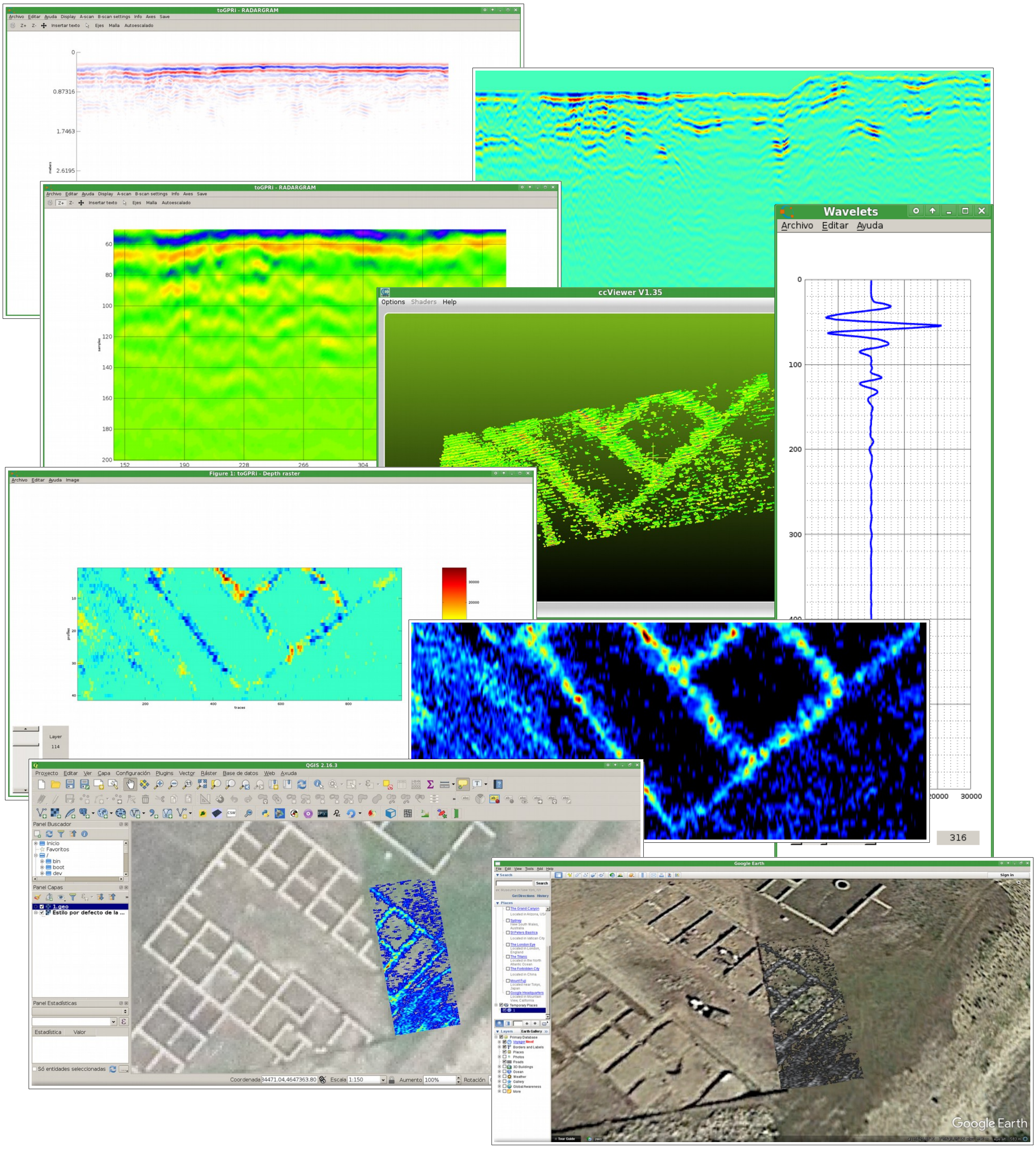
toGPRi v1

A tiny GNU Octave ground-penetrating radar integration of tools.



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toGPRi v1

A *tiny GNU Octave ground-penetrating radar integration* of tools.

toGPRi v1 tools have been created for primarily analyzing RAMAC©[1] ground-penetrating radar data and for building 3D matrices to generate georeferencied rasters of underground elements[2].

As part of my PhD in Cultural Heritage Protection at Universidade Vigo.

What the *toGPRi* v1 tools can do?

At this moment *toGPRi* v1 can open .rd3 Måla files, read .rad data files and **display the 2D associated radargram** with different color maps and contrast levels.

toGPRi v1 can **apply several filters to these data**: a time zero cut, a linear and an exponential gain recovery, a basic mean trace removal, a smoothing filter and a noise put-out. Besides this, the **wavelet** for any trace can be watched at any stage.

It is also possible to use 3 columns plain text files to generate **hypsography** variations.

In respect of 3D options:

toGPRi v1 can be used to generate a series of 2D points .xyz files associated to the filtered profiles of a prospection (usable to originate a **point cloud**) and a GNU Octave three dimensional matrix wearable to automatically draw **georeferencied overlaid raster images** at different levels of depth.

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1 http://www.guidelinegeo.com/abem-mala/

2 All these tools were programmed with GNU Octave 4.0 and have been tested on Debian GNU/Linux Stretch (Debian 9) kernel 3.16 64 bit.

Starting *toGPRi* v1.

Once you have unzipped the files in the chosen directory you can start the first display running the **rb_start.m** function in the GNU Octave prompt.

ATTENTION:

toGPRi functions need to be executed in at least GNU Octave 4.0 with the **“image” package** installed and loaded and the **Qt graphics toolkit** available. You can check https://www.gnu.org/software/octave/doc/interpreter/Installing-and-Removing-Packages.html and https://www.gnu.org/software/octave/doc/interpreter/Graphics-Toolkits.html

The geospatial **GDAL** library tools (at least 'libgdal' and 'gdal-bin', version 2.1.1) are also necessary. Check http://www.gdal.org/.

In a GNU/Linux Debian system you will need at least the **octave**, **octave-common**, **octave-image**, **libgdal20** and **gdal-bin** packages.

In a shell you can start the GNU Octave prompt (without GUI) with the command **octave --no-gui**. Before this, simply execute **rb_start** (figure 1).

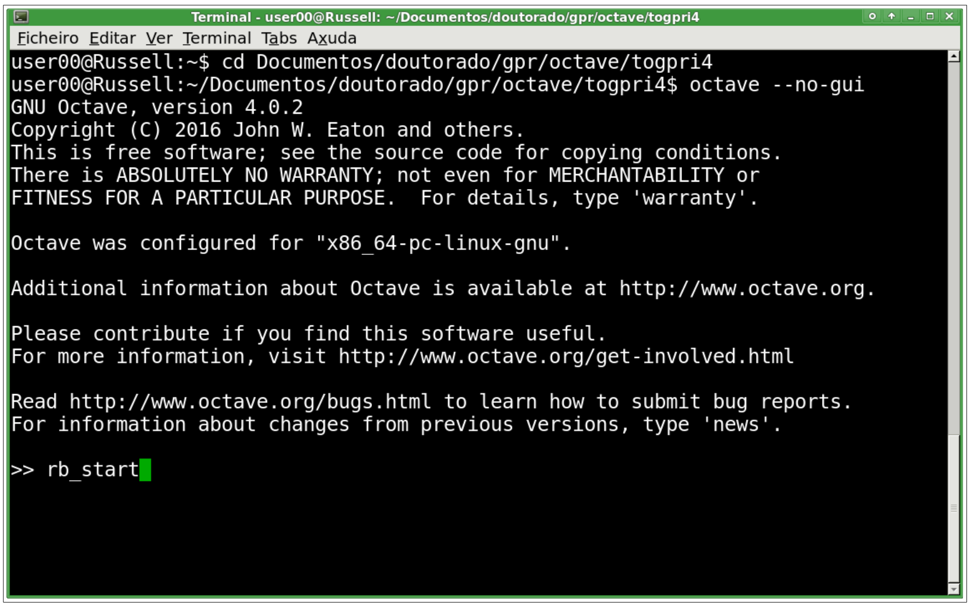

Figure 1. GNU Octave console.

The first display have a menu with three options (figure 2):

- *Load .rad file (2D)*
- *Builder and rasters menu*
- *View figure*

The first option loads a .rd3 file using the .rad data to set the correct geometry and to obtain another variables.

The second option starts the menu to apply consecutive filters to a series of .rd3 profiles, to build the 3D matrix and to generate the GeoTIFF rasters and

.kmz files.

The third one allows to watch an .ofig GNU Octave figure previously saved.

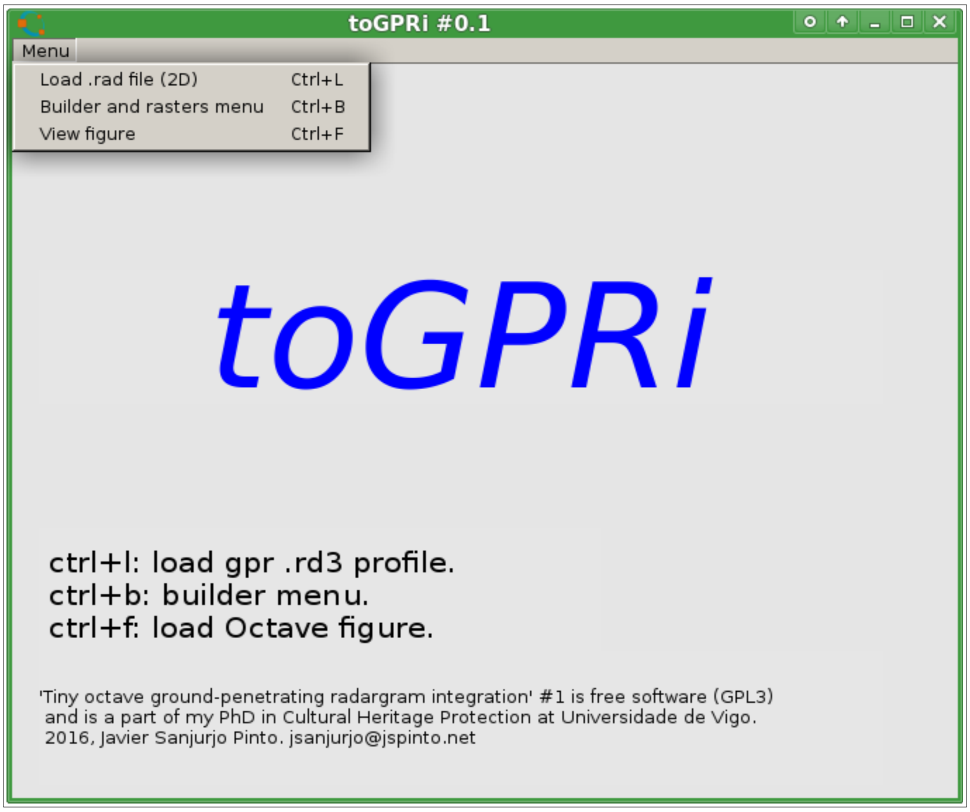

Figure 2. Initial display.

2D radargram settings.

Load .rad file (2D) in the initial display opens a window to select the profile (figure 3).

