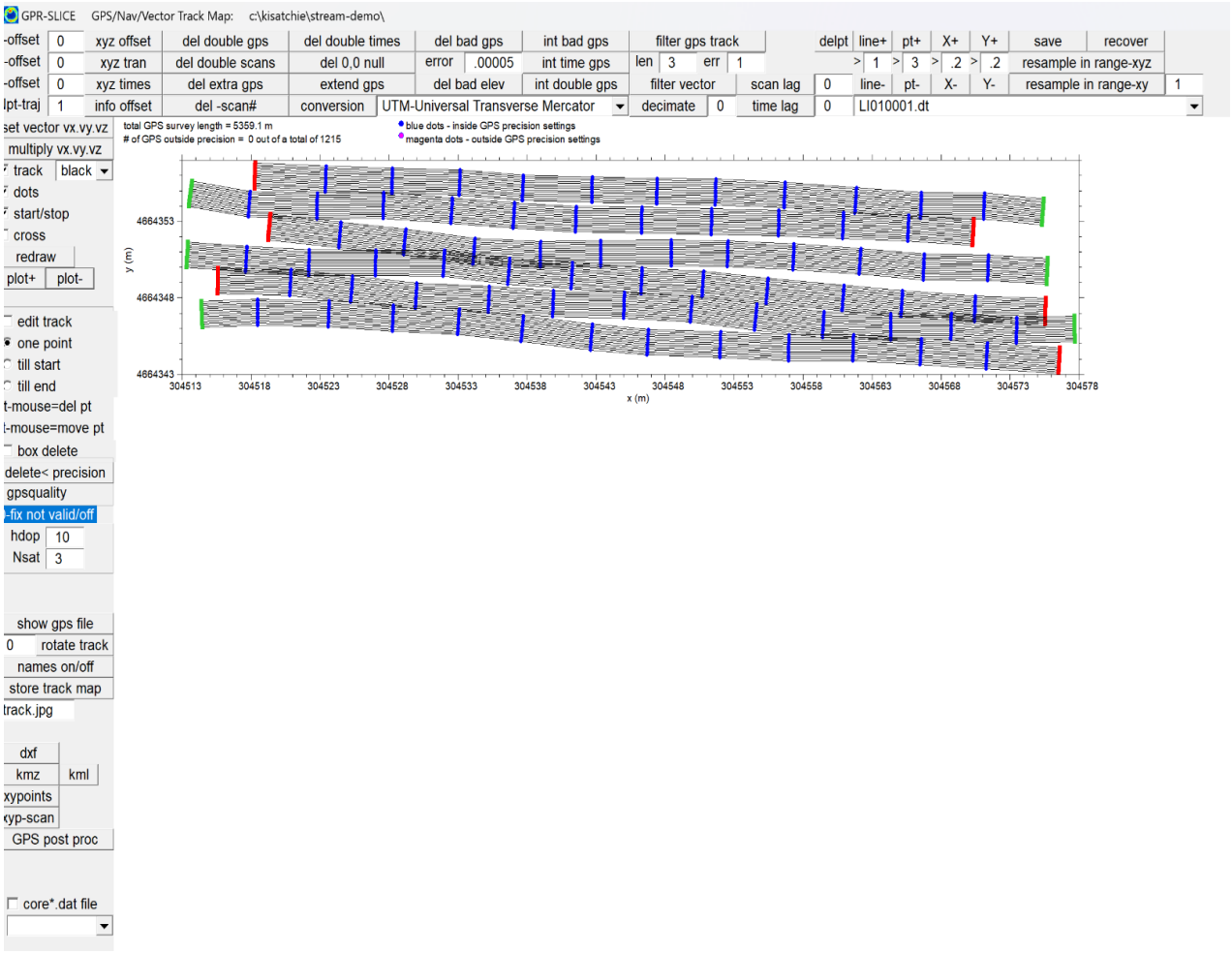
2a) IDS Stream UP and DP: Individual channels need to be extracted from the *.ogpr format using the Stream UP extract operation. The will also automatically create the *.GPS files for each individual channel.



2b) IDS Stream UP and DP: After the extract operation is done the infochannels.dat file is then highlighted and the button GPS Update List is clicked to compile the number of GPS listings for each channel. The *.ogpr contains navigation for each channel which is extracted.



An example of an IDS Stream X GPS track is shown below.



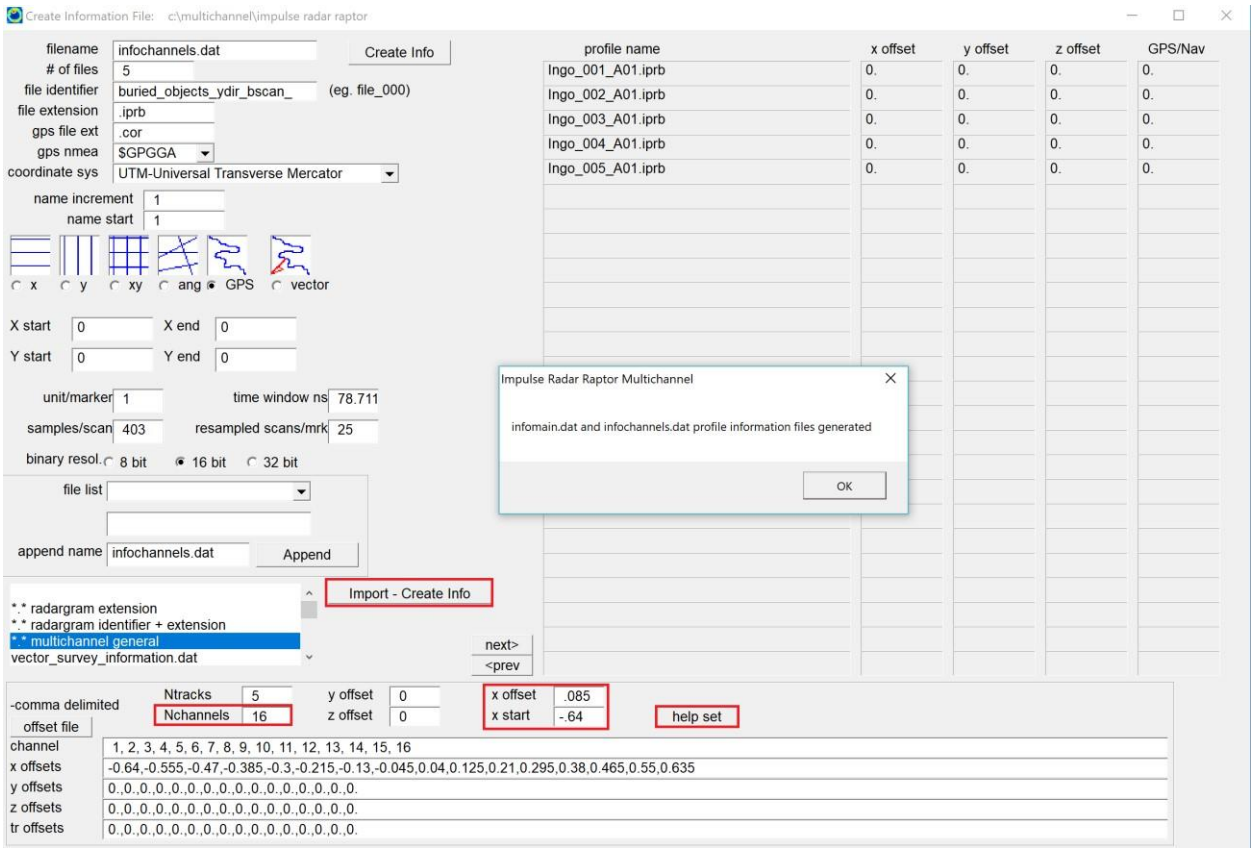
After these steps continue to the section entitled: **Processing Operations for all Multi-Channel GPR Systems.** This will show the steps for generalized signal processing for all multichannel GPR and how to compile these data to a 3D volume.

Impulse Radar - Raptor

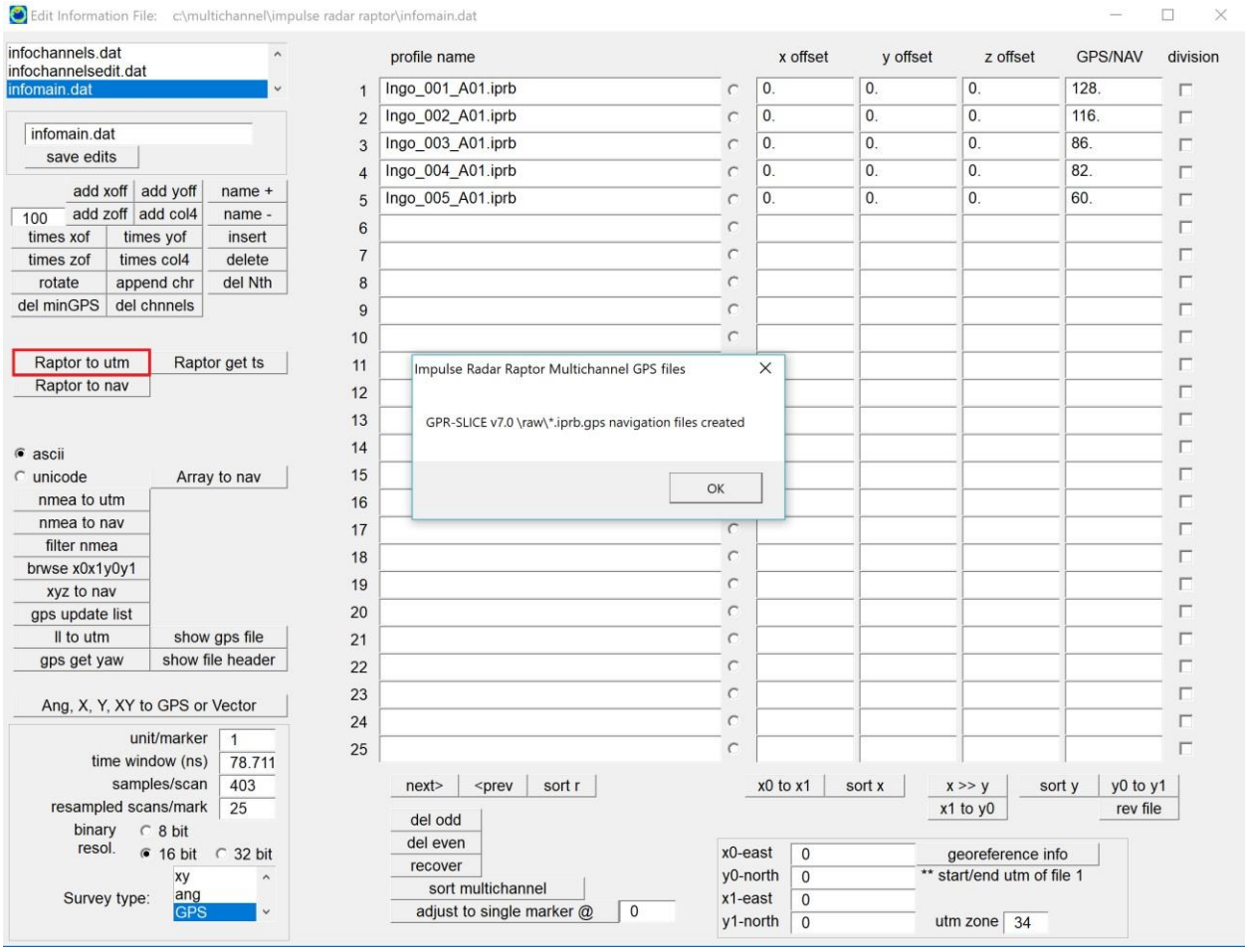
The basic processes for the 16 channel Impulse Radar Raptor multichannel system are:

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.

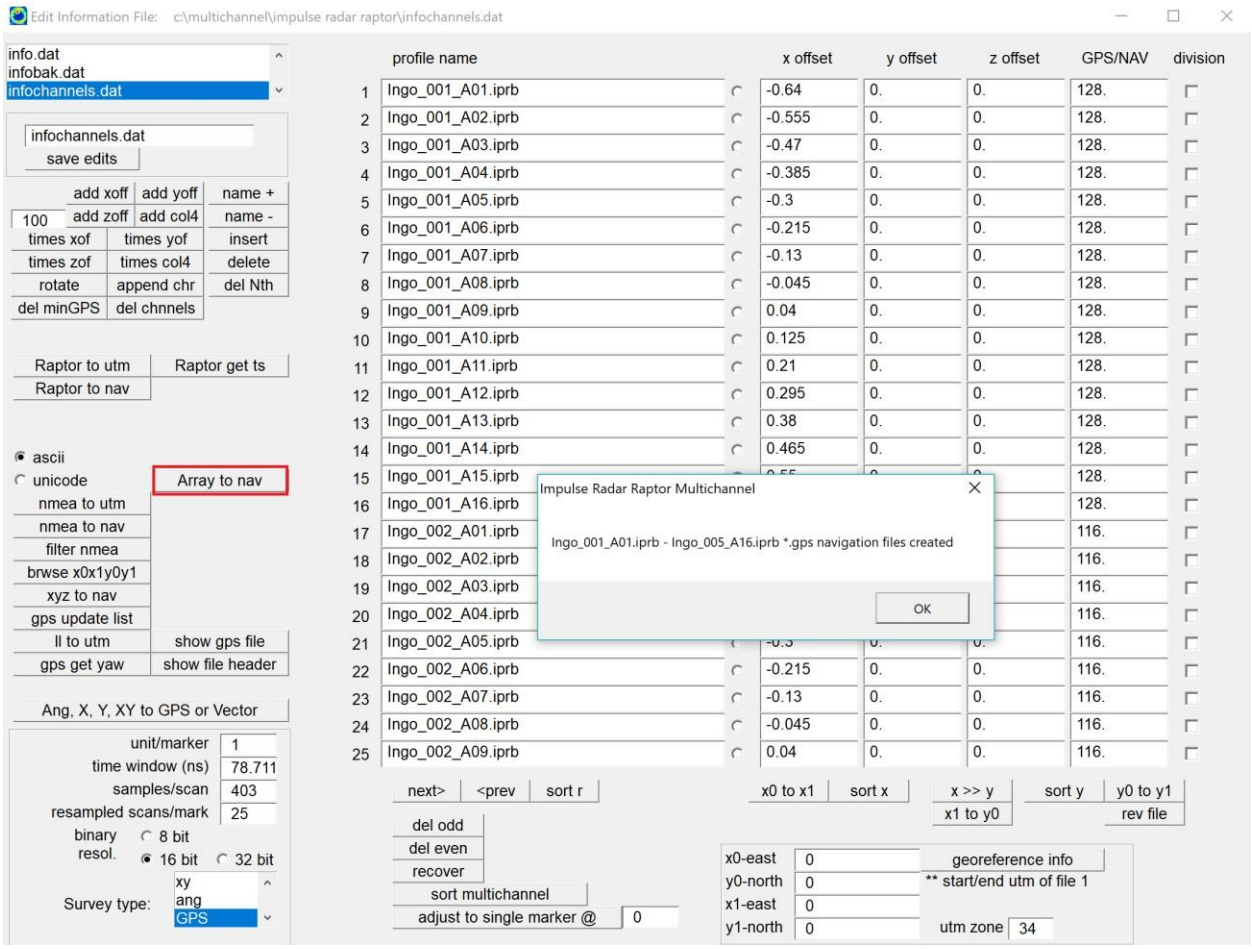
2) Click the "Import – Create Info" button in the Create Info File menu with the *.* multichannel general highlighted. This will create the infomain and infochannel information files.



