GPRSIM v3.0

Ground Penetrating Radar Simulation

User's Manual

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INTRODUCTION

GPRSIM c.1992-2017 - **G**round **P**enetrating **R**adar **Sim**ulation - is a forward modeling interactive software package for Windows that is designed specifically for simulating radargrams collected with a ground penetrating radar instrument. Since the user specifies many instrument design features in the software, radargrams collected from a variety of commercially available systems can be easily simulated.

A partial list of the features contained in the **GPRSIM Software** is:

- simulated radargrams based on exact ray tracing
- exact model structural/slope specification using lines,
        splines, and special functions (e.g. cylinders for
        pipe simulations) draw menu
- wave attenuation, geometrical spreading
- included wavetype multiples, peg-leg multiples, etc.
- antenna design
        directional response
        impulse response
        aperture
- conductive-dissipation/dielectric relaxation EM model
- wave polarization
- mono-static and bi-static simulations
        vertical profiling
        wide angle
        expanding spreads
- complete interactive menus
- full range of radargram display options
- capability to read a variety of GPR manufacturer data

The **GPRSIM Software** is all interactively controlled using specially designed menus that are easy to operate using the mouse, and are visually easy to comprehend.

The **GPRSIM Software** is a unique ray tracing software package in that the user can describe the model structures and interface slopes using shape functions, allowing for continuous or infinite measurement of model structural/slope information.

A published reference describing the theory used in **GPRSIM** along with applications of **GPRSIM** in engineering to archaeology is given in Goodman 1994 (GEOPHYSICS, February).

One of the distinctive advantages of using **GPRSIM** Ground Penetrating Radar Simulation **Software**, is that the antenna design and aperture size are considered in the synthetic calculations.   In the **GPRSIM Software**, the effective area of a particular radar antenna is incorporated into the ray traced radargram.   Aperture effects can cause what is uniquely identified as "aperture dispersion".   **GPRSIM** can provide the researcher the most accurate full waveform prediction code based on exact ray tracing, in a easy to use programming interface.

What's New

- GSSI, Mala, IDS, SS and GPR-SLICE 32 bit raw format import for impulse response
- E FarField computation for different surface dielectric as model model beam transmitter/receiver response
- Symmetric beam creation on transmitter receiver antenna
- Ricker wavelet generation added to the model the Impulse Response menu
- Borehole simulation with independent locations in x,y,z for the transmitter and receiver antennas
- Re-convolve a simulation already completed with a new impulse response function
- Export of 32 bit simulation radargrams in the Display menu
- Rectangle target added to Draw menu

Installing GPRSIM

To install **GPRSIM** do the following:

1. Copy the \sim\ folder to the local drive on your computer, e.g. c:\sim\

2.   Run the executable cbusetup.exe to install the USB security device. Updated drivers for the USB key are available at www.Marx.com

3. To run the GPRSIM make a shortcut to the executable gprsim-v3.exe on your desktop.

Based on your native screen resolution and your eyesight, one can adjust the menu font size shown in the SETTINGS menu to a comfortable size.   If your screen is 1280 by 1024, for instance, then insert these values into the x screen and y screen setting and use a menu font size of 8 or 9. With some higher resolution displays you may need to change the menu font size to much higher values. Also, if your eyes can not see small lettering, you can increase the size of the menu font size and this will globally change all the Windows text sizes. The is a limit to increase the size of the menus with the font size and if too large of a value is used some items might appear to be truncated on display. The minimum menu font size allowed is 6.
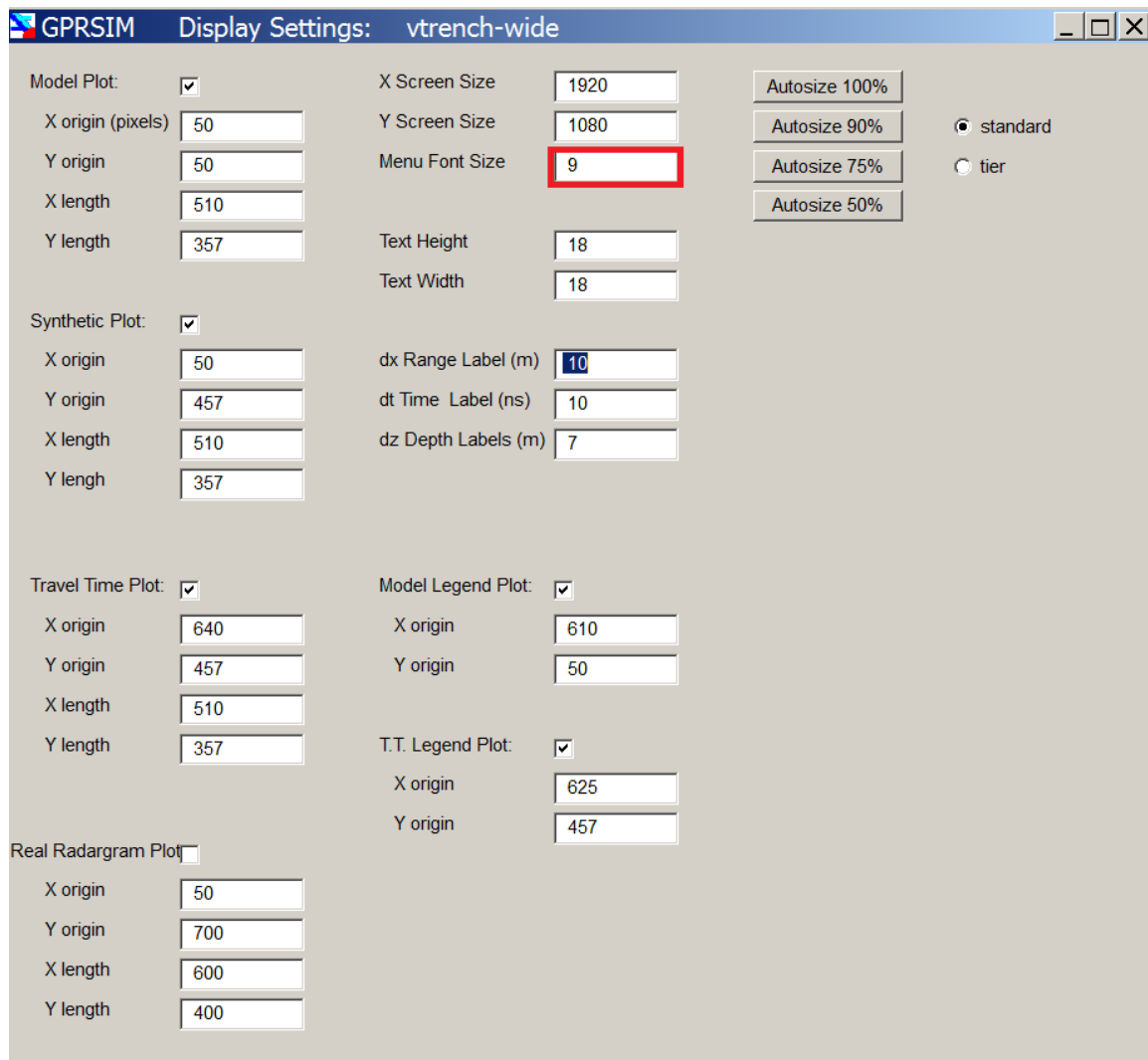

Figure A. The menu font size can be adjusted by the user between values of 6-12 (or more) based on their eyesight and native screen resolution shown.

Several **GPRSIM** subdirectories containing sample models are provided to the user for beginning their first training session. The user is encouraged to follow the steps in the QUICKSTART EXAMPLES section of this manual where a simple model will be recreated by the user.

A security key has been provided to the user. This security key must be attached to the USB port of the computer before a **GPRSIM** session can be started. Multiple copies of the software can be placed on other computers, however, because **GPRSIM** is USB key protected, the software can only be launched on one computer at a time.

QUICKSTART EXAMPLE

The best way to learn how to use **GPRSIM** is to jump right in a create, set, and run a simulation. So, here is a quickstart introduction to get you going right away with the software:

Let's say you have a V-shaped trench 1 meter wide with a vertex located 1.25 meters below the surface. (This model is the same as that given in Goodman 1994 and it is also provided for the user as the startup model example).   Assume the trench begins at a depth of 0.25 meters below the surface.   Also, lets assume the material above the trench has a dielectric of 10, conductivity of 0.001 mho/m; and below the trench a dielectric of 6 and a conductivity of 0.001 mho/m. The length of profile to simulate will be 4 meters long traversing over the center of the trench. Also, for the simple quickstart example lets use an impulse response that is a simple 300 MHz sinusoid, 1.5 cycles long.   All radar reflections within a 40 ns time window will be examined. The necessary steps to create this GPR simulation are as follows:

0) create a new simulation

1) draw the model and create the grid

2) set antenna impulse response

3) set antenna directional response

4) set wavetypes (raypaths) for the model

5) set locations for receiving and transmitting antenna

6) begin simulations

0) Create a new simulation
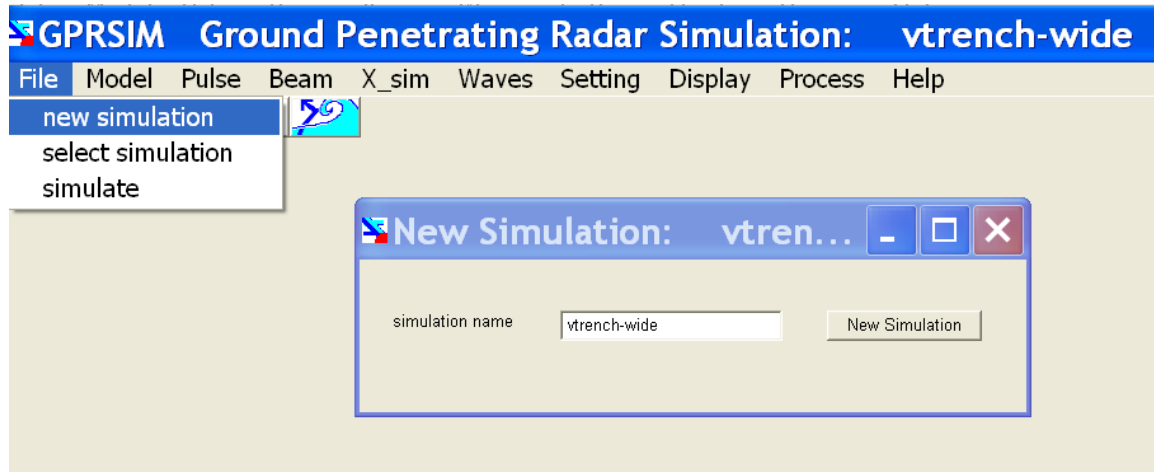
Step 0.1 enter the FILE menu and click on *new simulation*
      0.2 type in the name vtrench-wide e.g.
      0.3 click the *New Simulation* button

1) Draw the model and create the grid
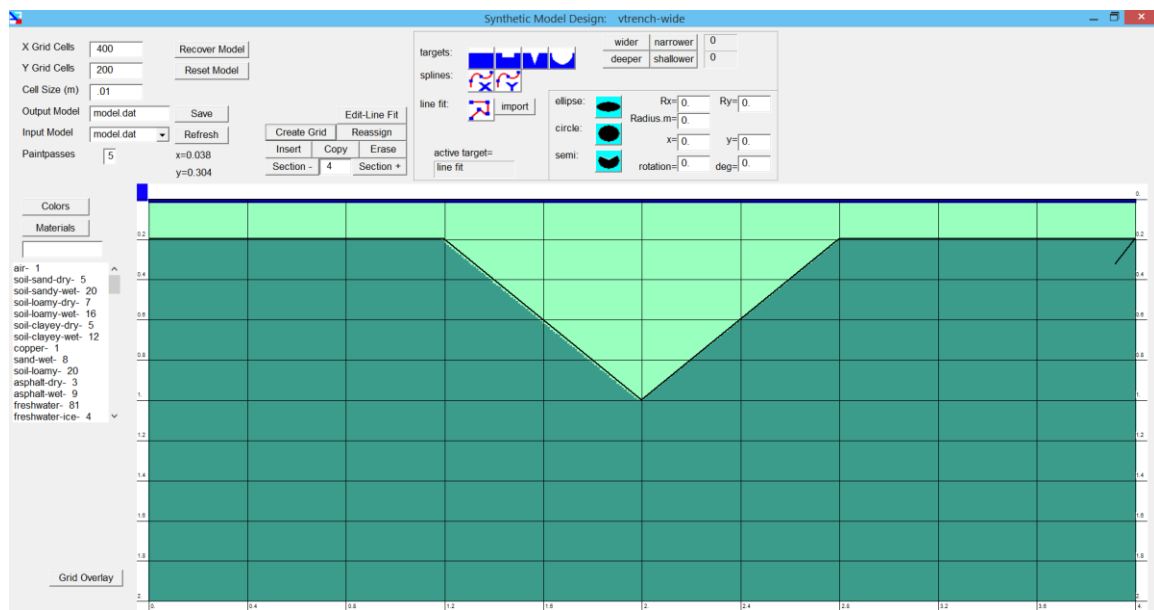
step 1.1   Enter the MODEL menu
      1.2   Set the X grid cells to 400
      1.3   Set the Y grid cells to 200 (or more)
      1.4   Set cell size to .01 (m)
      1.5   Choose a material in the listbox, e.g. number 4 – soil-
            loamy-dry (Er=7)

1.6　Start drawing the points defining the trench i.e draw the
points
(0, 0.25)
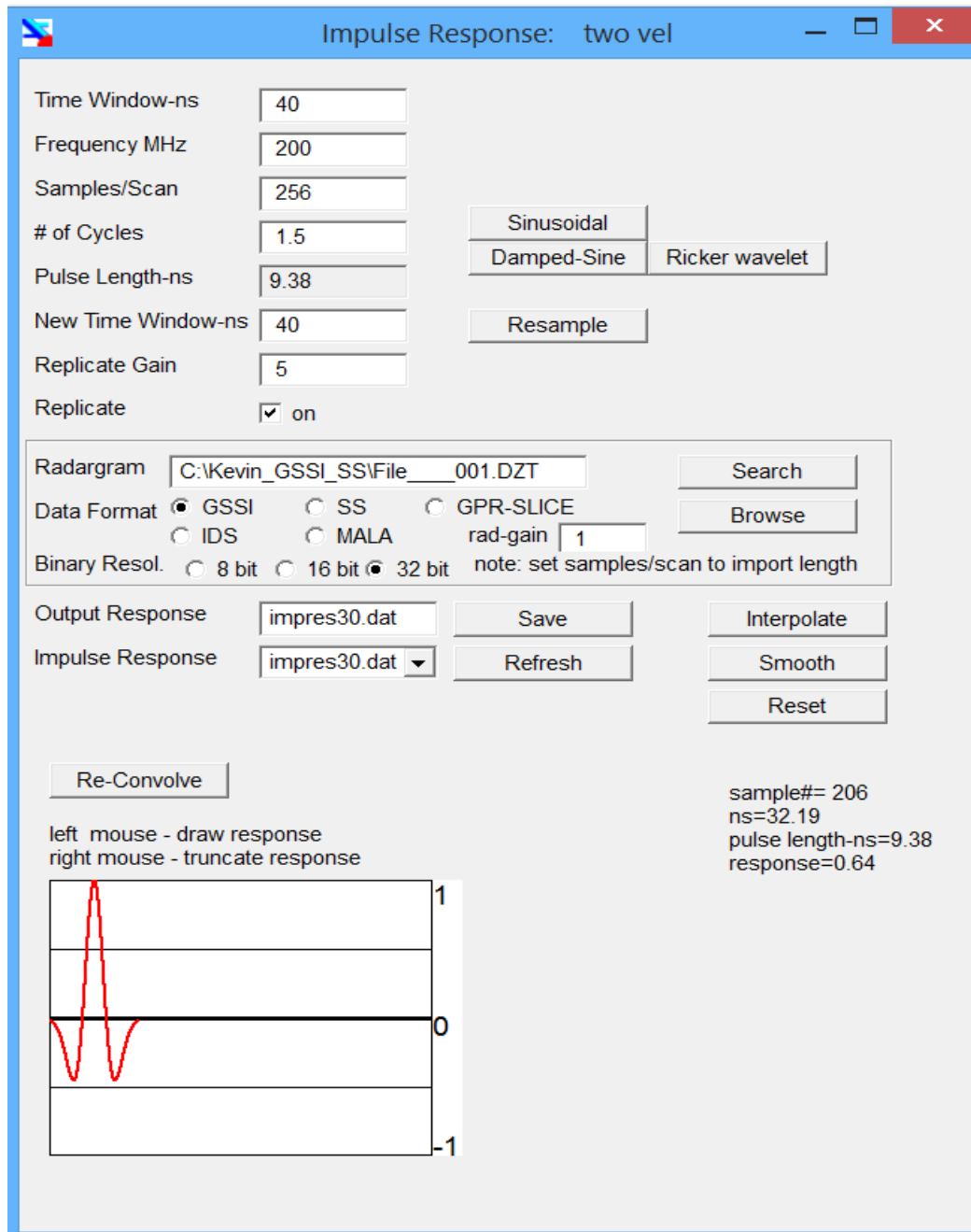(1.2, 0.25)
(2.0, 1.)
(2.8, 0.25)
(4.0, 0.25)
1.7 Click on one last point anywhere below the drawn structure
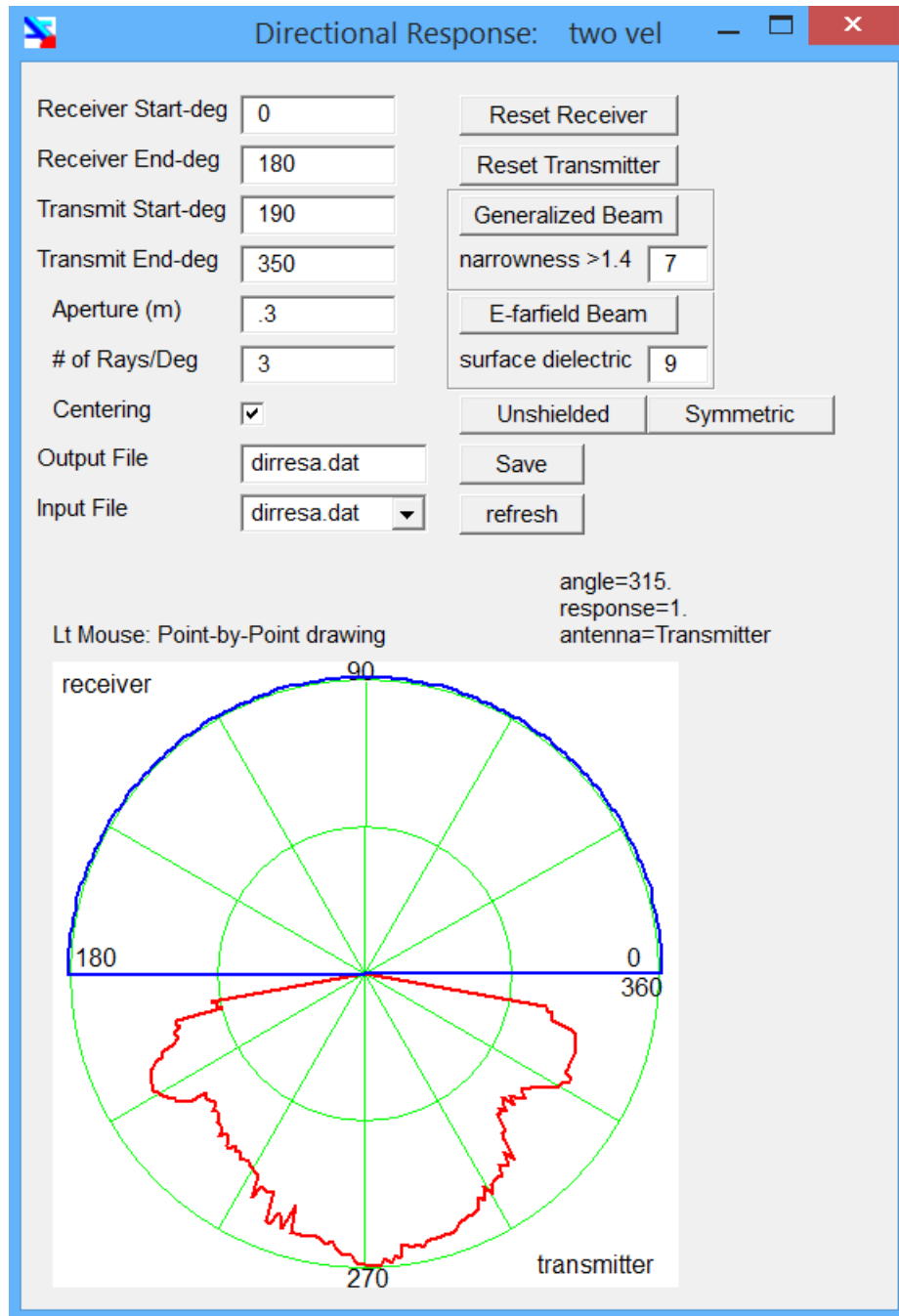1.8 Insert the drawn trench structure by clicking *Insert*
1.9 Start grid creation - a plot showing the grid created with an
overlay of the drawn model interface will be drawn.

2) Set antenna impulse response

step 2.1   Enter Impulse Response menu
    2.2   set the frequency to 400 MHz
    2.3   Set the number of samples/scan to 512 for example
    2.4   Set the time window to 40 nanoseconds
    2.5   Set the number of cycles to 1.5 cycles
    2.6   Click on the *Damped-Sine* button
    2.7   Save the impulse response

2) Set antenna beam directional response

Directional Response: two vel

Receiver Start-deg	0	Reset Receiver
Receiver End-deg	180	Reset Transmitter
Transmit Start-deg	190	Generalized Beam
Transmit End-deg	350	narrowness >1.4 7
Aperture (m)	.3	E-farfield Beam
# of Rays/Deg	3	surface dielectric 9
Centering	✔	Unshielded Symmetric
Output File	dirresa.dat	Save
Input File	dirresa.dat ▼	refresh

angle=315.
response=1.
antenna=Transmitter

Lt Mouse: Point-by-Point drawing

receiver

90

180   0
360

270   transmitter

step 3.1 lets assume that the directional response function provided for will be used

    3.2   set the aperture to .3
    3.3   set the # of rays/degree to 3
    3.4   click *Save* to update the dirres.dat file

step optional: make narrow transmitter (240-300 degrees - 60 degree beam)

      3.5.1 enter the transmitter as the active antenna
      3.5.2 enter a starting beam of 190
      3.5.3 enter an ending beam of 350
      3.5.4 enter the draw menu
      3.5.5 draw a response for the transmitter or click generalized
           beam
      3.5.6 save the changes

4) Set the wavetypes (raypaths) for the model
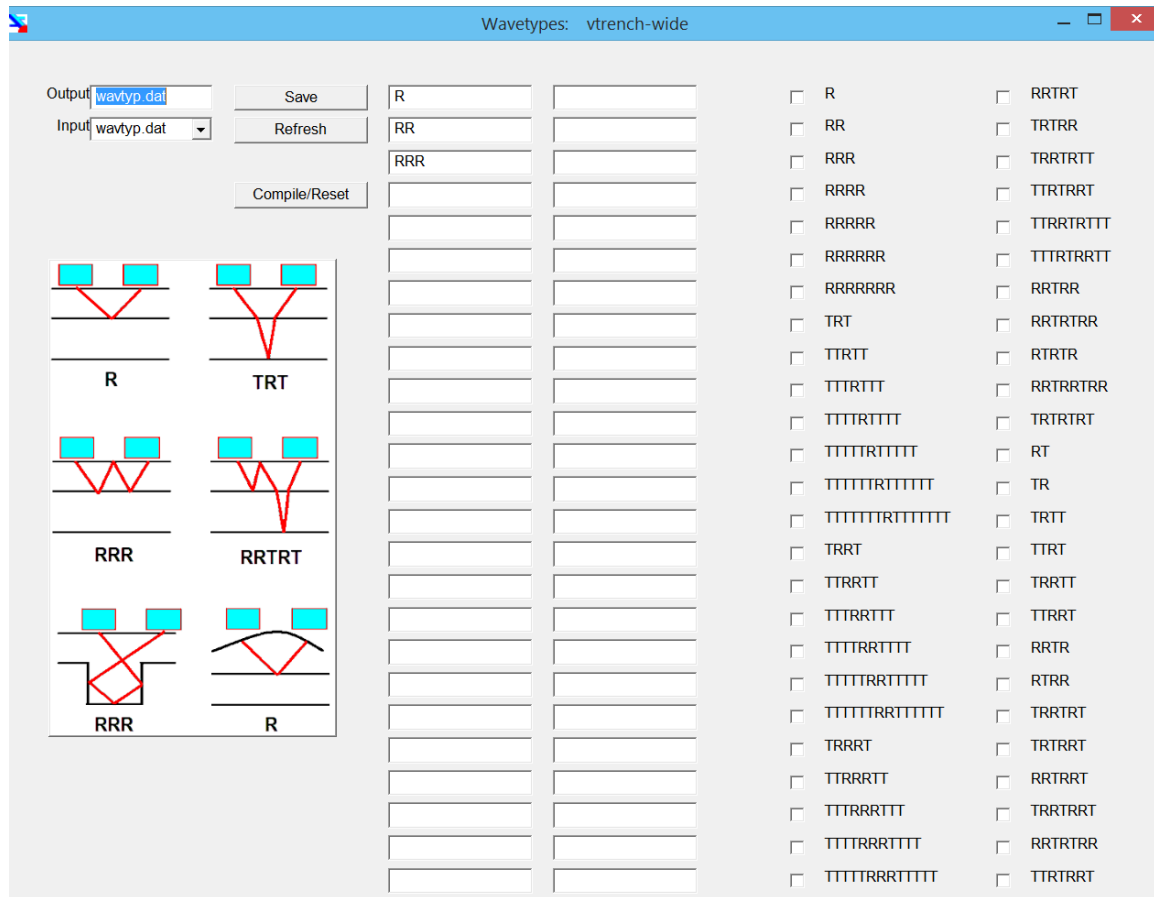
step 4.1 enter the WAVES menu
     4.2 the important wavetypes needed to be set are R, RR, RRR –
        check these on
        In the first three lines and then hit the *Compile/Reset* button
     4.3 update the changes the changes to the wavtyp.dat file by
        clicking *Save*

5) Set the antenna locations


```
X synthetic:  vtrench-wide                    —  □  ×

Scan Assignment      ○ Transmitter         Create Locations
                     ● Receiver
                     ○ (T+R)/2
                     ○ CMP

Transmitter Start (m)  0
Transmitter End (m)    4

Receiver Start (m)     0
Receiver End (m)       4

Number of points       100
Locations file         xloc.dat

☐ topography/borehole simulation on/off
transmitter grid section      0
receiver grid section         0

Note: borehole/topography antenna grid sections must be line fit drawn
```
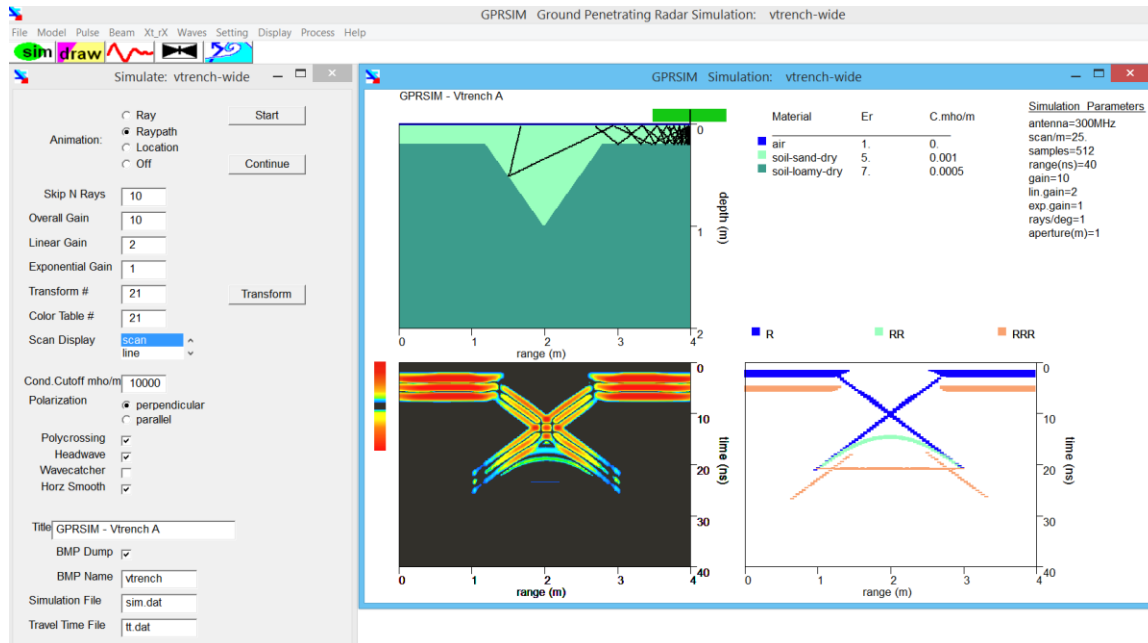
step 5.1 enter the Xt_rX Locations menu
5.2 set the transmitter starting location to 0
5.3 set the transmitter ending location to 4
5.4 set the receiver starting location to 0
5.5 set the receiver ending location to 4
5.6 set the number of antenna locations to 100 (for example)
5.7 save the changes by clicking the *Save* button

6) Simulate

step   6.1 enter the SIM menu
         6.2 check the animation box
         6.3 click the raypaths option to refresh the screen after all the
             rays for a single wavetype are animated
         6.4 set the number of rays to skip during animation to a
             comfortable number for your eyes! (e.g. 2-20)
         6.5 set the polarization to perpendicular (or parallel)
         6.6 check polycrossing, headwave, wavecatcher, horz smoother
             on.
         6.7 click the *Start* simulation switch

7) Option 1 - add another interface to the model e.g. an overburden layer 0.15 m thick

step   7.1 enter the MODEL Structure menu
         7.2 choose another material by clicking it on in the lefthand
             materials menu
         7.3 draw the layer draw some layer above or below
         7.4 choose a fill point below the new layer and click the right
             mouse button or place the fill point with the left mouse
             button and then click *Insert* section
         7.6 start the grid creation
         7.7 begin simulation etc. …e.g. Step 6.1-6.5

8) Option 2 - delete a drawn section from the model e.g. the option 1 structure

step   8.1 enter the MODEL menu
        8.2 click the *Section+ (or Section-)* button till the desired section
             to remove is highlighted
        8.3 click the *Erase* button to remove the section
        8.4 start the grid creation on the revised model, etc.