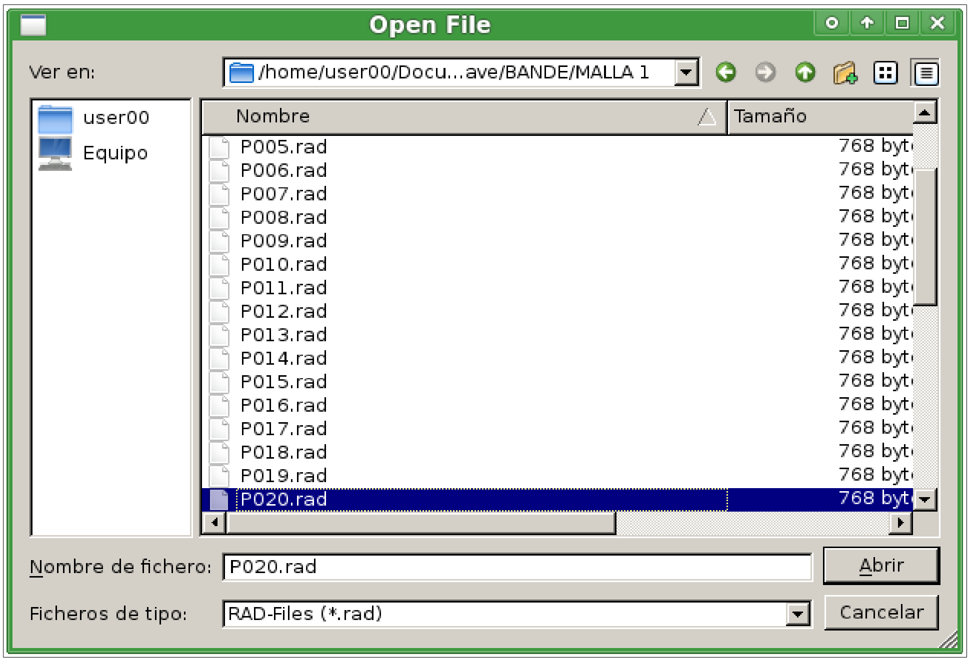

Figure 3. Selecting .rad/.rd3 files.

After this, we will have to introduce a value for the average propagation velocity (figure 4). View the textbox below.

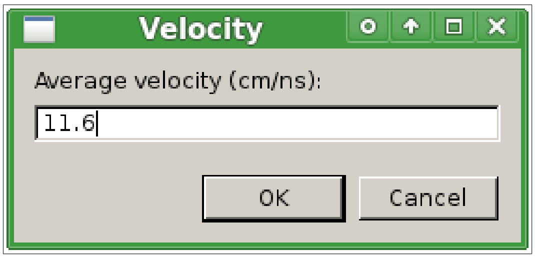

Figure 4. Selecting velocity.

toGPRi will draw the radargram figure in a new *RADARGRAM* display (figure 5).

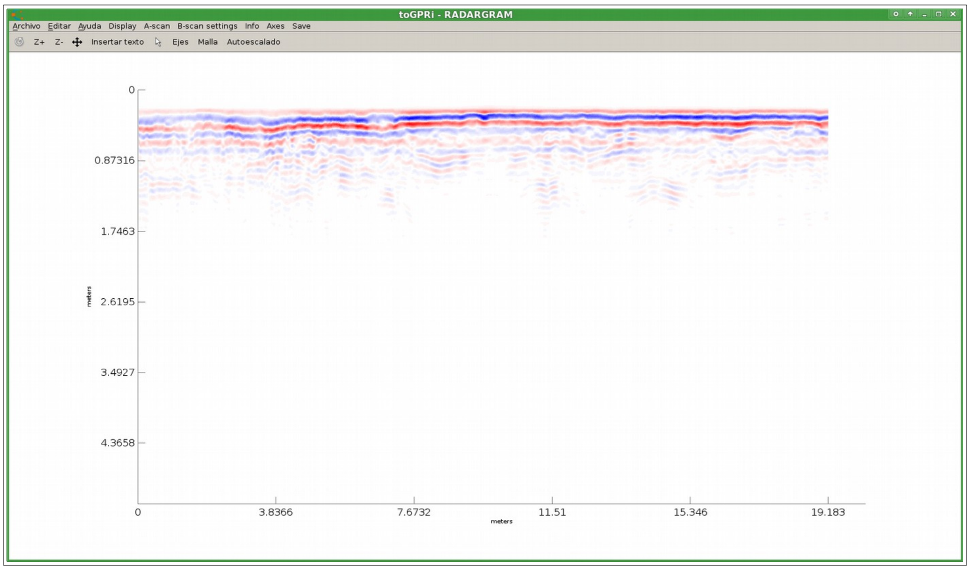

Figure 5. First display.

AVERAGE VELOCITY:

Radar reflections are generated by the changes in the relative dielectric permittivity of the buried materials (a kind of measurement of its electrical and magnetic properties), thus it is necessary to set an average relative permittivity of the ground on each place. For a lot of studies this relative permittivity of the ground can be inversely related with the radar energy travel velocity.

Some examples of relative permittivity/average velocity are the following:

Material	**Relative dielectric permittivity**	**GPR velocity(cm/ns)**
Air	1	30
Asphalt	3-6	14-17
Ice	3-4	16
Dry sand	3-5	15
Dry salt	5-6	13
Granite	4-6	13
Limestone	4-8	12
Shale	5-15	9
Silts	5-30	7-9
Clays	5-40	6
Saturated sand	20-30	6
Fresh water	80	3-4
Sea water	80	1-3

Davis and Annan, 1989 and gprrental.com, 2016.

Apart from the typical GNU Octave figure options (*File*, *Edit* and *Help*) the specific *toGPRi* menus and submenus are the following:

- *Display*
  - *Colormap*
  - *Visual contrast*
  - *Redraw*

Continue below.

- *A-scan*
  - *Waveform slider*
- *B-scan settings*
  - *Time-zero*
  - *Filter and gain settings*
    - *Substract mean trace*
    - *Gain recovery*
    - *Window constant gain*
    - *Vertical smooth*
    - *Horizontal smooth*
    - *Remove noise*
  - *Topography*
  - *Reset geometry and filters*
- *Info*
  - *Radargram info*
- *Axes*
  - *Height and weight*
  - *Samples and traces (fine grid)*
  - *Time and traces*
  - *Axes ratio*
- *Save*
  - *Save Octave binary*
  - *Save Octave figure*
  - *Save xyz ascii*
  - *Save tiff image*

Colormap and ***visual contrast*** allows us to select between different color sets and contrast levels for the figure. None of the selections will modify really the data (figures 6,7 and 8).

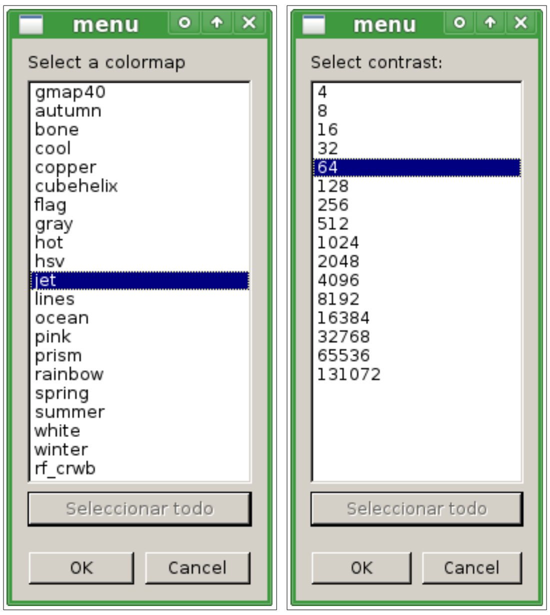

Figure 6. Selecting color map and contrast.

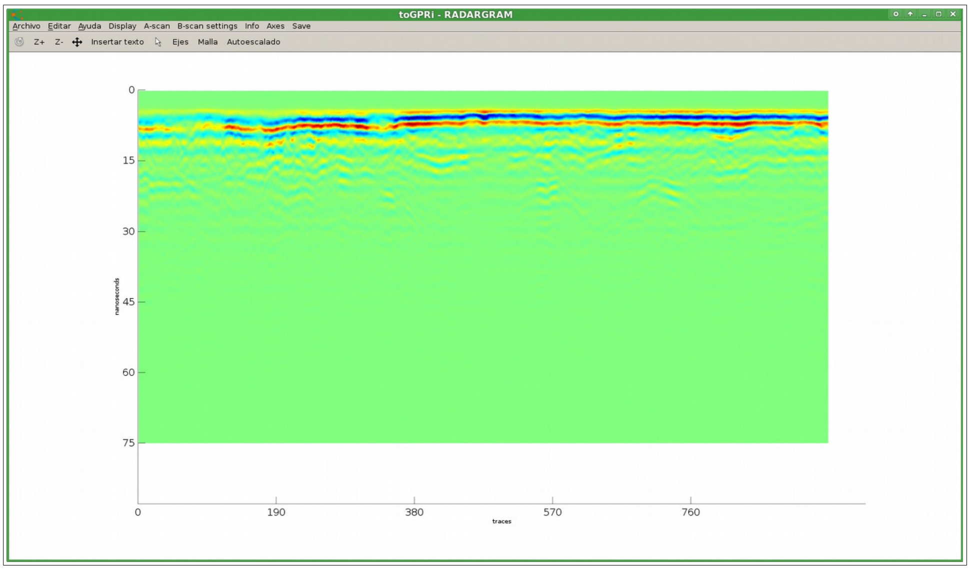

Figure 7. The same radargram in figure 5 with *jet* color map and *1024* colors.

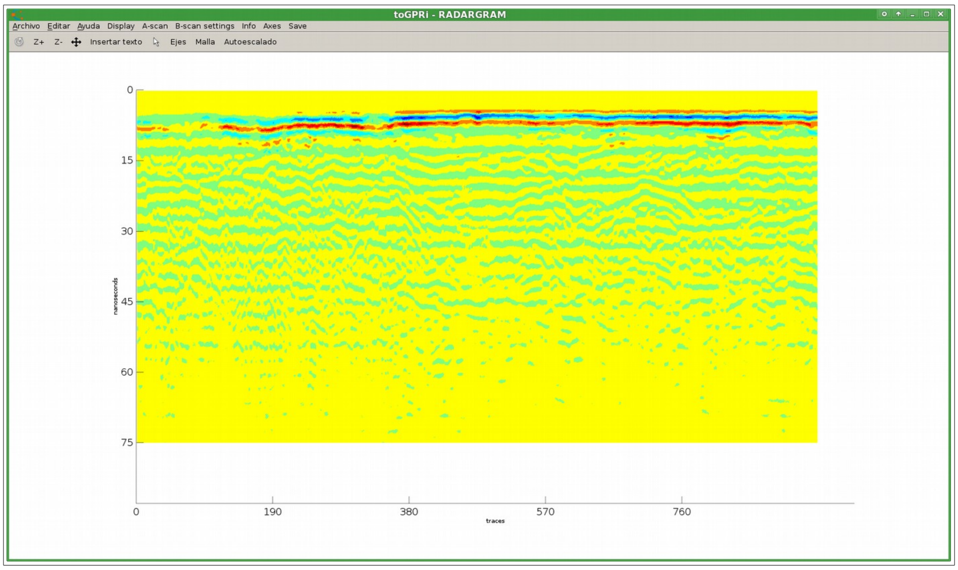

Figure 8. The same radargram in figures 5 and 7 with *jet* color map and 8 colors.