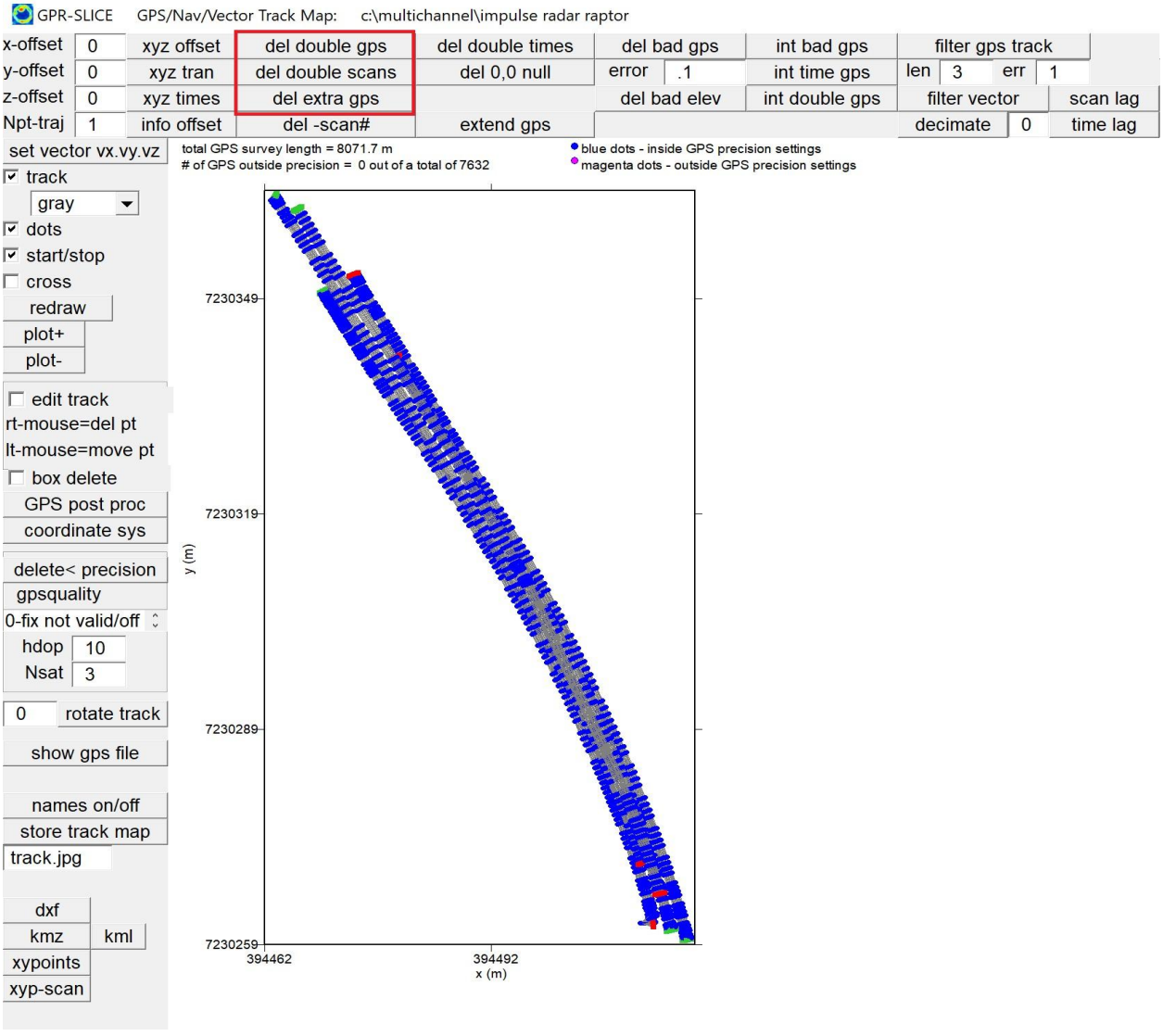
3) In the Edit Info File menu, click the "Raptor to utm" button with infomain.dat active to create the main track navigation. If navigation errors are reported those can be fixed in the GPS track first.



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

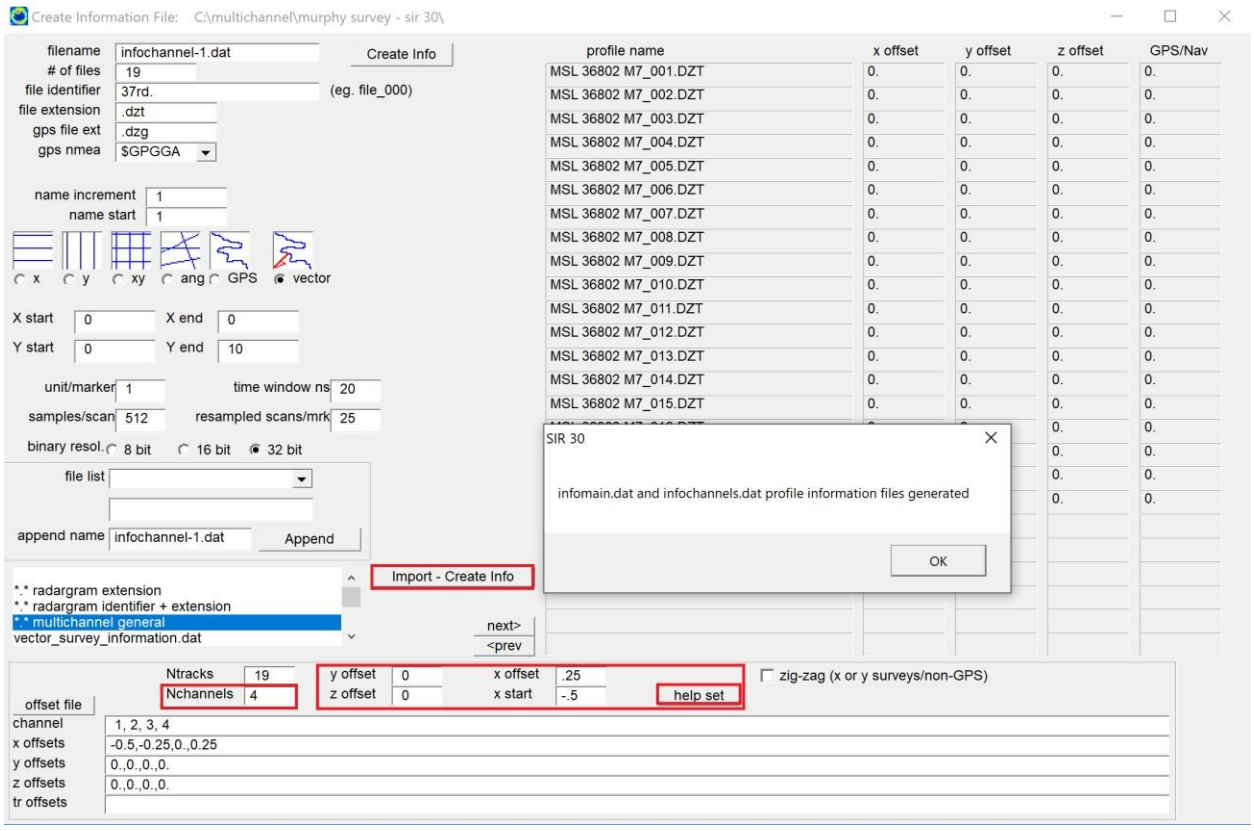
GSSI SIR 30

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.



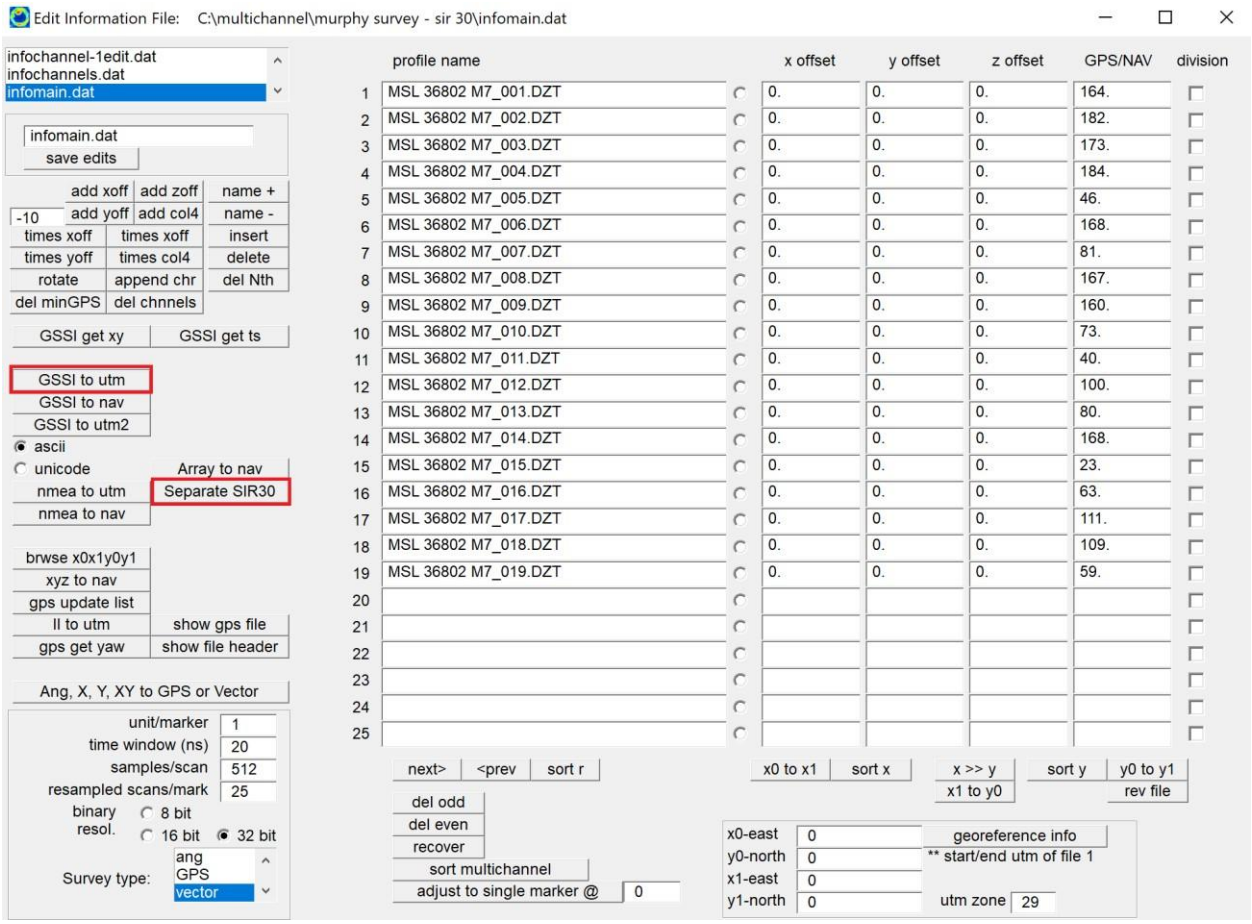
infomain.dat: contains the name of the main track 32 bit multiplexed radargrams
infochannels.dat: contains the extract channels with -N.dat designation

Edit Info File menu:

3) highlight the infomain.dat file

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

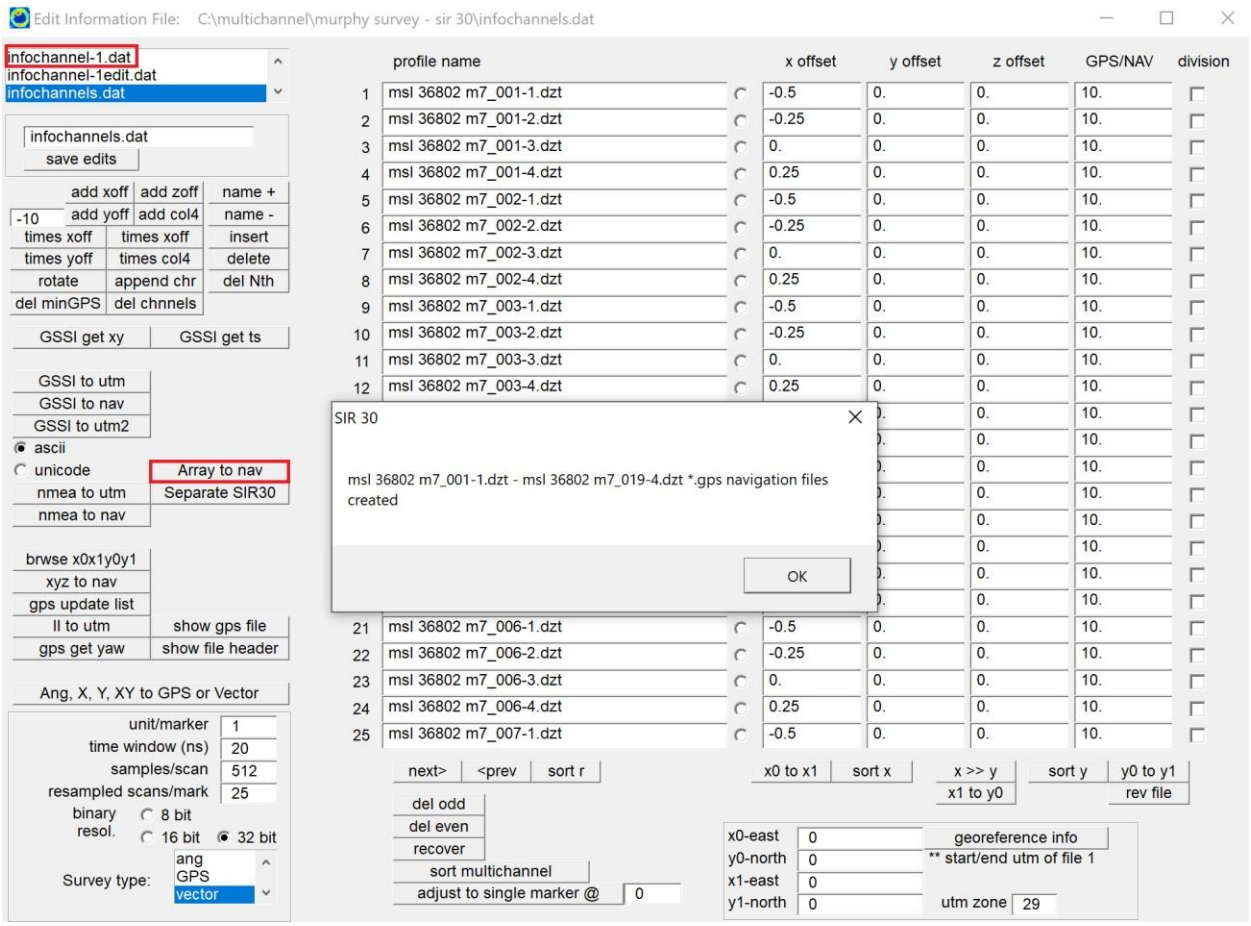
5) click the Separate SIR30 button to extract the individual channels



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.