9) Option 3 - change a previously defined model material

step   9.1 enter the MODEL menu
        9.2 click the *Section+* (or *Section-*) button to highlight the
             desired section to change the material
        9.3 chose a material with the mouse
        9.4 click the Reassign material button to change the material
        9.5 create the revised grid

10) Option 4 - add a pipe of diameter 30 cm to the test structure

 step 10.1 enter the MODEL menu and choose a material for the pipe
        10.2 click the *Circle* radio button
        10.3 set the circle radius, x location and y location (given in
               meters)
        10.4 click the Insert section button
        10.5 create the grid

12) Option 6 - do a bi-static/wideangle simulation with the transmitter fixed and the receiver moving

step   11.1 enter the Xt_rX Locations menu
        11.2 set the transmitter start location to 0m
        11.3 set the transmitter end location to 0m
        11.4 set the receiver start location to 1.0
        11.5 set the receiver end location to 4.0
        11.6 *Save* the changes
        11.7 Start the wide-angle simulation

12) Options - general

    Before starting the simulation the user can change the radargram

line types, etc. Also, the display mode can be changed before (or after) a simulation. The gains for the simulation can be adjusted before starting the simulation - the gains will not affect what is written during the simulation and are only display gains. In the case when a simulation is started and perhaps the gains are weak, the user can let the simulation finish before resetting the gains. The option also exists to discontinue the simulation by double clicking the mouse and then resetting the gains. The simulation can then be restarted without losing any previous work by clicking on the "continue" button.

The result from the V-shaped trench should be similar to the simulation given in Goodman (1994) - Figure 5c. If the user did not get a similar result then check the QUICKSTART EXAMPLES steps and make sure you implemented them correctly.   The user is also encouraged to adjust various other parameters in **GPRSIM** to see their affect on this simple structural example (e.g. different aperture sizes, resampling of the directional response function, antenna centering, display modes, etc, etc).

SIMULATE menu

The Simulate radargram menu can be used to start a simulation, continue a simulation after a previous interruption. Several switches in this menu control the how simulations are computed.   Switches for parallel or perpendicularly polarized waves, a switch to allow for headwaves to be continued in the simulation or stopped, as well a control switch to turn on or off finer detail ray trace calculations. The simulation can also have animation turned on to show the ray reflecting/transmitting/refracting through the model.
 Simulations should only be started after the following files have been created:

- model file and the grid file
- impulse response file
- directional response file
- wavetype file
- antenna transmitter/receiver locations file

The various processes within the SIMULATE menu are briefly discussed along with all the input parameters to the menu.
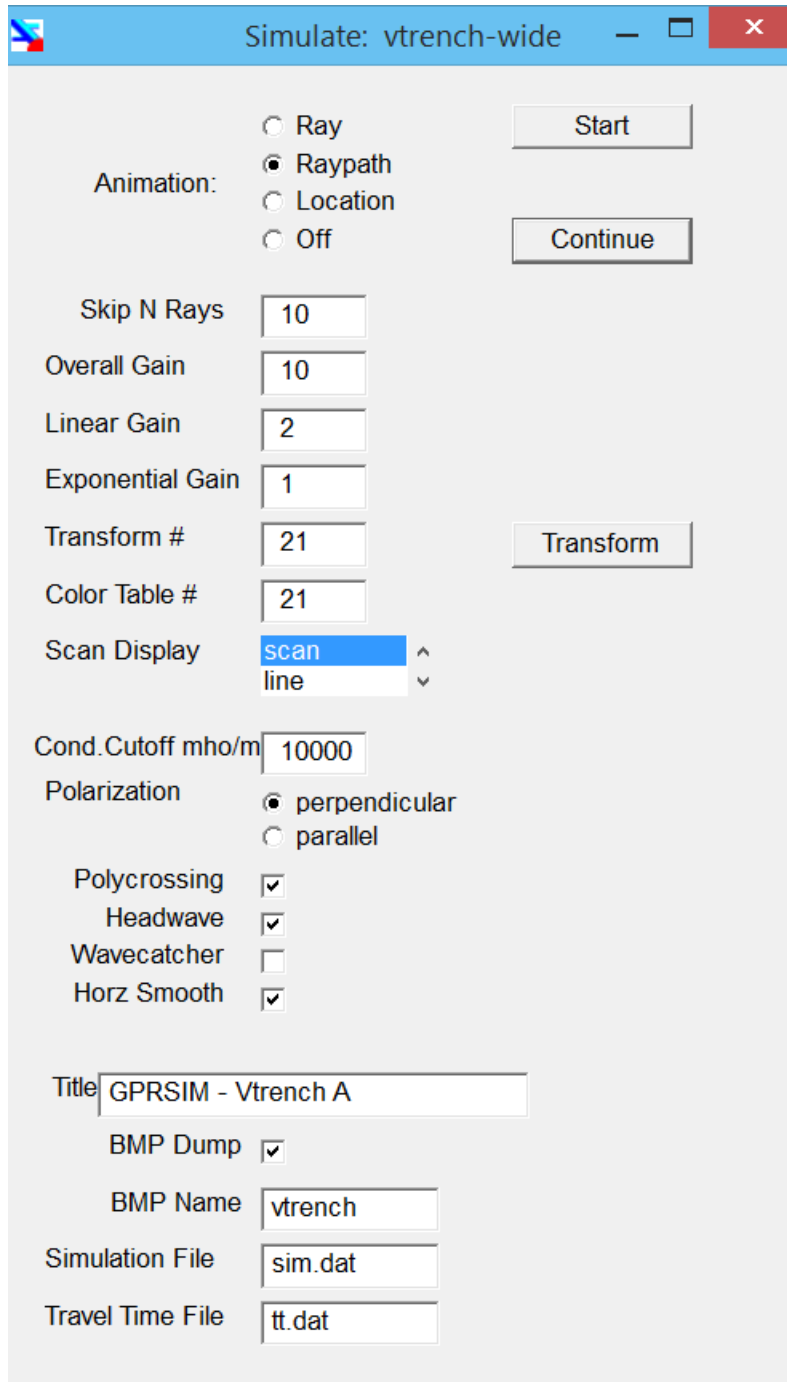
Figure 1a. The Simulate menu.

Start

  Begins the **GPRSIM** simulation

Continue

At any time during a simulation the user can terminate processing and do other activities in **GPRSIM** or completely exit as well. The continue switch allows the user to restart a simulation.

Transform

A submenu to adjust and edit up to 30 different radargram color transforms.

New Simulation

To create a new simulation the user can insert a name into the simulation name slot and then click on the New Simulation button. The current simulation will be copied to the new simulation directory for subsequent editing.

1.1 Animation

There are options to turn on or off animation of the real-time simulation while the processing is going on. Several animation styles given in 1.2 are available in GPRSIM Version 2.0.

1.2 Refresh: Ray, Raypath, Location

There are 3 option styles for animating the simulation:

a) Ray - will refresh the screen after every individual ray is traced through the model

b) Raypath – will refresh the animation after all the rays chosen for a single wavetype is are drawn

c) Location – will refresh the animation after all the rays for the different wavetypes are plotted and before the next location is simulated.

1.3 Overall Gain
1.4 Linear Gain

1.5 Exponential Gain

GPRSIM operations require gaining to be applied to the simulated radar reflections that are simulated (recorded). An overall constant, linear, exponential or any combination of these gain settings across the entire radar scan can be used to amplify the signal. These settings help to determine the colors contained in the radargram or the amplitude of the wiggles for various line display according to the equation:

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

where   gain   = overall gain factor
           rlgain = linear gain factor
         expgain = exponential gain factor
         irange = (i-1)/(nscan-1)
         nscan = number of samples per scan in the simulated
                     radargram

Notes:

Amplitudes from simulations will depend upon various factors including the density of rays sent into the model, refraction effects, antenna aperture (e.g. recording surface)etc. **GPRSIM** will compute the relative amplitudes very accurately; however, the overall gain and gain with depth will need to be adjusted to properly show the results of the simulation – just as is done with real data to show the weaker later arriving reflections.

1.6 Transform

The transform number from the user chosen colors transform tables to be used in assigning colors for the + and – of simulated radargram.

1.7 Scan Display

Various scan displays for presenting the synthetic radargram can be turned on by toggling this switch. The following displays are available:

        1) scan color
        2) line
        3) line + fill

4) line - fill
5) line +/- fill
6) color line

The color line scan will show a colored line changing according to the color levels specified by the color transform.

1.8 Polarization

Electromagnetic wave polarization.   Parallel and Perpendicular switches are available. Parallel refers to the E wave that is parallel to the plane of incidence; Perpendicular refers to the E wave that is perpendicular to the plane of incidence. The corresponding reflection and transmission coefficients are computed based on the wave polarization:

Parallel:
        T=k1*cos(theta1)/(k2*cos(theta1)+k1*cos(theta2))
        R=(k2*cos(theta2)-
k1*cos(theta1))/(k2*cos(theta2)+k1*cos(theta1))

Perpendicular:
        T=k1*cos(theta1)/(k1*cos(theta1)+k2*cos(theta2))
        R=(k2*cos(theta1)-
k1*cos(theta2))/(k2*cos(theta1)+k1*cos(theta2))

where
    T=transmission coefficient
    R=reflection coefficient
    k1,k2=wavenumber for materials 1 and 2
    theta1,theta2=angle of the incident and transmitted waves

For polarization parallel to the plane of incidence there is an angle of incidence, called the Brewsters angle, for which there is no reflected wave. This occurs when k1*cos(theta1) = k2*cos(theta2).

For mixed antenna properties, the simulation will have to be run once for each of the parallel and perpendicular switches and then the results added. (The user may want to run most simulations with the perpendicular switch on to simulate the most common profiling configuration).

1.9 Polycrossing

Model structures are recorded as polynomials or splines in grid cells (specified by the user in the MODEL menu). With polycrossing on, the intersection of the ray with the structure is found to within 1/50th of a grid cell for finer detail. For most simple structures that have gradually changing interfaces, this extra fine detail may be unnecessary and valuable processing time can be saved. For large structures which have been digitized into the grid using relatively coarse grid cell size, simulations with the polycrossing switch on can provide slightly more accurate calculations of travel times and ray/structure intersection parameters.

With this switch off, the location with which the ray enters an interface grid cell is used to compute the slope of the structure at that point. Thus every grid cell that is an interface will necessarily result in either reflection or transmission at that cell. With the switch on, this is not necessarily so since although a grid cell has an interface, unless an intersection point is found from polycrossing, the ray will continue on its course. In some cases near corners or strongly changing slope areas in the model, an interface/ray intersection point may sometimes not be detected.

1.10 Headwave

For waves beyond critical reflection, the microwave is assumed to be completely reflected. The critical angle is found from Snells law:

$$k1 \sin(theta1) = k2 \sin(theta2)$$

where k1, k2 are the wavenumbers of the two media and theta1, theta2 are the angles of incidence and transmission. When [k1/k2 sin(theta1)] is >+/- 1, then the ray has reached its critical angle. The transmitted wave amplitude is assumed to vanish beyond the critical angle, and therefore the transmitted wave is terminated by the software code, irrespective of whether or not the waves entire travel itinerary is completed. In reality, inhomogenous waves are generated beyond the critical angle. The modeling of these waves is presently beyond the scope of the software algorithm.

Note:

This switch should always be left in the on position. Using this switch in the off position and examining the raypaths with the animation switch on, may have some educational benefits for the user. The critical angles can be observed when a wave is abruptly terminated at an interface with the switch off.

1.11 Wave Catcher

For an antenna location which has some part of the antenna outside the simulated model (as can exist during the start of a simulation or the end if the full extent of the structure is simulated) the **GPRSIM** program re-gains these radargrams with this switch on. The gains are given by:

gain = 1 - (length of antenna outside model)/(aperture of antenna)

Simulations can also begin with the antenna completely within the simulated structures as specified in the Antenna Locations menu. Nonetheless, some waves may not be recorded near the ends of the model if structures are quite sloped near the boundaries. The user in these simulations should make the simulated model longer than the length to estimate the simulated radargram, in order to obtain the best results near the beginning and the end of the radargram without edge effects.

1.12 Title

A user title that will be printed above the simulated model.

1.13 Simulation File

This is the file name containing the synthetic radargram.

1.14 Travel Time File

The file name containing the attenuated reflection/transmission coefficients for each wave type.

1.15 BMP Dump

Bitmap output can be turned on and off for the simulation. The user can also create BMP output after the simulation is completed and redisplayed in the DISPLAY menu.

1.16 BMP Filename

This is the name to assign BMP dump of the simulation screen. The name should be given without the .bmp extension as it will automatically be placed into the given name.

Select Simulation menu

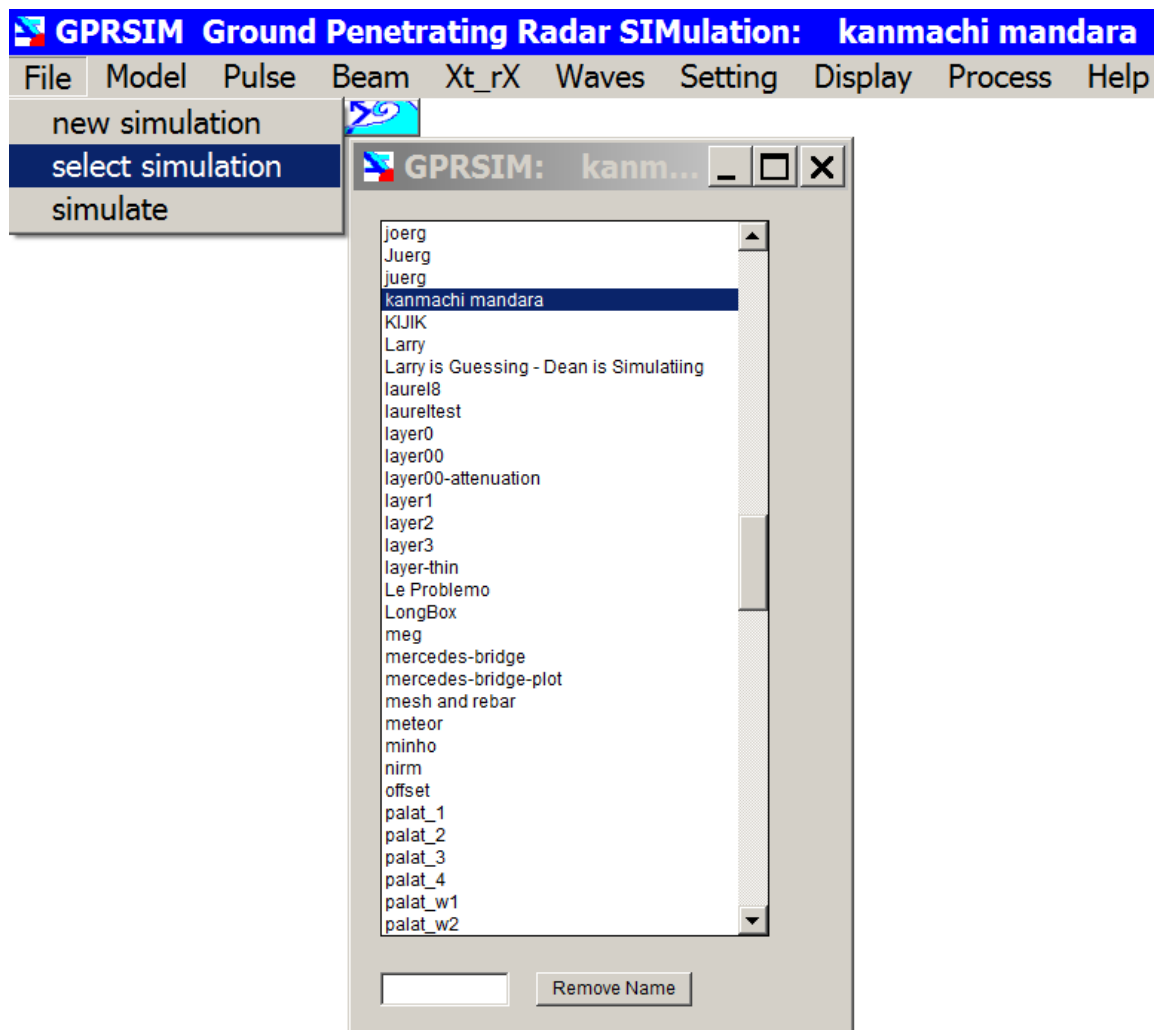In the FILES pulldown menu, the user can select previously completed simulations by clicking them on in the listbox.

Figure 1b. The Select Model menu.

Remove Name

A name within the simulation name databank can be removed by typing a simulation name into the menu slot and the clicking the Remove Name button. The next entry into the menu will display the changes made.

Note: Even though the simulation name will be removed, the actual subdirectory will not be deleted. To delete a \sim\ subdirectory the user must use Windows explorer.

MODEL menu
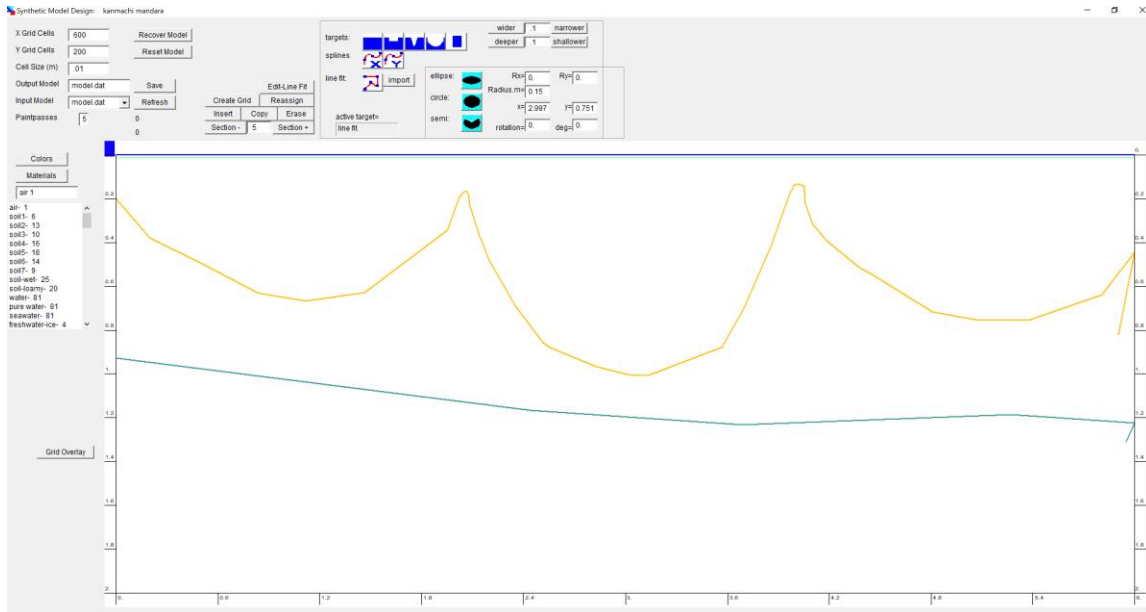
Figure 2a. The Model menu

A comprehensive model drawing menu is provided to input almost any kind of subsurface structure that a user can imagine. Included is a materials submenu where the user can set the complex dielectrics and conductivities for the designed structure in addition to assigning material identifier names.

The basic steps necessary to create a new model is to first set the size of the model and the cell size that the model will be digitized into. For many small scale structures a 1 cm cell size is convenient to use, but the user can use larger or smaller grid cells as well. The ultimate length of the model is given by setting the total number of grid cells in the X direction and the Y direction. For instance, for a model that is 4 meters long and 2 meters deep, the user can choose 400 grid cells in X and 200 grid cells in Y and a gridcell size of 1 cm to give the appropriate size.

In the drawing of interfaces, the top of the model (section 1) is assigned as the first material parameter, and the material below this (section 2) is assigned as the second material parameter in the table. These defaults can never be changed. Even after resetting or deleting a model file, these two sections of the model will always be written to the output file.

The top of the model set as section 1 (and usually assigned as air) is the location where the simulated antenna is located.   The second material is the material beginning from the ground surface.   The first waves that travel into the model are assumed to be located right at the ground surface and do not assume that there is an initial refraction or reflection from the air/ground interface.   The user can however, model the air/ground interface by assigning the same material for the second layer, e.g. air, as that for the first interface. In this case, even though and interface is drawn, **GPRSIM** understands that because the materials are the same, that an interface was not actually encountered.   The user can then insert a 3rd layer which is several centimeters corresponding to the height of the antenna above the ground surface.   For instance if they assumed the antenna were 5 centimeters above the ground, then the user could insert an interface at this depth. A whole set of new wavetypes or raypaths which would need to include a transmission through and returning to the air-air interface where the antenna is
located.

The following is a description of the processes or buttons in the drawing menu:

Create Grid

  Clicking this button will start the grid creation for the drawn model. After the grid is created it will be shown in the drawing menu and overlaid with interfaces point-point plot. The reason for overlaying the user drawn point plot on top of the grid is in the case of using splines, the user can check to see if the splines closely follow the desired structure – splines can have large undulations depending on the chosen points and if insufficient points are chosen the splines are not well confined in these blanked areas. A separate executable is chained to **GPRSIM** to create the digitized grid.   The grid is written to a reserved file name called ismgrid.dat.

Refresh

The user can click any drawn model from the Input Model combobox. The user can refresh this model into the grid by clicking this button.   Note, after the *Refresh* button is clicked the user will need to recreate the grid before starting the simulation

Save

A user may often want to backup a drawn model and they can do so by changing the output name parameter and then clicking the save switch. Any changes that were made prior to input model will be written to the output file. The input file is the active file shown in the drawing menu – thus the changes that are drawn will not appear in the drawing menu if the output file is a different name. To see the changes, the user must type the saved output filename to the input file name and the click the *Refresh* button.

Section+, Section-

Clicking these buttons will cause sections drawn within the model to be highlighted.

Erase Section

Any section to a drawn model can be deleted by first choosing a section by toggling the Section+ or Section- button and then clicking the Erase Section button.

Import

A comma delimited file with x,y points can be imported to define linear model sections.

Reassign

Any drawn section within the model can be reassigned a different material property. To do so the user will use the Section+ or Section- button to toggle to the desired interface and then click on the desired material from the material menu. Finally, clicking the Insert Section button will cause the updated material property to be edited into the model file.

Reset

The drawing window can be reset to a blank for beginning construction of a new model.

Materials

A submenu is provided to create the material parameter as well as the color palettes for the drawn model interfaces. Complex dielectrics, conductivity and magnetic permeability can be set in this menu. The velocities corresponding to the dielectrics along with the attenuation and the wavelengths are also computed. The velocity V is

$$V=C/sqr(E)$$ where C= speed of light, 3x10^8m/s a
E=relative dielectric

And the attenuation factor is proportional to

Attenuation factor= EXP(-a^r)
a=w*SQR(mhu*e1/2.*(sqr(1+tandel^2)-1))
tandel=(cond+w*Eimag)/w/E=loss tangent
w=angular frequency=2 pi frequency
r =distance along the raypath
mhu=magnetic permeability in free space
4 pi 10^-7 H/m

and the wavelength is given by

Wavelength=V/f   where f is the antenna frequency.

Figure 2b. The Modeling Parameter menu.

The user can store the names of the materials in the Material menu item, as well as describe the complex dielectric permittivity, conductivity, and the magnetic permeability. Up to 100 material constants can be recorded for each model. Each material data file, which is stored as the "material.dat" file in the \sim\project\, is unique for each synthetic model. If one wants to have the same materials copied into a new model, you should start in a project that has the desired material names, and then create a new synthetic model. This will copy all the current files to the new project name. One can also paste the materials.dat file from one model project to another in Windows.

2.1 X Grid Cells

The number of square grid cells in the horizontal direction used to digitize the structural model. The length of the model is given by (X

grid cells)*(cell size).

2.2 Y Grid Cells

The number of square grid cells in the vertical direction used to digitize the structural model. The depth of the model is given by (Y grid cells)*(cell size) .

2.3 Cell Size (m)

The dimensions in meters assigned to a single square grid cell used to digitize the model to be simulated. Larger cell sizes will require less memory and take a shorter time to run a simulation. Smaller cell sizes will require more memory and take a longer time to run a simulation. For structure with very fine and relatively sharp features changes, a smaller cell size will yield more accurate ray tracing near sharp structures or discontinuities. Larger cell sizes may be appropriate for gradually changing model interfaces.

2.4 Input File

The input model file. A backup input file of a model during editing etc., should be written in case a reset or delete button is accidentally pressed, or edits are not wanted. The input file (not the output file) is active during grid creation.

2.5 Output File

The output model file name to save edits to.

2.6 Paintpasses

This is setting used to internally 'paint' or fill out a drawn interface model with the appropriate materials defined by the fill point of the drawn structure. For most applications leaving this setting to 5 will be more than sufficient for the grid to be properly filled and created. In some extreme instances, for example in drawing a spiral structure with upwards of five or more revolution or rings, to properly fill this kind of structure may require a slightly larger number of paint passes.

These kinds of structures are rarely drawn, so that leaving this number to 5 will speed up the grid creation process.

If very complicated structures are drawn and the user does not see the desired grid created, then increasing this number slightly should give the properly filled **GPRSIM** grid.

Drawing Introduction

Creating structures in **GPRSIM** is simple although is requires some understanding of the procedures for drawing a grid.   The 4 general drawing instructions for GPRSIM are:

1) choose a material
2) choose a drawing fit type e.g. line, x or y spline or a circle
3) draw the model
4) draw the last point of the drawn structure to use as a fill point

1) To choose a material for drawing the user simply clicks on a material in the legend provided on the lefthand side of the MODEL menu (Figure 1).   The material names and dielectrics and conductivities can be edited in the MATERIAL Submenu by clicking on the *Material* button in the menu.

2) The type of line fit to the drawn model consists of 4 possibilities, a line drawing, x or y spline or a circle which can be inserted into the model. To choose a fit type the user simply clicks on the desired radio button shown in the MODEL menu (Figure 2c). For most structure it is recommend to use the the line fit.

3) To draw the model the user needs to click the left mouse button at the various points contained within the desired model to draw. These points are initially drawn with the straight lines connecting the points. If the user is using straight line fit type, then the drawn model will be nearly identical to the digitized grid after it is created. (If the fit types are x or y splines, the points drawn will be included within the fitted splines found after running the *Create Grid*.   However, if the points are ill conditioned, the splines can have numerous undulations which may result in undesirable fit to the drawn points. In this case, the user should slightly redraw the desired model or include more points within the desired model to better constrain the splines. X splines can be used for fitting structures which are drawn more or less horizontally and y splines for more vertically drawn model sections).

4) Once the desired structure or layer is drawn, the user needs to draw one last point below or within the drawn structure and then they can insert the the structure using the right mouse button, or the "Insert" button in the Model menu.

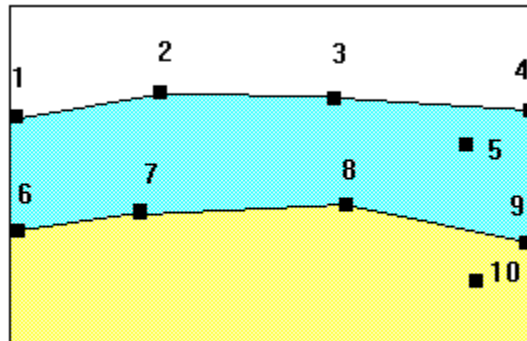A simple example on how to draw a 3 layer model is shown as follows:

Figure 2c. An example of a 3 layer model.