The different options in *Axes* help us to change the information in the *time window* axis and the horizontal divisions:

Height and weight sets the axes in meters (like in figure 5). We have the possibility of to change the velocity if we need it.

Every time we select ***Samples and traces*** we can choose the vertical and horizontal lines in which the grid will be divided (figures 9 and 10).

Time and traces displays the time window vertical axis in nanoseconds and the horizontal axis in the number of traces (figure 11).

Axes ratio modifies the aspect ratio to display the radargram in the selected proportions, where *1* is equivalent to the original one (figures 12 and 13).

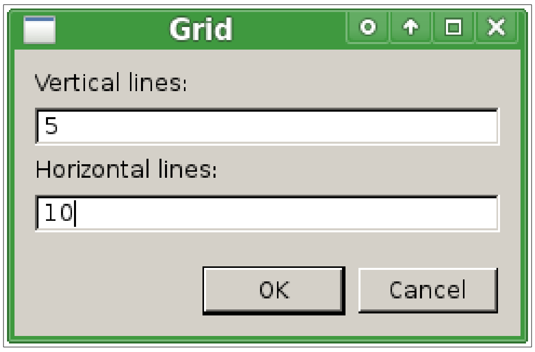

Figure 9. Fine grid selection.

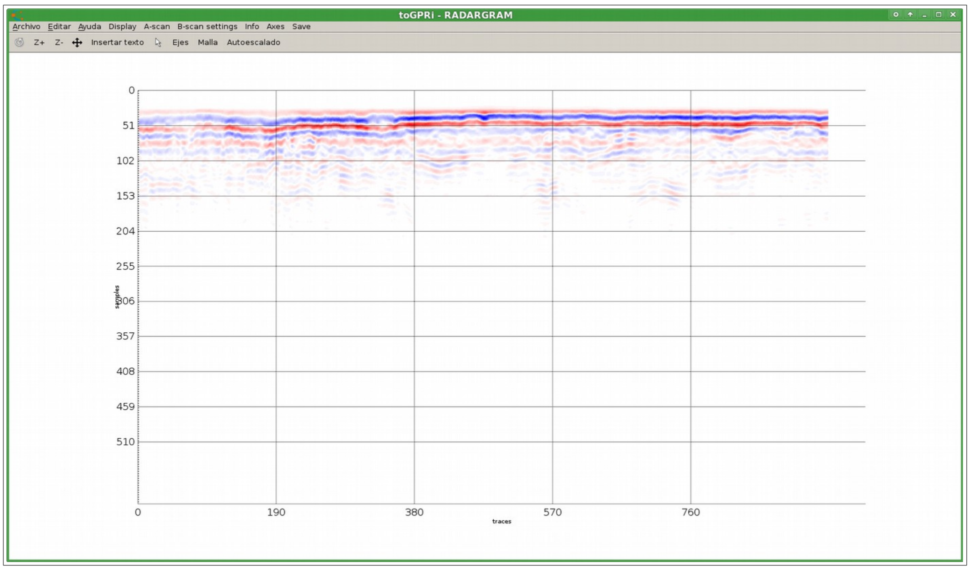

Figure 10. Samples and traces (fine grid selected).

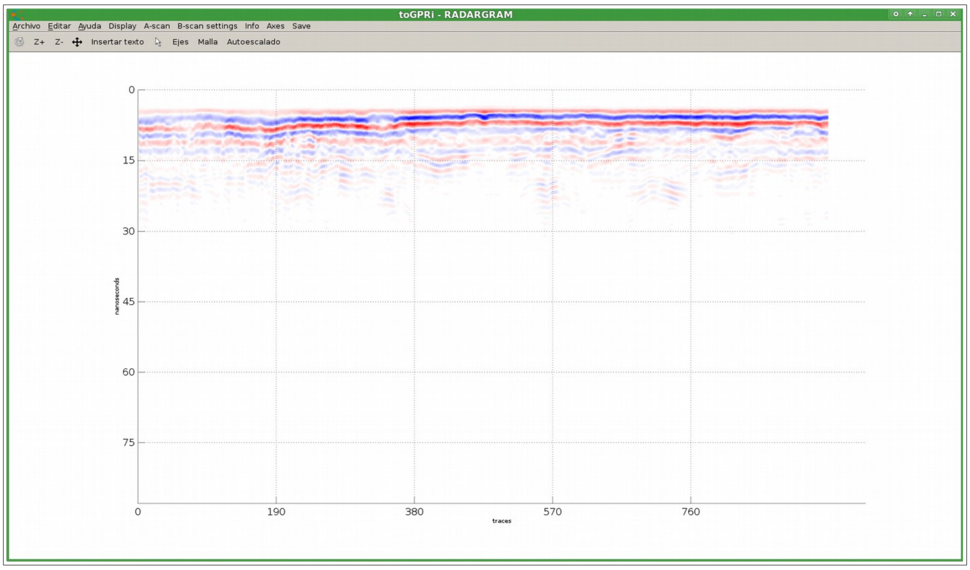

Figure 11. Time and traces (simple grid on).

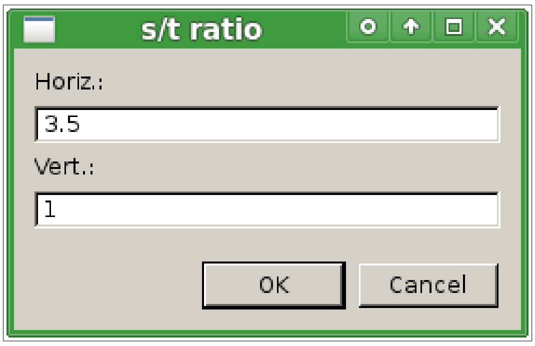

Figure 12. Ratio selection.

We can use too the **Z+** and **Z-** buttons to zoom in and out the image (it is more useful when the grid is on, figure 14).

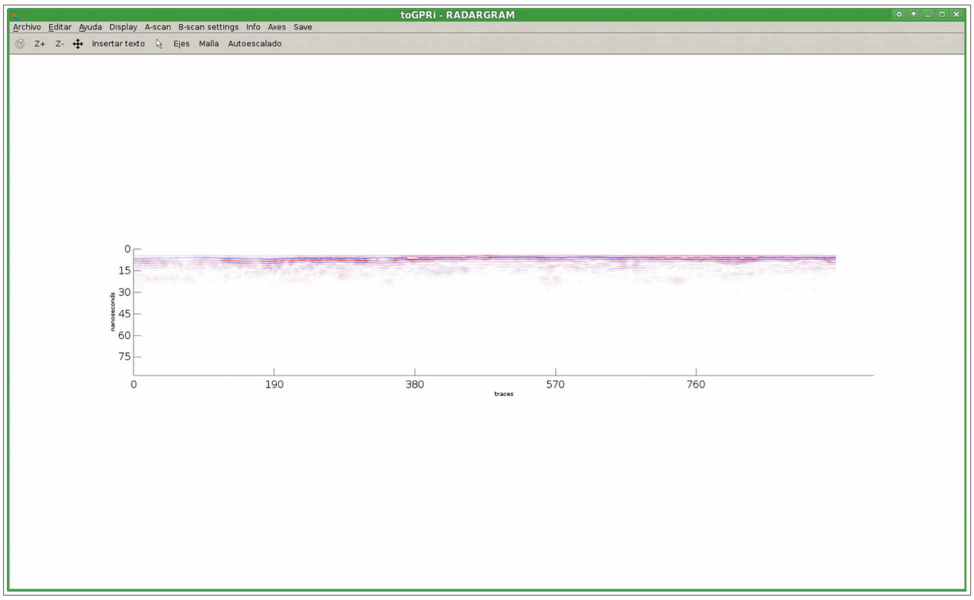

Figure 13. Example of radargram with the new 3.5 x 1 ratio.

The ***waveform slider*** helps us to check the 1D wavelets in each trace in any moment of the process (figure 15).

Radargram info extracts the main information data of the corresponding *.rad* file and also show us the current geometry (figure 16).

In respect of the 2D settings (gains, filters and topography) we have for the time being the next options:

Time-zero selects a starting place of the traces to correct the misalignment of the first break in a reflection profile between the air and ground mediums. This correction changes the geometry of the radargram (figures 17 and 18).

Substract mean trace allows us to deduct the corresponding sample mean value in each pixel of the trace to reduce the horizontal features. We can select the percentage of traces on each side of the target trace to calculate the mean (figures 19 and 20).

Gain recovery is convenient to make up for the amplitude attenuation and the geometrical spreading. We can set a function, more or less like the “Time-Gain” filter of Måla Groundvision software, that combines a linear and an exponential factor: each sample since the initial one is multiplied by the equation $\mathbf{p*(t/s)*n+e^{q*(t/s)*n}}$, where **p** is the linear factor, **q** is the exponential factor, **t** is the “time window” value in microseconds, **s** is the number of samples per trace and **n** is the number of samples filtered until that moment (figures 21 and 22).

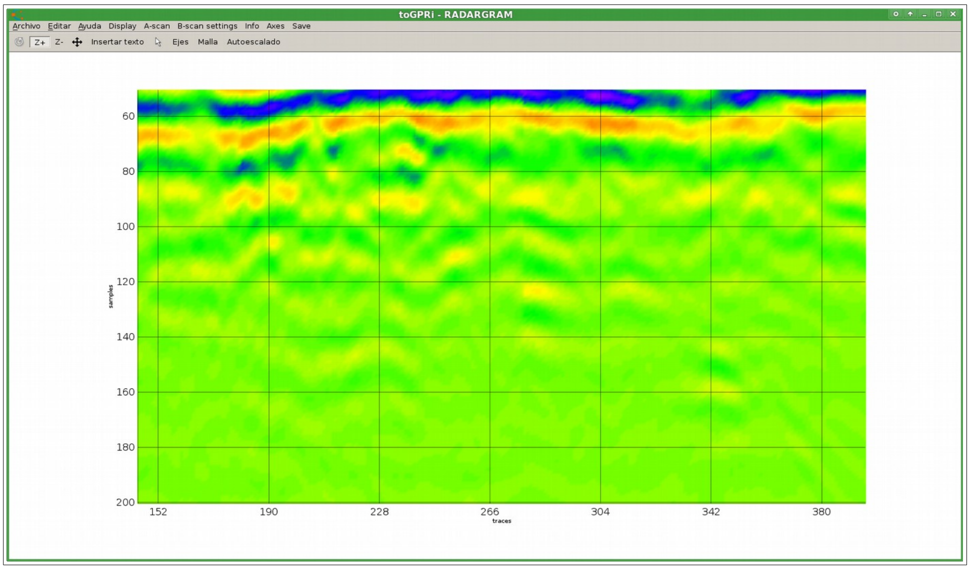

Figure 14. Zoom over image with *rainbow* color map.