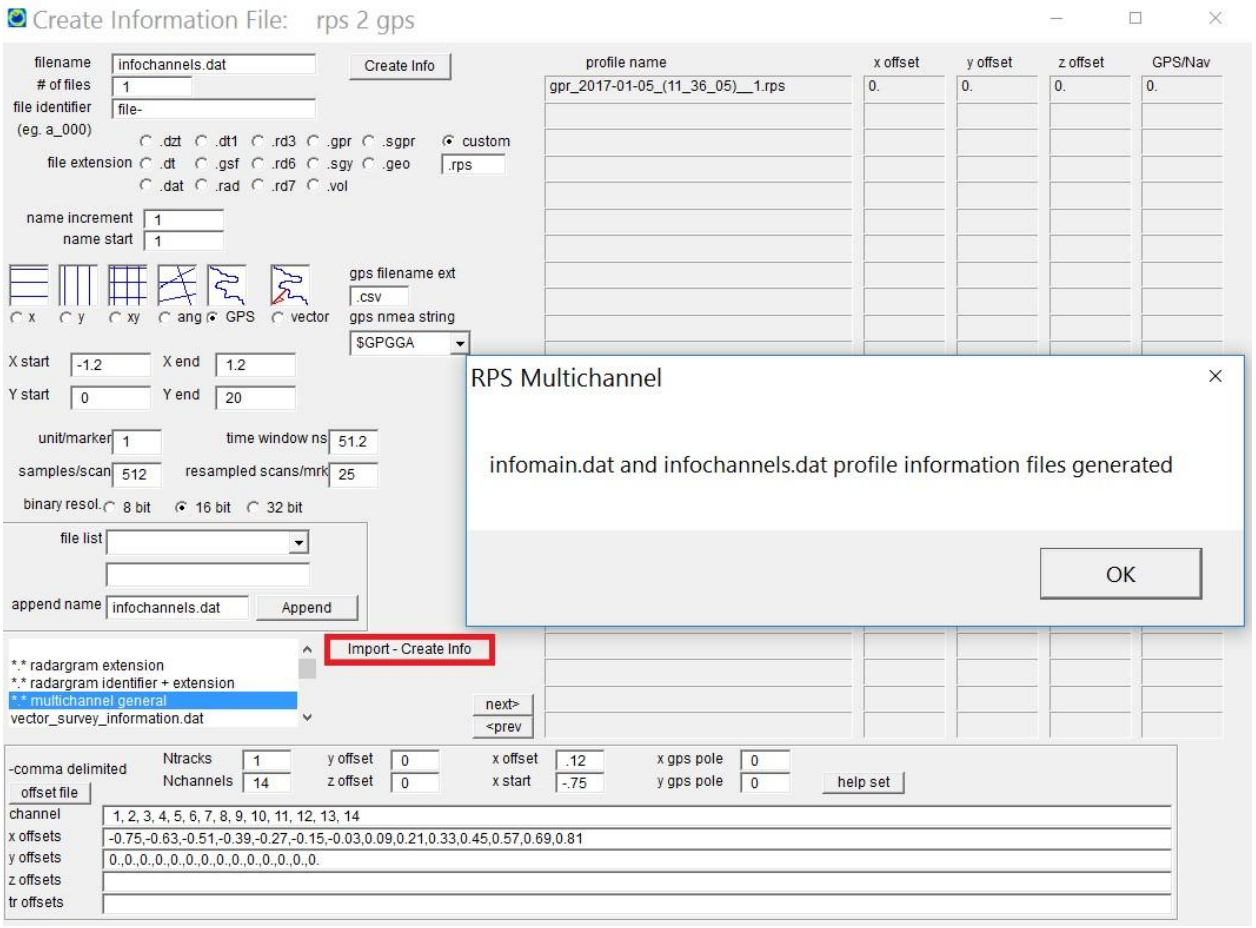
8) click on the infochannel-1.dat (or -2,-3,-4.dat) and begin standard processing….



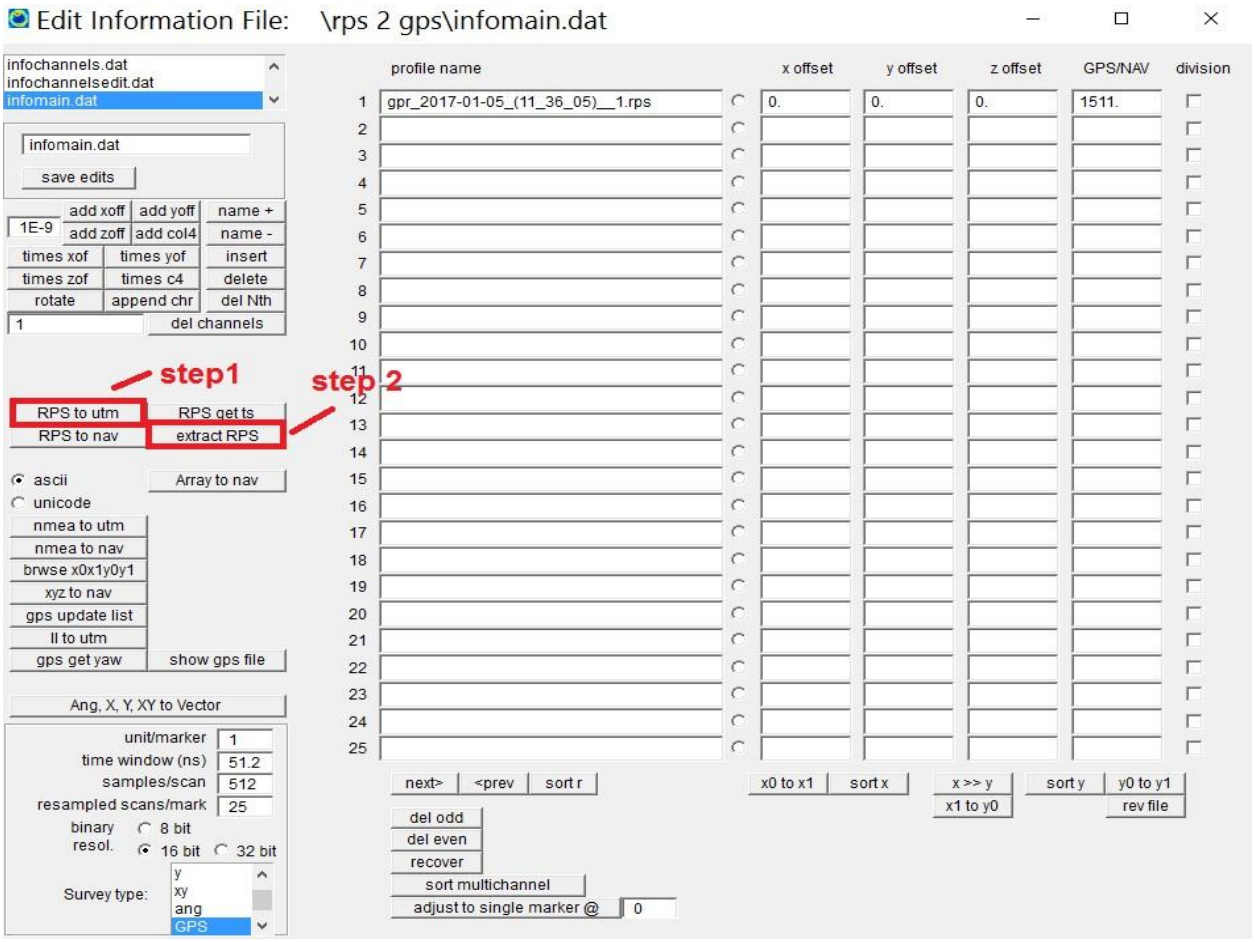
RPS Multichannel

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 :

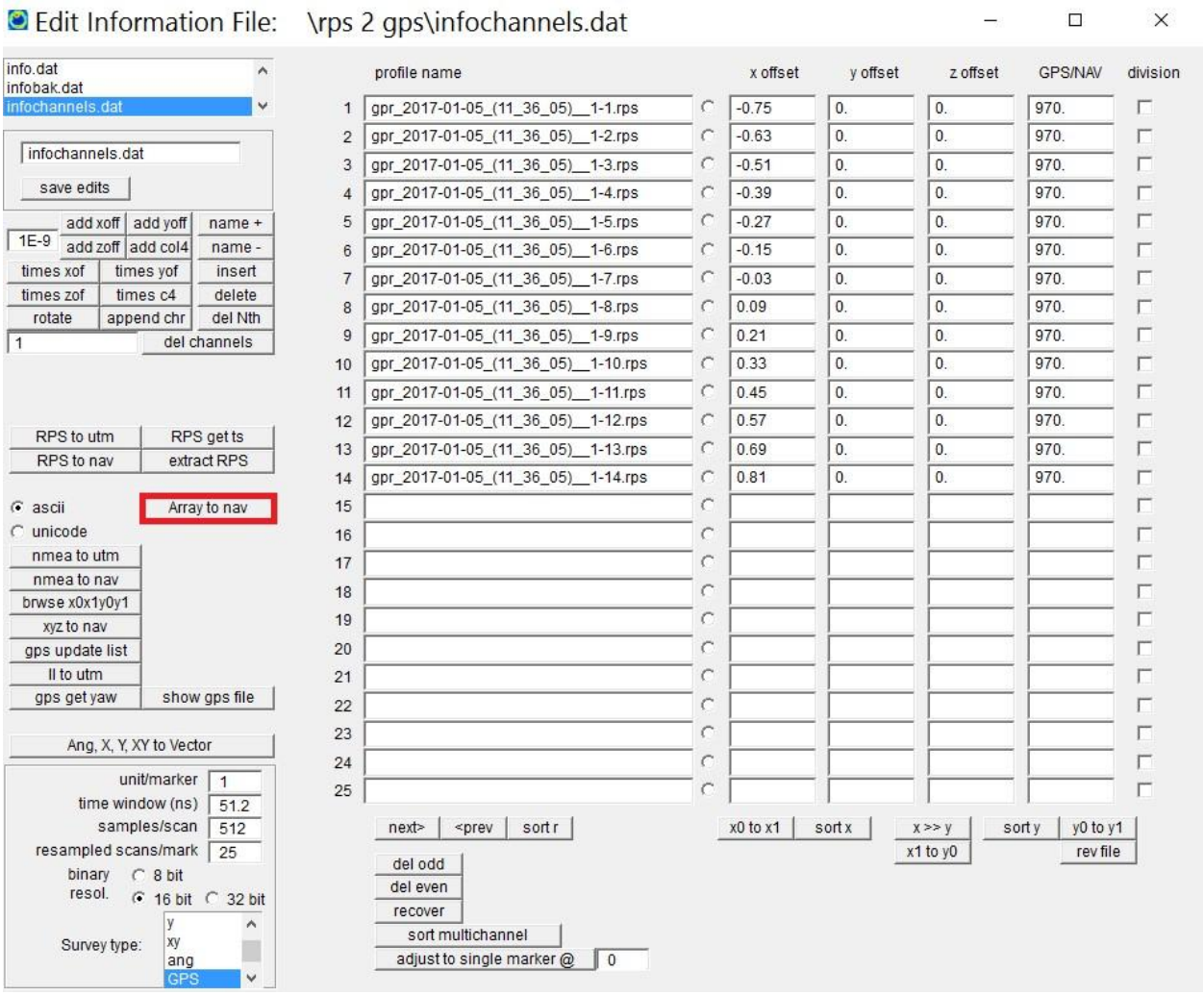
1) Create the infomain and infochannels.dat file in the Create New Info menu.



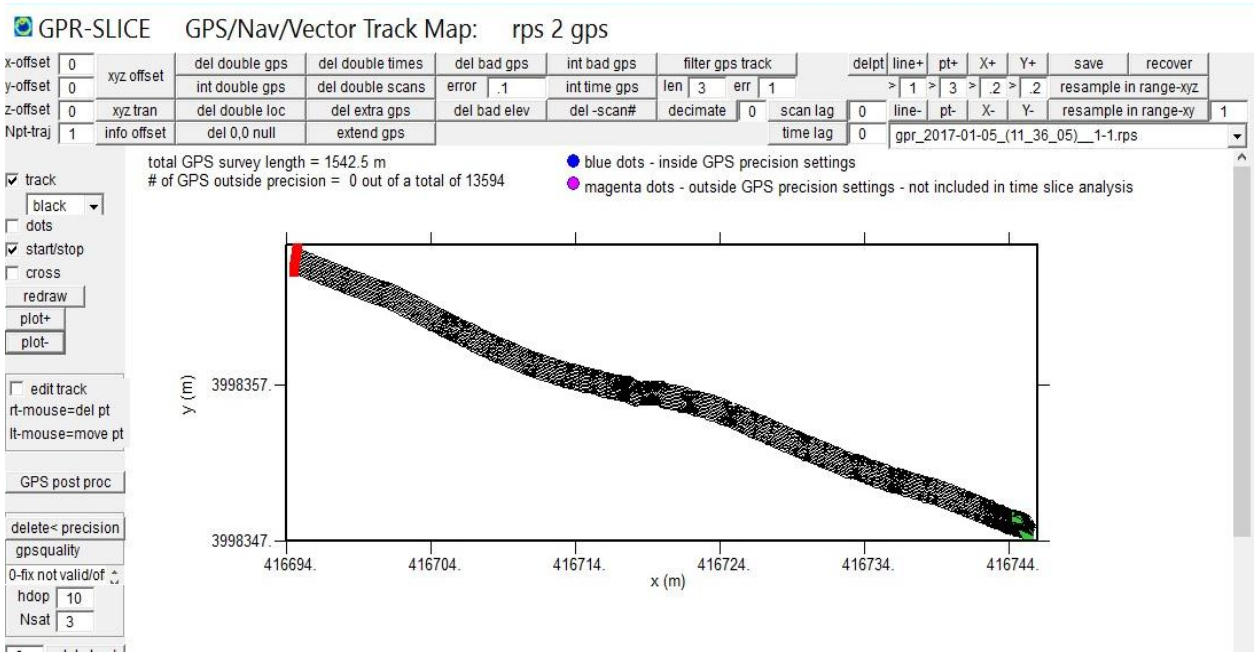
2) Create the navigation using the RPS to UTM button. As of 4/13/17 RPS is still developing their file conventions, but there current *.csv navigation files needs to have the same name as the main track names in the infomain.dat, but just with the *.csv extention. Clicking RPS to UTM will generate the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



An example of an RPS multichannel GPS track is shown below:

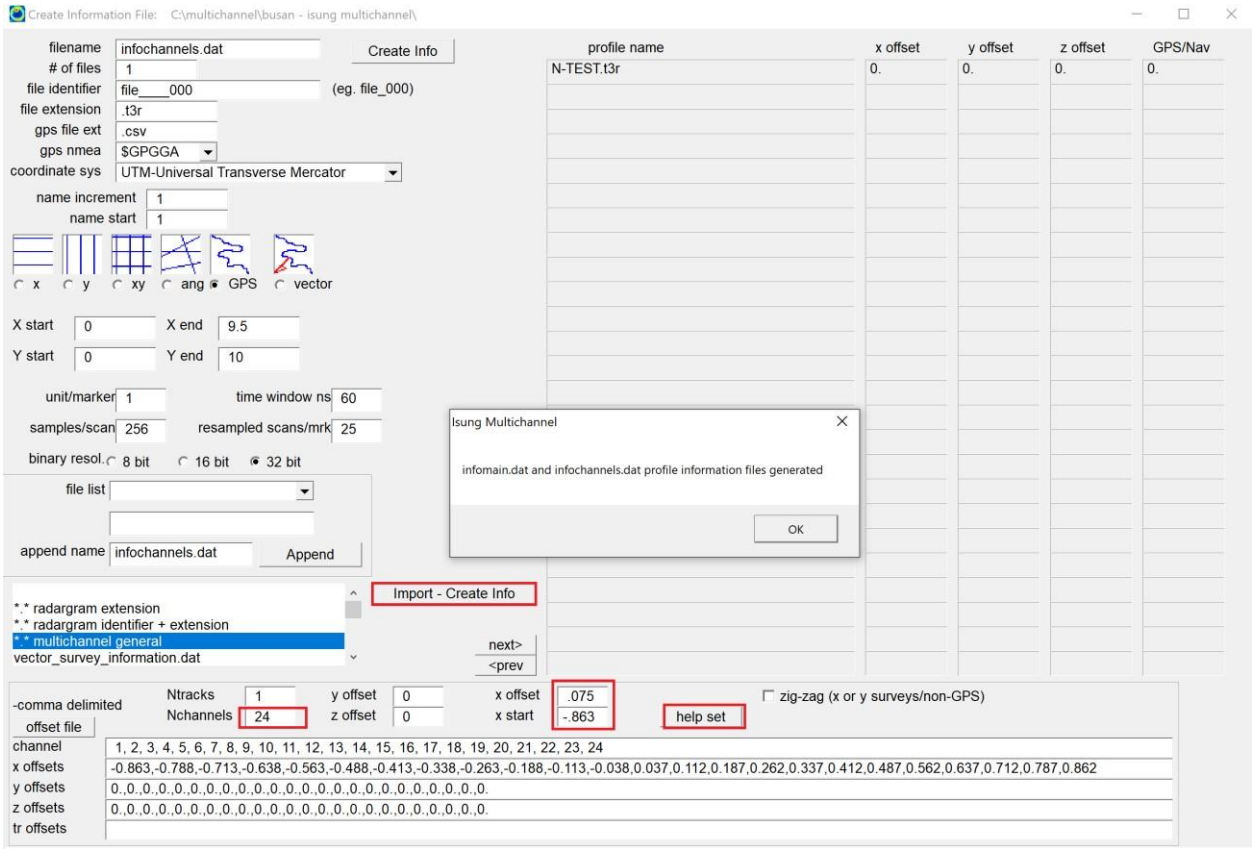


After these steps continue to the section entitled: **Processing Operations for all Multi-Channel GPR Systems.** This will show the steps for generalized signal processing for all multichannel GPR and how to compile these data to a 3D volume.