Points 1,2,3,4 are chosen with the left mouse button and point 5 is chosen to identify the area above or below the region to fill. To insert the newly draw feature the user clicks the Insert Section button shown in the Model meun.   Then points 6,7,8,9 are chosen with the left mouse button and point 10 is chosen with the right mouse button to fill the lower region. Note that the fill points 5 and 10 fall within their respective layers. If for instance fill point 5 were accidentally chosen to fall within the bottommost layer, then the second layer would not be filled - in addition, the bottom layer may also be filled incorrectly. To resolve a problem as discussed, the user will have to erase the bad section and start the drawing for that section over with a proper fill point.

Note: The fill points are not interfaces within the model, and they only describe the side of the drawn points to fill with the chosen material. Even though the last fill point is drawn with a continued line drawing from that model section, the drawn portion is NOT an interface with **GPRSIM** grid creation – it is only drawn to better inform the user where the fill point is located and to what section it corresponds to in the model.

An example on how to draw and how not to draw are shown in the next diagram. There are two possible and proper ways to draw the desired structure. In the first example three sections are drawn using material "a" and material "b": a square is drawn and filled with material "b" and 2 linear sections are drawn and filled with material "a". In drawing the model this way, until the last "a" section is inserted into the model the drawing and filling of just one "a" section, the "a" section fill will "bleed" into the upper model layer material. However, after inserting and filling the second "a" section, the proper model will be shown.

Desired Model to Draw
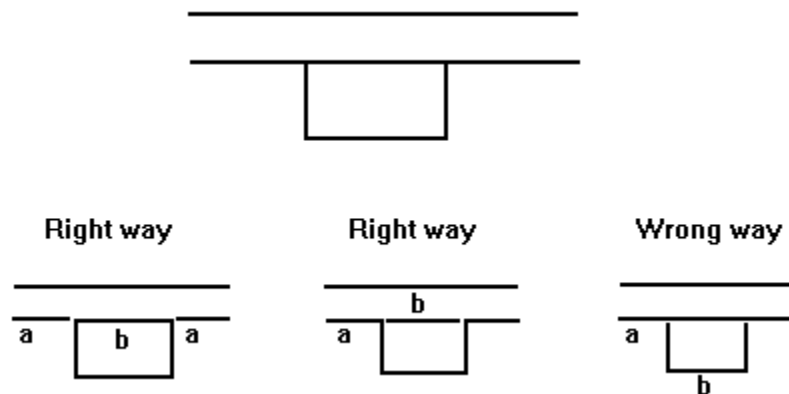
Figure 2d. Examples of correctly and incorrectly drawn models.

Another way to properly draw model is to use the second example. In this case the trench like structure is drawn first; the top of the trench is then drawn and filled with the "b" material.

The WRONG way to draw the trench model is to draw a straight line across the whole model using the "a" material, and then to draw the trench section with the "b" material. The reason for this is that as discussed in the previous note, the interface between trench and the upper material will be an interface which would include the "a" material which would be wrong! The drawn interface always includes the material which is used to draw it!.   This draw error would also make itself apparent when the user starts a simulation as the model

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grid that is output will show and incorrect assignment color for the interface grid cells in the improperly drawn region.

Also, the user should remember that the upper layer material section assignment and the second material section assignment are unchangeable. An interface is always automatically placed at the top of the model for the user by the **GPRSIM** software. The material above the first interface (which is usually air) is given by the first model material in the Model Structure menu. This is also automatic to any drawn model. Resetting or erasing an entire model will not affect these default assignments.

Note 2:
In drawing structures, all spline model sections must be connected by points which form a real polynomial when using a spline fit. Thus, if an x-spline is chosen for the fit then no double valued function can be drawn - the same for a y-spline - no more than 1 x value for each consecutive y value. Also sharp edges/corners when fitted with a spline can produce undesirable splines. Straight line fits need not form a real polynomial - they can be connected continuously with numerous corners or sharp edges to create filled regions.

Note 3:
When connecting other structures to a spline fitted structure, the user should connect structures at a known point that was inserted in drawing the spline points. Otherwise, the spline may not connect with the newly drawn structure. Spline structures are only shown after the grid has been created. Errors in filling a region may also arise as a result of not properly closing structures to a known point in the model. Filled regions need not get filled by a single independent spline section - but on a second (or third etc) spline section that all have a fill point within their defined bounds.

Note 4:
To start drawing a new model section, use the mouse to connect points with the left button presses. After the structure or interface is drawn the user will want to fill the new section using the right button press on the mouse.

More Examples of Basic Drawing Instructions for *GPRSIM* v3.0:

We will draw a trench that has 2 different soils in it.

step 1: choose a material from the listbox
step 2: choose the *line fit* drawing option
step 3: draw the trench, with the last point below the trench which represents the fill point
step 4: click **Insert** to update the model
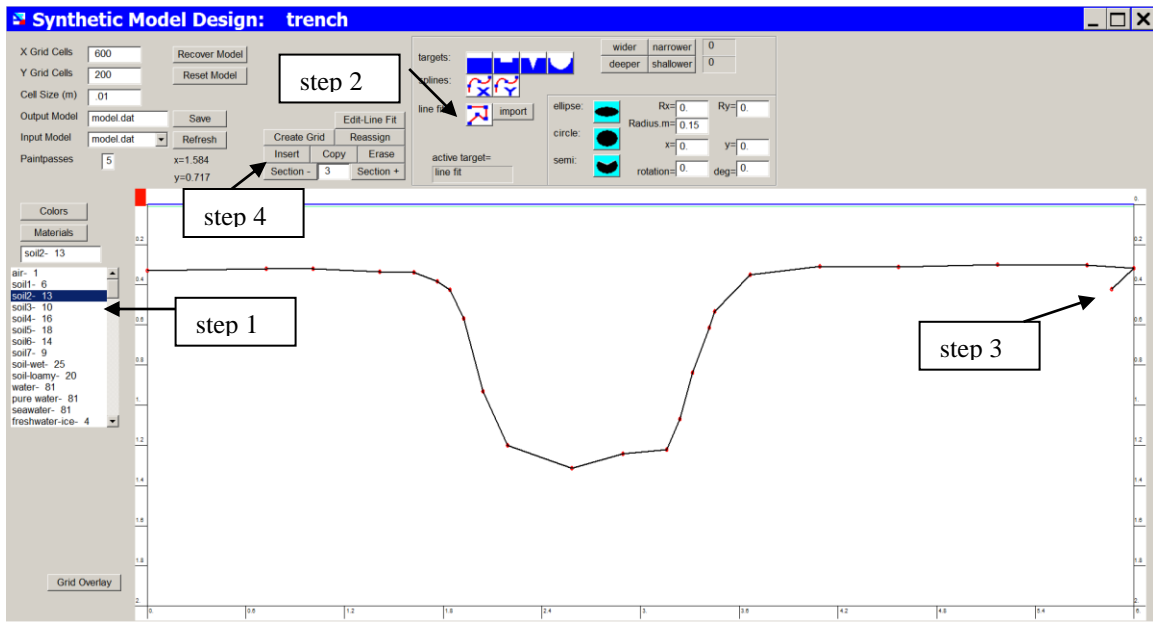
step 5: choose a second material from the listbox
step 6: draw the soil at the bottom of the trench, making sure that the start and endpoints connect with the trench wall, i.e. do not leave a gap
step 7: click **Insert** to update the model
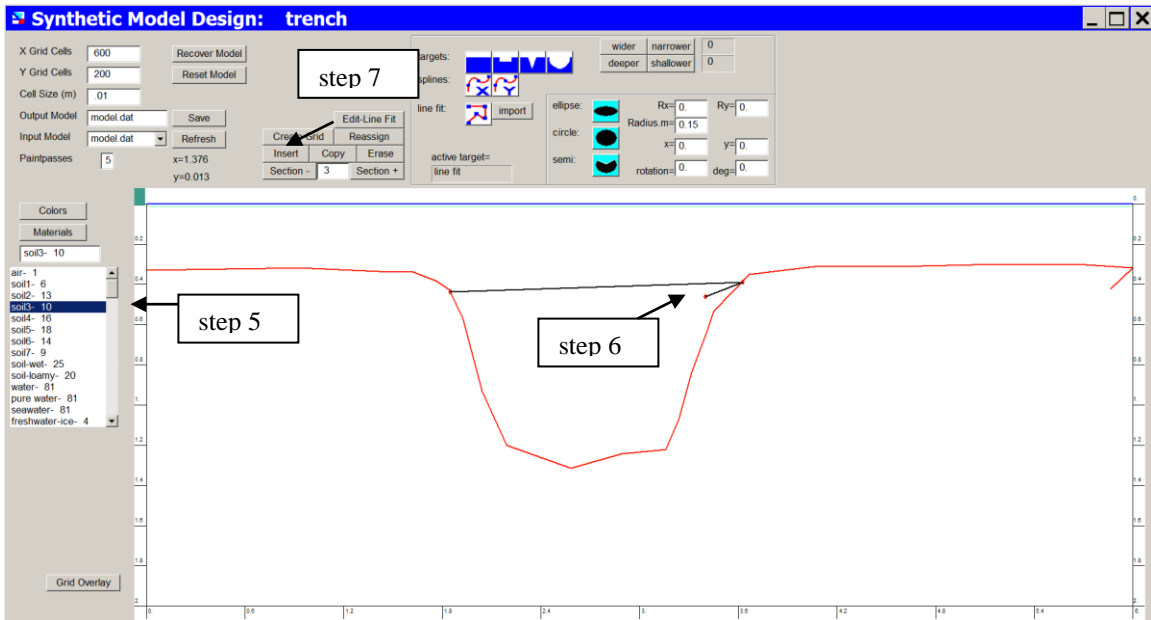
step 8: choose a third material from the listbox
step 9: draw the next layer in the trench
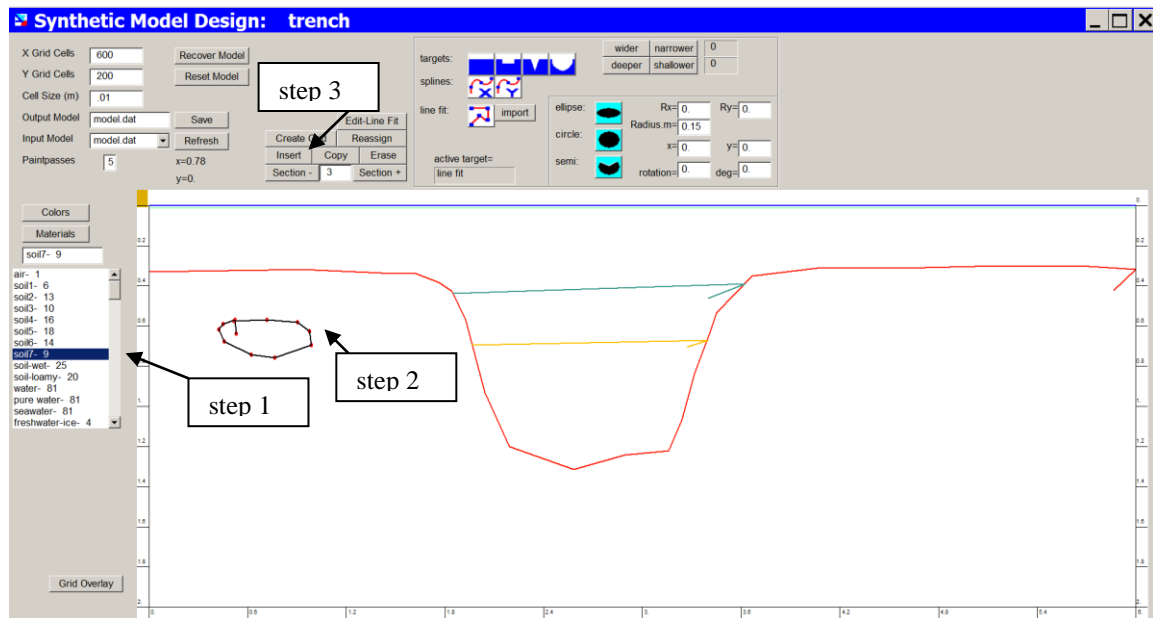step 10: click ***Insert*** to update the model
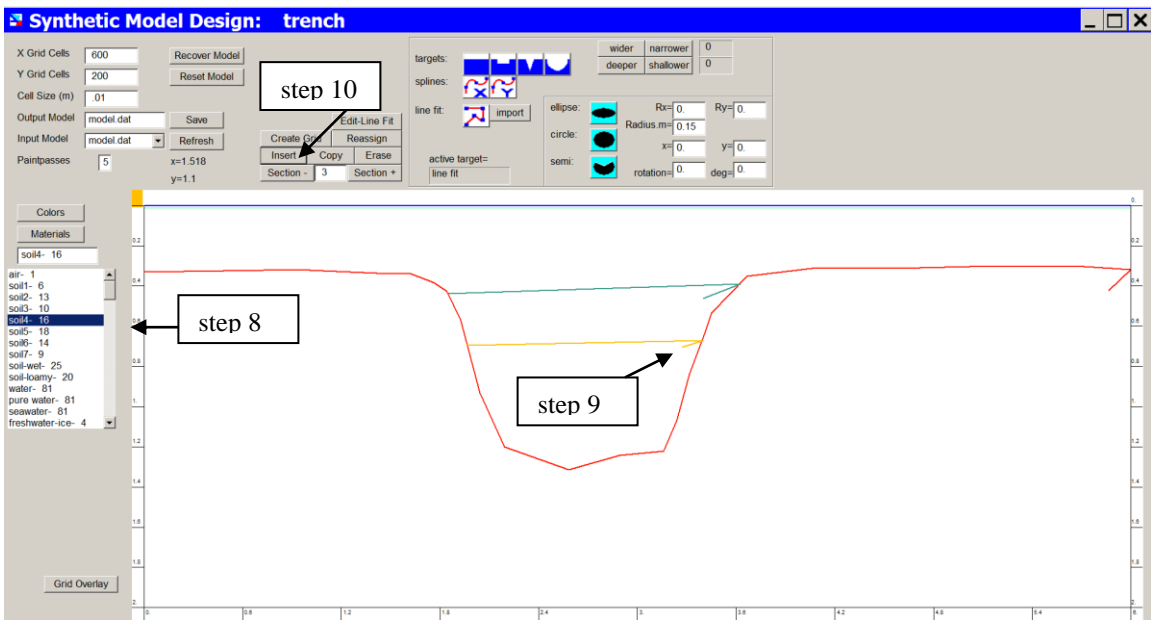
Drawing instruction to insert an isolated object:

step 1: choose a material
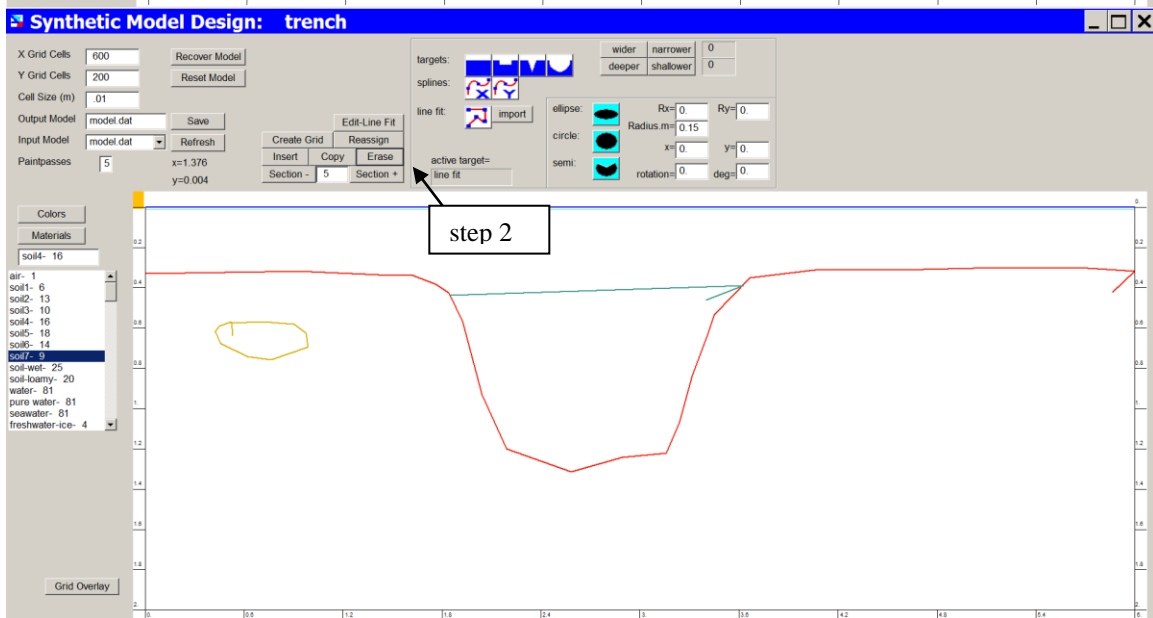step 2: draw an object and close it off, making sure the last fill point is inside the drawn object
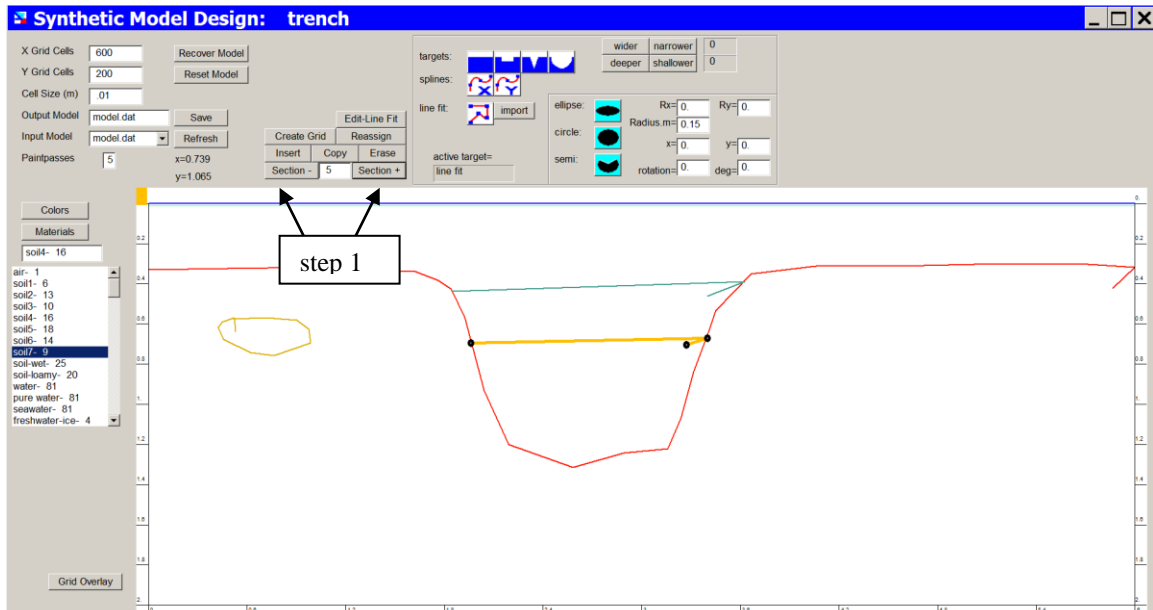step 3: click *Insert* to update the model

**Drawing instructions for deleting a section in the model:**

step 1: use the section +/- button to highlight the desired section to delete

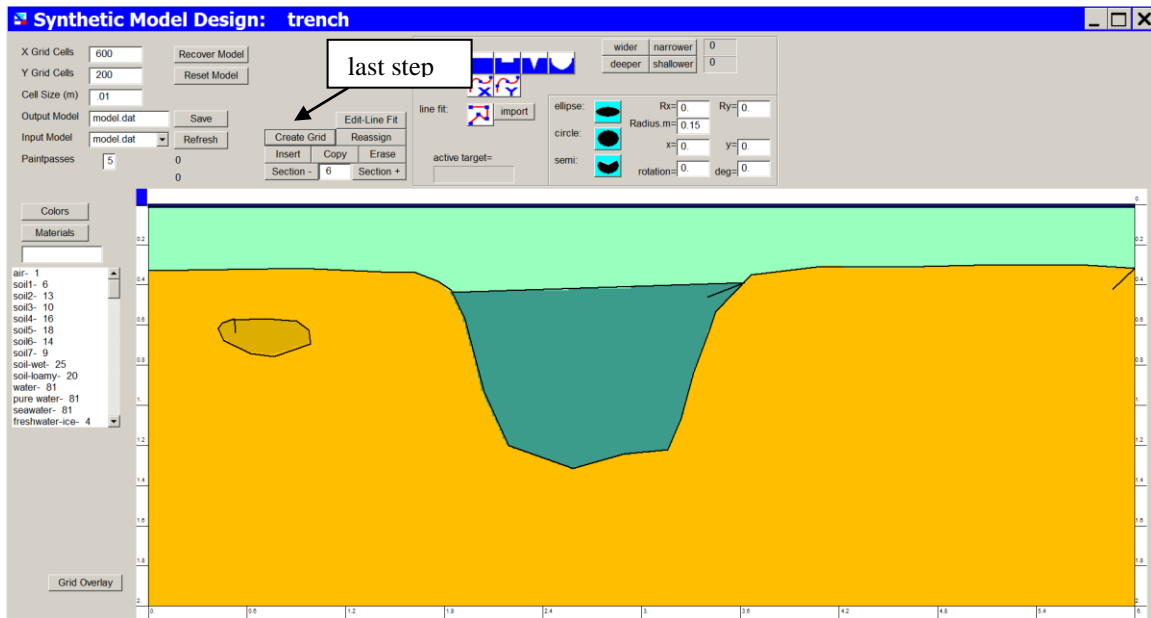step 2: click the Erase button – this will automatically update the model

Drawing instruction for reassigning a material to a previously drawn section:

step 1: use the Section +/- button to highlight the desired section
step 2: choose a material from the listbox
step 3: click the *Reassign* button
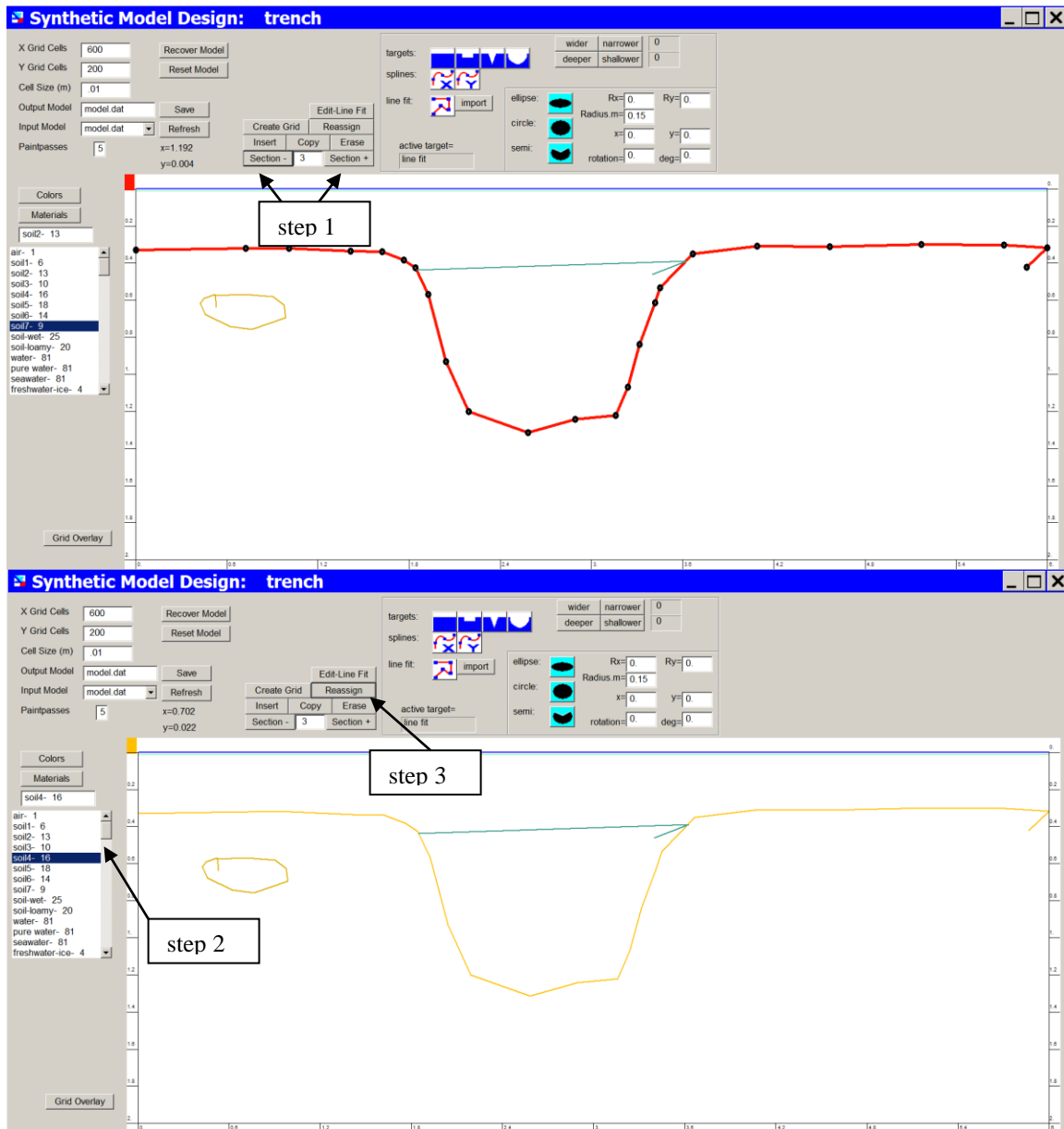
The last step after drawing the model is to click the **Create Grid** button.


Notes on drawing:

- After the grid creation is completed, the filled in grid colors are overlaid on the section lines in order for the user to see if the grid is filled in properly. If any sections are not the correct colors, this indicates that some points are not connected or the user did not draw interfaces that start and/or end at the grid boundaries. In the case of using X or Y splines to draw a structure, unless properly conditioned points are chosen, the create grid may show large cubic spline functions between the drawn points. The quality of spline fitting can be viewed after grid creation.

Importing an external file for creating an line drawn feature

step 1: Click the import button in the Drawing menu

step 2: Browse for a file that is x,y comman delimited without any header which contains the points of a model section that is desired to be imported. Note, the last point of the imported model section must be a fill point inside the drawn object (see example for importtest.dat which is a file for importing a rectangular object).
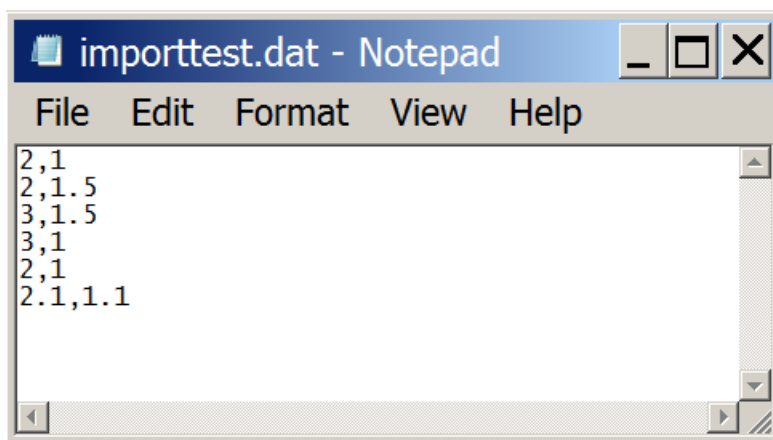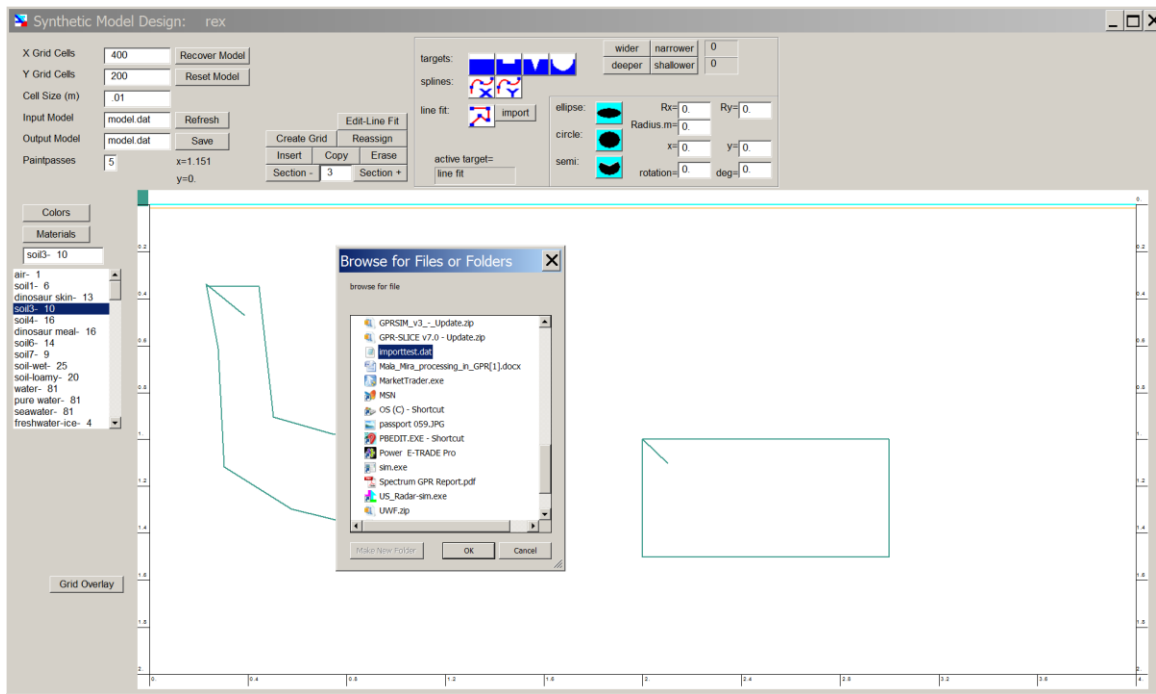
Color Assignment

In the color menu, the user can choose colors for each of the model materials as well as design and store there own radargram color table. To create a new color table the user can toggle through the available color tables which will appear in the top table. Clicking on a color and then inserting several colors in different locations in the blank color palette, the user can create a new color table. Using the "interpolate" button will interpolate a solid color table between individual colors placed in the blank palette. To save the color table, choose a location somewhere at a color table that one does not favor too much, and then record it there for posterity!