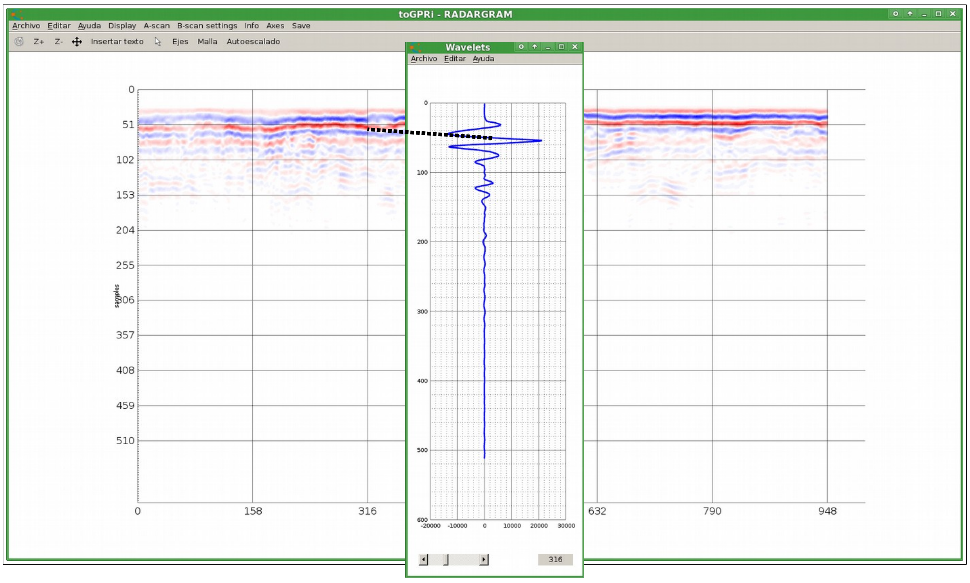

Figure 15. Waveform.

Window constant gain simply multiplies the value of samples in selected rows by a direct factor. Sometimes it can be used to minimize the values from a certain depth (figures 23 and 24).

Vertical smoothing and ***horizontal smoothing*** soften data vertically or horizontally in a specific horizontal section and time window. We can select the percentage of approach to the average sample in vertical smoothing or to the average trace in horizontal smoothing (figures 25 and 26).

Remove noise takes out every pixel value below a percentage of the positive and the negative means for every trace (figures 27 and 28).

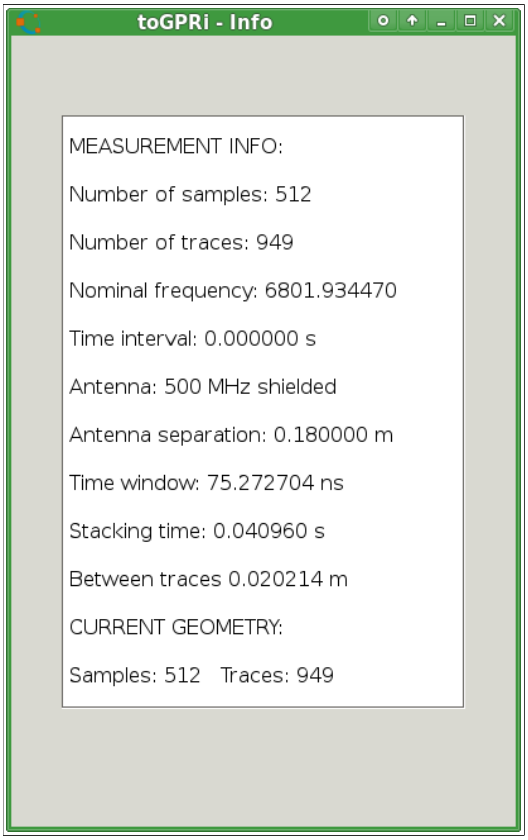

Figure 16. Info box.

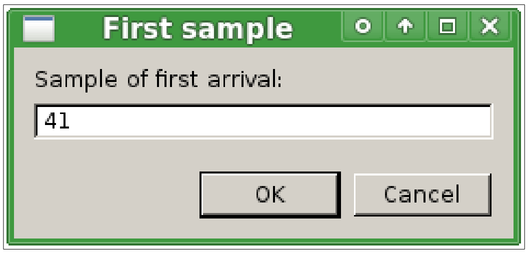

Figure 17. Time-zero selection.

Topography loads a .txt elevation file to compensate the ground height along the profile line. The file has to have the three columns format XYZ in meters, but only x and z columns are processed in this 2D tool (figures 29 and 30).

In any moment we can save the processed data as an Octave binary matrix selecting ***Save Octave binary*** and the correspondent Octave figure with ***Save Octave figure***. We can also save an indexed 8-bit TIFF image file with **Save TIFF image** (figure 31).

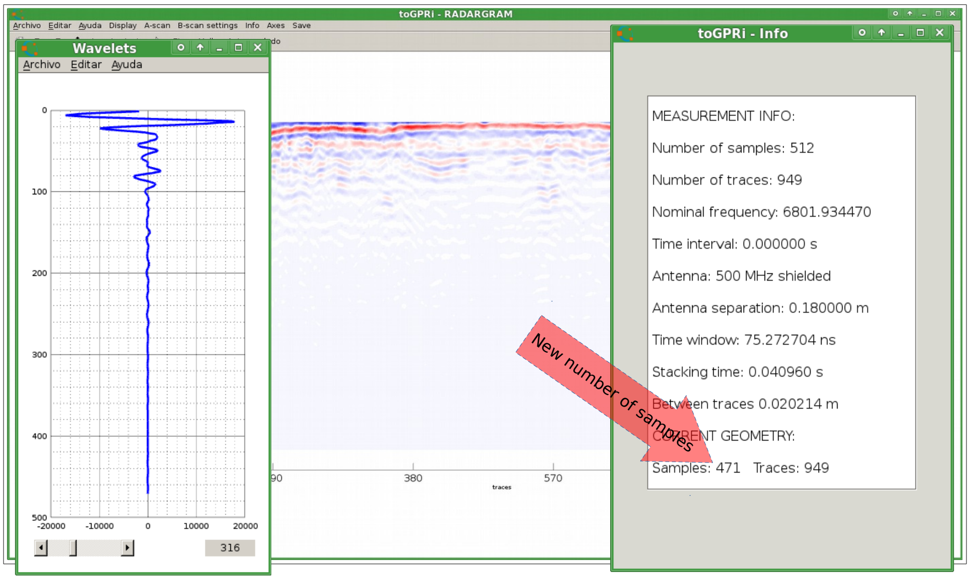

Figure 18. Radargram after the time-zero selection.

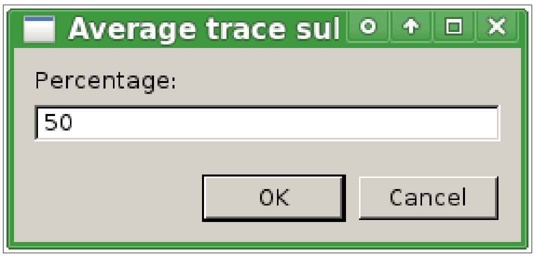

Figure 19. Percentage selection for subtract mean trace.

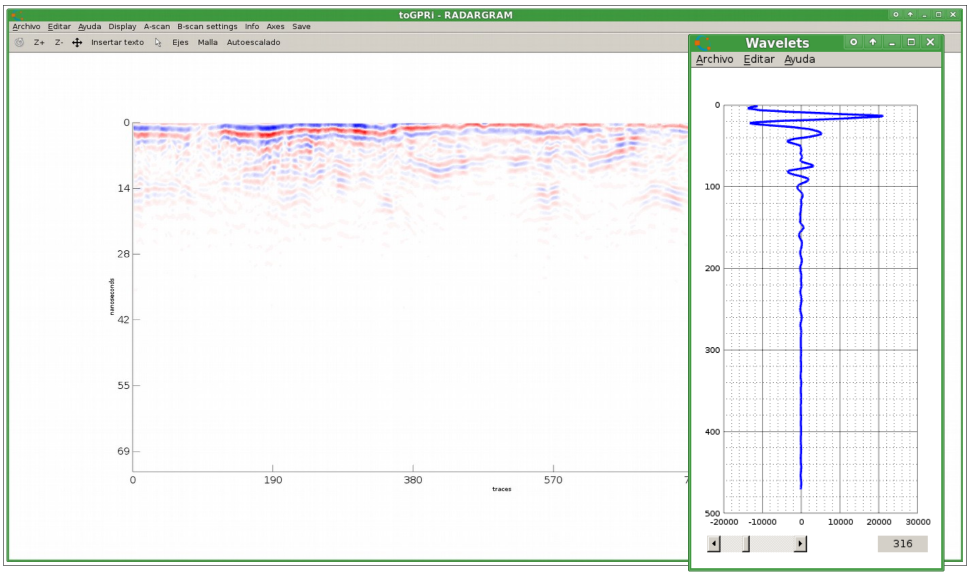

Figure 20. Radargram after *time-zero* and 50% subtract *mean trace*.

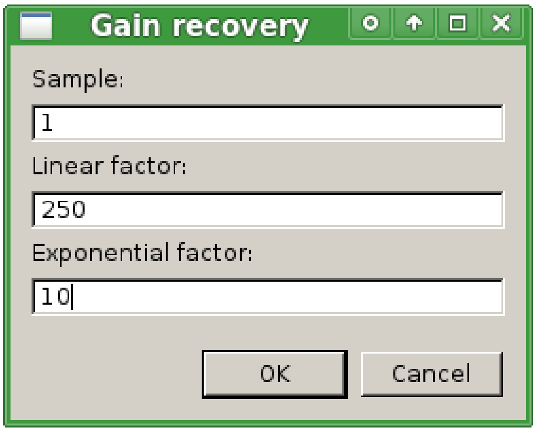

Figure 21. Manual gain settings.

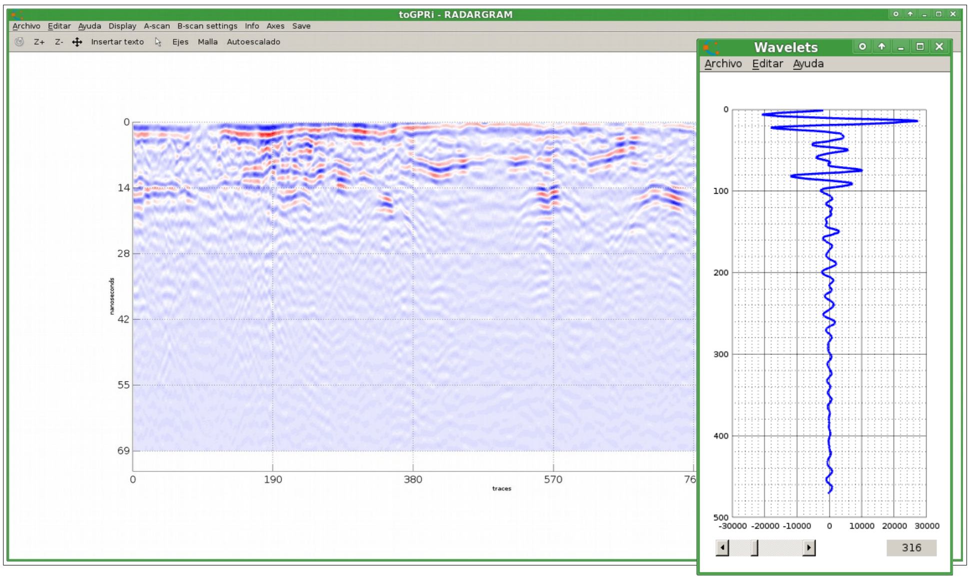

Figure 22. The same radargram in figure 20 after *gain recovery* $(250*(0.075272704/471)*n+e^{10*(0.075272704/471)*n})$ since the first sample.