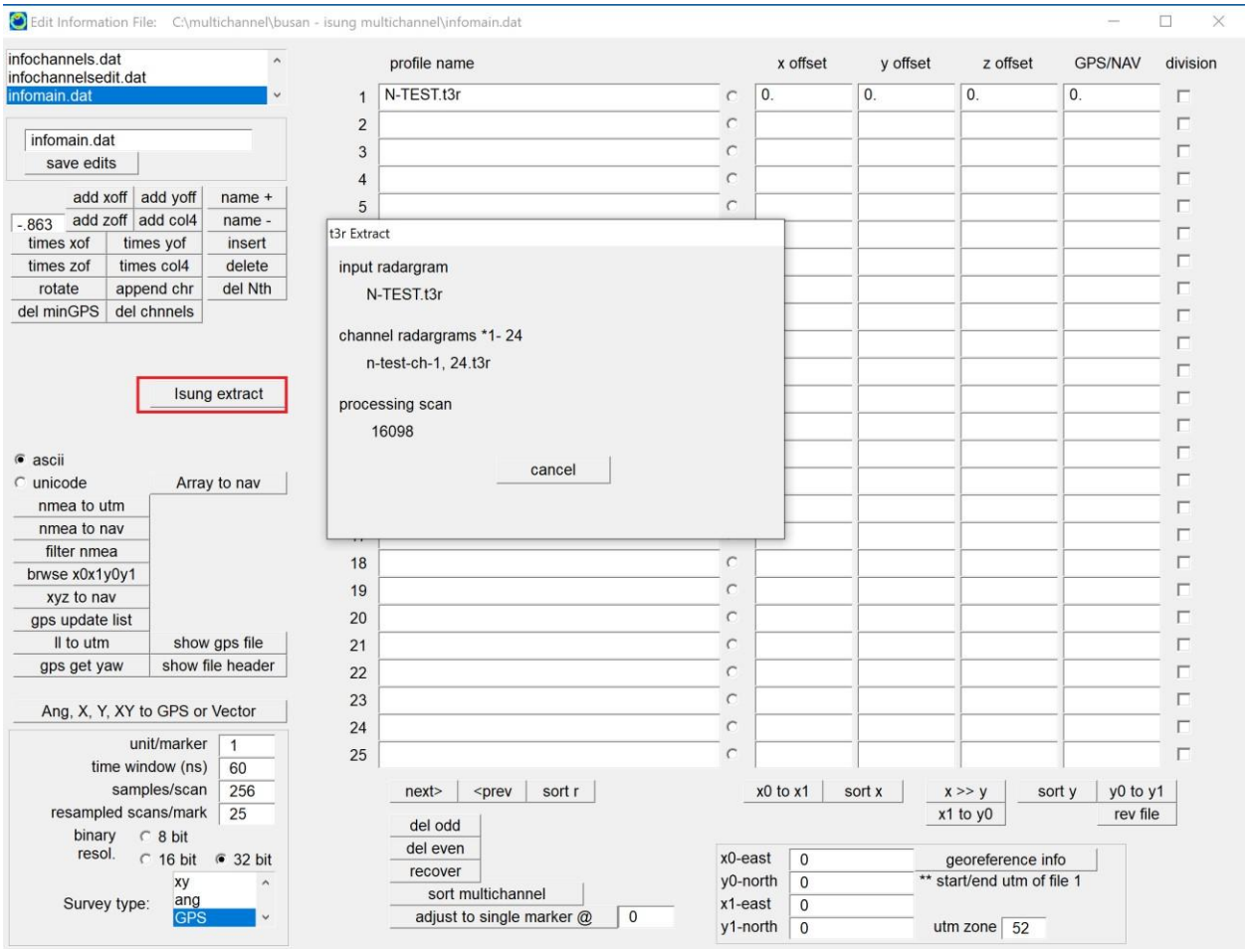
ISUNG Multichannel

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:

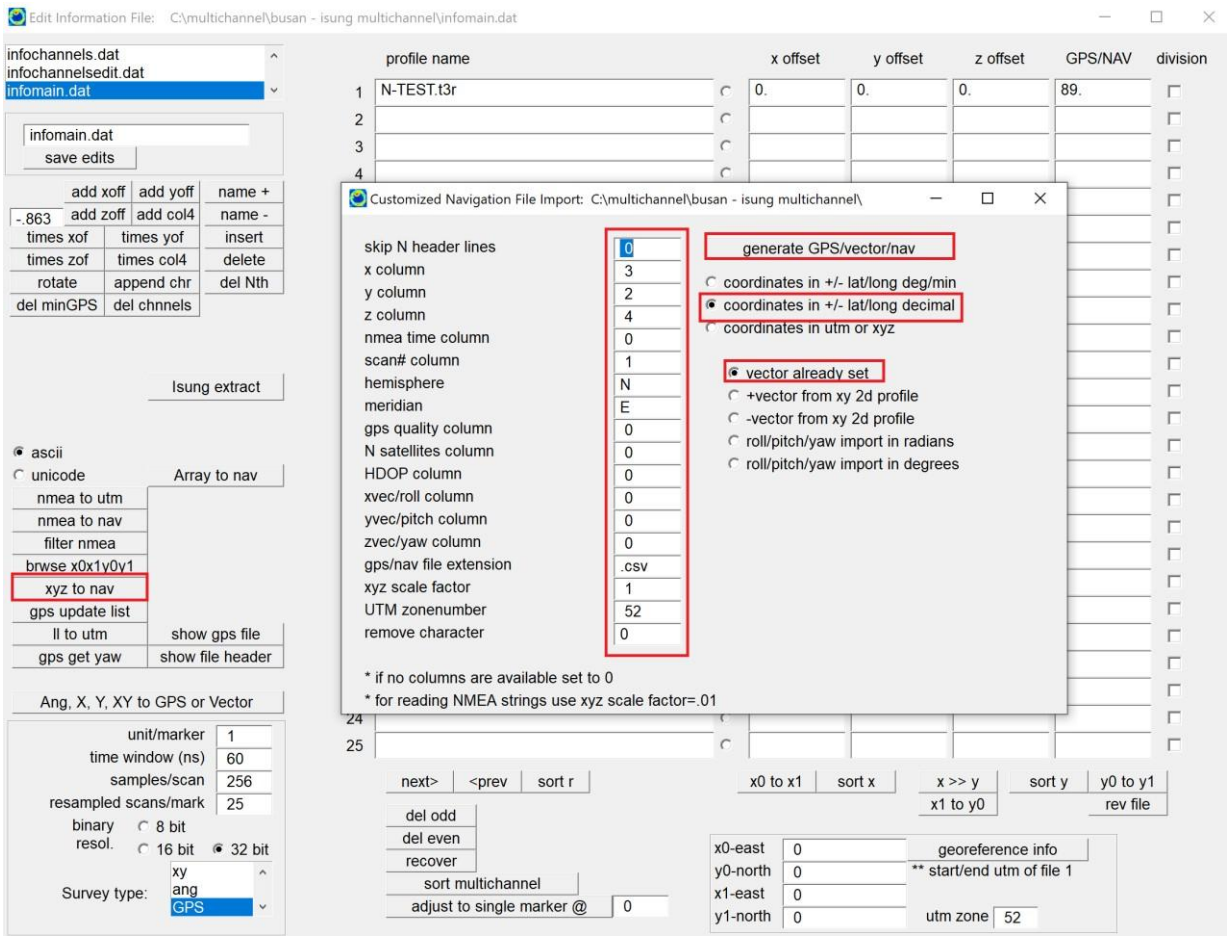
1) Create the infomain and infochannels.dat file in the Create New Info menu. One will need to set the Xoffset between channels and the Xstart value for channel. Also, the number of channels are set before the button Help Set is clicked.



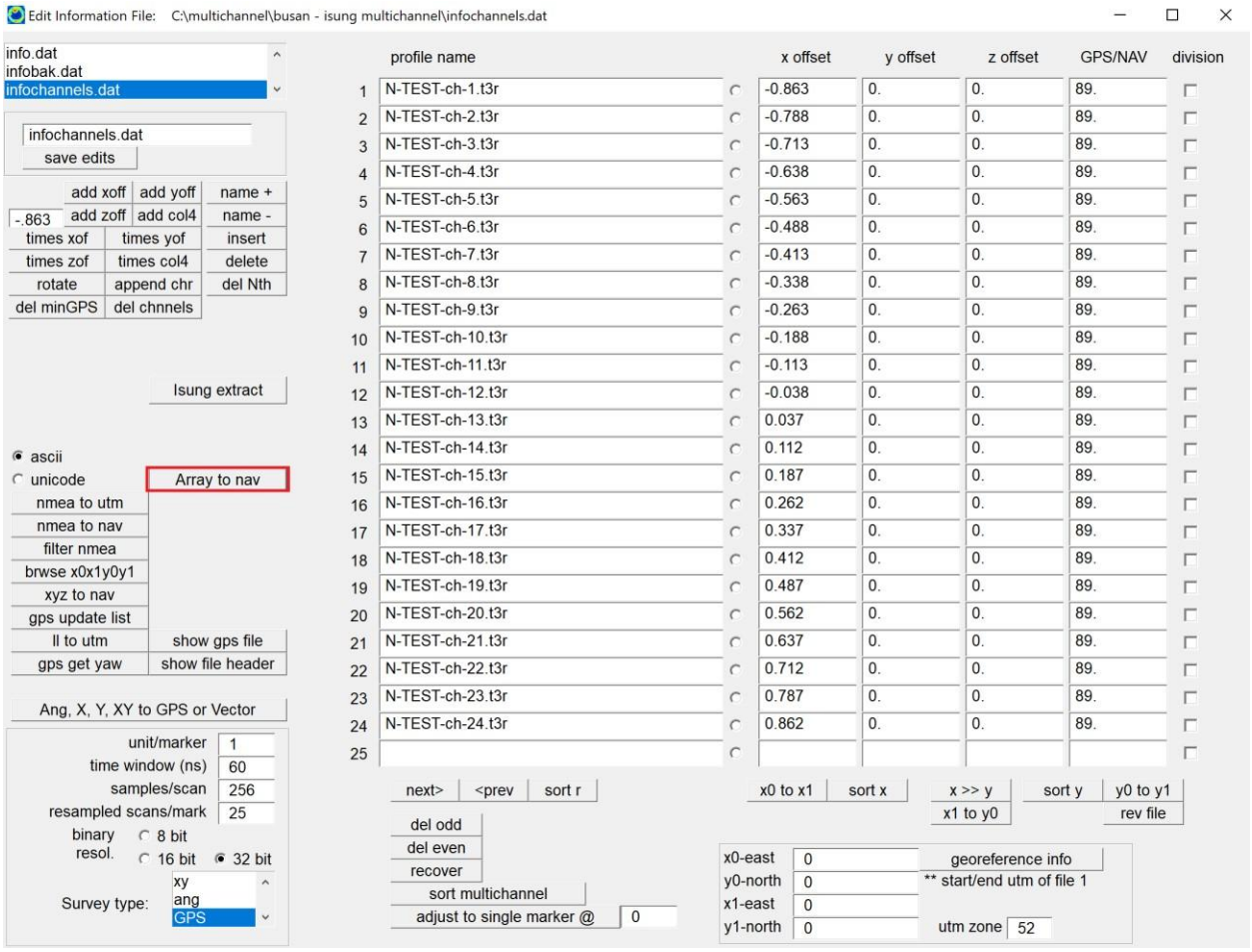
2) Next step is to extract the individual channels from the multiplexed radargrams from the infomain.dat file. The extracted channels are written to the \radar\ folder of the project.



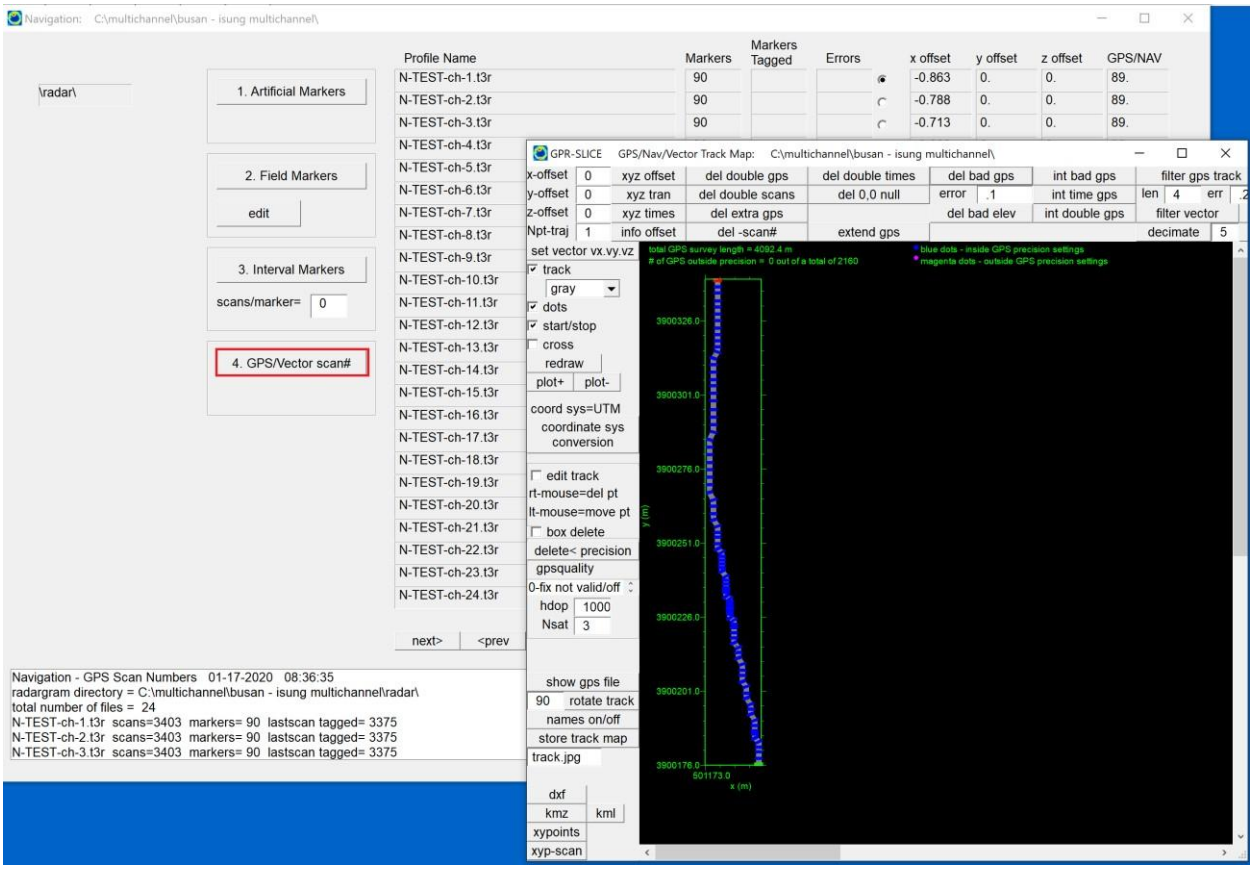
3) Create the navigation using the XYZ to NAV button with the all the settings shown in the menu. This reads the *.csv file containing all the information on the GPS navigation and will convert to GPR-SLICE format and make all the UTM conversions.