In the example on the following diagram, 5 colors were inserted into the blank palette. Clicking the "Interpolate" button creates a solid continuous color table which is shown in the very bottom palette.

To assign a color table to a model parameter, on simply click on a color and then places the mouse over the little rectangular box next to the desired model material. To save the changes to the model color table, which is color table #1, do not forget to click the "Save Model Colors" button
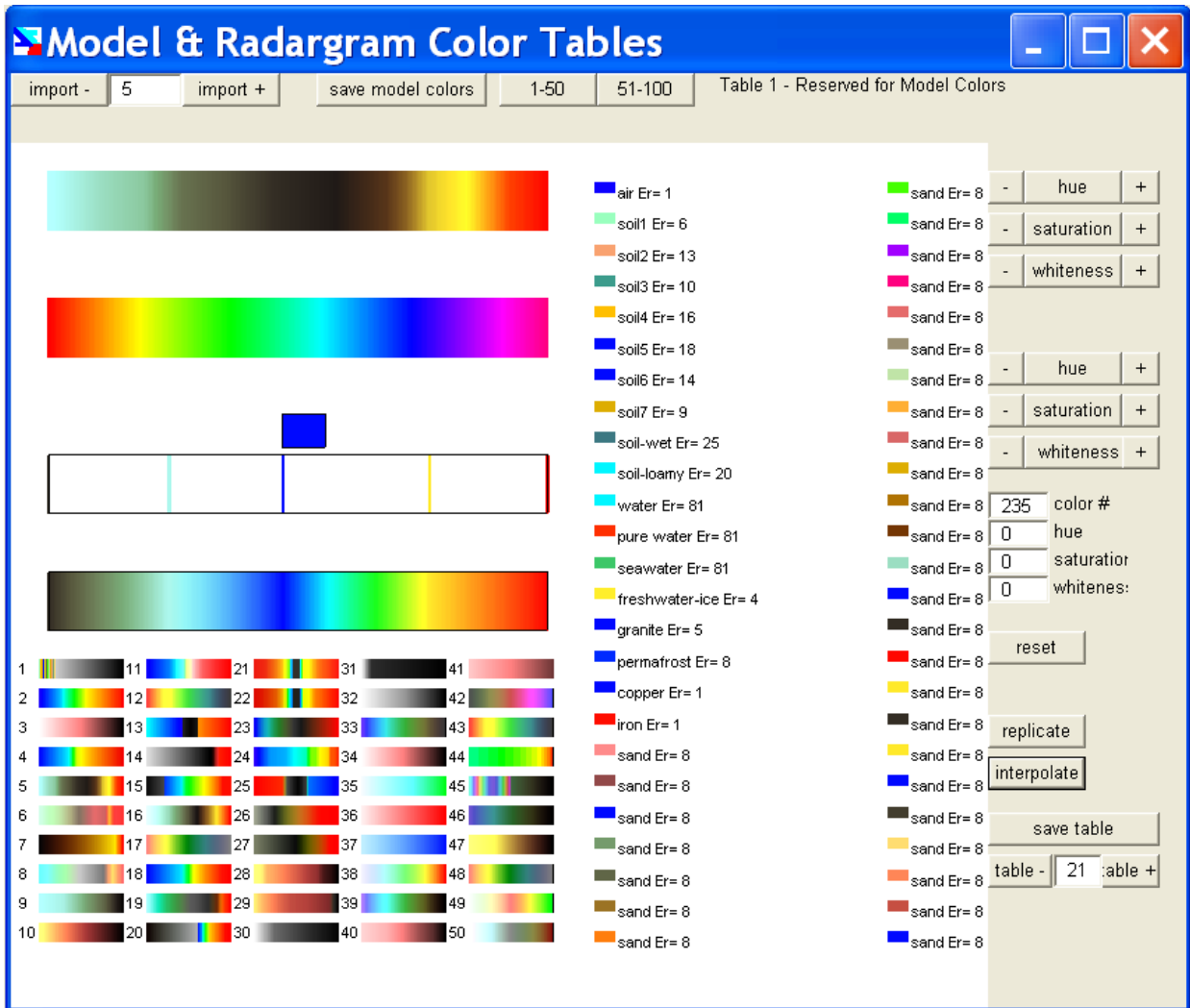
Model & Radargram Color Tables

import - | 5 | import + | save model colors | 1-50 | 51-100 | Table 1 - Reserved for Model Colors

air Er= 1
soil1 Er= 6
soil2 Er= 13
soil3 Er= 10
soil4 Er= 16
soil5 Er= 18
soil6 Er= 14
soil7 Er= 9
soil-wet Er= 25
soil-loamy Er= 20
water Er= 81
pure water Er= 81
seawater Er= 81
freshwater-ice Er= 4
granite Er= 5
permafrost Er= 8
copper Er= 1
iron Er= 1
sand Er= 8
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- hue +
- saturation +
- whiteness +

- hue +
- saturation +
- whiteness +

235 color #
0 hue
0 saturation
0 whiteness

reset

replicate

interpolate

save table

table - | 21 | table +

1 11 21 31 41
2 12 22 32 42
3 13 23 33 43
4 14 24 34 44
5 15 25 35 45
6 16 26 36 46
7 17 27 37 47
8 18 28 38 48
9 19 29 39 49
10 20 30 40 50

Figure 2e. The color table menus
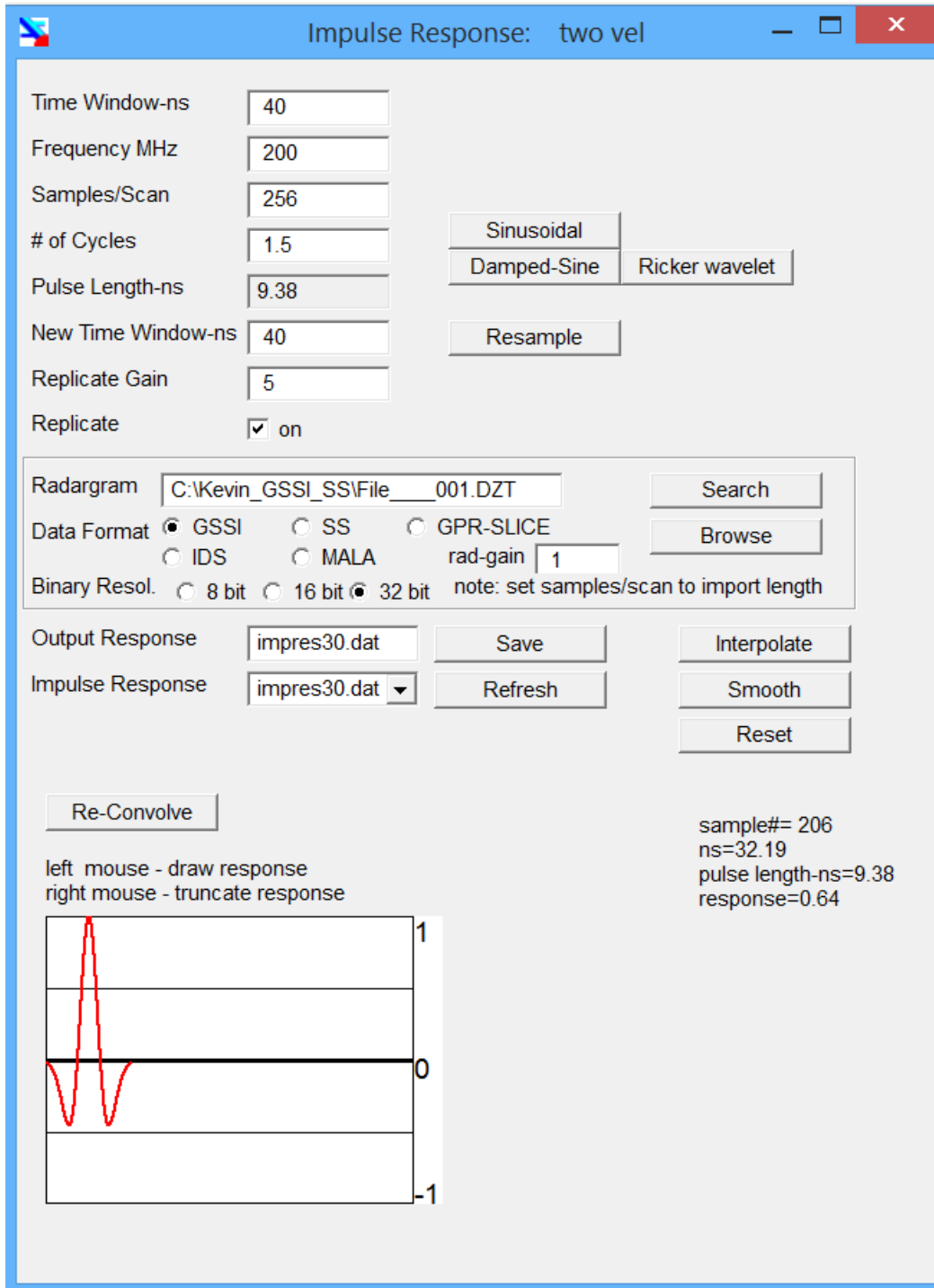
IMPULSE menu

Figure 3a. The PULSE menu

The PULSE menu can be used to (1) cut an impulse response function from a real radargram file, (2) create a sinusoidal or damped sine response, (3) draw or edit an impulse response function, or (4) resample a response function. The processes contained in the PULSE menu are:

Sinusoidal

The user can use a simulated impulse response in the simulation that contains X number of cycles that the user also sets.

Damped-Sine

The user can use a simulated damped sine impulse response. The damping is hardwired for the response to decay by 50% over the desired number of cycles chosen.

Ricker Wavelet

$$\psi(t) = \frac{2}{\sqrt{3}\sigma\pi^{\frac{1}{4}}} \left(1 - \frac{t^2}{\sigma^2}\right) e^{\frac{-t^2}{2\sigma^2}}$$

The Ricker wavelet formula can also be used to model an impulse response function from the transmit antenna, where omega is the inverse frequency and t is time. The example shown Figure 3a is a Ricker wavelet.

Resample

A active impulse response function can be resampled to include more or less nanoseconds in its response, depending on a new time window that will be chosen to run the simulation. For instance, if a impulse response function was digitized or created a 100 ns, and a new time window for the simulation of say 50 ns is desired, then the digitized impulse response function will be resampled to 50ns and will thus contain twice as many data. Likewise, when a new time window to run a simulation is longer than the time window that the impulse response function was digitized or created at, the impulse response will be compressed. In this case, the user should make sure that the resampled response is not under sampled.

Search Response

GPRSIM has the ability to include real impulse response functions that can be chosen from real radargrams. **GPRSIM** is capability of reading 8 or 16 bit raw radargrams from 3 different GPR manufacturers including Geophysical Survey Systems Inc (GSSI) of New Hampshire, Sensors and Software (SS) of Canada MALA Geoscience of Sweden (and IDS of Italy - use Mala setting but samples/scan of 1 less).   To use this operation the user must set the time window, the digitization of the radargram, and the binary resolution (8 or 16 bit) to be imported manually in the menu first. The user then browses the desired radargram and clicks Search submenu. In the submenu the user can then choose a scan within the radargrams and cut the portion of the response by setting the impulse time window with the lefthand mouse button.

Refresh

Refresh will replot the active impulse response function that is typed into the input file menu item.

Save Response

Save response will write the edited or cut impulse response function to the output file name. Any changes made to a impulse response function will not be shown unless the input file name is changed to the edited impulse file – only the input file is active in the drawing menu.

Reset

This process will reset the impulse response function to 0.

Interpolate

The interpolate operation will create a continuous response function between discreet impulse response function points chosen.

Smooth

The smooth function will smooth out a drawn response function. Clicking this button several times is needed to obtain the desired amount of smoothing to the artificial response function drawn.

Re-convolve

This operation takes a simulation that has already been calculated and will allow the user to re-convolve a new impulse response function without having to generated the simulation from scratch, saving processing time.

3.1 Frequency (MHz)

The frequency of the simulated impulse response of the antenna. Although multi-frequency signals can be drawn in the Impulse Response menu, a single frequency is needed to compute reflection, transmission coefficients, as well as attenuation and microwave velocities. Currently dispersive effects of GPR are not modeled in **GPRSIM**. Nonetheless, the user can use **GPRSIM** to do dispersive modeling by running the software at various frequencies vs dielectric (and conductivity) and then adding these radargrams together.

3.2 Time Window (ns)

The time window in nanoseconds over which simulations will be computed. In some cases when it is not known what an appropriate time window is for a particular model, a longer time window should be used.

3.3 Samples/Scan

The number of samples/scan used to simulate a single radargram. Any values from 2 to 1024 can be used. 256, 512 or 1024 are more common values. The samples/scan need not be the same as the real radargram that is modeled.

3.4 # of Cycles

The number of cycles to create a sinusoidal response. Values close to 1.5 or more closely mimic impulse response functions for real antenna. Of course, real impulse response functions are not true sinusoids but have a whole spectrum of frequencies near the central antenna frequency.

3.5 New Time Window

A new time window to be used to resample a digitized impulse response function.

3.6 Replicate

Replicate switch in the on position will write (replicate) the impulse response function at the top of the simulated radargram during a runtime simulation. The user may want to use this option when top surface is not modeled or the impulse response is representative of the top surface reflection.   In the case when the user is modeling the air-ground reflection to the antenna, this switch should be shut-off.   The impulse response function chosen will be replicated at the top of the radargram using the replicate gain. In general, the user will want to use a replicate gain equal to or slightly less than the overall gain factor that is set in the SIMULATE menu, prior to beginning a simulation.

3.7 Replicate Gain

The gain factor used in multiplying the impulse response that is written (replicated) at the top of the synthetic radar scan. When a directional response digitization factor that is quite large is used, the return responses when added up can be significantly larger than the replicated impulse response written at the top of the radar scan. This gain factor allows the user to match synthetics with real data amplitudes etc., in the case when a precise impulse response function at the surface is not going to be modeled.

3.8 Radargram Filename

The name of a radargram (also containing the directory name) to cut an impulse response function from.

3.9 Data Format

The Data Format item specifies the type of equipment that the user would like to cut a impulse response function from a radargram. Data formats are different between the 3 major manufacturers, GSSI, SS, and MALA.

3.10 Binary Recording

GSSI radargrams can be read at 8 or 16 bit recording – SS, MALA

and IDS radargrams by default will be read in as 16 bit radargrams. F

3.11 Input File

Impulse response function input file. The input file (not the output) is active during any simulation run.

3.12 Output File

Impulse response function output file.   The input file (not the output) is active during any simulation run.

Drawing a response function, interpolating it, and then smoothing it out

The Impulse Response function menu has an option for the user to create an "artificial" impulse response function for the GPR antenna. To do this, just draw the discreet points of the desired response function (as shown in Figure 3b). After these points are drawn the user will then click the "Interpolate" button.   This will create an interpolated response function between the drawn points (Figure 3c). Because these points will normally be rough, the user can then applying the "Smoothing" button several times to this artificial response to smooth out the drawn response (Figure 3d).
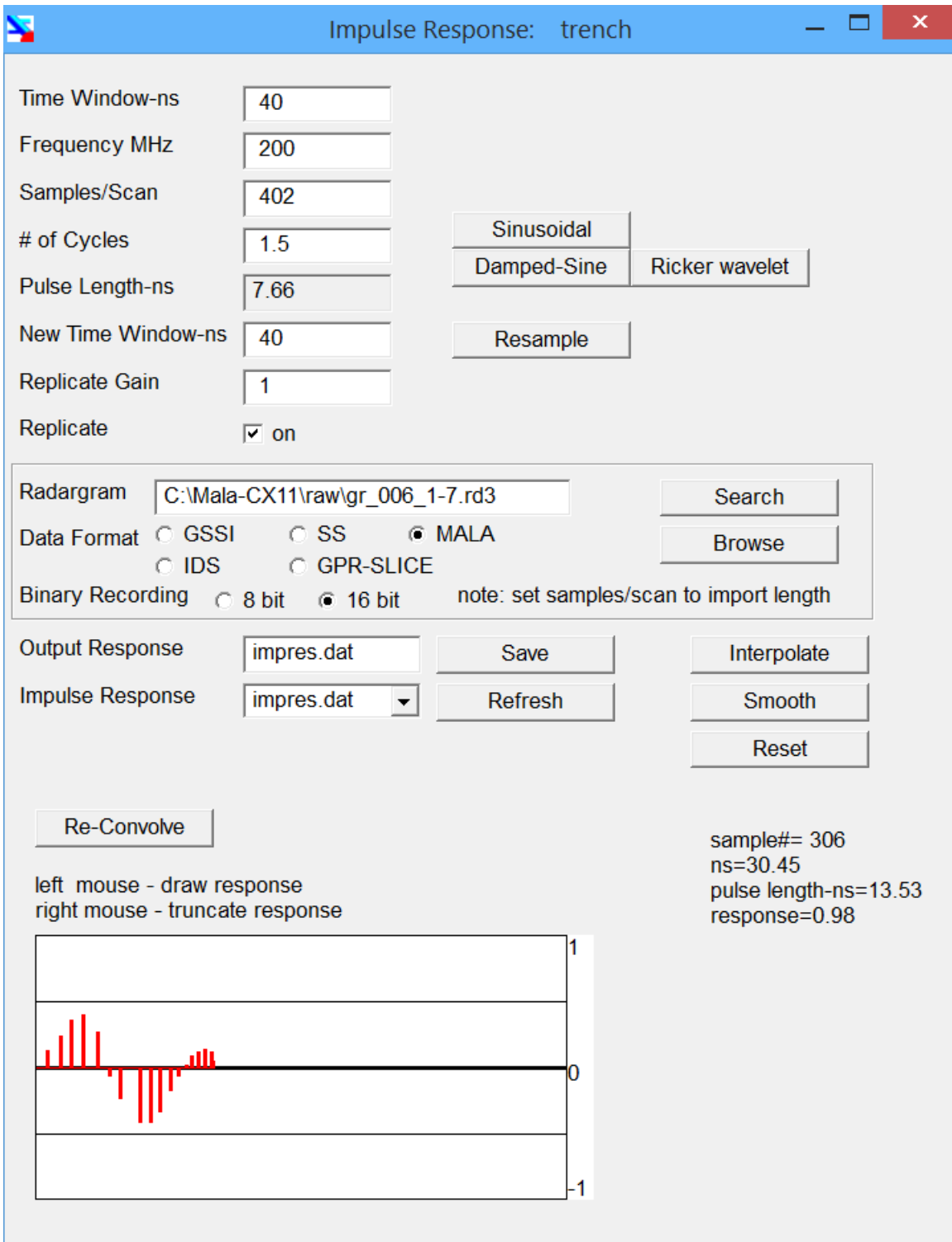
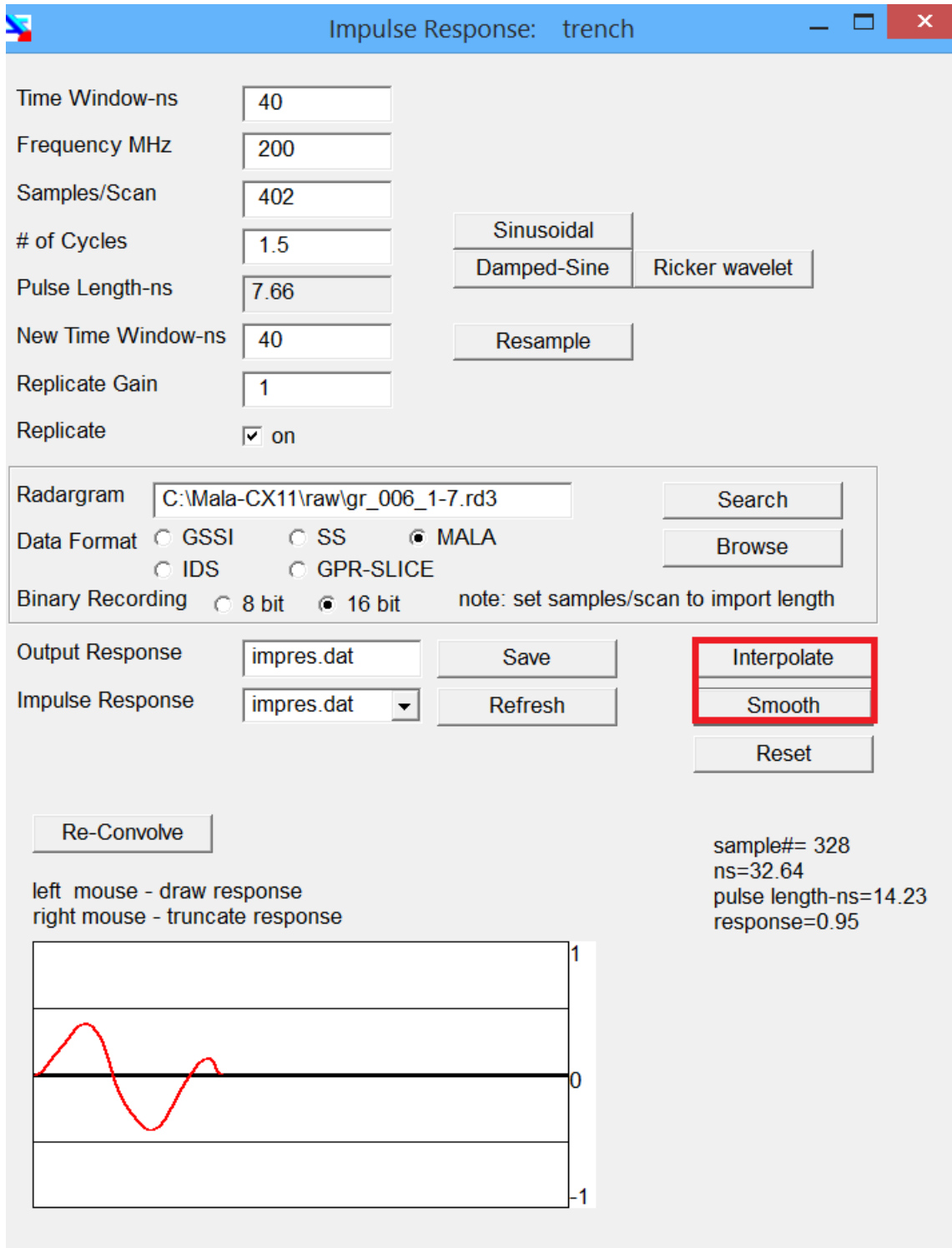**Figure 3b.** Drawing discreet impulse response function values.

Figure 3c. Interpolating between discreet impulse response functions values shown in Figure 3b and clicking the smooth button several times.

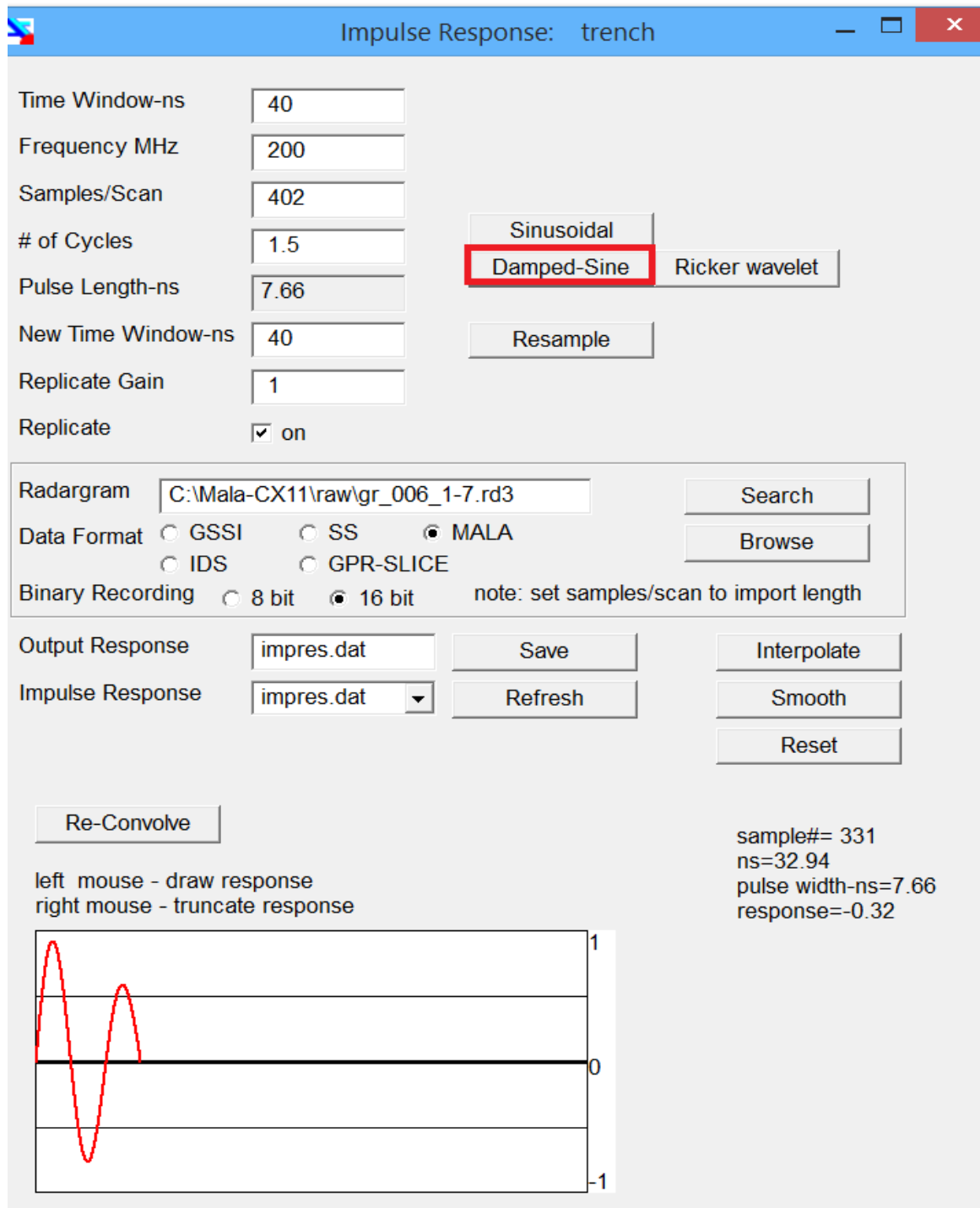**Generating an artificial damped sine wave for a simulated impulse response function:**

Figure 3e. Generating a damped sine wave of 1.5 cycles.