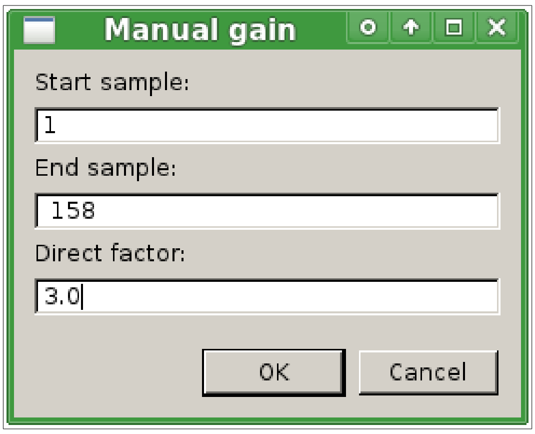

Figure 23. Manual gain settings.

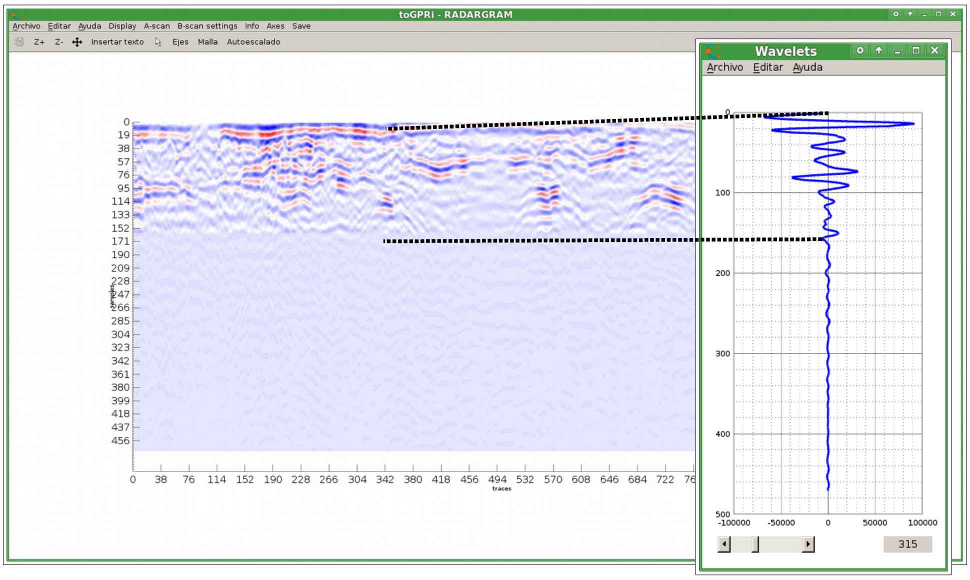

Figure 24. Radargram after *window constant gain* (samples 1-158, factor 3.0).

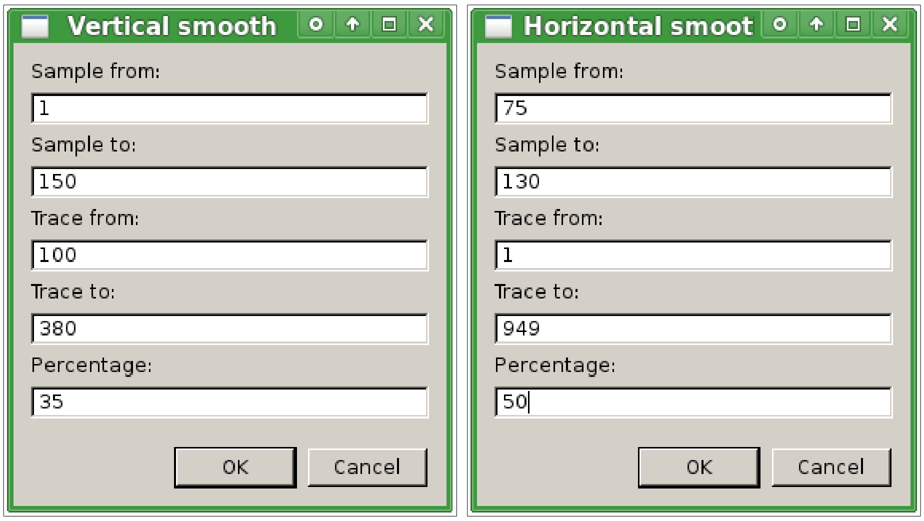

Figure 25. Example of *smoothing* settings.

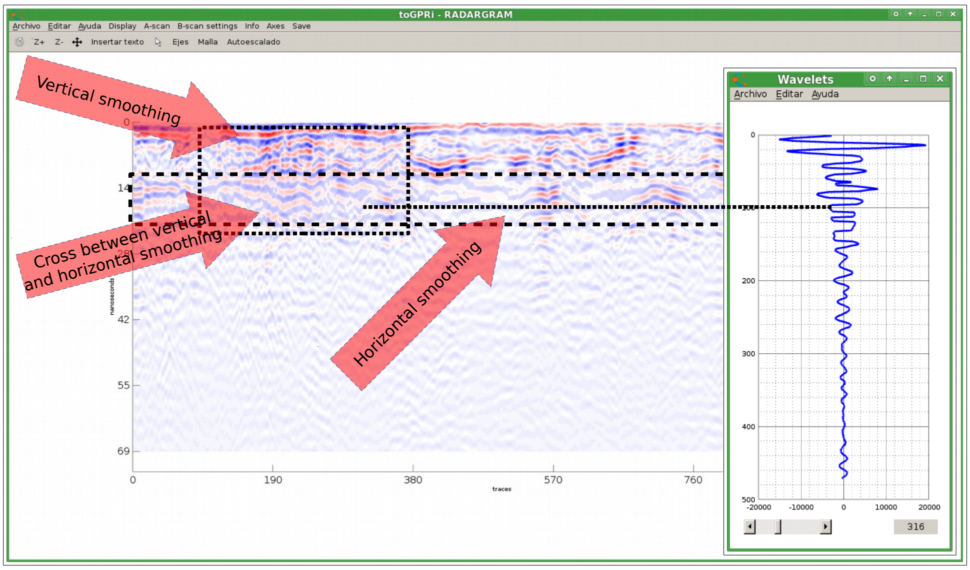

Figure 26. Example of vertical and horizontal smoothing: the same radargram in figure 22 after the settings of figure 25.

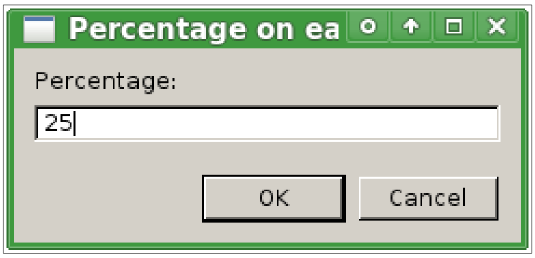

Figure 27. Percentage in *remove noise*.

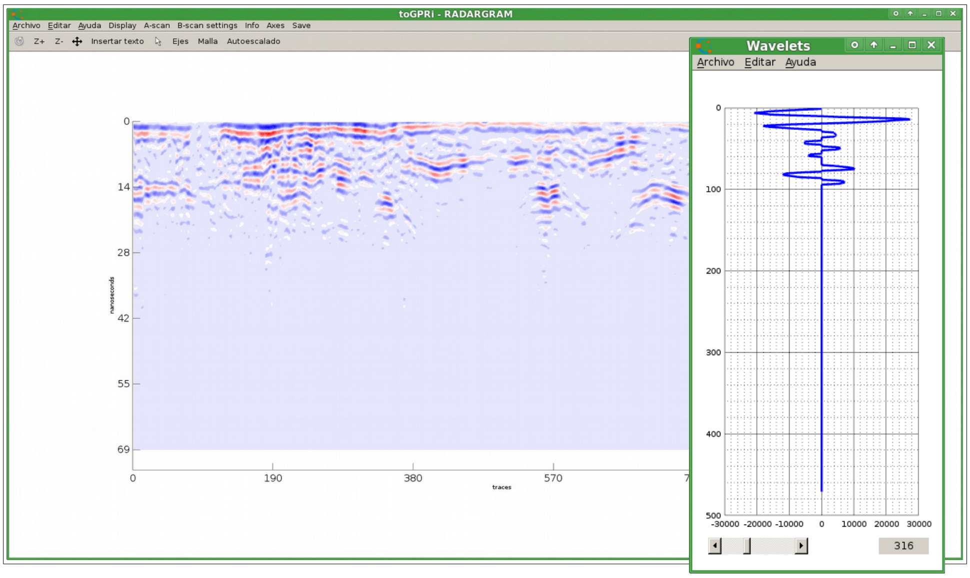

Figure 28. *Remove noise* at 25% in the radargram of the figure 22.

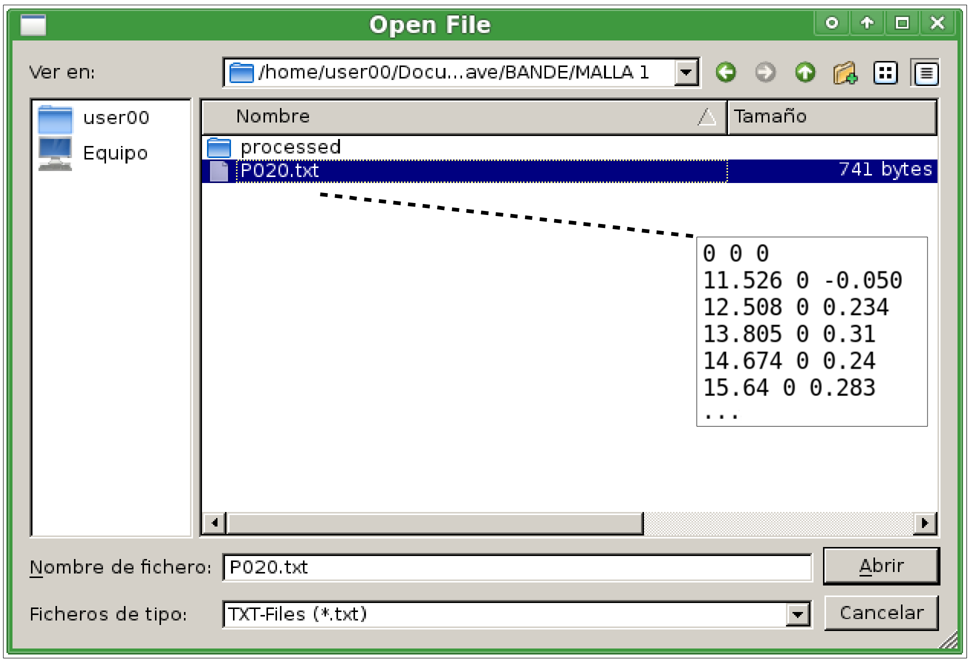

Figure 29. Selecting topography file.

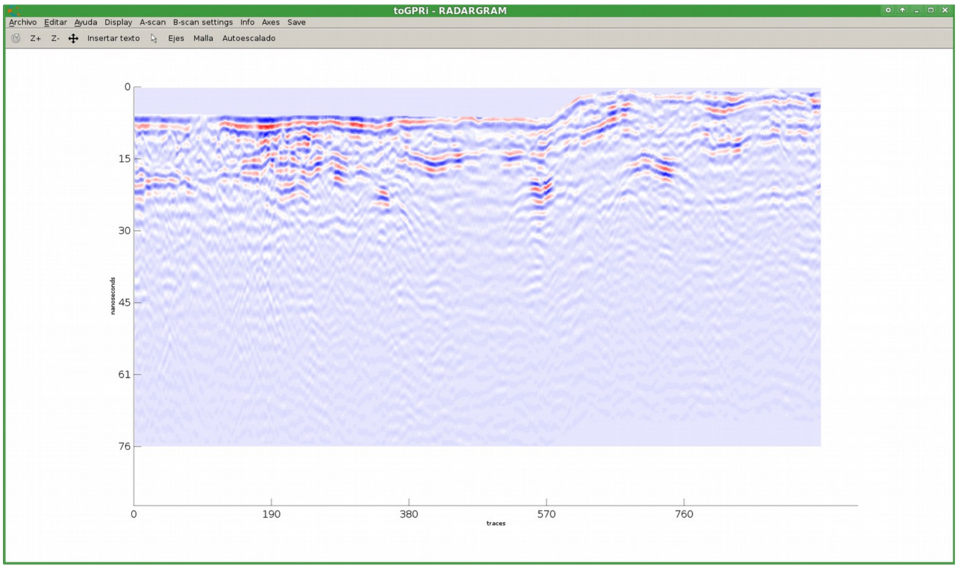

Figure 30. Radargram after topographic correction.

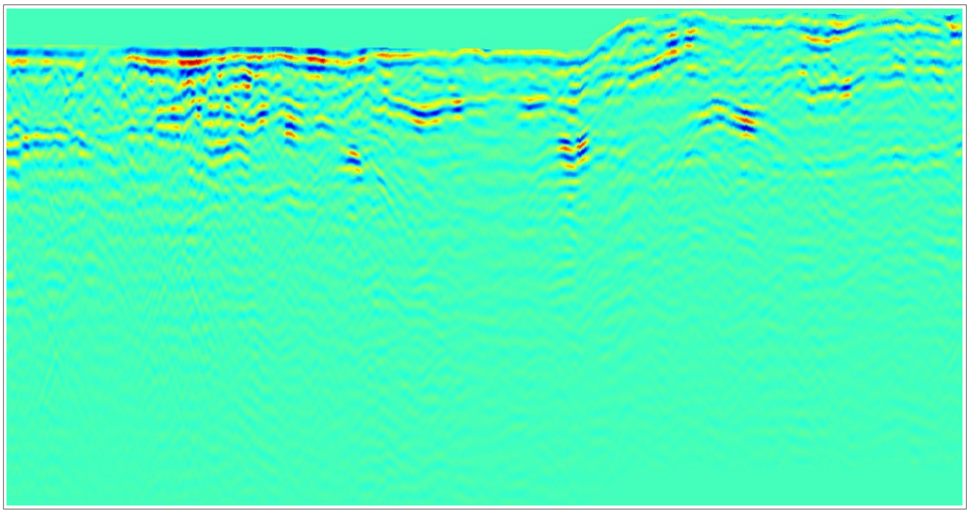

Figure 31. Radargram 8-bit indexed TIFF.

3D settings.

The main idea of the *toGPRi tools* is to help us to set up georeferencied overlay raster images at different levels of depth and secondarily to generate clouds of points with the data. To get this target we need to build a 3D matrix with previously processed and topographically corrected data and to extract horizontal layers and spatially located points (figure 32).

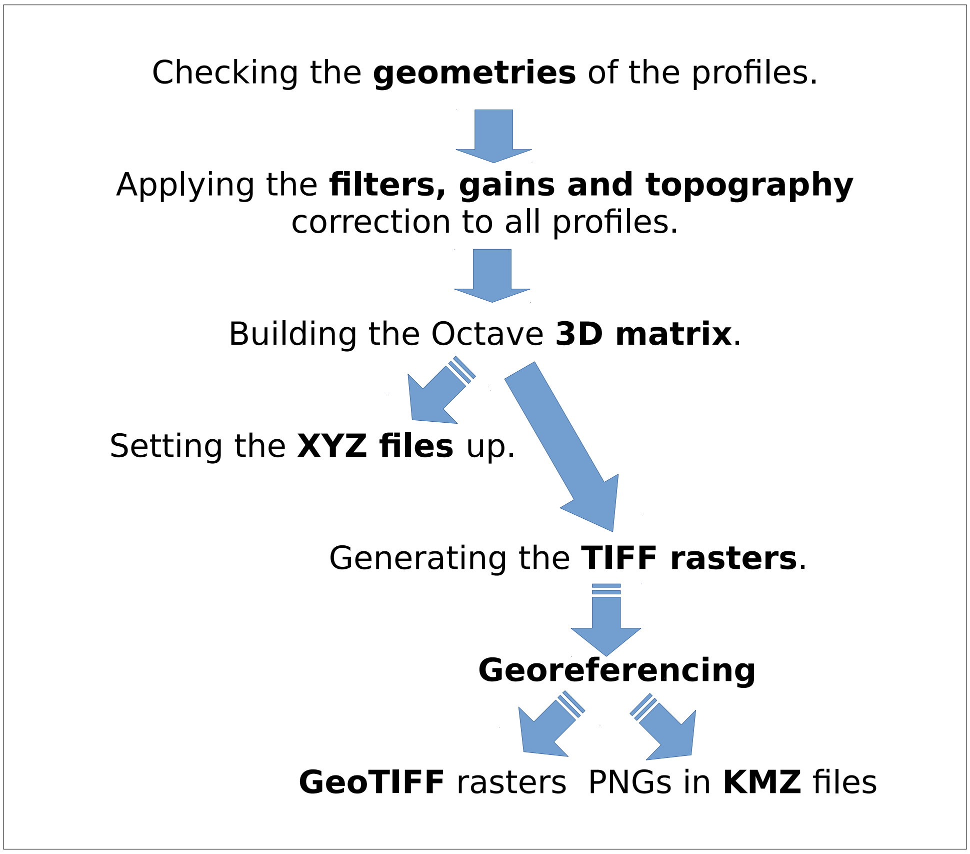

Figure 32. From vertical profiles to horizontal overlaid georeferencied rasters.

Selecting ***Builder and rasters menu*** in the initial display a new list of options will appear (figure 33).

Once we have selected the different cuts, gains and filters to apply to a series of parallel profiles, the first operation we need to do is to make sure of the geometry of our profiles meshes, with ***Check geometries*** we can know the maximum number of traces and samples in a profile series. We have to select the directory and a pattern of file names to designate the set (figures 34, 35 and 36). If we need it, we can repeat the checking with different patterns and to select the maximum values.

After that we will begin the effective processing with ***Consecutive filters*** (figure 37).

In the *Consecutive filters* display we have to insert the *Max. samples* and *Max. traces* values necessarily and we can insert the various values for the other actions. The correspondent button have to been pushed to be effective.

Fliplr buttons have a specific spatial function. If *Fliplr odd* is on, every odd profiles will be flipped, if *Fliplr even* is on, then the even profiles will be flipped. It is useful when the profiles have been obtained on zigzag and/or when the mesh have been formed from right to left since the first profile.

After pushing the ***START*** button we will have to select the set of profiles again.

If we want to apply topography corrections (*Topography* button on), the elevation .txt file name of each profile has to be the same of the .rad/.rd3 one (e. g. *P1.txt* for the *P1.rad*, *P2.txt* for the *P2.rad*,...)

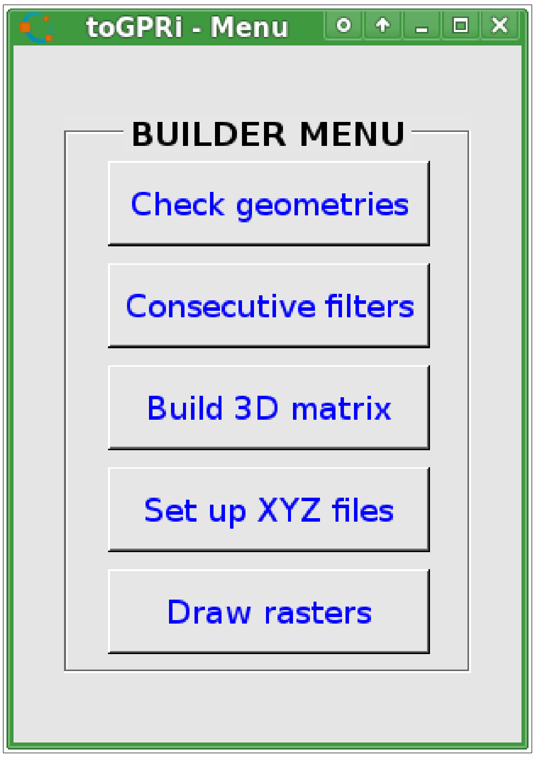

Figure 33. Builder menu.

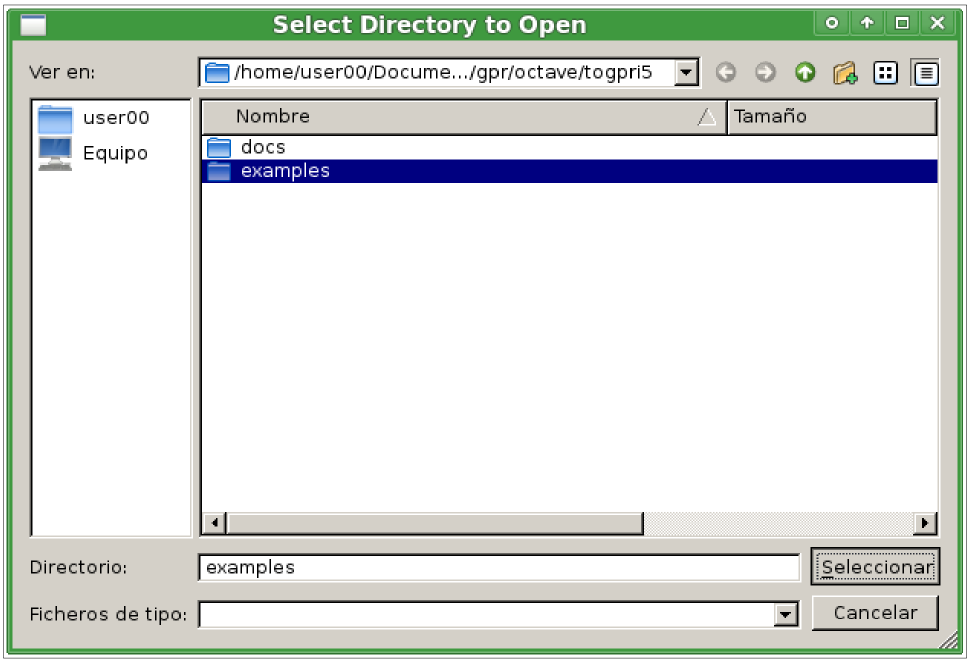

Figure 34. Selecting the directory where the parallel profiles of a mesh are.

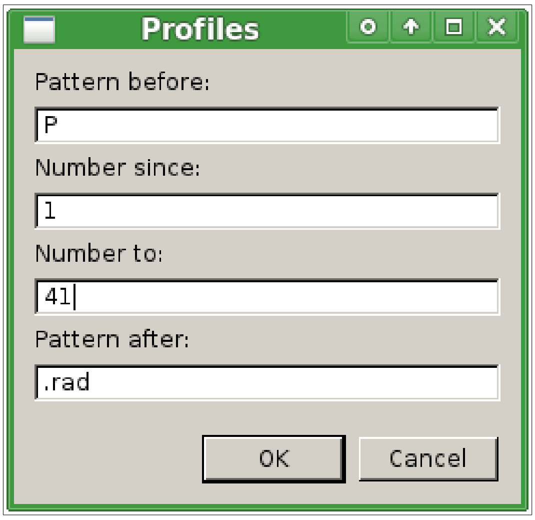

Figure 35. Establishing the pattern. In this case .rad files from *P1.rad* to *P41.rad*.

Figure 36. *Check geometries* result.

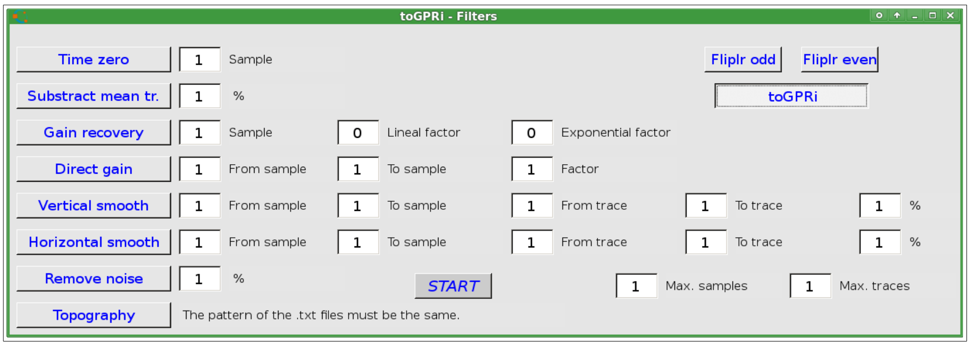

Figure 37. The *Consecutive filters* display.

We may prefer to start more than one GNU Octave prompt and start several *Consecutive filters* processes for several subsets of profiles to take advantage of the different processor cores and to reduce the needed time.

When this step is over we will have a new series of processed profiles with the extension *.gpr*. This .gpr files are binary GNU Octave files with 2D matrices variables. “

.GPR FILES:

The processed binary .gpr files will be used to build a 3D matrix but they can be directly open by means of the GNU Octave prompt. The command **load ("/home/user/togpri/examples/P1.gpr")** will load a new matrix called **r_A** from the file *P1.gpr* in the path */home/user/togpri/examples/* and we could, for example, to generate a new figure:
surface(r_A,"facecolor","interp","edgecolor","none");
set(gca,"ydir","reverse");

Build 3D matrix is used to set up the three dimensional matrix. We have to select the directory where the .gpr files are and establish a pattern again, this time the extension will be *.gpr* instead of *.rad*. The matrix is always a variable called **AY3D** in a GNU Octave binary file with the name *3D.b* that will be saved in the same directory. From this moment we can to form a series of XYZ files with the spatially located points or/and to start the making of rasters.

Set up XYZ files needs more information than the previous processes. To set the right three dimensional geometry we need to know the distance between traces (it can be read in any .rad file in the eleventh row called *DISTANCE INTERVAL*, but be aware that this datum is in meters), the distance between profiles (if the distance is not always the same you will have to setting up the XYZ files in several phases), the time window (the nineteenth datum in a .rad file), the original maximum number of samples (before the time-zero cut) and the average velocity (figure 38). We will also have to select the horizontal layers between which we want to draw. The new files will have the extension *.gpr.xyz* (figure 39). We can open them with a application for managing 3D point clouds like *CloudCompare* or *MeshLab*.

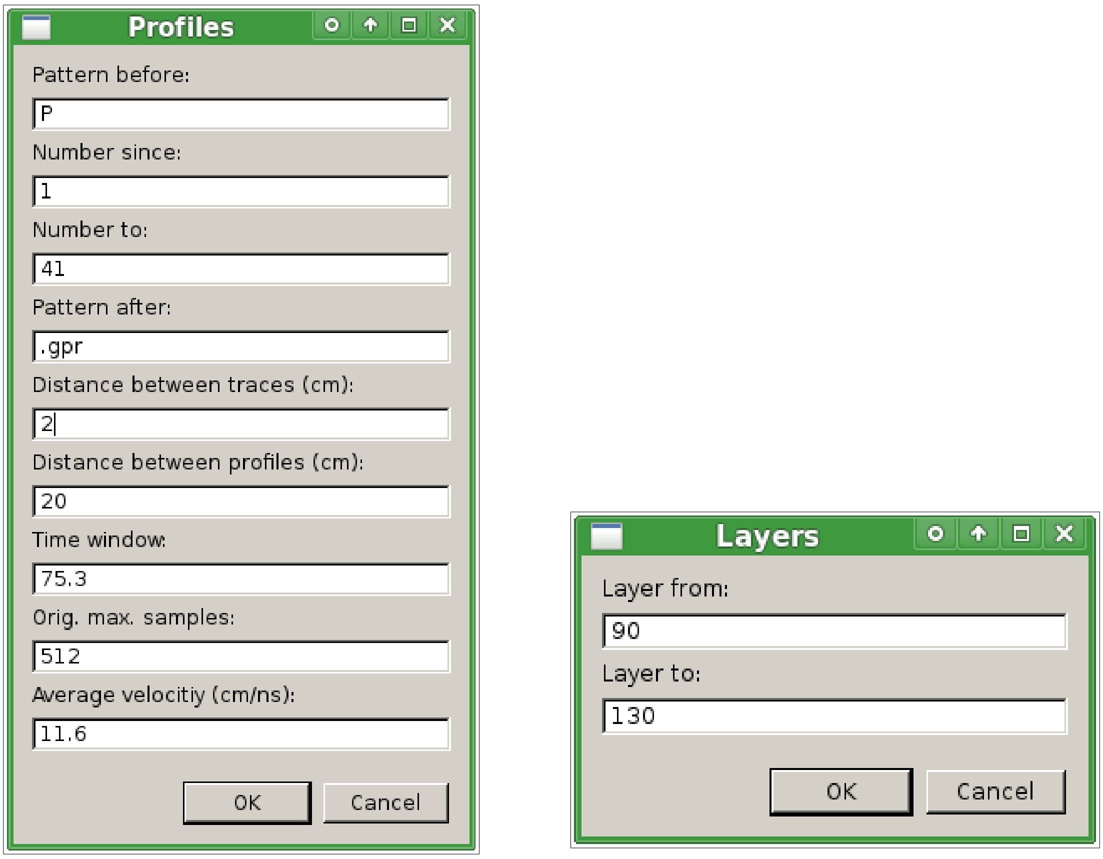

Figure 38. Example of the setting up of the .gpr.xyz files.

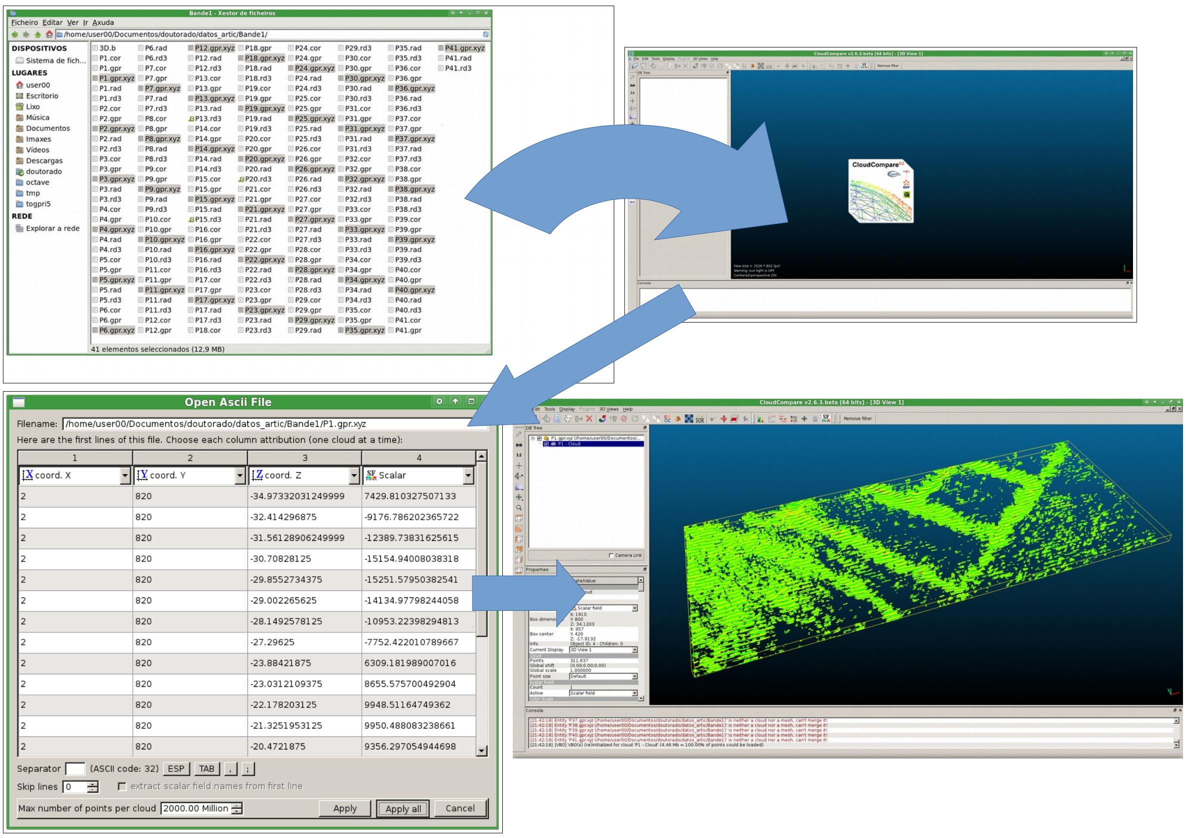

Figure 39. Opening the .gpr.xyz files in a cloud of points viewer (*CloudCompare*).

Horizontal rasters and georeferencing.

The last button on the *Builder menu* is ***Draw rasters***. We will be asked again for the directory where the 3D matrix is (*3D.b* file) and for the next data: average velocity, time window, distance between traces and distance between profiles (figure 40). After that, we will be able to move up and down by the different horizontal layers with the indication of depth in centimeters (we have to take into account that the value *Depth* starts just in the time-zero cut) (figure 41).

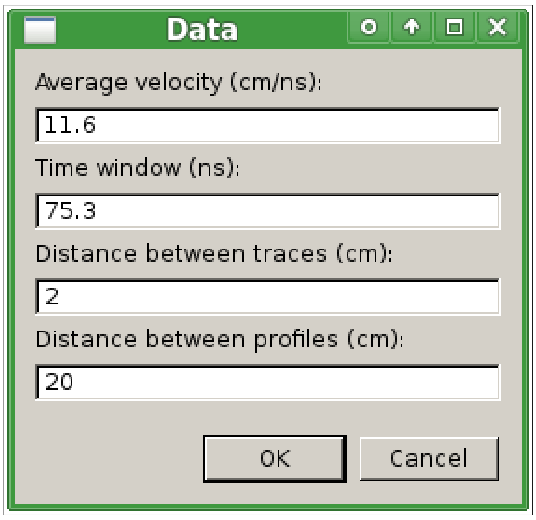

Figure 40. Data to draw the rasters.

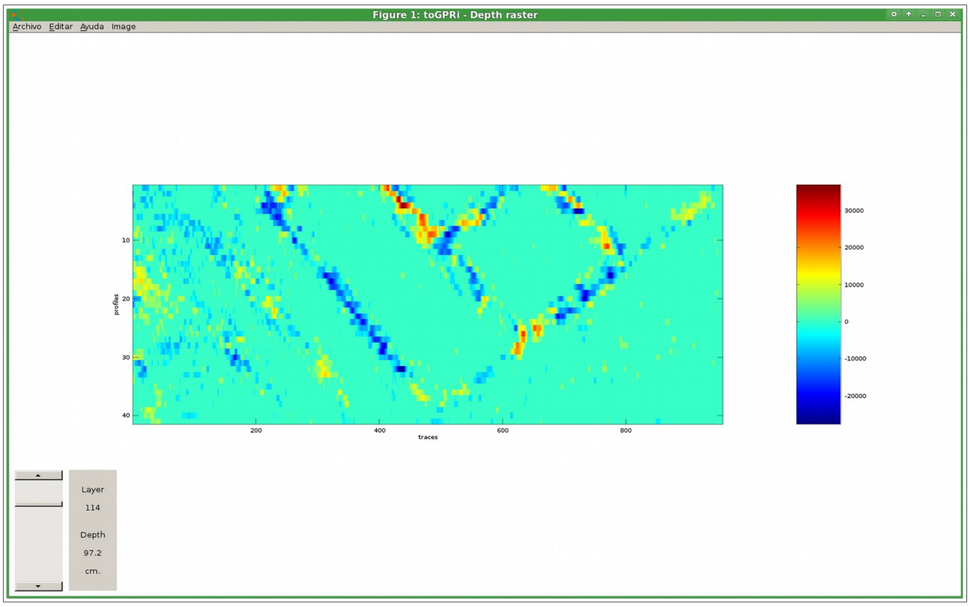

Figure 41. Horizontal layer rasters.

Now, in *Depth raster* we have the menu option *Image/Overlay raster* that allows us to draw a new overlaid image with union of several layers selecting the maximum pixel values (image 42).

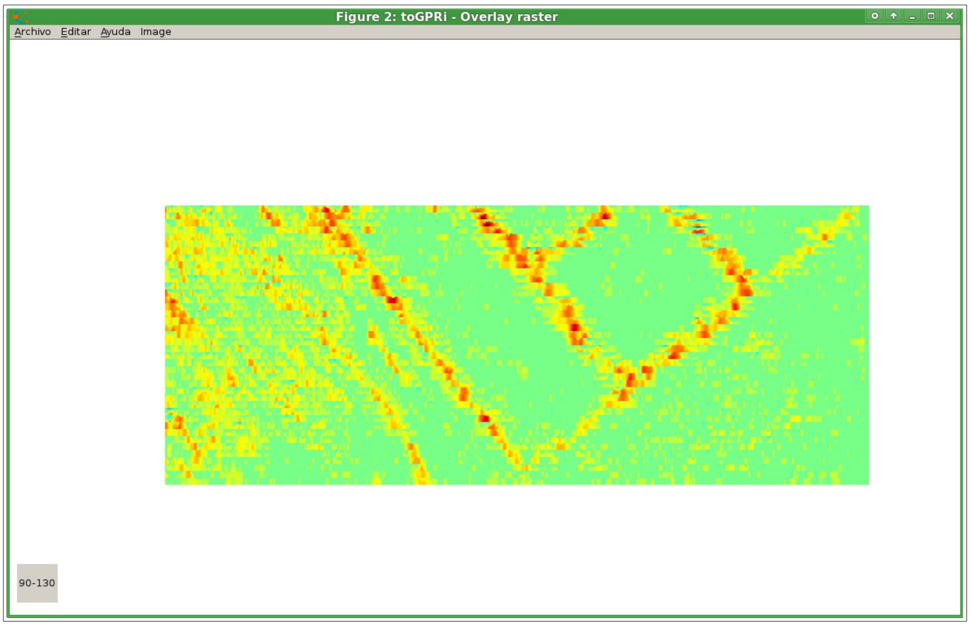

Figure 42. Overlaid raster.

The drawn overlaid raster is useful to give us an idea about the 8-bit TIFF and optionally PNG images now we can generate with the option *Image/Save TIFF files*.

To save the TIFF files we have to select a way to overlay the layers (maximum, minimum or mean pixel values) and a name for the main image (always with the *.tiff* extension). Optionally we can to select an alpha channel and a range of transparent pixel (from 0 to 255). If we do not choose the alpha option, the image will be an indexed colored TIFF, otherwise it will be a B/W one. Before that, we can also choose if we want to set up georeferenced files.

If we choose the georeferencing option a *.wld w*orld file, two GeoTIFF files (one of them with the WGS84 geographic coordinate system) and a compressed KML *.kmz* file will be created. It is imperative to select an UTM geographic coordinate system (EPSG number), the X and Y coordinates and the rotation of the raster around the upper left corner point of the pre-drawn one (Figures 43, 44, 45 and 46).

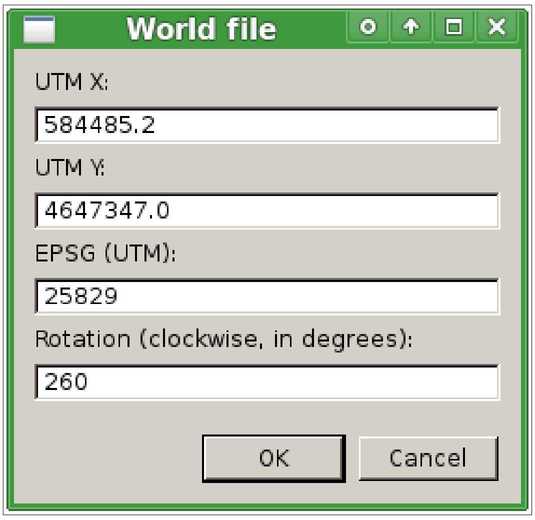

Figure 43. Selecting coordinates and rotation.

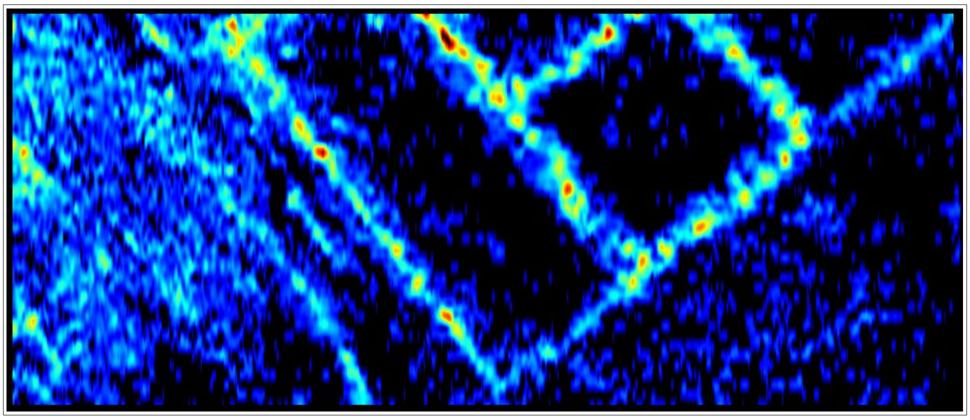

Figure 44. Example of indexed TIFF image.

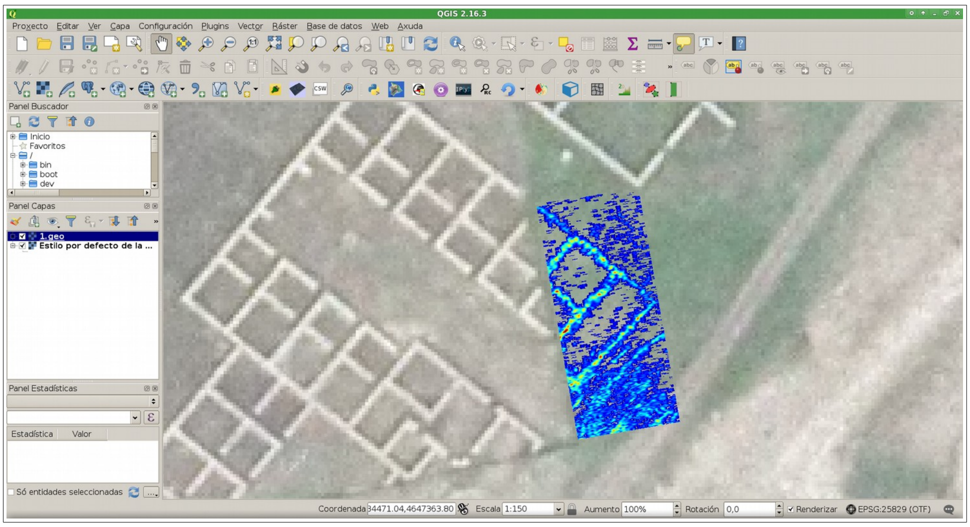

Figure 45. GeoTIFF image loaded in a GIS software (*QGIS*). Example of buried structures in an archaeological context.

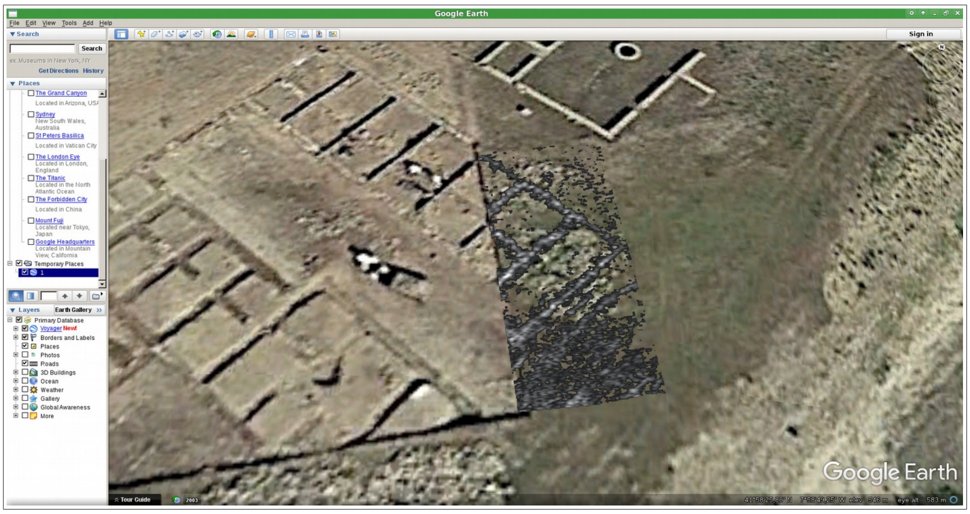

Figure 45. KMZ file loaded in *Google Earth*.

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