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.



An example of a single swath of an Isung multichannel GPS track is shown below:



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

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
- Background removal
- Spectra+Gain/Bandpass filtering
- 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

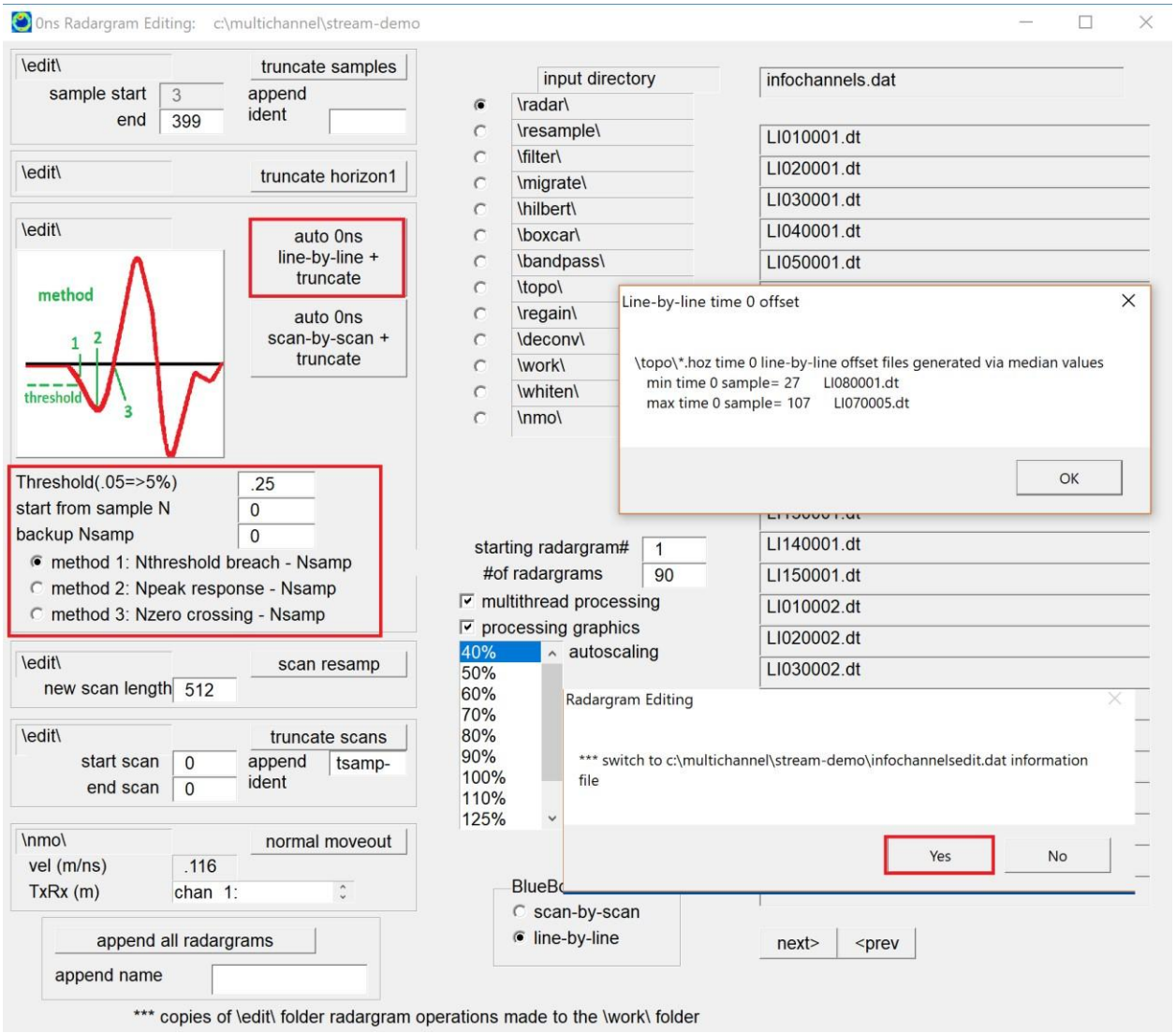
The 0ns editing is a critical step. The user should experiment and view the 0ns edited radargrams of the extracted channels to make sure their settings for the 0ns triggering and detection look reasonably good. In this example above, a threshold of .2 on the peak response is set. If there is digital 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.

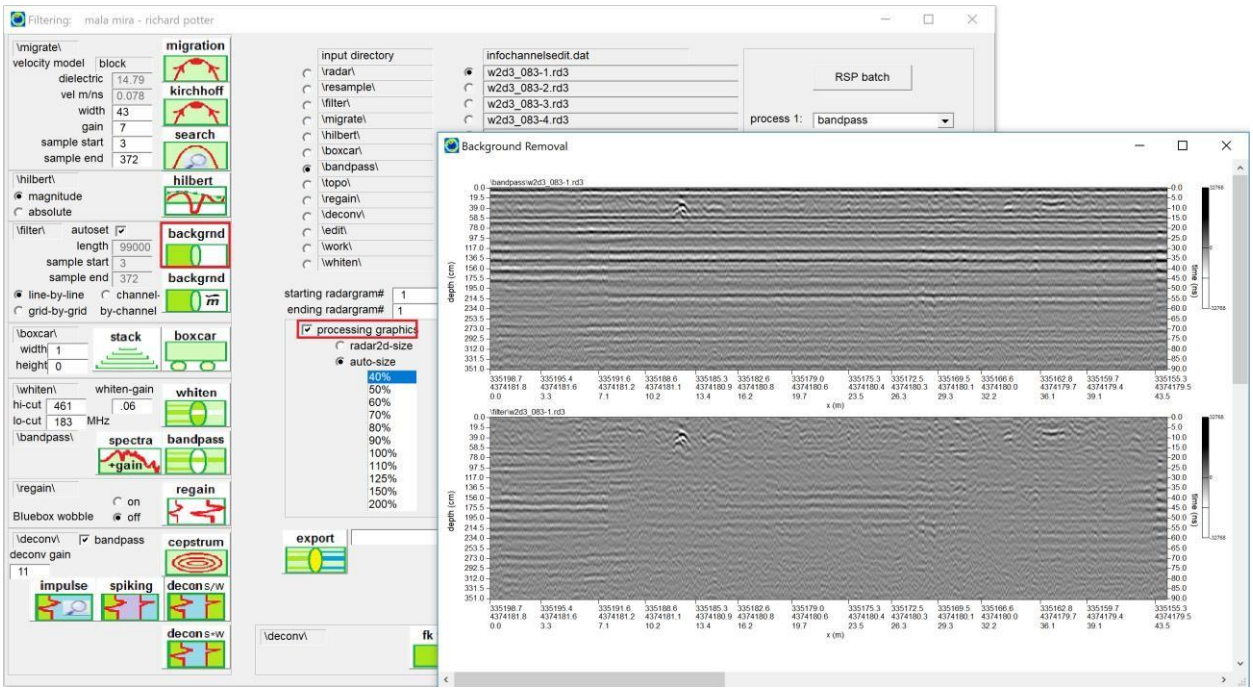
After the 0ns editing is done, a new information file, infochannelsedit.dat is automatically generated which will have the new samples/scan of the 0ns edited radargrams which are written to the \edit\ folder of the project. After completing the 0ns editing process, the user needs to go back to the Edit 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.



Background Filtering

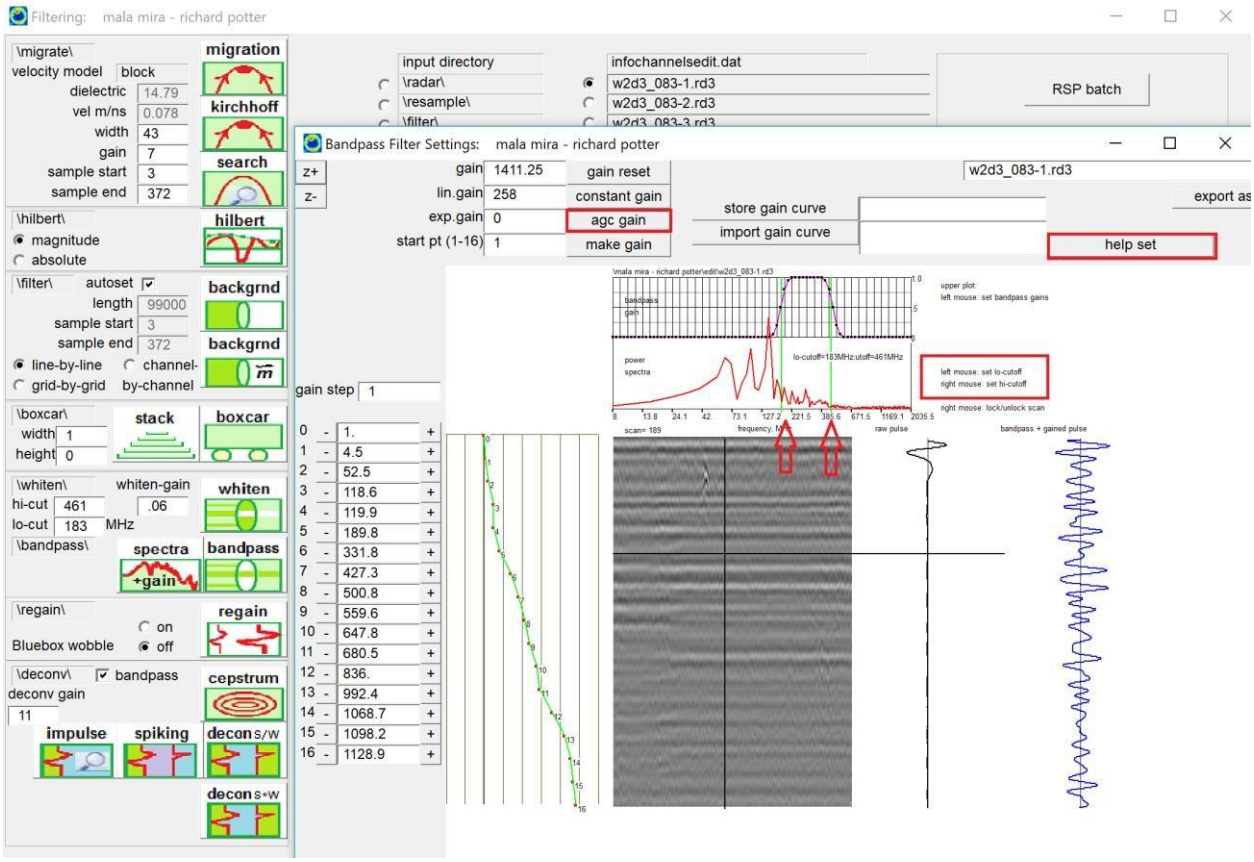
Background filtering is usually necessary for multi-channel systems to better balance the channels and to remove banding noises. The background filtering process is run on the \bandpass\ folder. Note, a long filter length – greater than the total length of the radargram – should normally be set here 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.)



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.

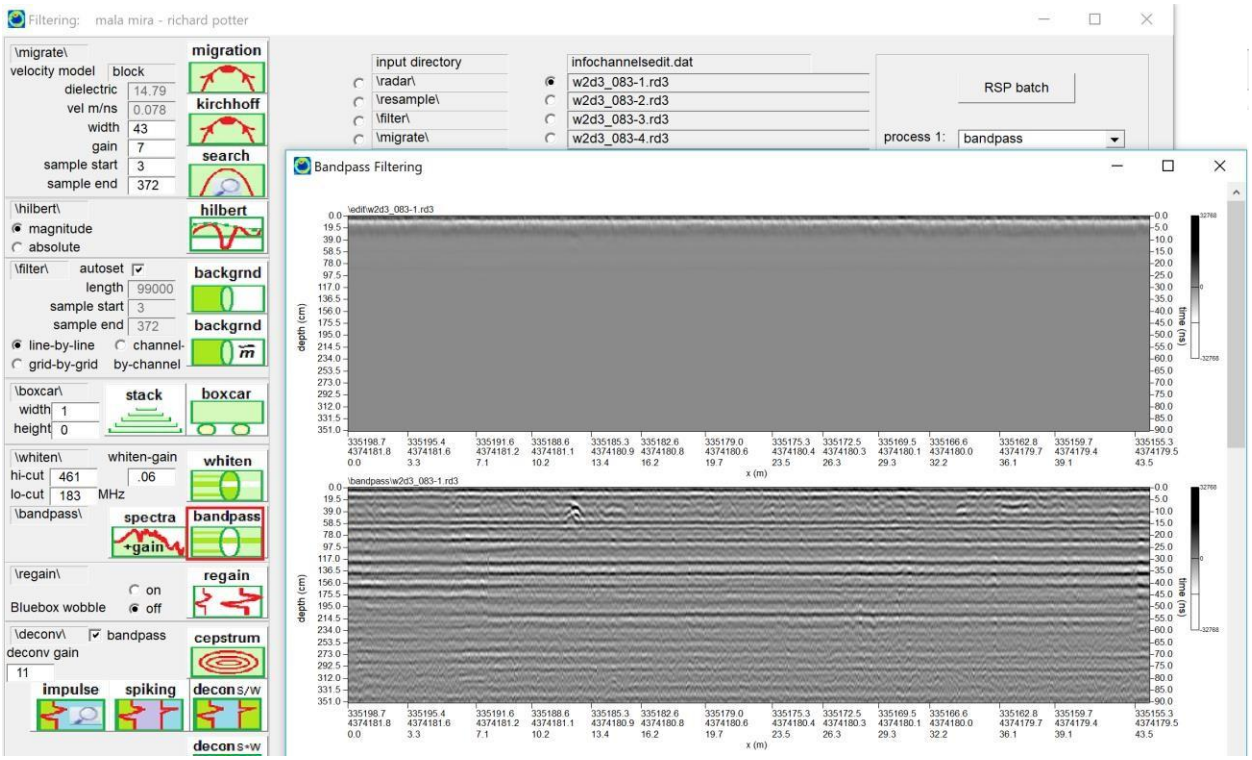


In the Spectra+Gain menu the first operation the user will do is click the AGC Gain button. After this they will then set the lo-cut and hi-cut bandpass

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.