Extracting the impulse response function from a real radargram:

In GPRSIM v3.0, the user can extract an impulse response function from a real radargram. In the Impulse Response function menu, inserting a file name followed by clicking the "Search" button, a menu will come up with the chosen radargram. Clicking the left mouse at the start and end points of the estimated response function, and then clicking the "cut save" button, will extract the chosen parts of the radar pulse. Upon re-entering the Impulse Response menu, the chosen pulse will appear as the active response function. Further editing, such as cutting off the end of the pulse or smoothing the pulse can also be implemented. Note: If the displayed radargram is undergained in the Search menu, then set an appropriate rad-grain value before launching.
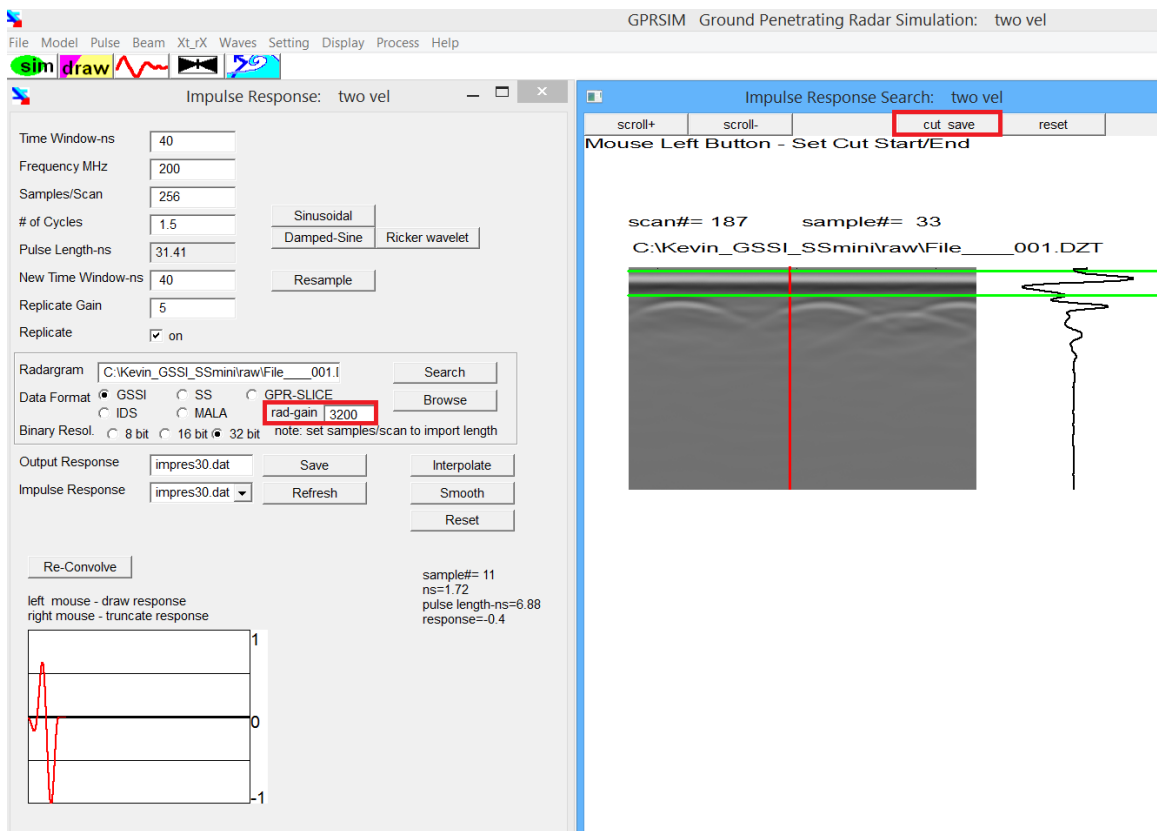

Figure 3f. Example how to extract an estimated impulse response function from a real radargram. The left mouse clicks are used to define the top portion of the pulse, and the *Cut Save* button is pressed to extract the desired part of the pulse.
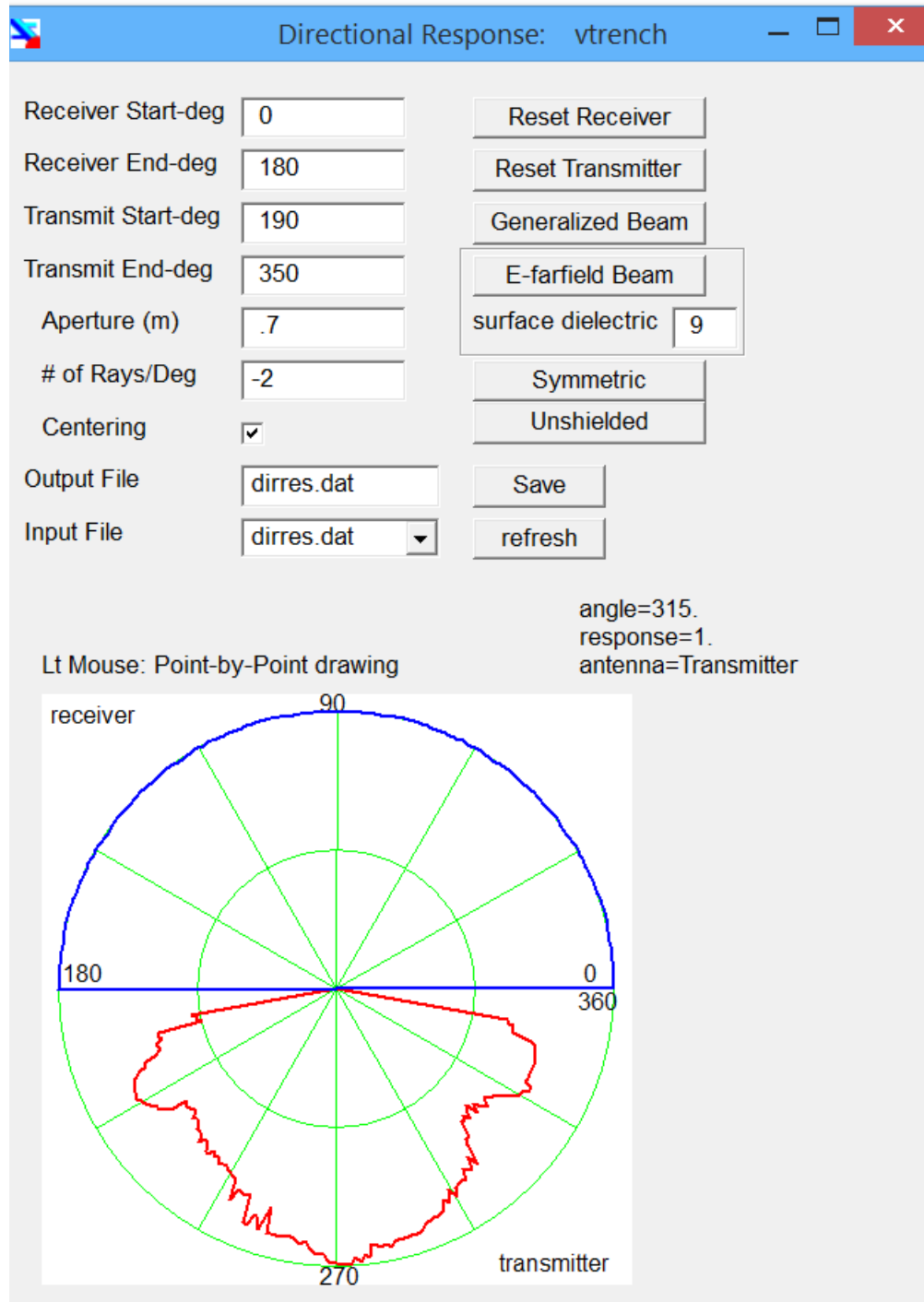
BEAM menu

Figure 4a. The Directional Response menu.

The BEAM menu can be used to (1) draw or edit an antenna directional response for either the transmitter or receiver, (2) constrict

or enlarge the antenna beams, (3) set the digitization or resampling of the beam, (4) set the antenna aperture size, and also (5) to set a centering switch which will describe what part of the (receiving) antenna surface the ray tracing will be calculated to. Constricting the antenna beam is useful for simulations in which only a small angle of the full beam is responsible for recorded radar reflections. Processing time can be saved by knowing what beam angle comes into play in the simulation. Using animation and storing raypaths in the Simulate Radargram menu, can help the user to investigate the maximum required beam start and beam end values.

Reset Transmitter

Hitting this switch will reset the transmitter response function to unity over the transmitting beam angles chosen.

Reset Receiver

This button will reset the receiving response function to unity over the receiving beam angles chosen.

Generalized Beam

This button will create a narrow beam lobe as a model directional response function.

E-farfield Beam (with setting for surface dielectric)

This operation will create a model E farfield beam using a surface dielectric.

Symmetric

Symmetric operations will project the drawn transmitter response in the lower hemisphere as the receiver response in the upper hemispher

Unshielded

Selecting this button will symmetrically project the transmitter

response and receiver responses drawn in the lower and upper hemispheres into the opposite hemispheres so that each antenna can have a response over the entire 360 degrees if desired.

Save

The Save action will store any edited directional response function to the output directional response filename.

Refresh

The refresh button will input and draw any directional response function that is clicked on in the combobox. Different directional response functions can be saved a retrieved at this combobox.

4.1 Transmitter Start (deg)
4.2 Transmitter End (deg)

The effective beam start and end angle of the transmitting directional response function. The beam must be between 180-360 degrees. The beam end must be >=beam start and <=360. For vertical ray tracing only, the beam start and beam end can be set to 270 along with a resampling factor of 1.

4.3 Receiver Start (deg)
4.4 Receiver End (deg)

The effective beam start and end angle of the receiving directional response function. The receiving response function contains all angles on the upper hemisphere from 0-180 degrees. The receiving response can be set differently from the transmitting response function. The user can more or less turn off variation in recording response by setting the receiving directional response function to unity as is shown in Figure 3.

4.5 Aperture (m)

The estimated aperture of the radar antenna to use in meters. The aperture is defined as the horizontal width – recording surface - of the antenna. Waves that return to the antenna will all be convolved into

the final synthetic pulse.   The actual size of the antenna is drawn on the model during the real-time simulation animation.

4.6 # of Rays/Deg

   To obtain simulated radargrams with relative amplitudes estimated as well as obtaining reflection from all parts of the model, a proper setting for the # of rays per degree to send into the model is needed. The broad structures the # of rays needed to record reflections across these kinds of structures is less than for very sharp structures, which require a larger # of rays to properly predict the reflected returns. The larger this setting is the longer the simulation will take.   The # of rays per deg can also be set to a negative integer which will skip the n degrees, e.g. a setting of -2 would send rays every 2 degrees into the model. For most applications the user will want to send in several rays per degree and thus this input parameter would be a positive (integer) number

4.7 Input file

   Input directional response function. The input file (not the output file is active during any simulation run. For editing purposes and when the full width of the beam is not necessary, the original input file should be kept in a backup file.

4.8 Output File

   Output directional response function file.   The input file (not the output file) is active during a simulation run.

4.9 Centering

   With centering on, the waves that arrive at some location occupied by the antenna, (i.e. at some grid cell where the antenna is), the extra travel time (and attenuation), of a plane wave that needs to transect the center of the antenna is computed and the adjustments applied to the radargram travel times.   For small aperture antenna these adjustments are small, but they can be several nanoseconds for larger antenna. With the switch in the off position, some broadening of the recorded rays will occur - which may be desired in many if not most applications.

   Graphically, with centering on the extra travel time dT will be

added or subtracted.   The extra travel time can be likened to the single ray representing a plane wave.   The front of the plane wave requires some extra time before hitting the bottom surface of the center of the antenna. In the case of the given ray arriving on the left half of the antenna, and with the angle shown below, the extra travel time is subtracted from the recorded time.   For the wave arriving on the right side of the antenna with the given direction, the extra travel time with centering on is added.   For normal incidence notice that there is no extra travel time added with centering on.

   Note: Centering is only applicable for the receiving antenna.
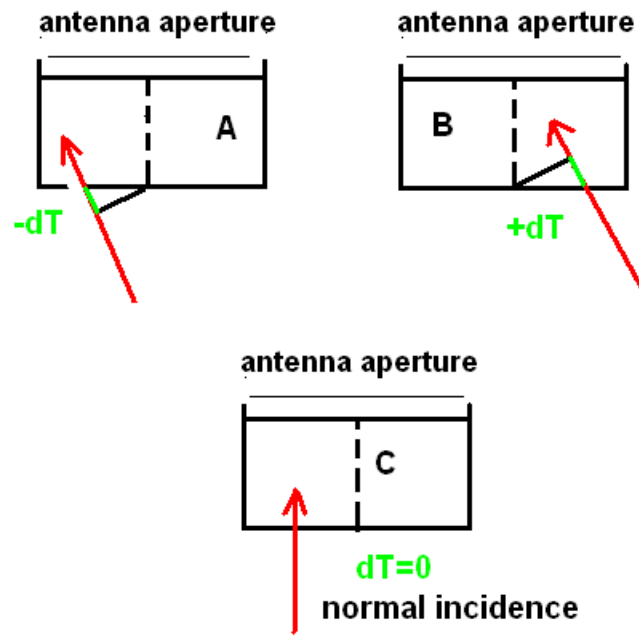
Figure 4b. Description of the extra travel added/subtracted due to propagating the ray to the bottom surface at the center of the antenna.

To generate a narrow beam lobe as a model directional response function the Generate Beam button is clicked:
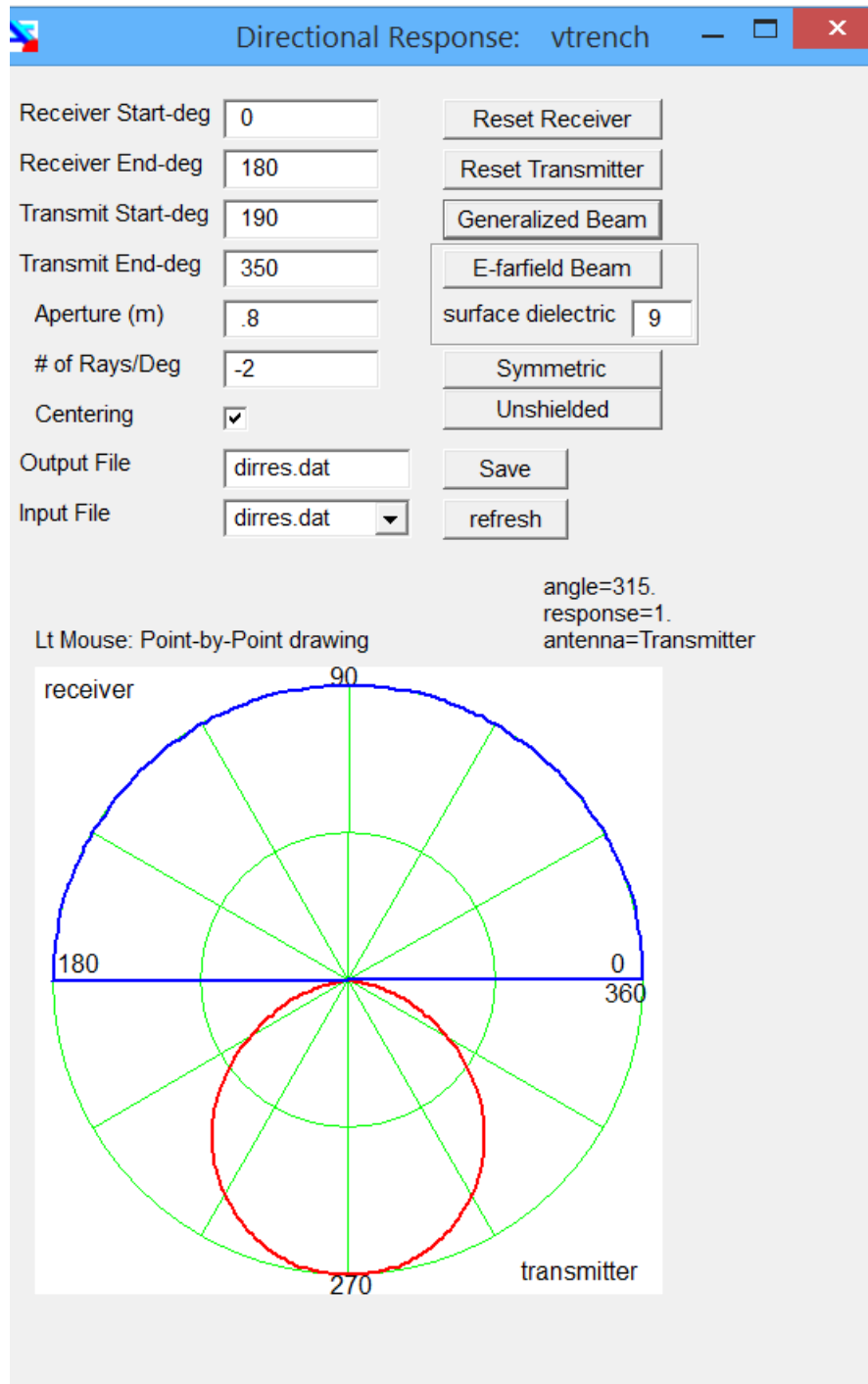
Figure 4c. A narrow beam over 180 degrees is created with the Generalized Beam button.

To generate response reflected into the lower and upper hemispheres for the transmitter and receiver the Unshielded button is clicked:
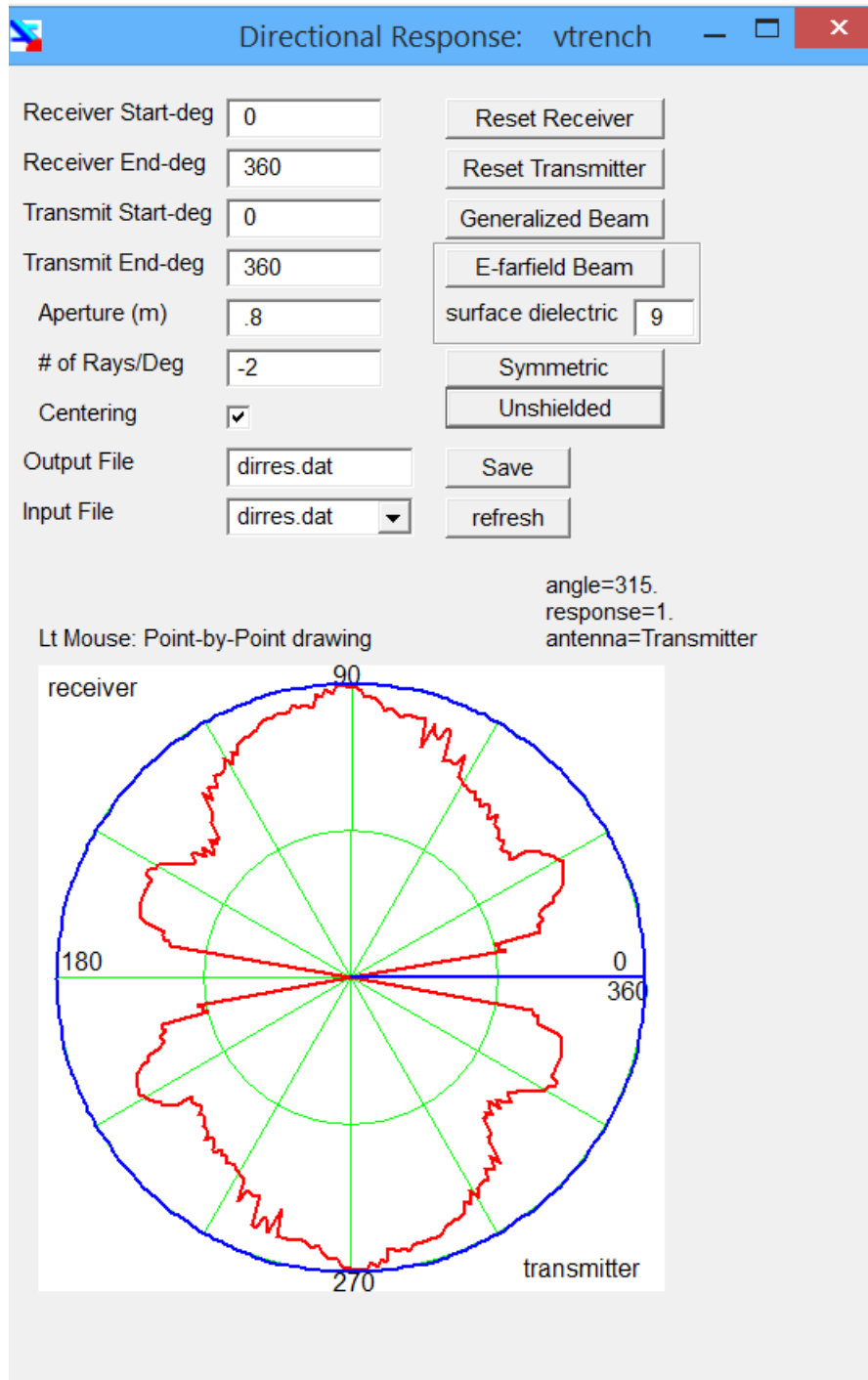
Figure 4d. A symmetrical beam for the transmitter and receiver in the upper and lower hemispheres following the existing beams is available.

To generate a symmetrical response of the drawn transmitter response onto the upper hemisphere for the receiver response the Symmetric button is clicked:
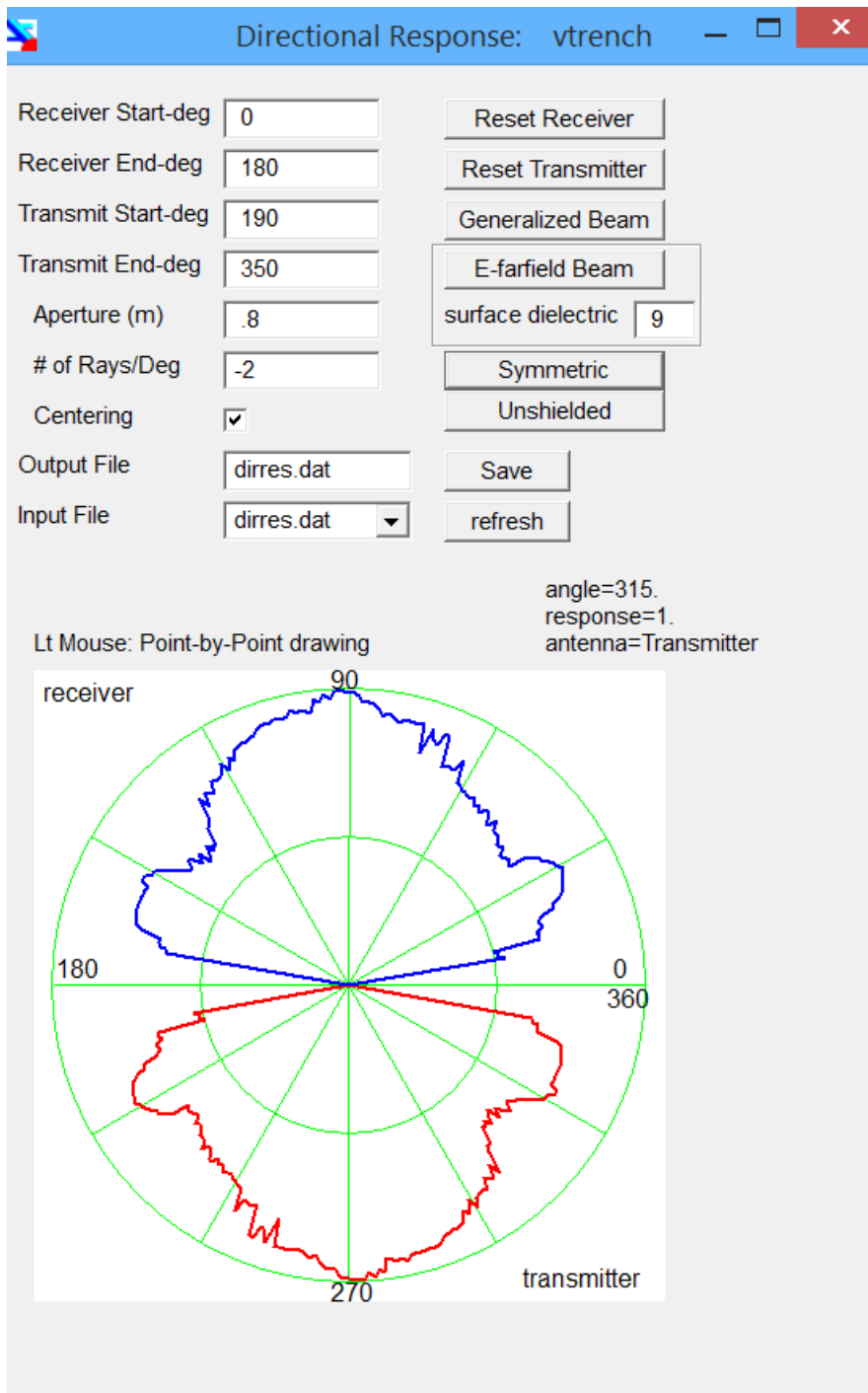
Figure e. A symmetrical – duplicate beam of the transmitter is created for the receiver antenna.

Xt_rX locations menu

Figure 5a.   Menu for setting the scan location definition and the number of locations to calculate the synthetic radargram.

The Antenna Locations menu can is used to set transmitter and receiver start and end locations over simulation. The transmitter and receiver locations can be independently set to allow for bistatic, monostatic, constant offset or wide angle profiling.   This menu is used to set the graphic location of the recorded pulse.   In addition, the menu can be used to set the corresponding model grid section to lock the transmitter or receiver to such that topographic or borehole simulations can be made.

Create Locations

GPRSIM requires a file containing the locations of the transmitting and receiving antenna. Clicking on the *Create Locations* button will create this file for input to the simulation code.

5.1   Profiling Mode

Sets the graphic location of the simulated radargram.   Three choices are available:

    1) Transmitter location
    2) Receiver location
    3) (Transmitter+Receiver)/2

Usually the user will want to have the graphic location assigned to the antenna that is moving over the model. In the case of monostatic profiling, using the transmitter or the receiver location yields identical plots.   For wide angle profiling the user may want to use option number 3 which assigns the graphic location to the center point between the transmitter and receiver.

5.2   Transmitter Start
5.3   Transmitter End
    The starting and ending location of the simulated transmitting antenna.

5.4 Receiver Start
5.5 Receiver End
    The starting and ending location of the simulated receiving antenna.

5.6 Number of Points
    The number of locations across the model to compute synthetic radargrams. In the case of doing symmetric simulations, an odd number of locations are required for proper plotting. The fewer the number of points there are, the rougher the synthetic radargrams will look when displayed in the scan mode, particularly for higher frequency impulse responses.

5.7 Locations File
    Filename containing the transmitter and receiver locations to be

simulated across the model structure.

5.8 Topography/borehole simulation on/off
5.9 Transmitter location on grid section# defines the model section where rays start from and for either topographic or borehole simulations
5.10 Receiver location on grid section# defines the model section where rays are received from for either topographic or borehole simulations

WAVETYPE menu

Figure 6a. The Wavetypes menu showing various kinds of rays possible for inclusion in the simulation.

The essential feature of **GPRSIM** software is that it is a raytracing algorithm. True amplitudes from reflected returns of subsurface structures can be closely estimated by sending many different kinds of waves with various traveling itineraries into the model. The travel paths referred to as raypaths or wavetypes are specified according to the orientation and shape of interfaces in the model. Some wavetype examples are:

       R - direct reflected wave
     TRT - transmitted, reflected, transmitted wave
   TRRRT - interlayer multiple
   RRTRT - peg-leg multiple
    TTRR - asymmetrical path

As an example, in the case of a model with flat homogenous layers, R, TRT, TTRTT, ... and RRR, TRRRT .... and RRTRT, TRTRR, TRRTRT ... are all possible wavetypes that can get back to the antenna. However, wavetypes like RR, or TRRT ..., will need to have a corner like feature or a basin like features, in order to be returned to the antenna. Some wavetypes may be found to be unimportant after simulations as well. The user with minimal experience using GPRSIM, can quickly determine which wavetypes, also when considering electromagnetic contrasts, will have significant contributions to the GPR simulations. For some of the wavetypes there will be reciprocal raypaths, e.g. RRTRT and TRTRR, etc. For homogenous layers these wavetypes will give identical results. However, for the most general 2-D structures, reciprocal wavetypes can be different. Both must be included in the simulation calculation that is computed.

In the WAVETYPE menu the user compiles a list of the kind waves they want to include for their particular model. In this menu there is a generalized list of wavetypes which the user can compile to the wavetype file which will be sent to the **GPRSIM** simulator.
Several functions in this menu are described:

Save

Clicking the Save button will create the wavetype file with any editing or additions that may have been made.

Compile/Reset

A set of general raypaths is listed in the WAVETYPE menu. Theses general raypaths are stored in an ASCII file called waves99.dat which resides in the \sim\ main directory.

The user can click on any of the different raypaths and then by pressing the *Compile/Reset* button can collect these different waves to a working list file. The user will need to *Save* these results before leaving the WAVETYPE menu. By clicking the Compile/Reset button without any raypaths chosen will clear (reset) the working wavetype list file to blank. The user can also type in by hand using R and T or lower case R and T wavetypes that may not be provided in the general list. The user can also remove a single wavetype from a file by simply blanking out that file and the saving the results.

6.1 Input File

   Input file specifying the wavetypes (raypaths) to be examined. The input file (not the output file) is active during any simulation. Currently up to 50 wavetypes can be examined during any single simulation.

SETTINGS menu

GPRSIM   Display Settings: kanmachi man...

Model Plot: ✓		X Screen Size	1920		Autosize 100%	
X origin (pixels)	50	Y Screen Size	1080		Autosize 90%	● standard
Y origin	50	Menu Font Size	9		Autosize 75%	○ tier
X length	336				Autosize 50%	
Y length	240	Text Height	20			
		Text Width	20			
Synthetic Plot: ✓						
X origin	50	dx Range Label (m)	10			
Y origin	340	dt Time Label (ns)	10			
X length	336	dz Depth Labels (m)	7			
Y lengh	240					
Travel Time Plot: ✓		Model Legend Plot: ✓				
X origin	436	X origin	436			
Y origin	340	Y origin	50			
X length	336					
Y length	240	T.T. Legend Plot: ✓				
		X origin	436			
		Y origin	340			
Real Radargram Plot ☐						
X origin	50					
Y origin	700					
X length	600					
Y length	400					

Figure 7a.   The Settings menu allows the user to automate the simulation plot displays or to customize the sizes based on the height, length and plot origins set in pixels.

The SETTINGS menu contains parameters which allows the user to customize the layout of their simulations. The user can specify the plotting origin and plot lengths for output to the computer screen for the model, synthetic radargram, the travel time plot as well as the location of several simulation legends.
7.1 Model Plot

7.2 X origin
7.3 Y origin
7.4 X length
7.5 Y length

    The user can turn on or off drawing the model grid to the screen by checking the Model Plot switch. The origin to plot the grid along with the lengths of the plot axis is given in screen pixels.

Note: The model plot that is drawn to the computer screen is the actual grid used in the simulation and not the point plots used in the Model menu. The clarity of this plot will depend on the number of grid cells and the grid cell size that the user implemented in the creation of the grid. To get a higher resolution plot the user may want to increase the density of the cells in creating the grid found in the MODEL menu.

7.6 Synthetic Plot
7.7 X origin
7.8 Y origin
7.9 X length
7.10 Y length

    The parameter 7.6-7.10 specify the location and size of the synthetic radargram computed in **GPRSIM.**

7.11 Travel Time Plot
7.12 X origin
7.13 Y origin
7.14 X length
7.15 Y length

    These parameter determine the location and size of the travel time plot.

7.16 Real Radargram Plot
7.17 X origin
7.18 Y origin
7.19 X length
7.20 Y length

    Parameter 7.16-7.20 determine the location and size of the plot of a real radargram for comparison with the synthetic radargram computed in **GPRSIM**.

7.21 Model Legend
7.22 X origin
7.23 Y origin

    The location of the model legend containing the color, descriptor name, and the dielectric value for the different materials used in simulation.

7.24 Travel Time Legend
7.25 X origin
7.26 Y origin

    The location of the travel time legend containing the color assignment for the various wavetypes sent into the GPRSIM simulator.

7.27 X Screen Size
7.28 Y Screen Size
7.29 Menu Font Size

    The size of the of users computer screen given in pixels.   The user should change these values to match their computer's native resolution.   An appropriate Menu Font Size should also be used to globally adjust the size of the Windows text and menu items..   Once these values are changed, any new simulation created will continue to propagate these values and the user will not need to change them again, unless they want to move the software to a different computer.

7.29 Text Height
7.30 Text Width

    The user can set the text height and width of the characters drawn to the screen. Typical values for the height and width may be (22,10), (18,8), (16,6) although the user can choose numerous combinations.

7.31 dx Range Labels (m)
7.32 dt Time Labels (ns)
7.33 dt Depth Labels (m)

    The number of tick marks and labeling across the various plots can be individually customized by the user.

Autosize100-automatic scaling buttons for sizing the simulation display
Autosize90
Autosize75
Autosize50

7.34 Standard - standard simulation display showing simulation below the model, and the travel time and model legends to the rightside of the simulation

7.35 Tier - simulation display with model, synthetic radargram and the travel time curve all shown in parallel, with the model legend and travel time legends only shown to the rightside.
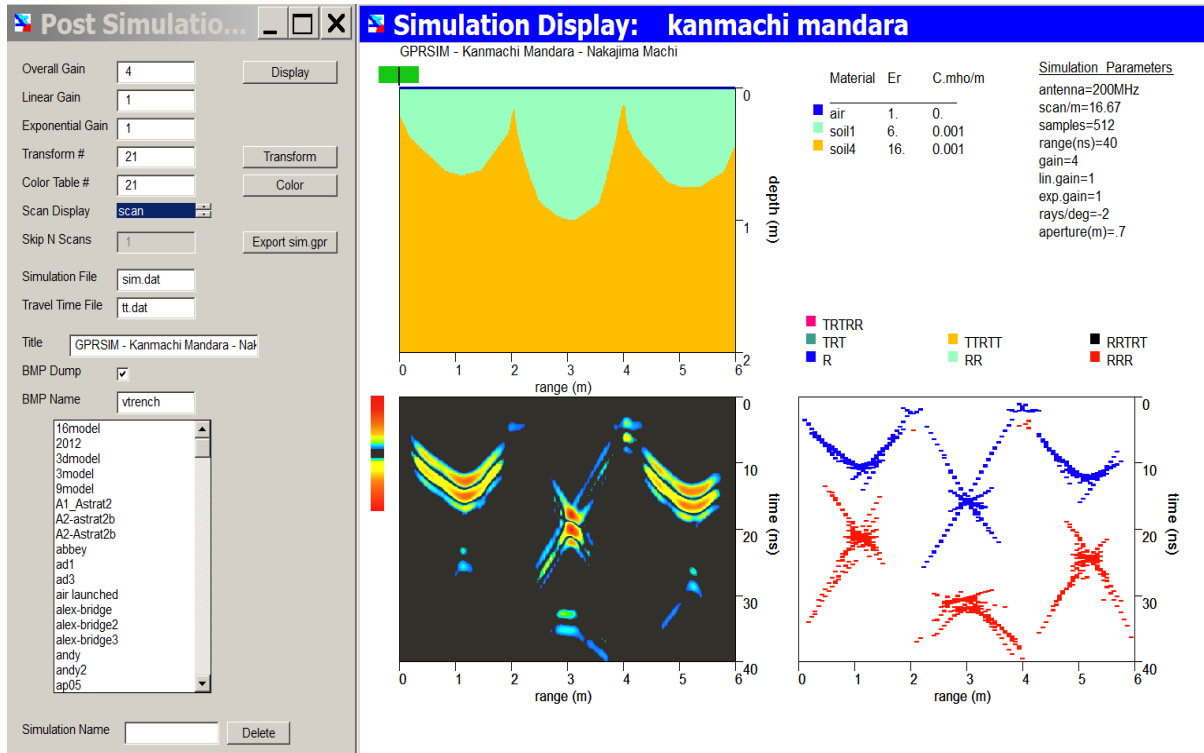
DISPLAY menu

Figure 8a. Example of a post processing display of a **GPRSIM** simulation (with Standard radio button option in the Setting menu engaged
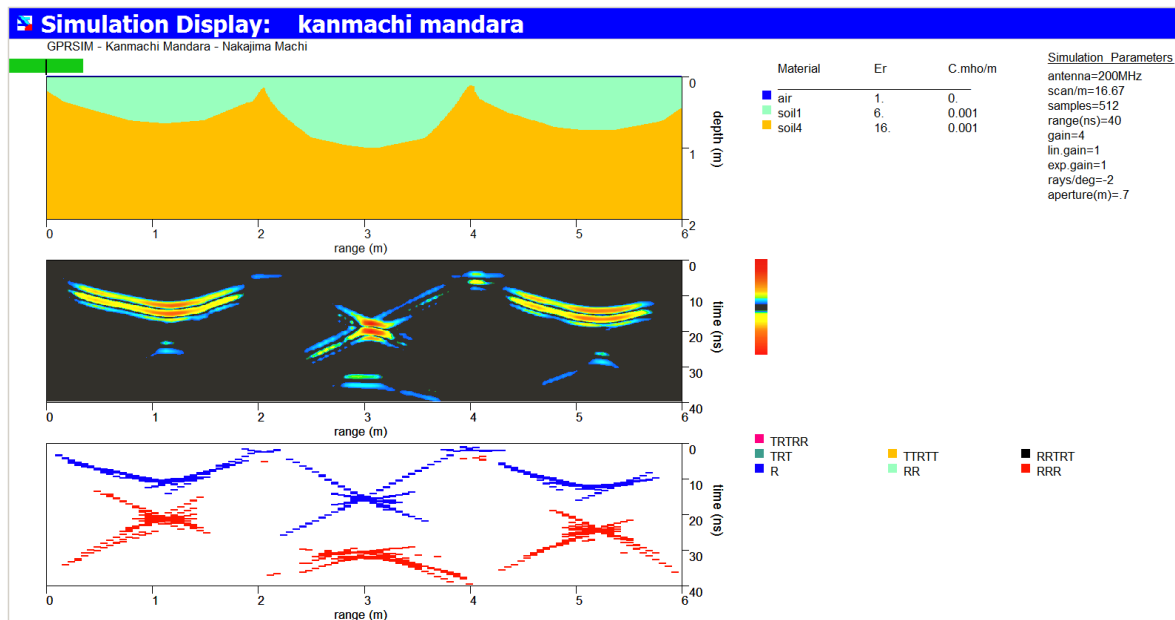

Figure 8b. Example of a post processing display using the Tier radio button option in the Setting menu.

The DISPLAY menu is used for post-simulation display. The parameters and menu items are almost identical to those discussed in the SIMULATE menu.

Display

This function starts the displays of the chosen the active simulation.

Transform

A submenu to adjust and edit up to 30 different radargram color transforms.

Color

A submenu for adjusting the colors of the model sections as well as for adjusting the color tables for the radargrams. Up to 50 color tables are available. Color table #1 is reserved for the model.

Export sim.gpr

This option will write an exportable radargram called sim.gpr in the simulation project folder which is readable inside GPR-SLICE v7.0 Ground Penetrating Radar Imaging Software. The steps for exporting are:

1) Click the Export SIM.GPR button to generate the binary simulated radargram
2) Create a new GPR-SLICE project
3) Copy the SIM.GPR radargram to the \radar\ folder (not the \raw\)
4) Make an info.dat file following the specifications you had in GPRSIM, e.g. time window, samples per scan, 8/16 bit etc

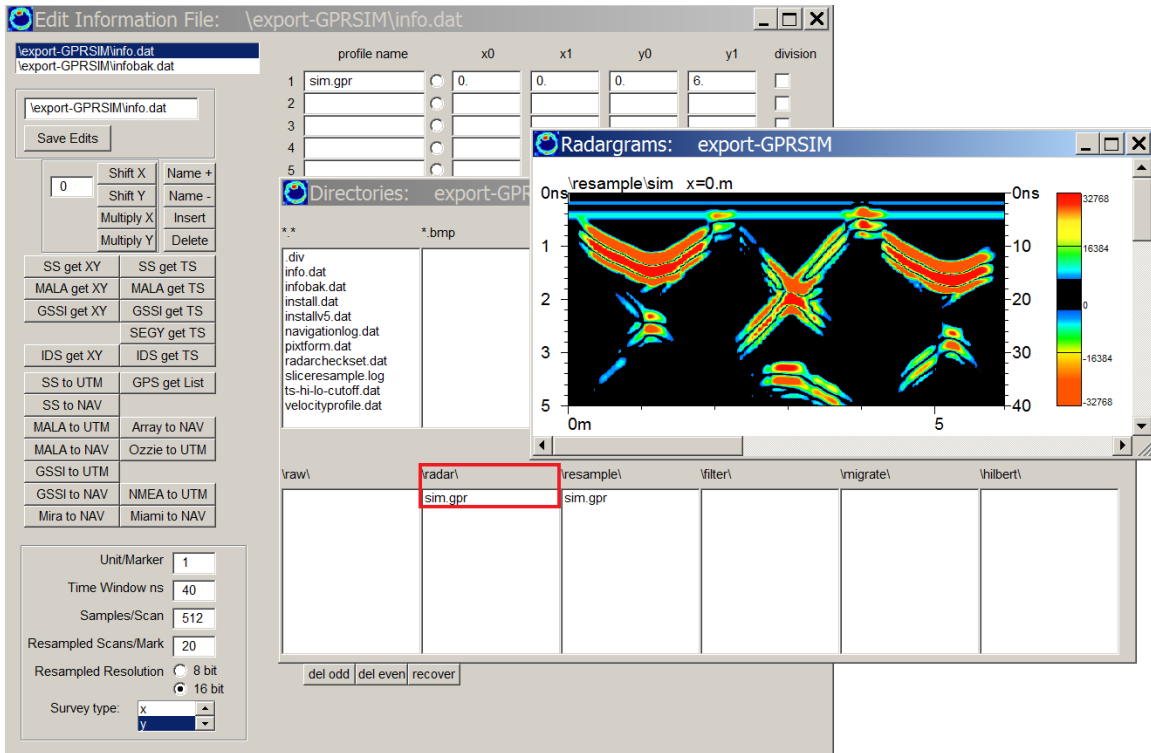After step 4 you can proceed as usual to do resampling and then display in the GPR-SLICE.

Figure 8c. Example of settings in GPR-SLICE to display an exported radargram from GPRSIM.

8.1 Overall Gain
8.2 Linear Gain
8.3 Exponential Gain

  GPRSIM operations require gaining to be applied to the simulated radar reflections that are simulated (recorded). An overall constant, linear, exponential or any combination of these gain settings across the entire radar scan can be used to amplify the signal. These settings help to determine the colors contained in the radargram or the amplitude of the wiggles for various line display according to the equation:

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

where   gain   = overall gain factor
         rlgain = linear gain factor
       expgain = exponential gain factor
        irange   = (i-1)/(nscan-1)
         nscan   = number of samples per scan in the simulated
                      radargram

Notes:
Amplitudes from simulations will depend upon various factors including the density of rays sent into the model, refraction effects, antenna aperture (e.g. recording surface)etc.

GPRSIM will compute the relative amplitudes very accurately, however, the overall gain and gain with depth will need to be adjusted to properly show the results of the simulation – just as is done with real data to show the weaker later arriving reflections.

8.4 Transform #

  The transform number from the user chosen colors transform tables to be used in assigning colors for the + and – of simulated radargram.

8.5 Color Table #

    The color table to used for displaying the radargram simulation. Color Table #1 is reserved for the model colors and travel time color assignments. The user should use any color table other than #1 for display of the radargram. The color tables can also be edited in the color menu.

8.6 Scan Display
    Various scan displays for presenting the synthetic radargram can be turned on by toggling this switch. The following displays are available:

        1) scan color
        2) line
        3) line + fill
        4) line - fill
        5) line +/- fill
        6) color line

The color line scan will show a colored line changing according to the color levels specified by the color transform.

8.7 Title

A user title that will be printed above the simulated model.

8.8 Simulation File

The file name containing the output simulation radargram.

8.9 Travel Time File

The file name containing the attenuated reflection/transmission coefficients for each wave type.

8.10 BMP Dump

Bitmap output can be turned on and off for the simulation. The user can also created BMP output after the simulation is completed and redisplayed in the DISPLAY menu.

8.11 BMP Filename

The name to assign BMP dump of the simulation screen. The name should be given without the .bmp extension as it will automatically be placed into the given name.

PROCESS: Hyperbola Search/Migration menu

   GPRSIM v3.0 is equipped with a processing menu which allows the user to search for a hyperbola using the mouse. The shape of the hyperbola is a function of the velocity.   For those not familiar with the effect of surveying with GPR antennas, cylindrical or round objects buried in the ground create hyperbolic reflections patterns. Because GPR antenna have a broad directional response function and send radar wave out of the antenna in many directions, objects off to the side of the antenna can reflect energy back and be recorded. When the object is directly below the antenna the two-way travel time is small, but when it is off to the side of the antenna, the two-way travel is longer – the net effect – creating a hyperbolic pattern.

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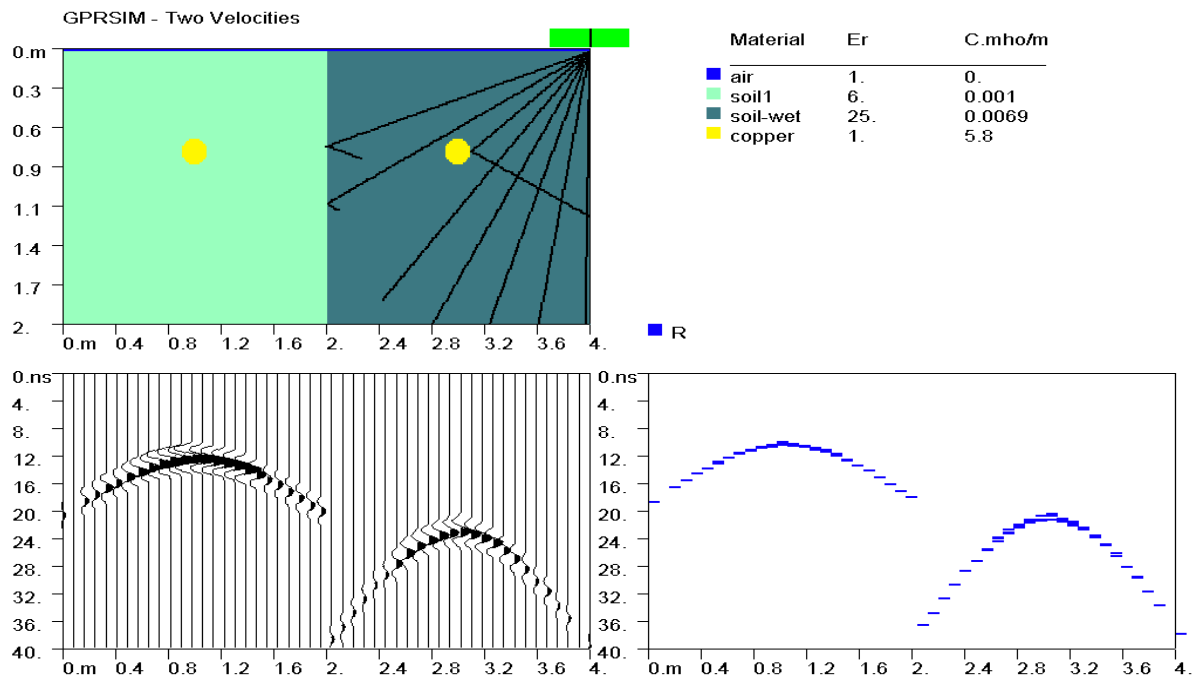

Material	Er	C.mho/m
air	1.	0.
soil1	6.	0.001
soil-wet	25.	0.0069
copper	1.	5.8

Figure 9a.   **GPRSIM** simulation showing the hyperbolic reflections from 2 round objects buried at the same depth, but in different dielectric materials.

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

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

Shown below is a hyperbola fit for one of the cylindrical objects measured on the right hand side simulation. After migration, the hyperbolic reflections are fairly well collapsed at the apex where the cylinder actually is. The other object, because and incorrect velocity is being used to migrate the structures over here, the hyperbolic reflections are not collapsed.
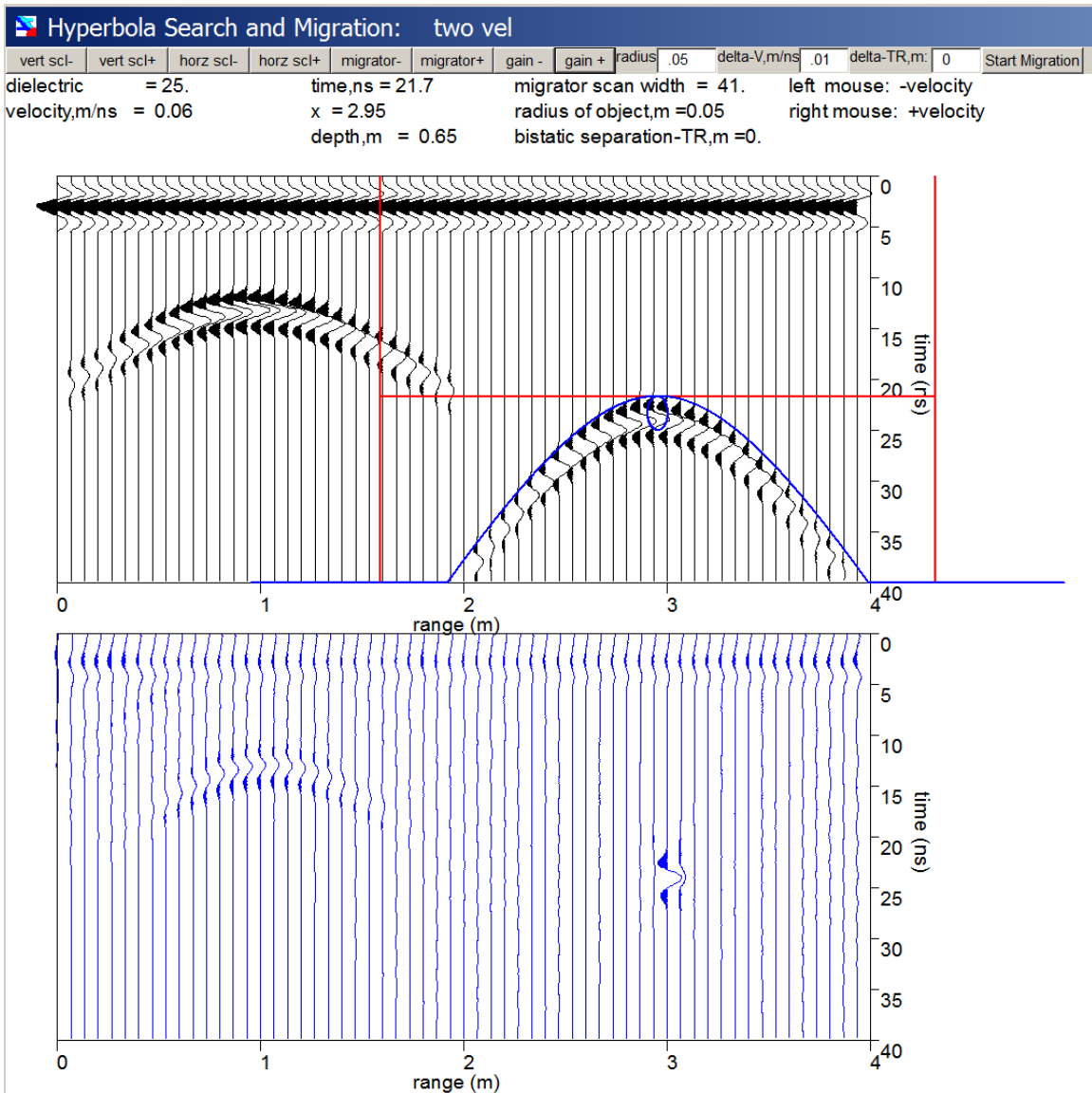
Figure 9b. Hyperbola fitting of a synthetic radargram (top diagram) and its migrated radargram (bottom diagram). Note, only one of the hyperbolas is collapsed.

Note: There are options to set the velocity increment to search the hyperbola in the Processing menu. Also, the separation of antennas, delta t-r can also be set. The antenna separation will affect the shape of the hyperbolas and make them look broader.

Special sections:

A. Surface Reflection Modeling

In many GPR reflection profiling arrangements, the antenna is elevated at some distance above the ground. Surface reflections on these profiles can be quite strong as well as having a very complicated looking pulse shape. In many simulation applications, the user may need to accurately model the surface reflection pulse shapes. **GPRSIM Software** can be conveniently used to model the upper surface reflection.

The steps necessary to model the surface include the following:

1) Create a model of the antenna-air-surface structure. As the first interface is always written at the top of the model, the user will have to draw another (straight) interface given at the depth (elevation) of the antenna above the ground surface.

2) Set the first and second electromagnetic constants in the parameter table to air: dielectric permittivity = 1; conductivity = 0 (e.g.). Set the appropriate constants for the ground material(s).

3) Simulate the structure using the wavetypes, R, RRR and maybe even include RRRRR for complete accuracy, etc. Also, in the case of near field ground structures include the appropriate transmitted waves as well.

4) Simulate the full model structure that is desired. The simulation should be run with the replicate switch in the OFF position in the Impulse Response menu. The user should also not to forget to rename simulation filenames before starting the full model calculation.

5) After the full model simulation is complete, cut the surface radargram using the Impulse Respnse menu to make it the active impulse response function.

6) In the Edit menu, replicate the active impulse into the full model simulation which was computed without the surface reflection.

Also in doing the above procedure, 2 different directional response functions might be considered : 1) the free-air antenna response

functions for the surface modeling, and 2) the response function of the antenna in the ground for the full model simulation without the antenna-air-surface structure. In general, no one I know has accurately determined the response functions of typical GPR antenna, thus user may have to guess what the responses may be.

An **EASIER** method exists for the user which does not require knowledge of the ground antenna response function - only the free-air antenna response. The method requires the user to just simply include the antenna-air-surface structure in the full model structure as well:

Full model   Full model without
                          antenna-air-surface structure
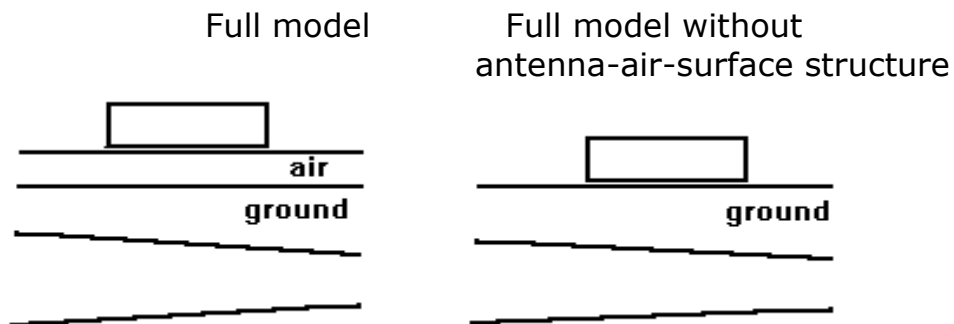
Figure a1.

In this case, reflections from the first interface within the ground will require a trt wavetype, whereas without an air takeoff, only an r wavetype is needed. In summary, all the wavetypes will now require an extra transmission at the beginning and at the end of the raypath in order to be recorded by the "airborne" antenna. And, because **GPRSIM Software** monitors the refraction of the rays at structural boundaries, the transmitted response functions are completely calculated - as they are natural to the **GPRSIM** algorithm!

B. Topographic Simulation

GPRSIM v3.0 is equipped to generate GPR profiles taken over sites with topography.   Topographic simulations take into account how the antenna tilts across the topography of the model. This is done for both the receiver and the transmitter separately as based on their positions across the model.

To prepare for a topographic simulation the user must make several settings:

Draw menu:

1) The 2nd layer in the model should be assigned as air (Figure b1).