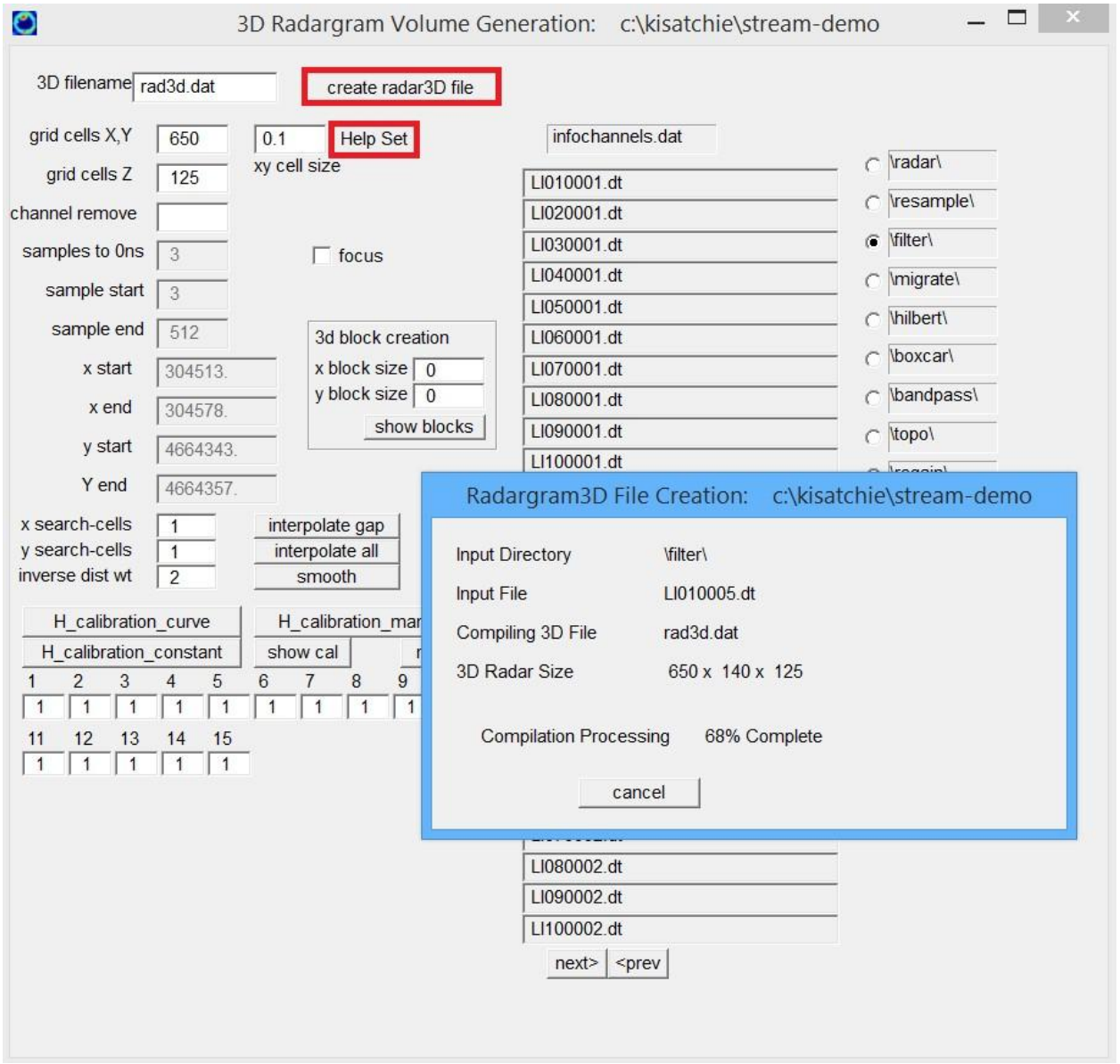
3D Radargram Volume Generation

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

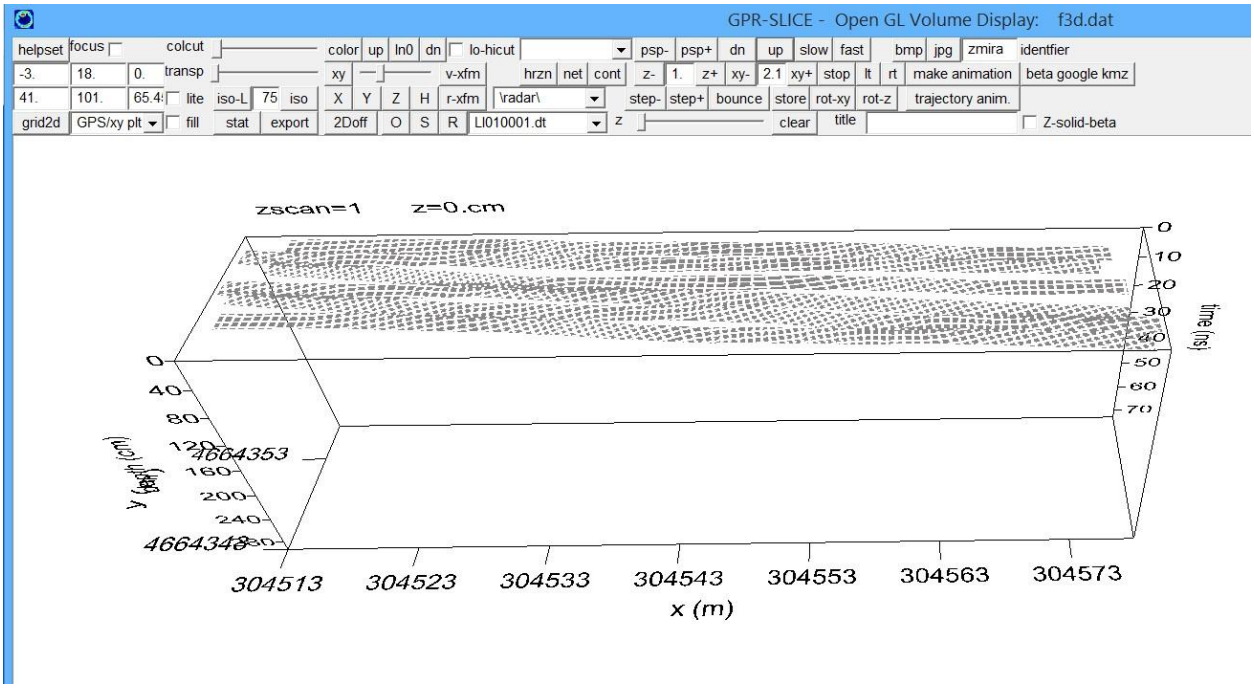
set to the exact sample length as well – generating a volume that is exactly the total resolution of the recorded pulse. Heavy volumes though, may sometimes have limits in Open GL if a good himemory graphics card is not be used.



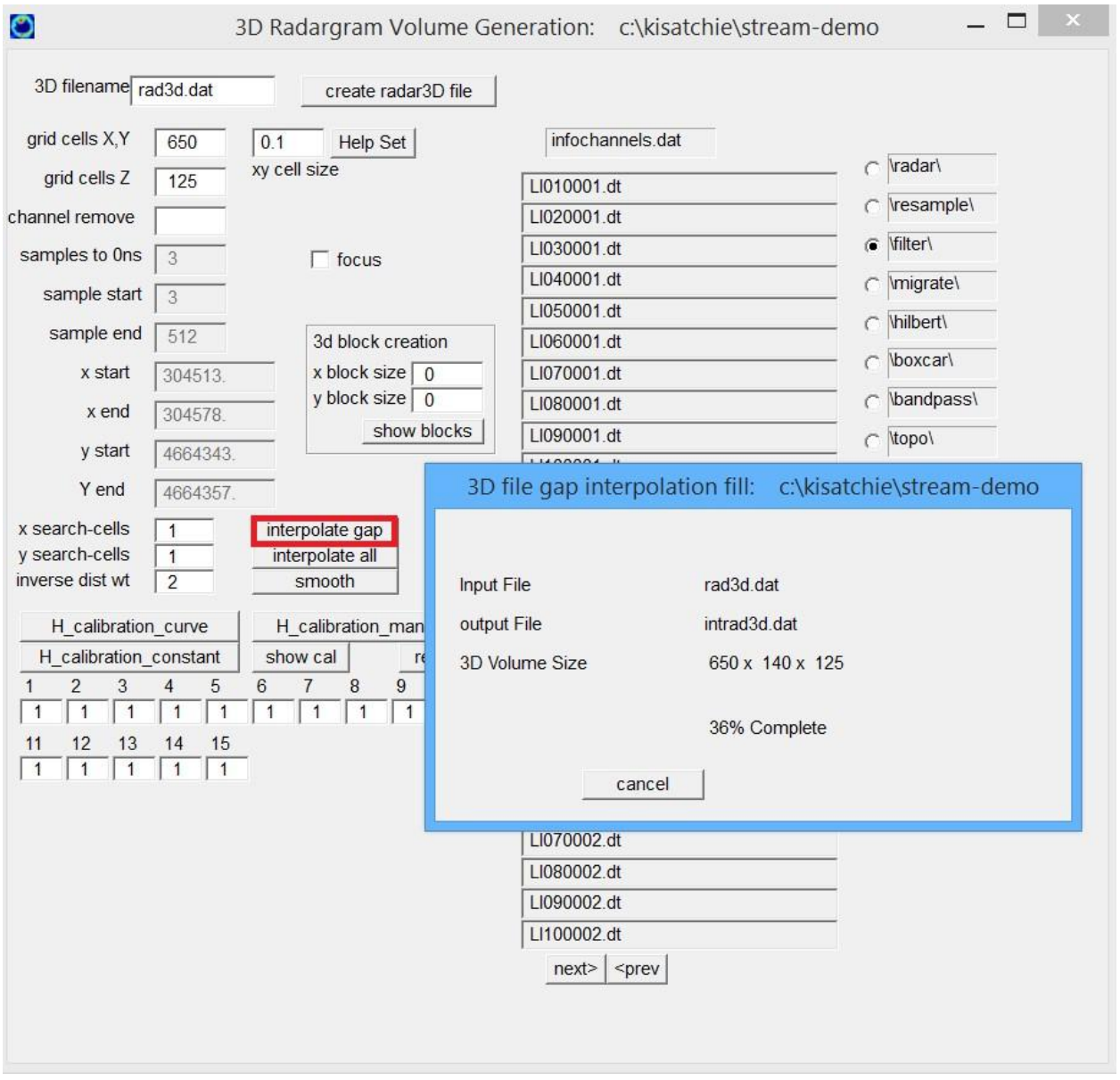
Interpolate Gap

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.

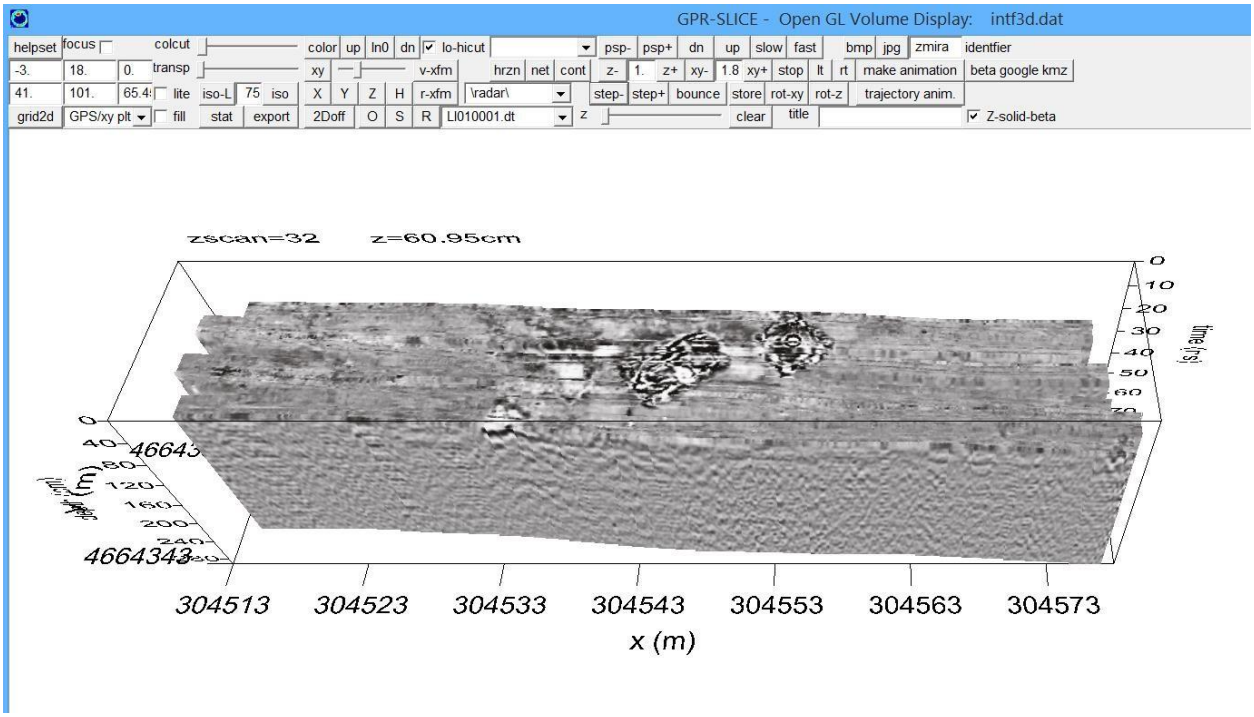


To fill in the gaps in the 3D volume, the Interpolate Gap operation is run. In this example, the x and y search-cells is set 1. The searching looks an equal distance in all directions to fine nearby cells that have data for the inverse distance interpolation. (Optionally, a button called Interpolate 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.

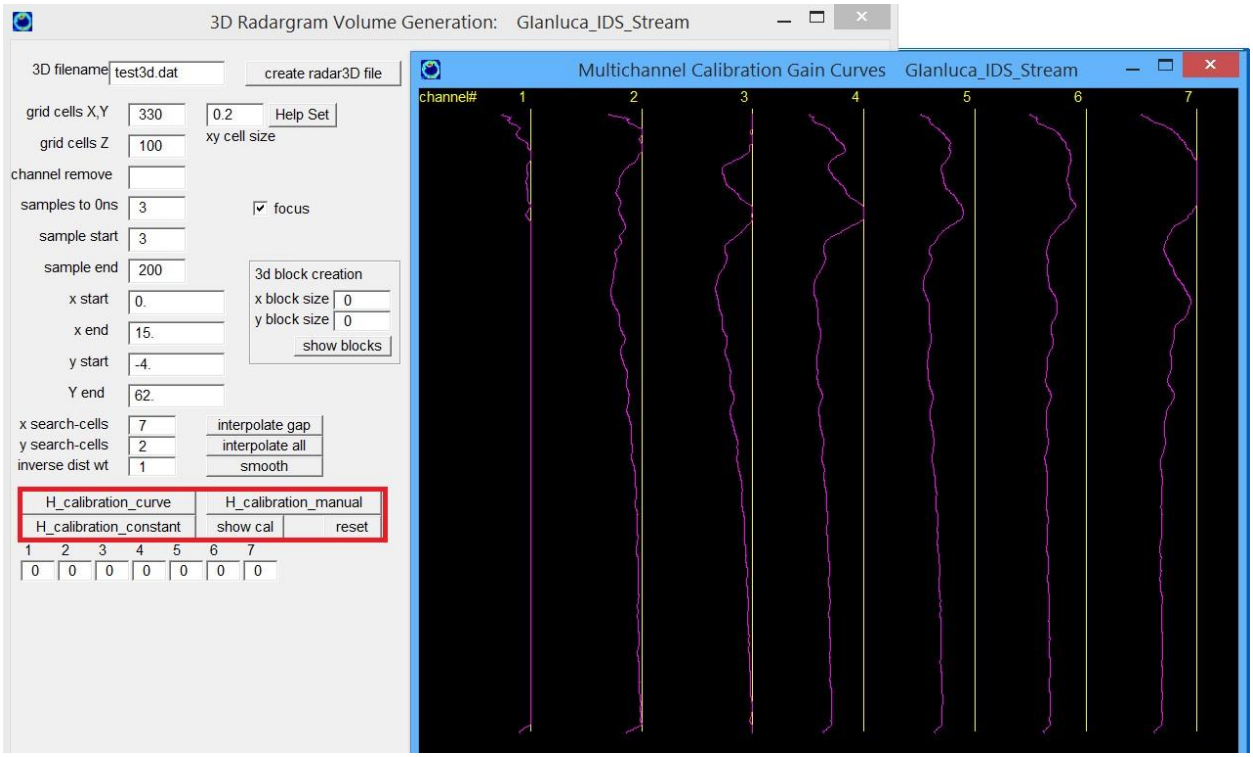
An example of the previous dataset with interpolation is shown in the next figure:



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.