2) Draw the topography for the simulation, noting the section number that is assigned for the topography.
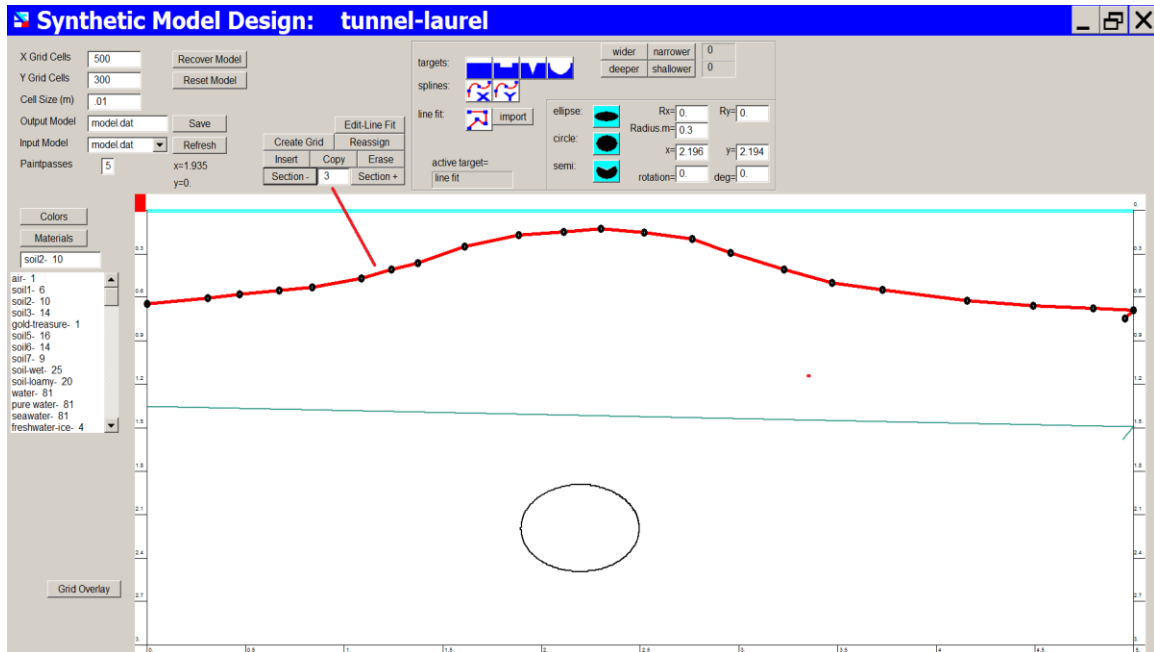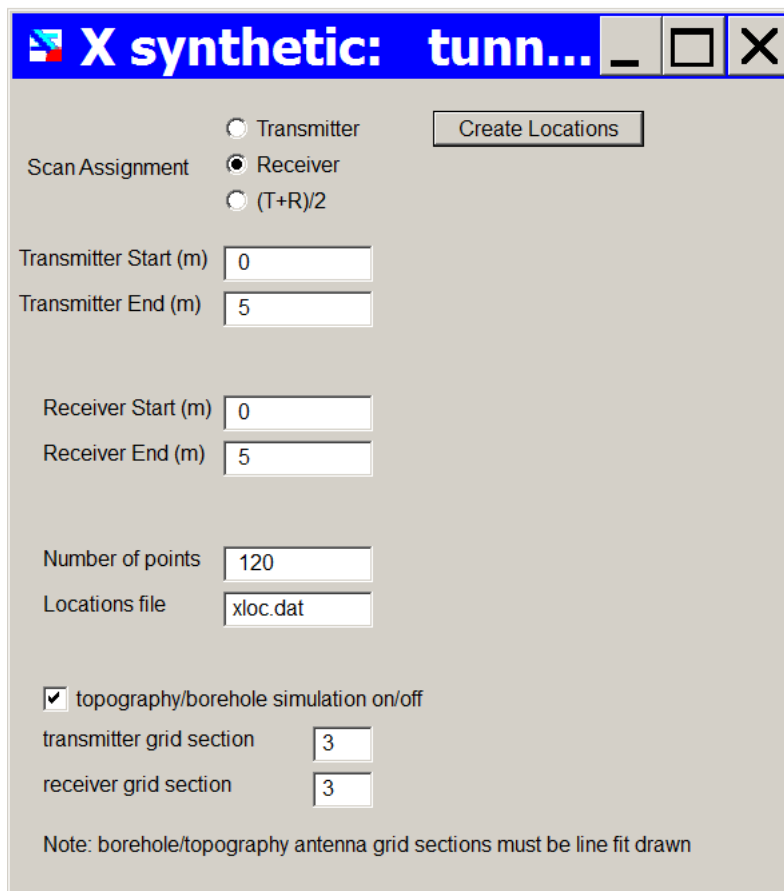
Figure b1. A topographic model is designed with section 3 defined as the topography where the antennas will follow.

Tx-xR Antenna Locations menu:

3) Set the topography grid section number that the topography is drawn in the Draw menu and also click on the topography simulation checkbox.

4) Click the Create Locations button to generate the x, y and tilt of the transmitter and the receiver antenna.   The tilt of the antennas are calculated separately based on their position over the model and are given -Arctang(dx/dy) which is the change in the (model) topography slope.

Figure b2. Xt-rX menu showing where topography is defined. In this case both the transmitter and receiver are co-located at model section 3.

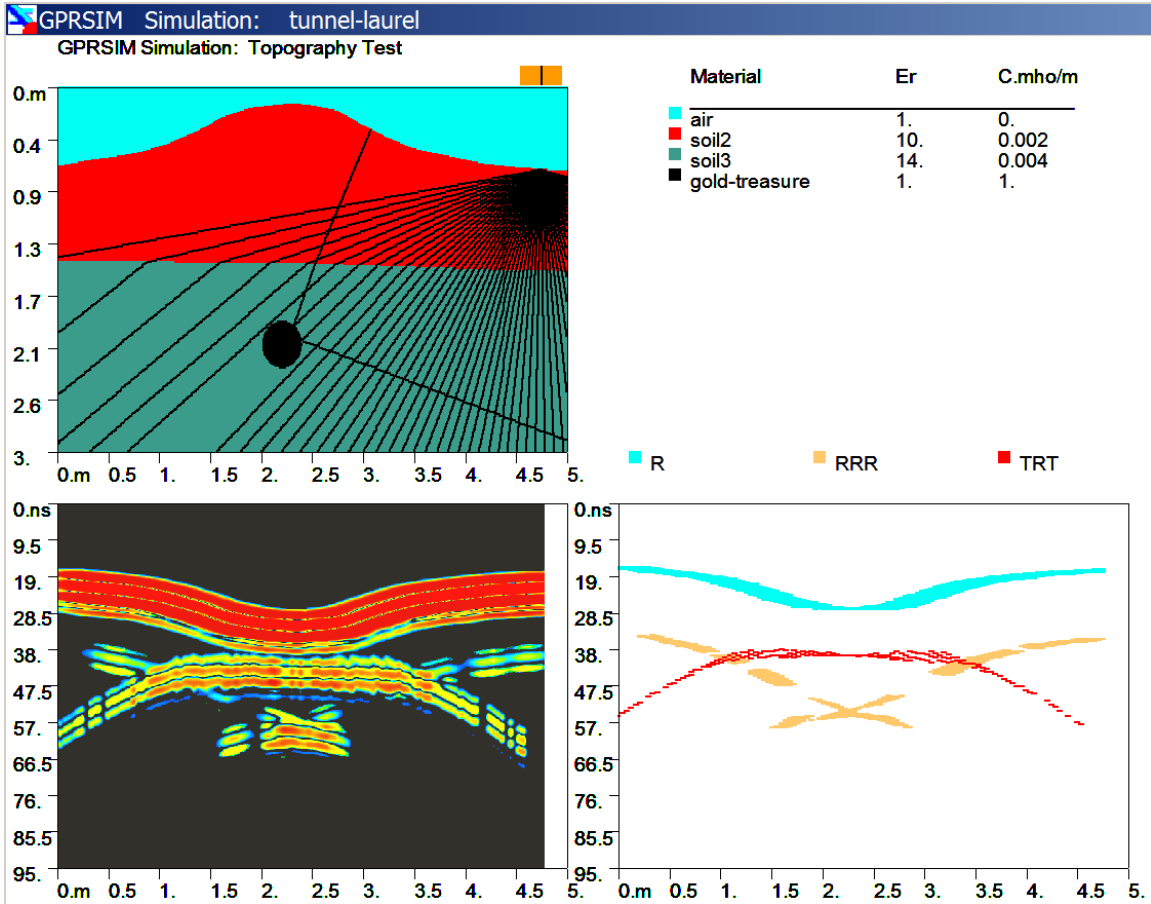5) Run the simulation (Figure b3):

Figure b3. A GPRSIM topographic simulation of a pipe buried below layer.   Note, the material above the (red) topography is set to air in section 2 (and 1).

C. Borehole Simulation

GPRSIM was enhanced to handle borehole simulations. To simulate boreholes, GPRSIM currently requires line fit surfaces. These drawn model sections can undulate but should not turn back on itself to lower ranges. An example is shown for two parallel boreholes where the transmitter is in a separate borehole from the receiver and the two antenna are moved equidistantly along the boreholes (Figure c1). Two sections of air are used to draw the borehole and the lower air sections are used to assign the location of the transmitter and receiver.
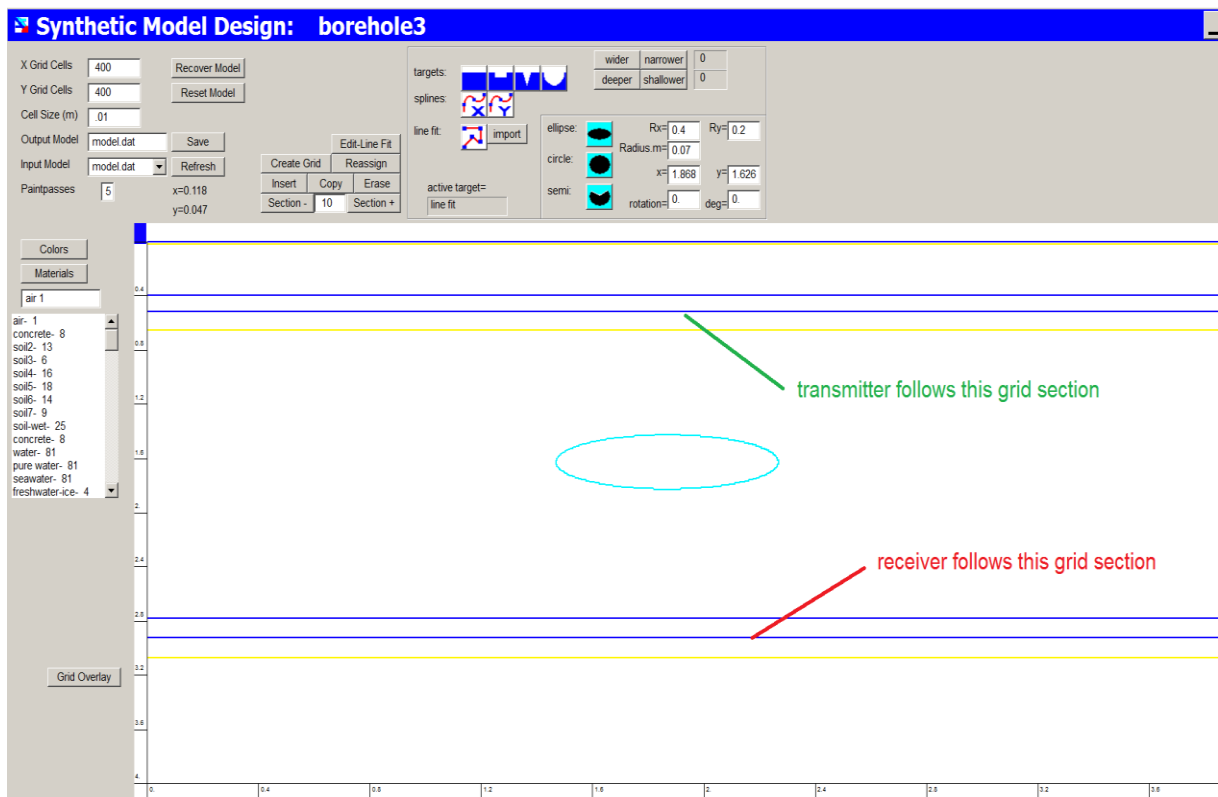

Figure c1. A borehole model with 2 parallel air filled boreholes are drawn.

After the model is drawn the user can set the borehole transmitter and receiveing antennas to their desired model grid sections in the Xt-rX locations menu (Figure c2). Once the locations are set, the directional response function is defined. The best estimate of the actual antenna responses should be inserted if known. An artificial response function with transmissions upward and downward but with negligible transmission off to the side is shown shown in Figure c3. The borehold simulation for this model is shown in Figure c4.
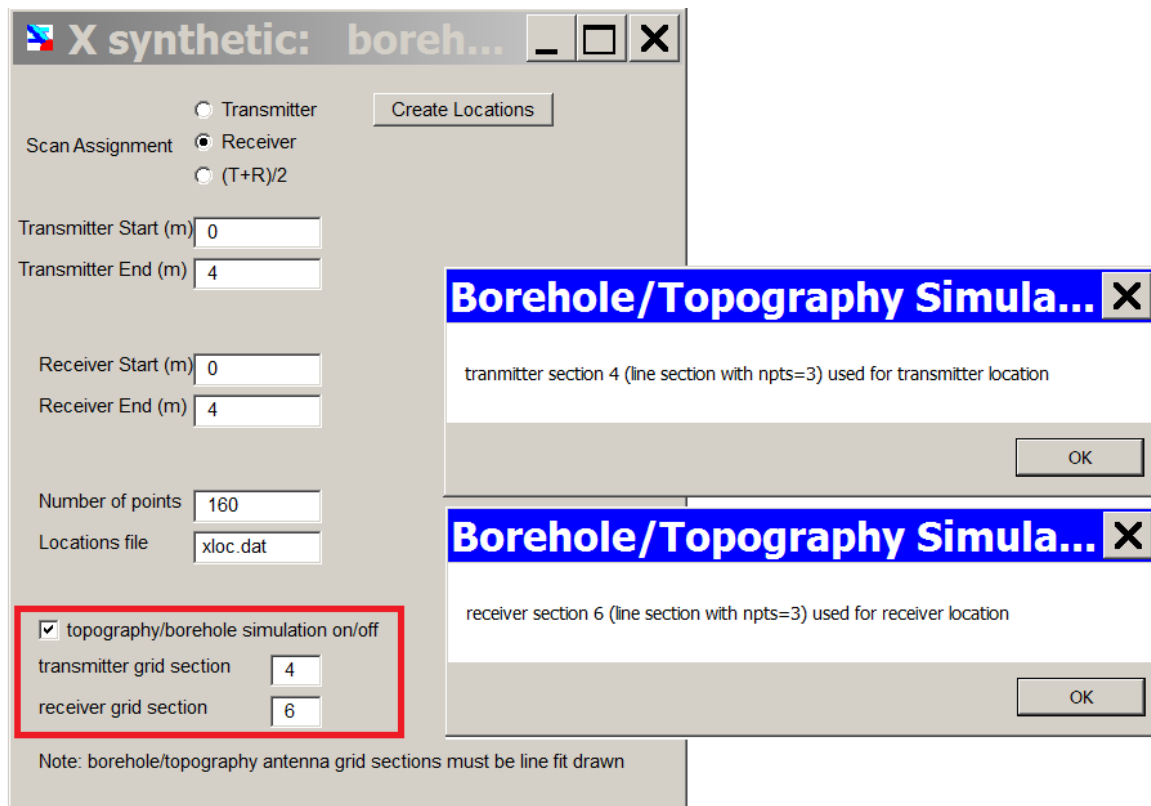
Figure c2. The borehole transmitter is located on the air section 4 and the borehole receiver is located on the air section 6 in the drawn model in Figure c1. Clicking the Create Locations button generates equidistantly space synthetic borehole locations across the model sections.
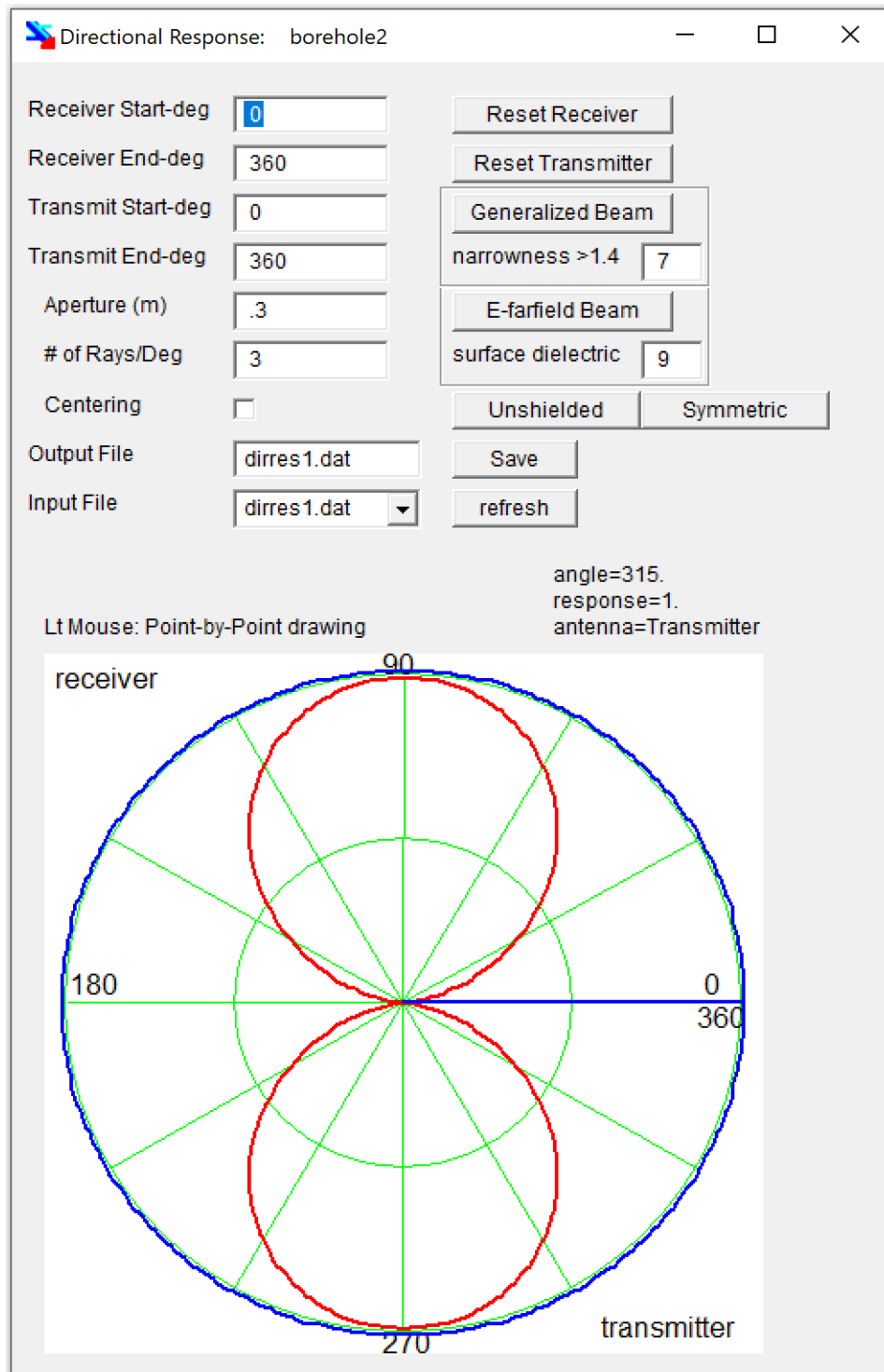
Figure c3. An unshielded antenna which transmits upward and downward can be set for this borehole simulation. This artificial directional response function assumes a transmitter which has 0 energy being transmitted off to the sides but equal energy being transmitted upward and downward.
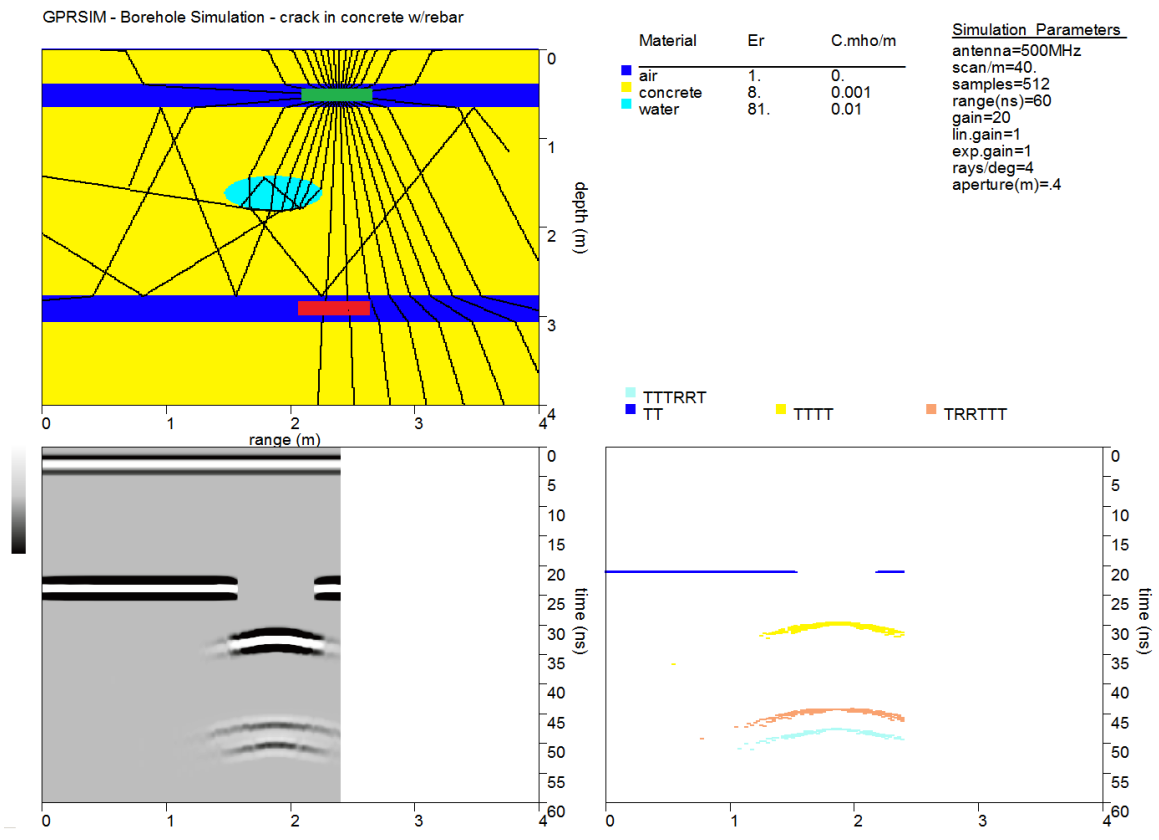
Figure c4. An example borehole simulation is shown. Raypaths are chosen to insure that the transmitted and reflected waves can be recorded at the receiving antenna.

GPRSIM Ground Penetrating Radar Simulation: Examples

Material	Er	C.mho/m
air	1.	0.
soil1	7.	0.001
iron	1.	1000000.
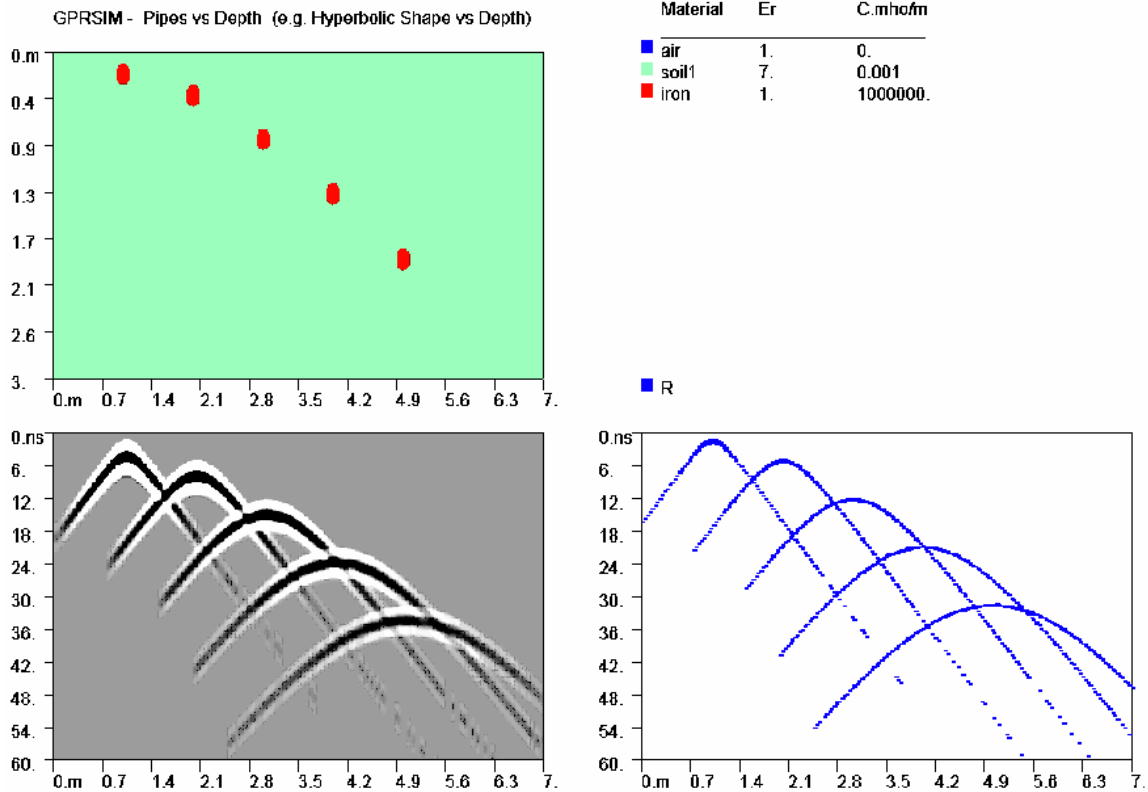
Example. The effects of hyperbolic shape versus depth is shown. The deeper objects are the broader the reflections become.

GPRIM: Undulations+Flat Layer--- Velocity Pullups

Material	Er	C.mho/m
air	1.	0.
soil2	6.	0.001
soil3	8.	0.001
soil5	25.	0.001

R   TRT
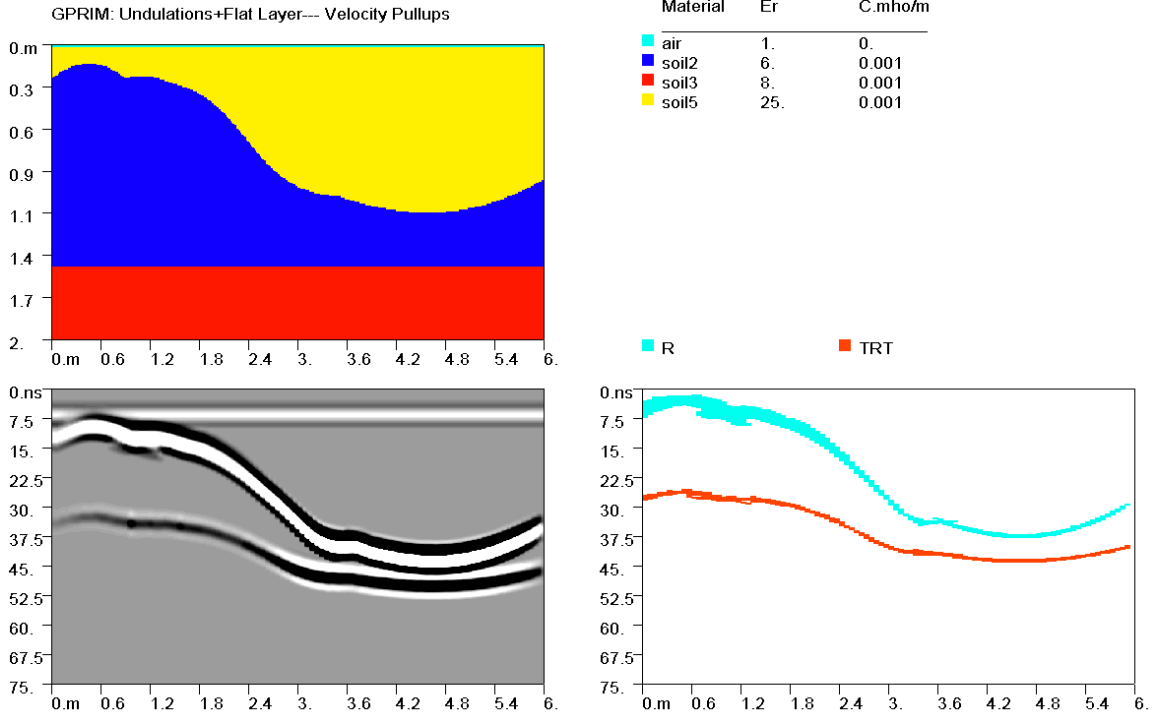
Example. The effects of an undulating subsurface layer has on a deeper flat layer is shown. Particularly in the case when upper layers have significant velocity contrasts, deeper flat layers will have what are called "velocity pull-ups" and these flat layers will not have flat reflection patterns from GPR profiling.

GPRIM: Roman Wall

Material	Er	C.mho/m
air	1.	0.
soil1	7.	0.001
soil2	13.	0.001
soil3	10.	0.001

RRTRT   TRTRR
TRT   TRRT   TRRRT
R   RR   RRR
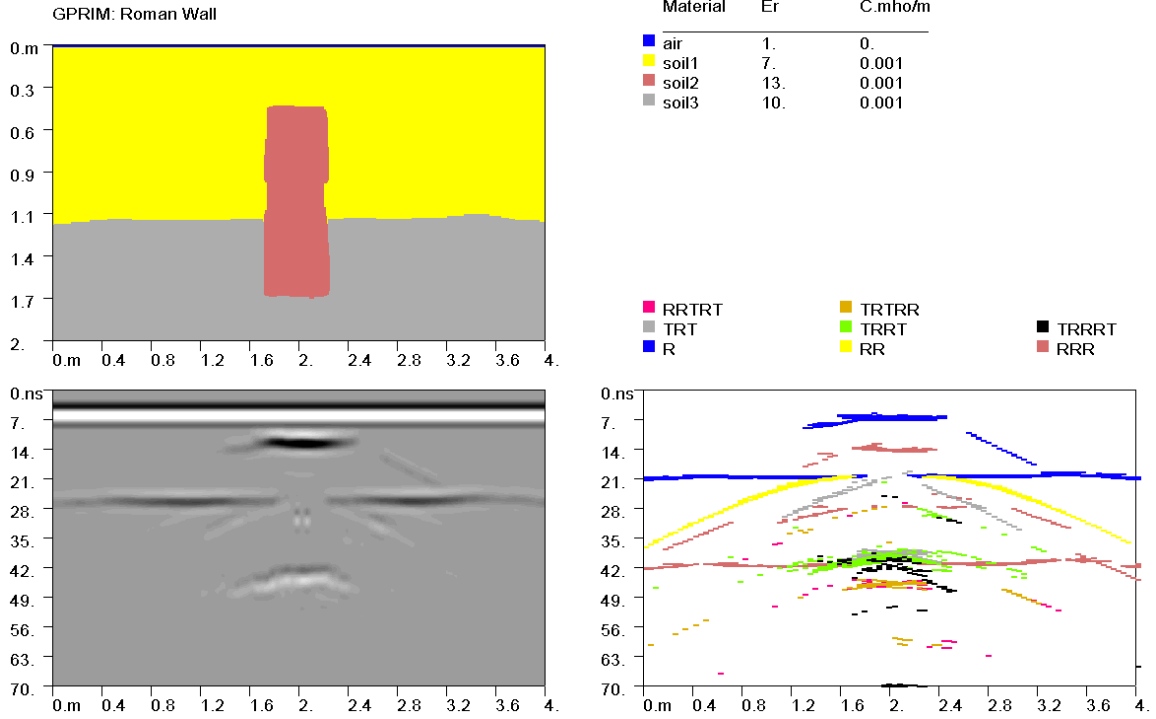
**Example**. A **GPRSIM** simulation of a buried (Roman) wall is shown. The faint hyperbolic reflections are not from the top of the wall but are from double RR reflections between the first layer interface and the sides of the wall.
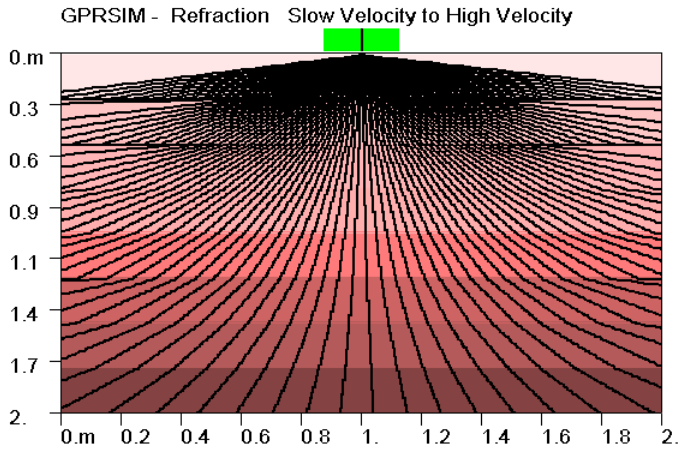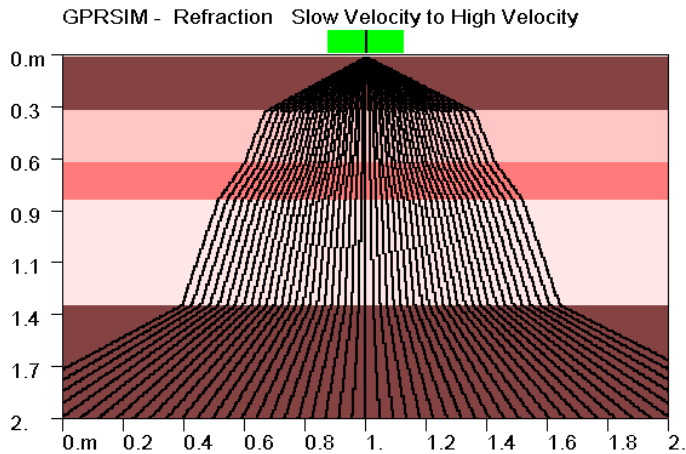
Material	Er	C.mho/m
air	1.	0.
soil1	80.	0.
soil2	60.	0.
soil3	40.	0.
soil4	32.	0.
soil5	22.	0.
soil6	12.	0.
soil7	8.	0.
soil8	6.	0.

Example. The refraction of microwaves for soil increasing in velocity with depth is shown. (Note: In this particular simulation the synthetic model and the travel time plot and legends were turned off in the SETTINGS menu.)
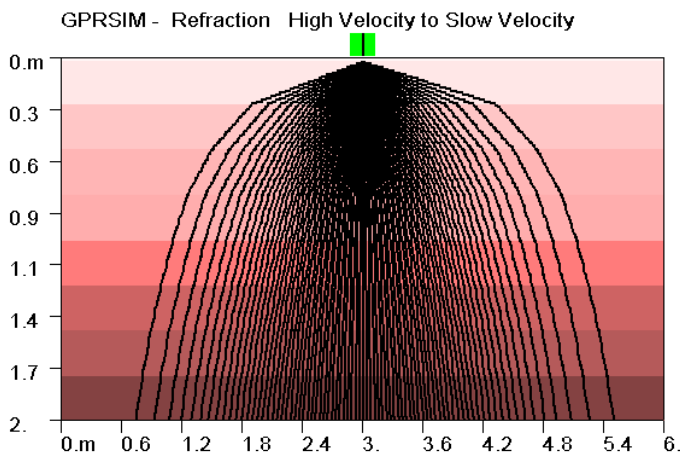
Material	Er	C.mho/m
air	1.	0.
soil1	6.	0.
soil2	8.	0.
soil3	12.	0.
soil4	22.	0.
soil5	32.	0.
soil6	40.	0.
soil7	60.	0.
soil8	81.	0.

Example. The refraction of microwaves for soil decreasing in velocity with is shown.   Microwaves are focused downward in this model.

GPRSIM - Refraction   Slow Velocity to High Velocity

Material	Er	C.mho/m
air	1.	0.
soil1	80.	0.
soil2	60.	0.
soil5	22.	0.
soil8	6.	0.

Example. Various focusing and broadening of the GPR microwaves can occur when low velocity and high velocity zones exist at various levels in the ground.

GPRSIM - Shadow Zones Caused By Refraction
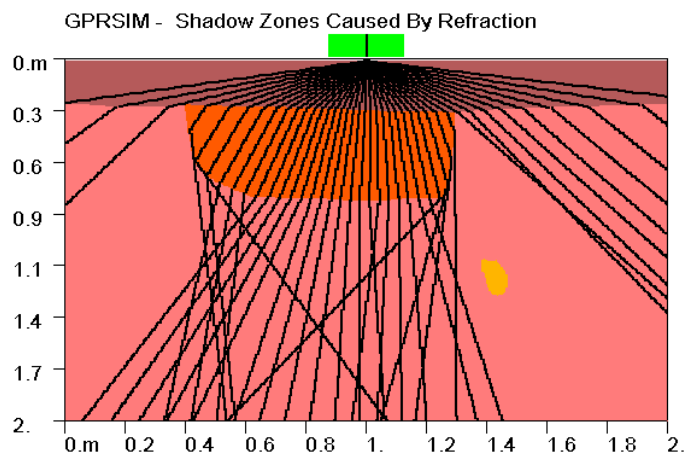
Material	Er	C.mho/m
air	1.	0.
soil2	60.	0.
soil5	22.	0.
soil7	8.	0.
granite	5.	0.

Example. Shadow zones can occur in certain kinds of earth situation. In this case, a low velocity zone focuses the GPR microwaves downward and objects located near the edges of these zones can go undetected.

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GPRSIM - Focusing and Scattering of Microwaves

Material	Er	C.mho/m
air	1.	0.
soil6	12.	0.
soil7	8.	0.
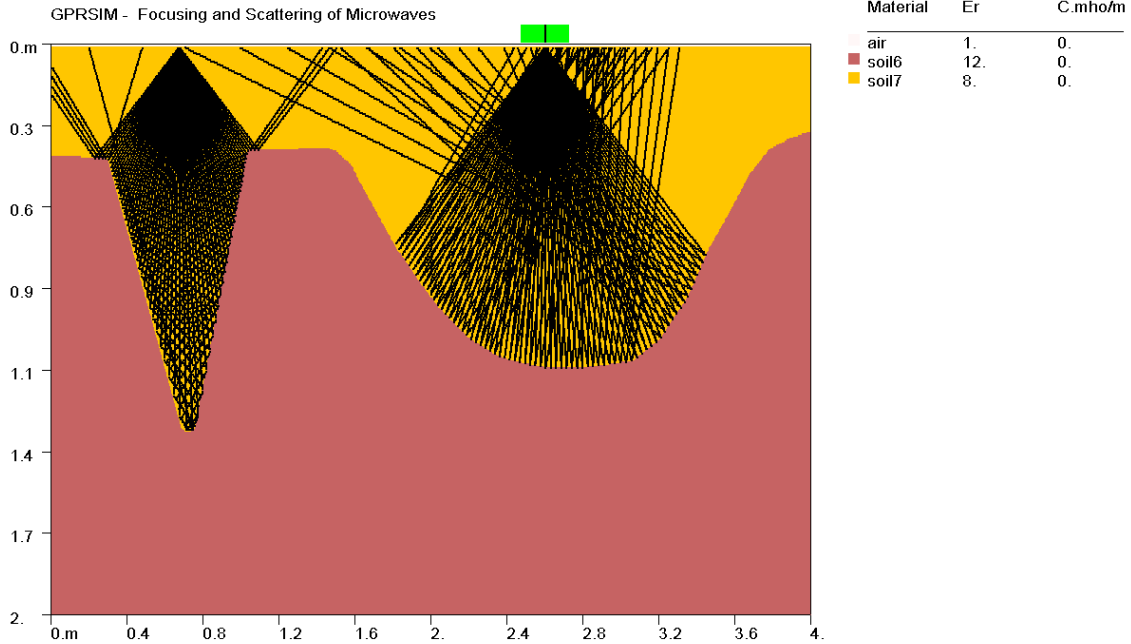
Example. The focusing and scattering of microwaves is highly dependent on the shapes of subsurface structures. Narrow structure may tend to scatter more waves where broader structures may focus more waves back to the recording antenna.

GPRIM: Pit Dwelling - Air/Groundwave modelled

Material	Er	C.mho/m
air	1.	0.
soil2	13.	0.001
soil3	10.	0.001
soil4	16.	0.001
soil6	14.	0.001
soil-loamy	20.	0.0001

TTRRTRTTT · TTTRTRRTT · TTRTRRT
TRTRR · TRRTRTT · TTRTRRT
TTTRRRTTT · TTTTRRRTTTT · RRTRT
TTTTRRTTTT · TRRRT · TTRRRTT
TTTRTTT · TTTTRTTTT · TTTRRTTT
R · TRT · TTRTT
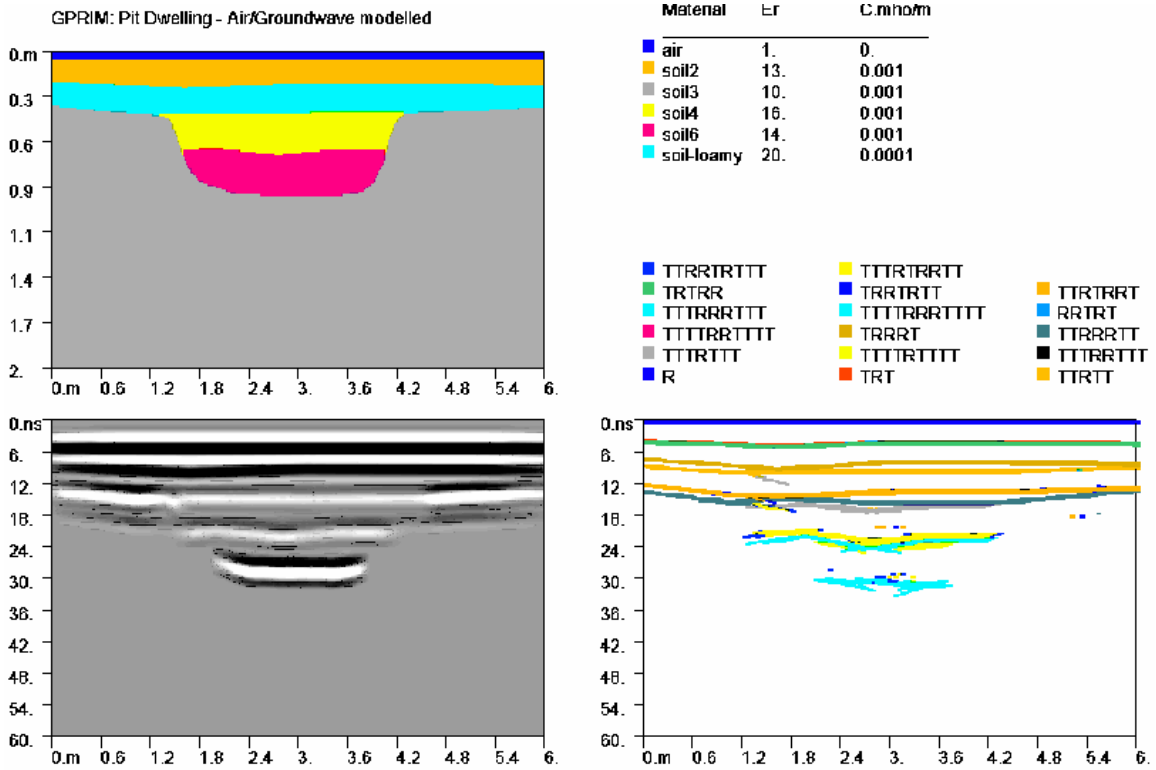
Example. A pit dwelling simulation shows the reflections to closely match the real-world situation.

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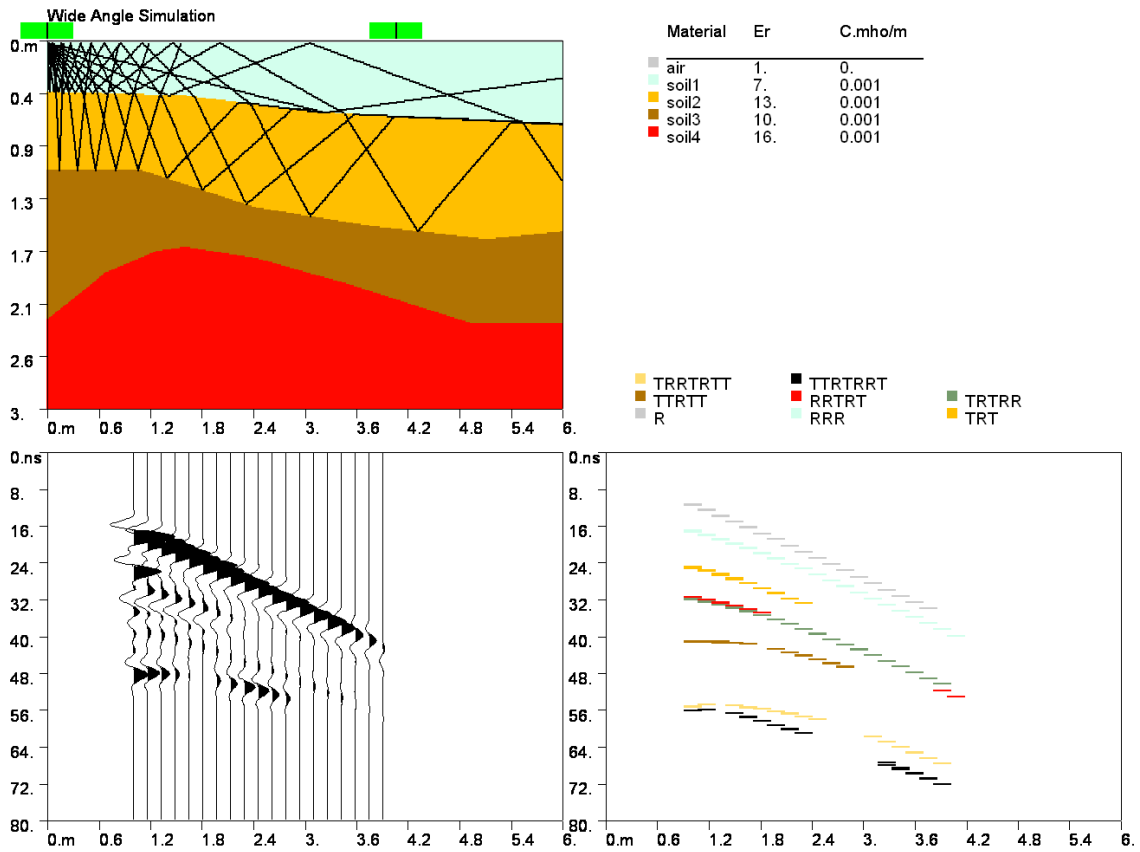
Example. A wide-angle simulation over a layered ground.

THE GOLDEN TRIANGLE

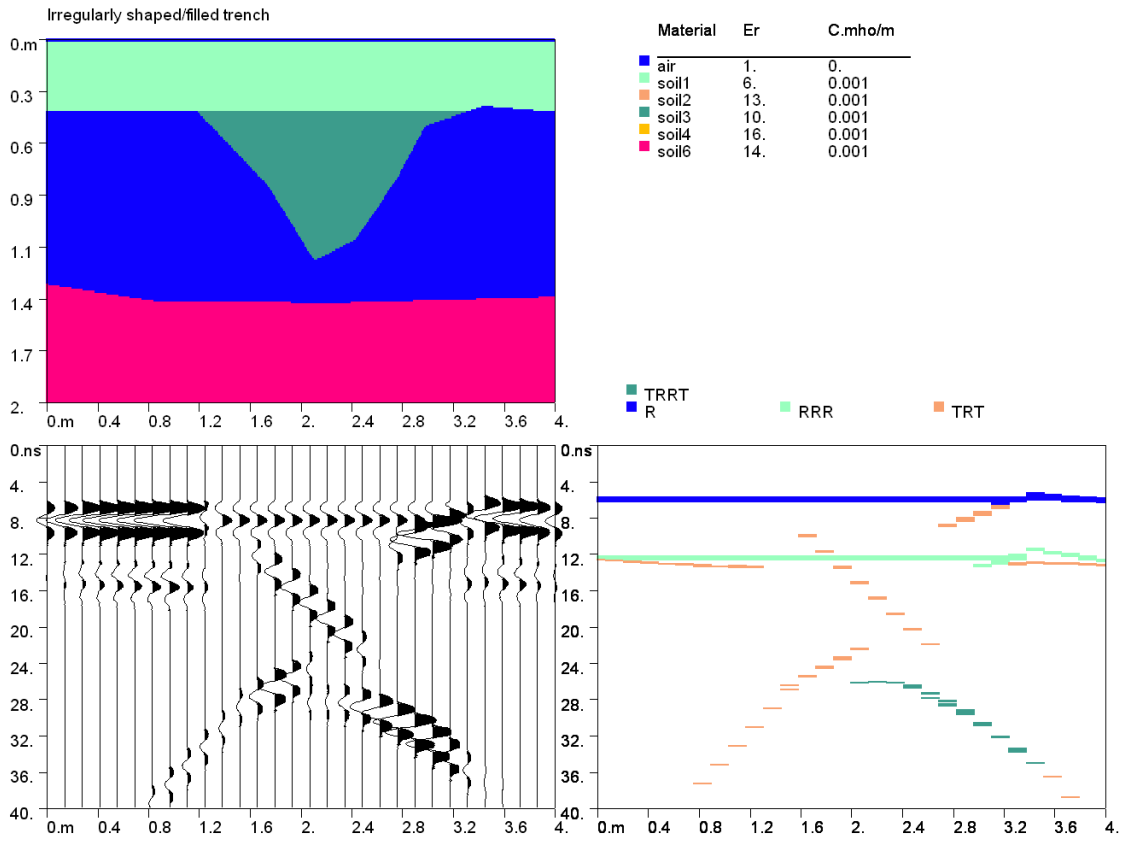| Material	Er	C.mho/m
air	1.	0.
soil1	7.	0.001
GOLD	1.	5.8
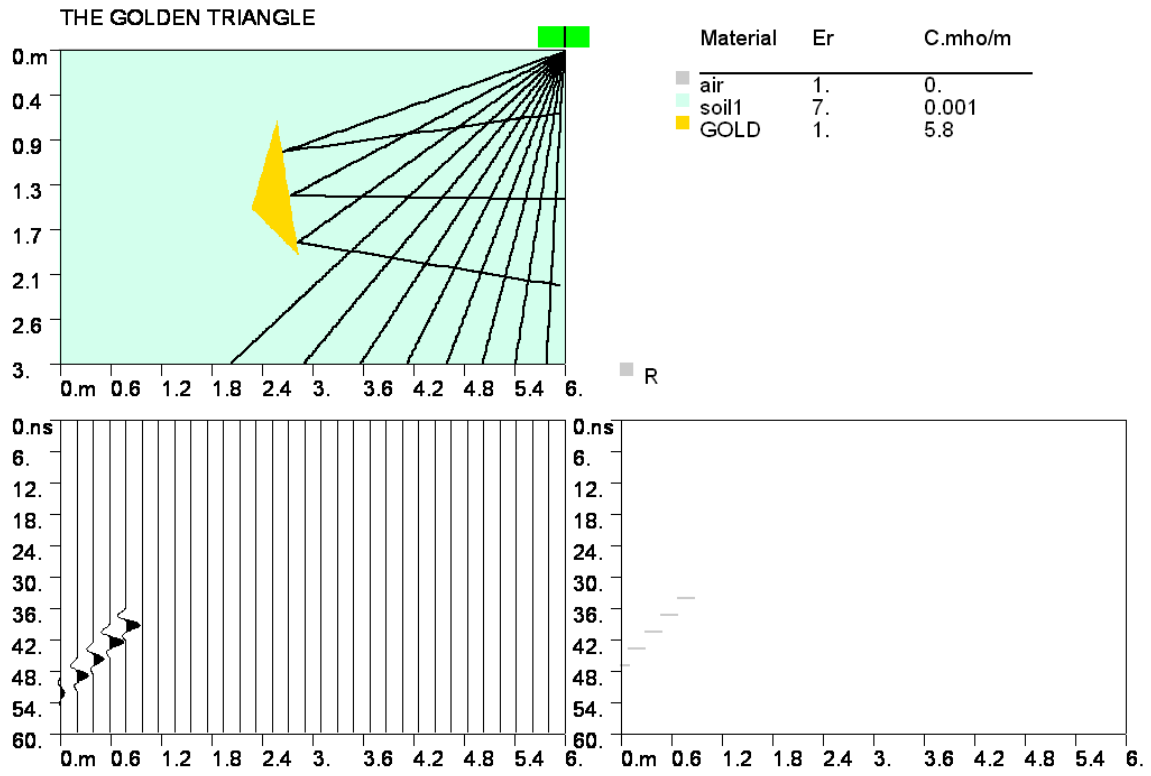
Example. A "false" location of a reflection from a triangular buried object.

Irregularly shaped/filled trench

Material	Er	C.mho/m
air	1.	0.
soil1	6.	0.001
soil2	13.	0.001
soil3	10.	0.001
soil4	16.	0.001
soil6	14.	0.001

Example. An irregularly shaped trench filled, and buried beneath a shallow surface layer.

GPRSIM - Baby T-rex

Material	Er	C.mho/m
air	1.	0.
soil1	6.	0.001
soil2	13.	0.001
copper	1.	5.8

■ R   ■ RRR   ■ TRT
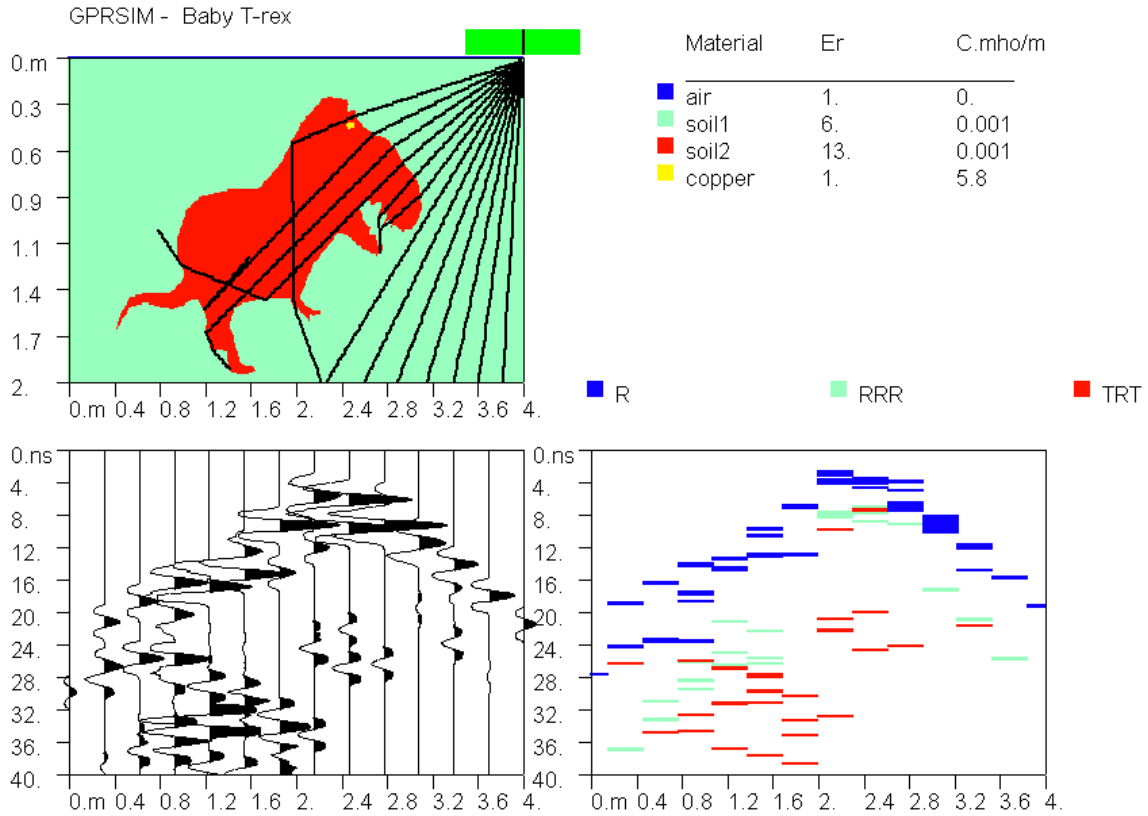
Example. Baby T-rex

There are many more examples and possibilities.… Happy simulating!!

Reserved Filenames and Formats

To run **GPRSIM** several working filenames are used. The following names should not be used to name output files:

install.dat file containing installation parameters for GPRSIM
Version 1 & 2

installv3.dat file containing the additional installation for
Software developments beginning with version 3

ismgrid.dat file containing the digitized grid

poly.dat file created by the grid program and
containing structural (line/spline) info

work.dat temporary work file for general operations

waves99.dat file containing the list of general wavetypes
for input to the simulator

materials.dat file containing all the electromagnetic properties
or model materials used in the simulations.

Travel Times - TT.dat

In some cases the user may want to use the attenuated reflection coefficient data contained in the travel time files for their own researches. The travel time files are quite large - sometimes N time the size of the radargram, where N is the number of wavetypes used in the simulation. This is because a scan for each wavetype is recorded in this file. If the user wishes to generate there own comprehensive attenuated reflection coefficient file then the following simple code can be used to put all these responses in a single travel time file:

```
dim x(#samples/scan)
open "travel time file" for input as #1
open "output file" for output as #2
for i=1 to #of antenna locations
   erase x(k)
   for j=1 to #of wavetypes
     for k=1 to #samples/scan
        input#1 data
       x(k)=x(k)+data
     next k
```

```
        next j
        write#2 x(k)
      next i
      close#1:close#2
```

Simulated Radargram - Sim.dat

The synthetic radargram is found by convolving the reflection/transmitted /attenuation coefficients contained in the travel time file with the impulse response function of the antenna. The file is an ASCII file containing the responses with a length given by the samples/scan. There is no header in this file

Impulse Response Function – Impres.dat

The impulse response function is an ASCII file with a one line header followed by the response function normalized between -1 to 1**,** The first line header contains the **time window, samples/scan, N points, frequency, replicate$, replicate gain**
....followed by the response function:

Example:
40,512,61,400000000,"off",1
0
0
.165594846010208
.280456840991974
.498396247625351
.56665050983429
.641250014305115
.665000021457672
.689999997615814
.699999988079071
.692499995231628
.68000007152557
.694999992847443
.682500004768372

Directional Response – Dirres.dat

The directional response function has both the receiver and the transmitted information contained in a single file. The first is the

transmitted directional response function of the antenna, having a one line header:

Transmitted beam start, beam end, aperture in meters, ray angle step, centering$,...... followed by the response function. Similarly, the receiver function will follow the transmitter information in the same file. In the case below, the receiver function is set to a constant of 1 – equal recording response in all directions.

Example:
190,350,.600000023841858,-1,"on"   ' transmitter
190,.529528081417084
191,.509901940822601
192,.512683570384979
        …..
0,180,.600000023841858,-1,"on"   ' receiver
0,1
1,1
2,1
3,1
4,1
        …..

179,1
180,1