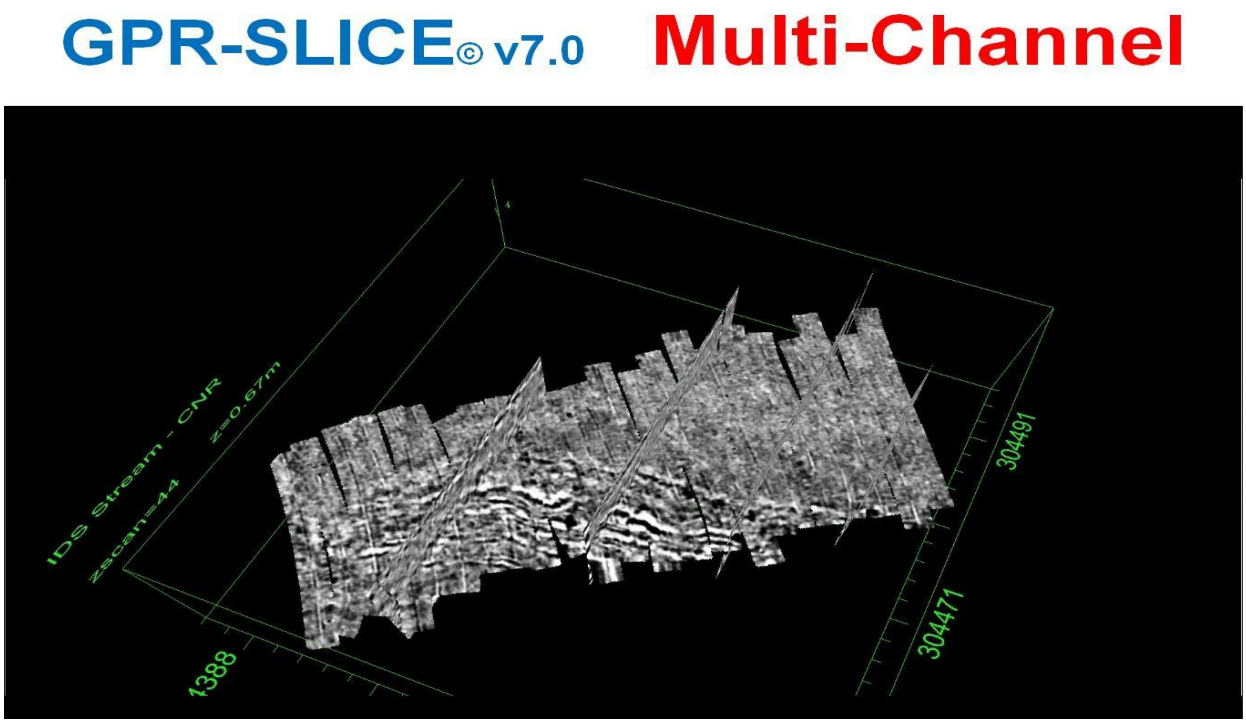


Examples of Multi-Channel Imaging

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.

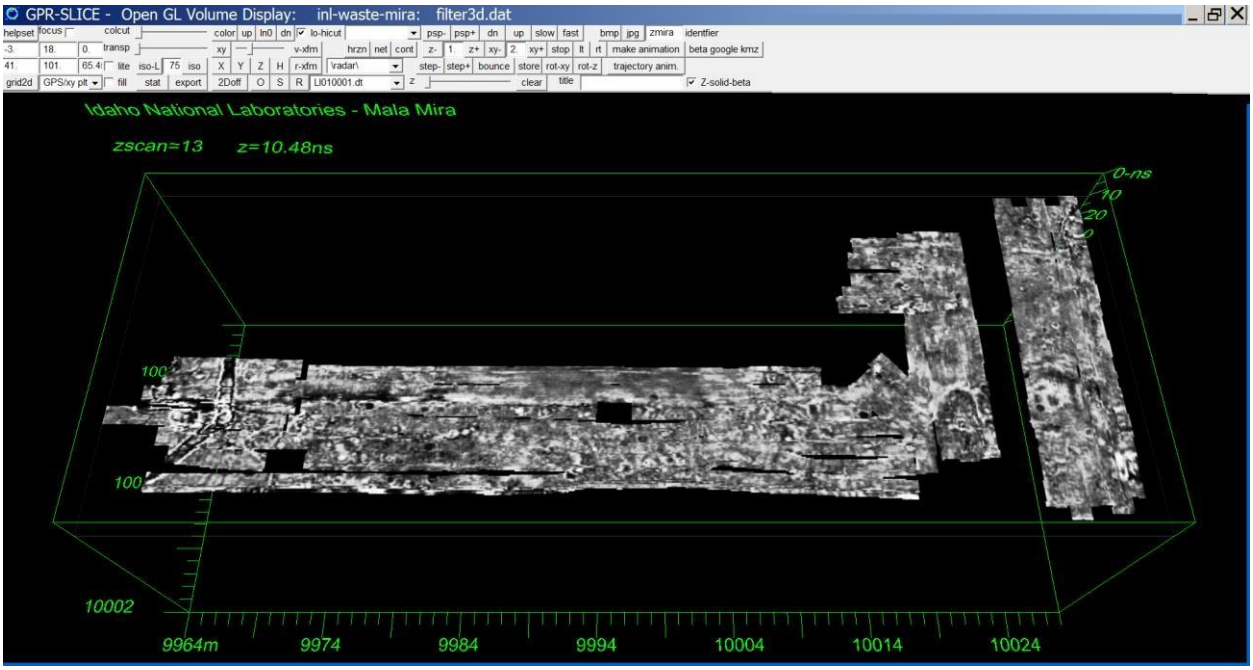
A recent survey done for a 1.5 hectare section of the Carnuntum site in Austria with 1232 radargrams was compiled to a 3D volume in just 75 seconds - after which viewing in Open GL Volume Texture Method menu could be easily accessed!

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:



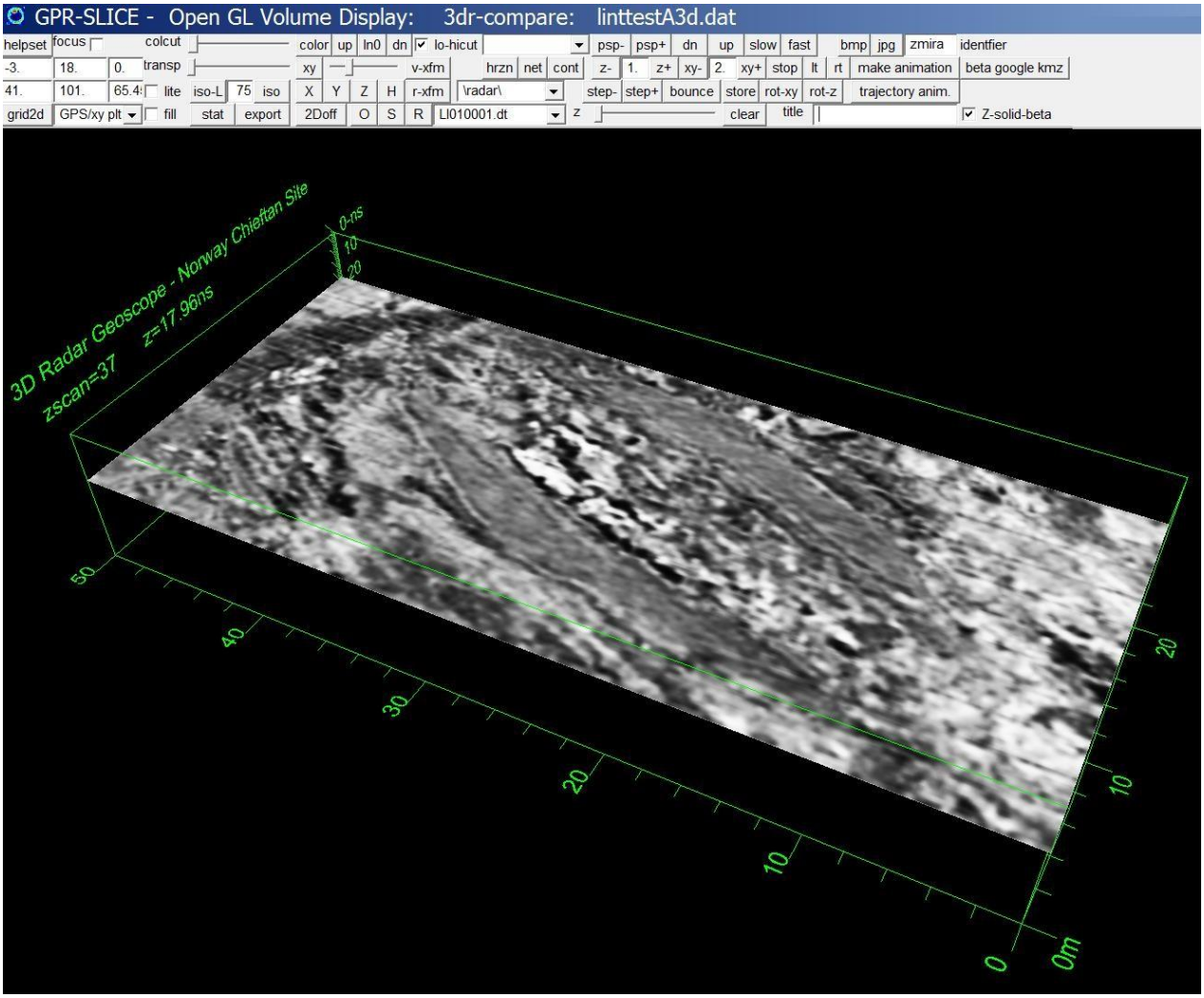
(Data courtesy Gianfranco Morelli of Geostudi Astier, Italy, www.geostudiastier.com)

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.)

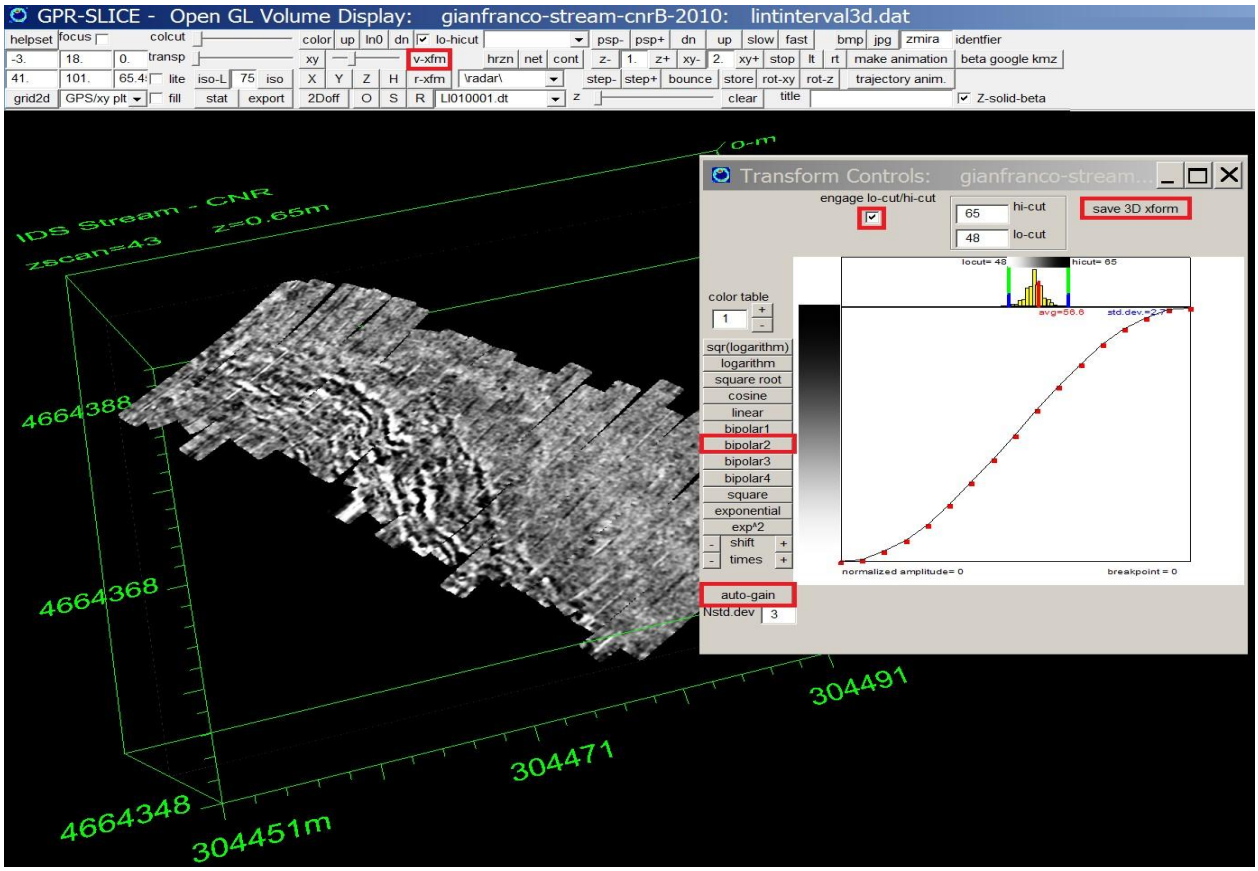
A GPR-SLICE image made from data collected at an archaeological site in Norway and using the 3D Radar Geoscope multichannel system is shown in the next screen shot. The equipment was configured in a 31 channel configuration with 5 cm separation between antenna. The image shown used only half the channels 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

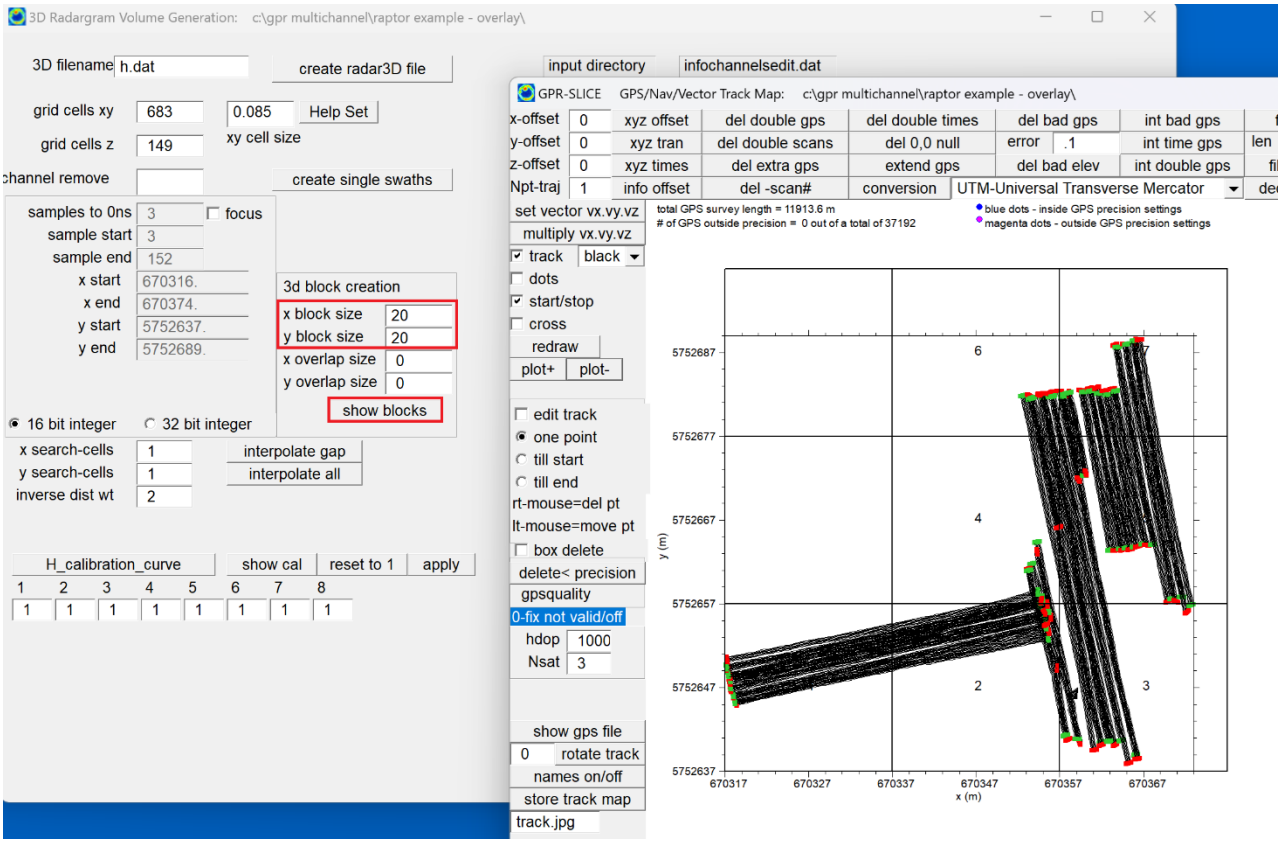
With the new 3D Radargram Volume Generation menu, it will be more common to also generate volumes of the processed pulses. For this reason, it was useful for GPR-SLICE to have additional transforms to optimize the colorization of pulse 3D volumes. Bipolar transforms 1-4 are now included in the 3D and 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.

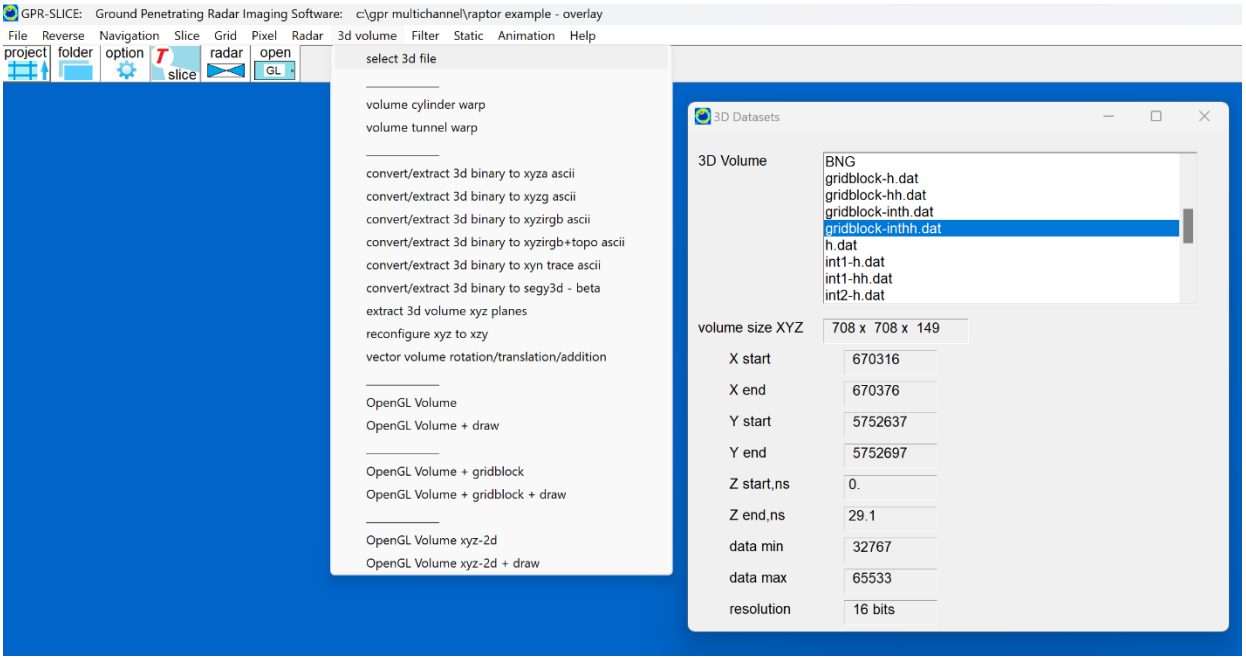


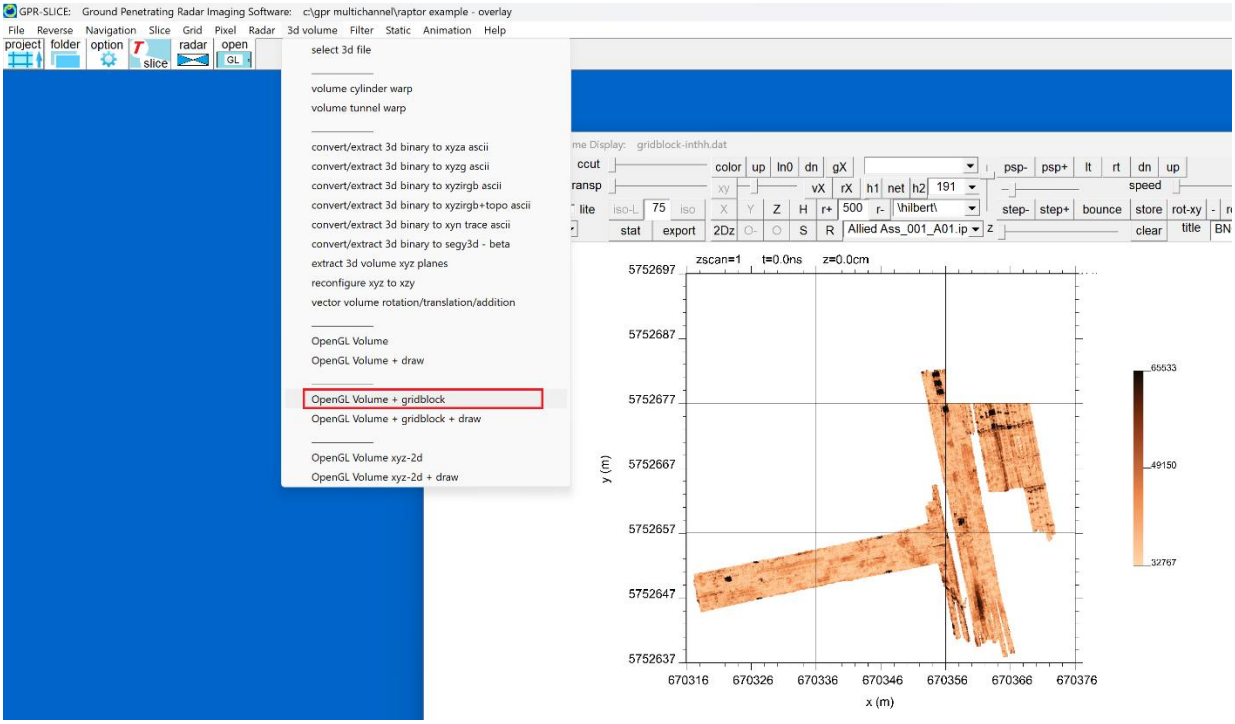
Gridblock Operations

When multichannel datasets get very large, the compilation of these sites to a single 3D volume will reach its memory limit. To overcome this GPR-SLICE was developed to create partition a site into equal size blocks and then to seamlessly put these blocks back together in OpenGL or in a specialized Pixel map menu. In particular when sites are above 100x100m or even less depending on the density of the multichannel array or the desired density to achieve in the 3D volume, the site can be broken into blocks of a convenient size, e.g. 50x50or 20x20m. The blocks can also be rectangular in length. An example of a block gridded site is shown in the diagram below. In this example the total site is represented by 7 blocks. On creating the 3D file, individual blocks with 1- to N- are appended to the 3D filename. The interpolate button will also automatically interpolate across the gridblock dataset and make a whole new set of 3D files with "int" appended to the filenames.

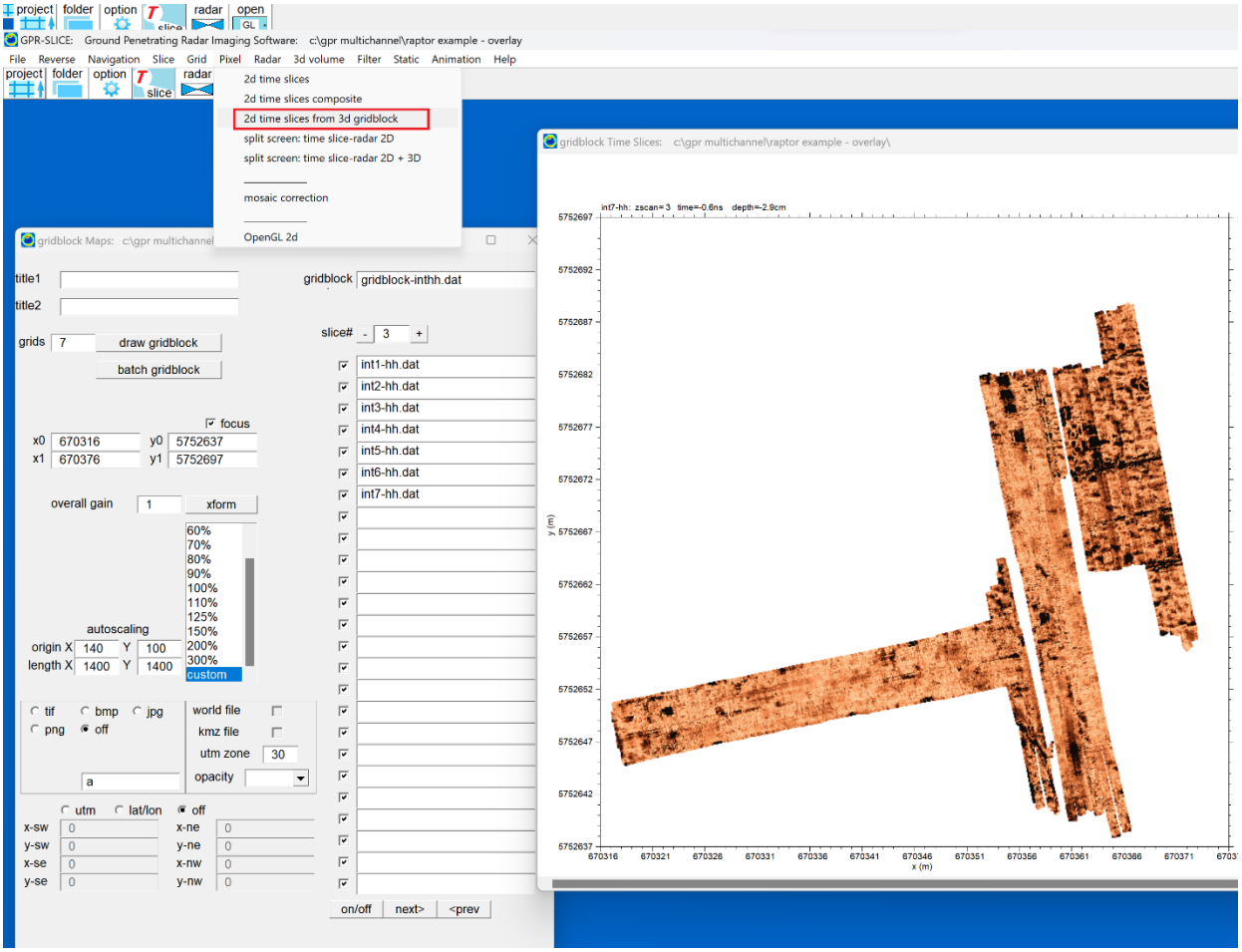


The individual blocks are available for opening separately in OpenGL. To show the entire gridblock dataset one will open the select 3D volume menu and highlight the gridblock dataset. Then they will use the OpenGL Volume + Gridblock operation to display the gridblock dataset in OpenGL. OpenGL displays in gridblock mode are limited to time slice displays. Isosurfaces and other features are disabled.





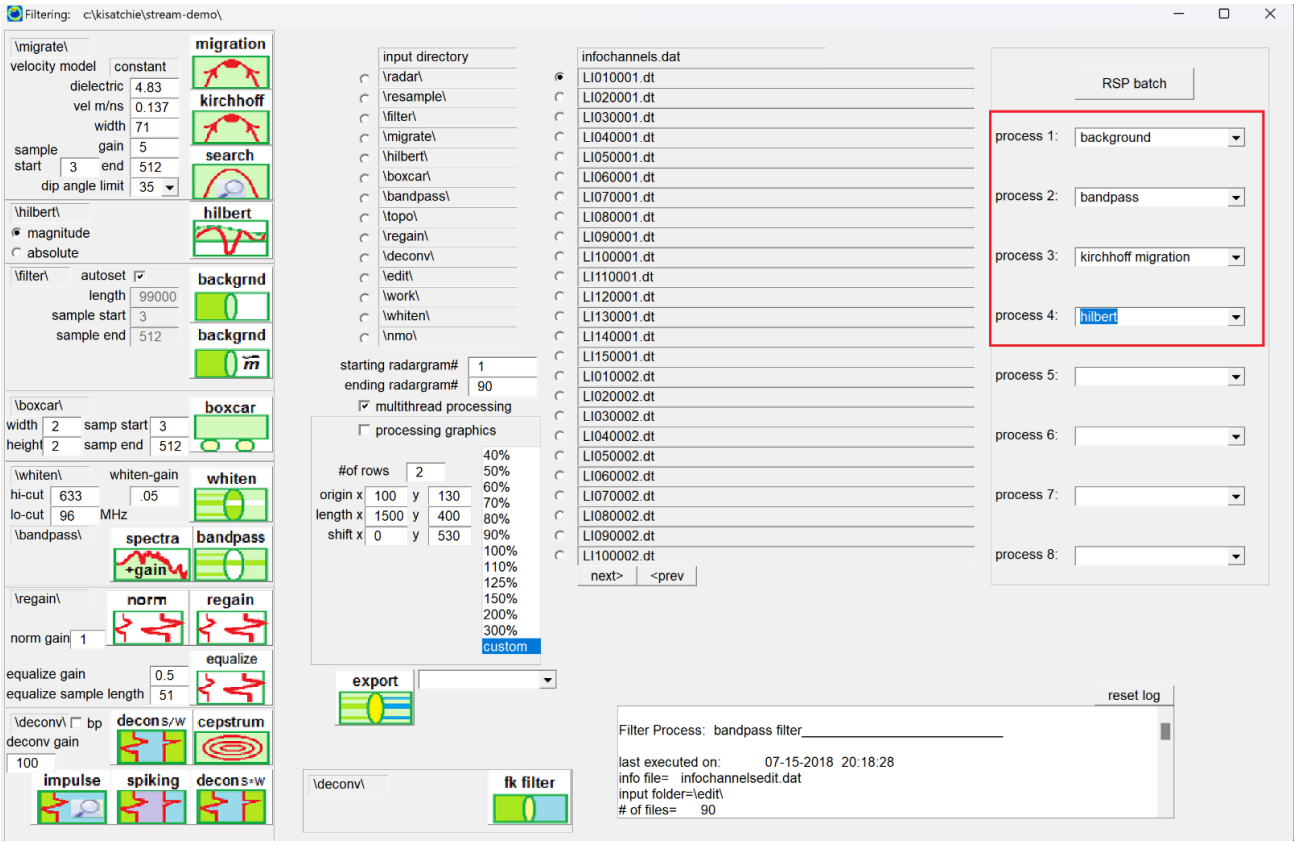
There is also a menu in the Pixel Map pulldown to draw the gridblock dataset. In this menu the user can achieve almost any pixel size resolution up to nearly 65k pixels in both x and y. This menu should be used for making Google Earth or Arc GIS image files as the full resolution of the site can be achieved.



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 data demultiplexing for some manufacturers. The typical filters used in the Bluebox are:

- Background filter
- Bandpass + simultaneous gain
- Kirchoff migration
- Hilbert transform



During the BlueBox Batch runs the user can prompt the software to show a menu to manually adjust settings 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: