

# Ground Penetrating Radar (GPR) exercise

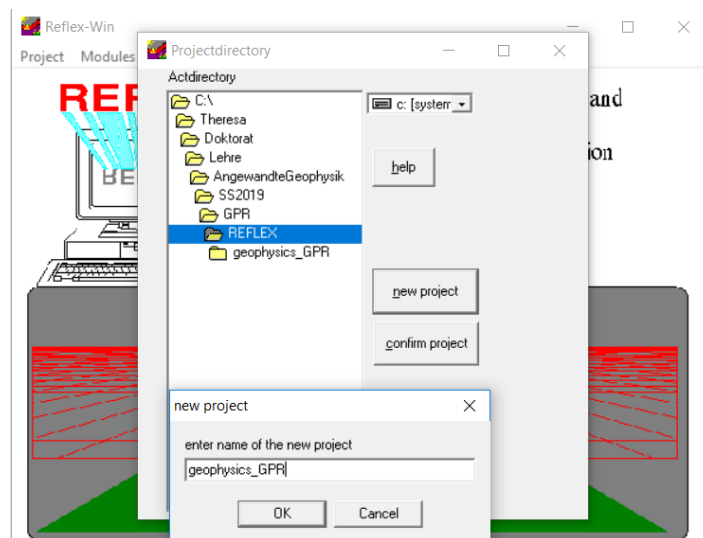
The first goal of this exercise is that you understand what to expect from a GPR signal. Therefore, you have to build a model of the subsurface and calculate the synthetic response of this model. By varying the geometry of the subsurface layers and also the frequency of the antenna, you get a feeling of different GPR responses and more experience for the interpretation of GPR data.

In a next step, you get a real GPR dataset collected at the field-scale in Stainach, a contaminated site in Steiermark. The GPR data were acquired with a 200 MHz antenna and 400 MHz antenna along 20 profiles of different length. Your work will be to plot the raw data, add a geometry to the profiles, process the data and give a first interpretation of the subsurface (pick interfaces and build a model).

In a last step you will have to calculate the synthetic response of this model and compare it with the measured data.

This exercise is performed within Reflexw, a popular geophysical near surface processing and interpretation software from Sandmeier. To install Reflexw on your laptop, you have to start the setup.exe and type the license-number and password which we will give you during the exercise. After installing the software, start it, define the project directory and set up a new project (you can give a name of your choice). The software contains different modules, the two following modules are important for this exercise:

- 2D-data-analysis (for the visualization, processing and interpretation of the GPR data)
- Modelling (for the calculation of a synthetic response of a subsurface model)



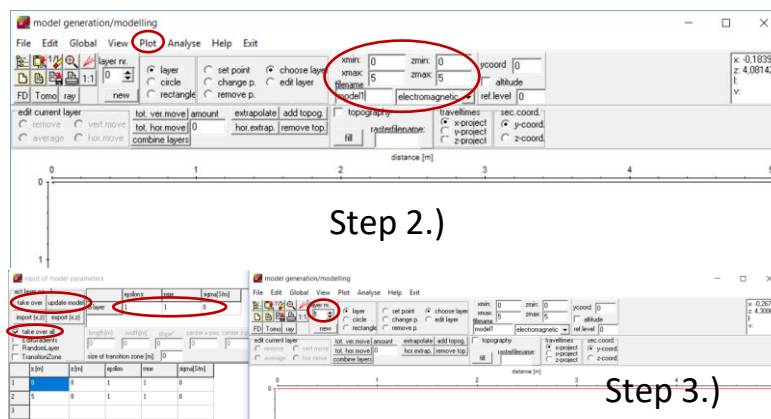
# 1. Exercise: What do we expect from a GPR signal?

Within this exercise you have to build a four-layer model of the subsurface. As you learned in the Angewandte Geophysik Vorlesung, the propagation of electromagnetic waves is dependent on two electrical properties: the electrical permittivity ( $\epsilon$ ) and the electrical conductivity ( $\sigma$ ). Thus, every layer within the subsurface has different electrical properties ( $\epsilon, \sigma$ ). The goal of this exercise is to calculate the response of different models:

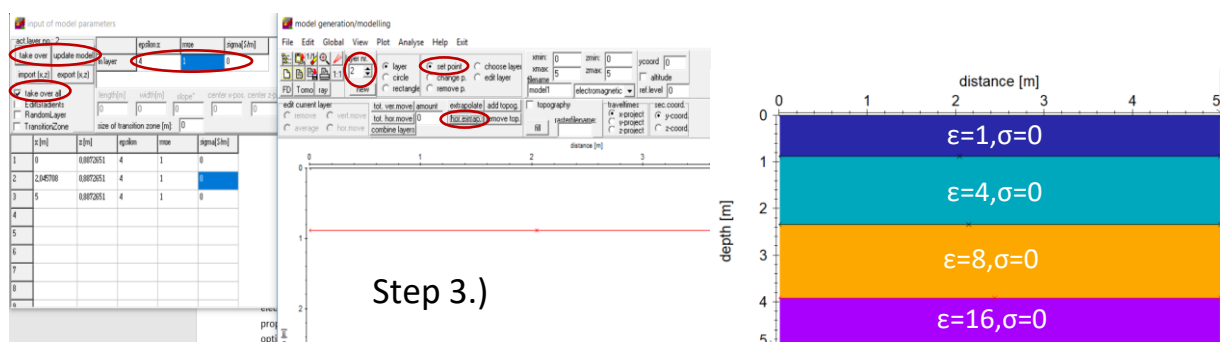
- Varying the electrical properties ( $\epsilon, \sigma$ )
- Varying the geometry of the interfaces
- Adding objects into the subsurface (for example a pipe or a cave)
- Testing different antenna frequencies

## Step-by-step guideline for the calculation of a synthetic model

- 1.) Open Reflexw, confirm the project you created and open the “Modelling” module
- 2.) Create a model with the dimensions (xmin=0 [m], xmax=5 [m]; zmin=0 [m], zmax=5 [m]), define a filename, the wavetype and apply this by (Plot >> Reset)



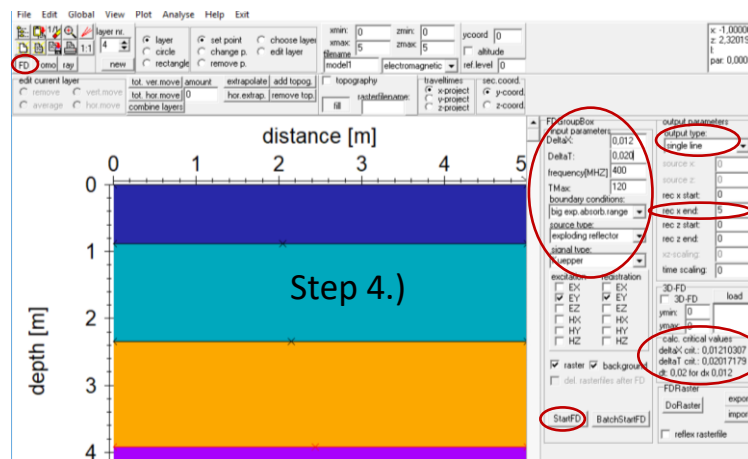
- 3.) Define 4 layers and assign different electrical permittivity values to each layer, and a constant electrical conductivity value to all layers. By increasing the layer nr. to 1, you can access the electrical properties for the first layer. Define an electrical permittivity value of your choice and apply it with the option “take over all” and “update mode”. For the second layer, you have to define a point and then horizontally extrapolate the interface to the left and right border of the model. Then you can define an electrical permittivity value of your choice to the second layer. For the third and fourth layer, the procedure is the same. In the end, you will get a four layer model of the subsurface with varying epsilon and constant sigma values.



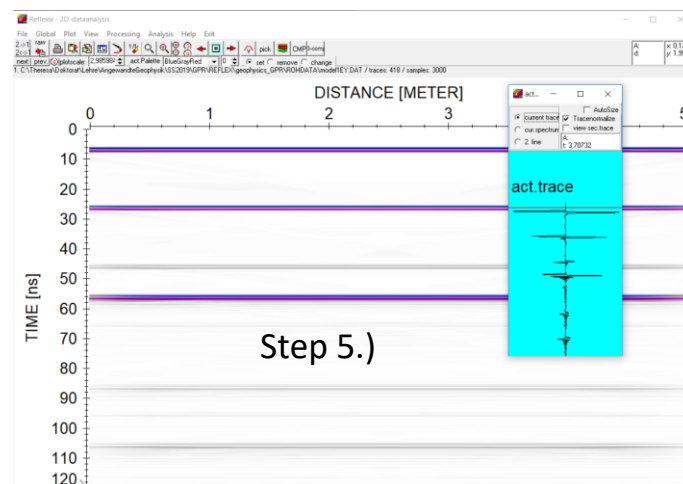
4.) The next step consists in the simulation of the electromagnetic wave propagation based on your model by means of finite difference (FD) methods. Therefore you have to define the simulation parameters first within the box “FD”:

- the antenna frequency (main frequency of the signal),
- a maximum time range for the signal to be recorded (the point of time in ns at which the simulation shall be terminated),
- a time increment (DeltaX) and space increment (DeltaT) (with this increment, the layer model is rastered - you can take the critical values from the box below),
- the boundary conditions, source type (exploding reflector for zero offset profile), signal type (Kuepper) and output type (single line).

In the end, you have to save your model and start the simulation.



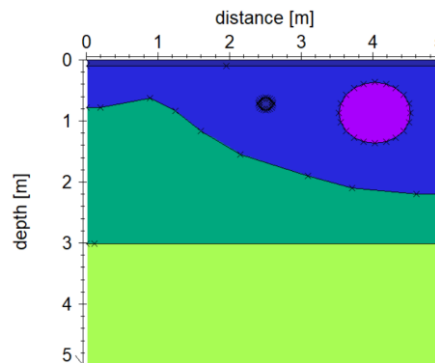
5.) After that the computation is finished, you have to open the module “2D-data-analysis” where you can visualize the computed synthetic response of your model (File >> open >> rohdata >> modelnameEY.dat)



Questions: What can you observe? Does the reflection amplitude change? Why? What about the polarity of the signal?

### Next steps to do:

- Vary the electrical permittivity for the second layer from 1 to 80 (four models), what is your observation/conclusion?
- Build a four-layer model with a constant electrical permittivity value for all four layers and varying electrical conductivity values for each layer. Choose a high conductivity for the second layer and explain your synthetic response.
- Build a realistic four layer model (for example: air, sand, gravel, limestone) with varying geometry and add a metallic pipe and an air-filled cave into your model. Visualize and explain your synthetic data. What is the influence of the geometry? If you exchange one of your layers with a clay layer, how would the synthetic response look like? Why?

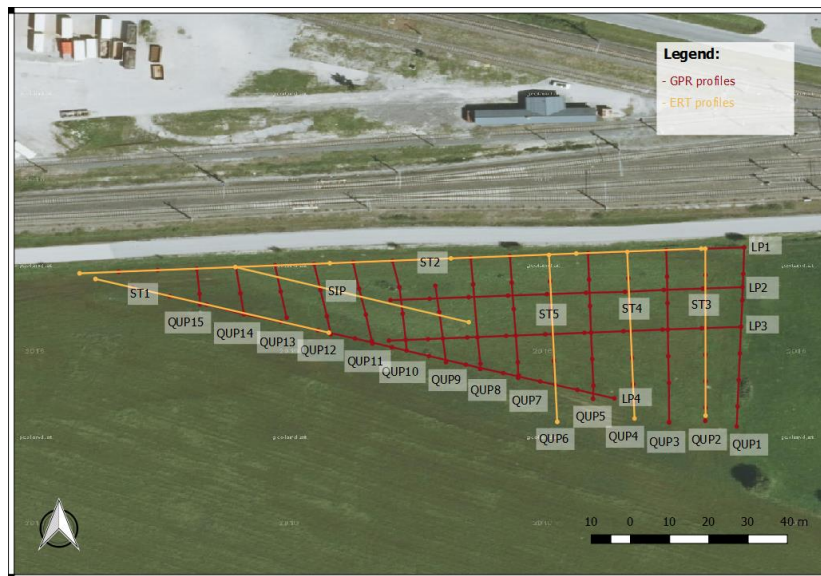


- Take your realistic four-layer model and calculate the synthetic response for different frequencies:
  - 100 Mhz
  - 200 Mhz
  - 400 Mhz
  - 800 Mhz

Are you able to resolve the cave with every frequency? If not, why?

## 2. Exercise: Visualization, processing and interpretation of measured GPR data

In this exercise, you have to visualize process and interpret the data collected in Stainach, Steiermark. The GPR data were acquired in 2017 with a 200 and 400 MHz antenna. ERT and IP data have been collected at the same time along 6 profiles.



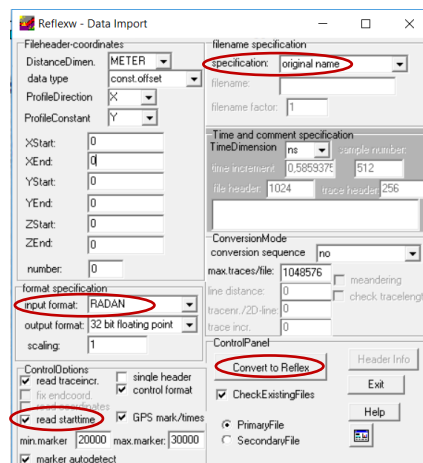
The goal of this exercise is to:

- plot the raw data (located in the folder rawdata)
- edit the geometry (marker interpolation, flipping files)
- process the data (dewow, time-zero corr., gain corr., bandpass filter, clutter reduction)
- interpretation of the data (picking interfaces, building a 2D-model)

Within this exercise, we will focus on profiles LP1 and ST1 collected with 200 Mhz and 400 Mhz.

### Step-by-step guideline for the visualization, processing and interpretation of the GPR data:

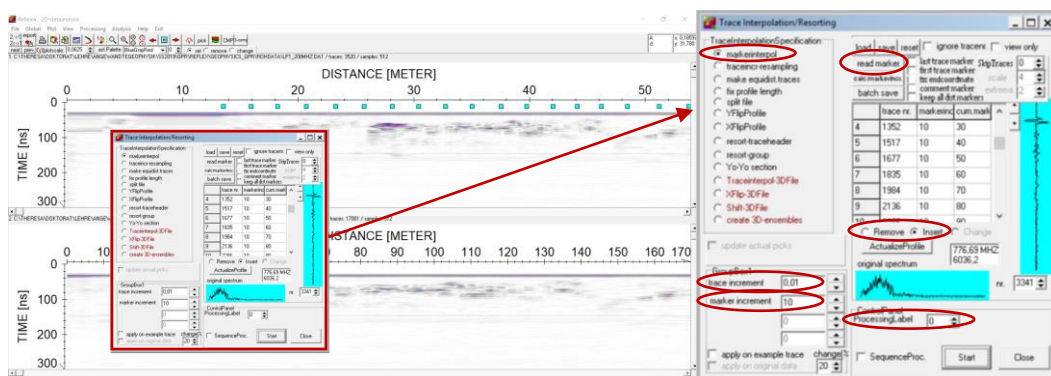
- 1.) Copy the \*.dzt Files into the folder “ASCII” within your project folder you created with Reflexw
- 2.) Open Reflexw, confirm the project you created and open the “2D data analysis” module
- 3.) If you put the \*.dzt files into the correct folder you should be able to import the data as follows:



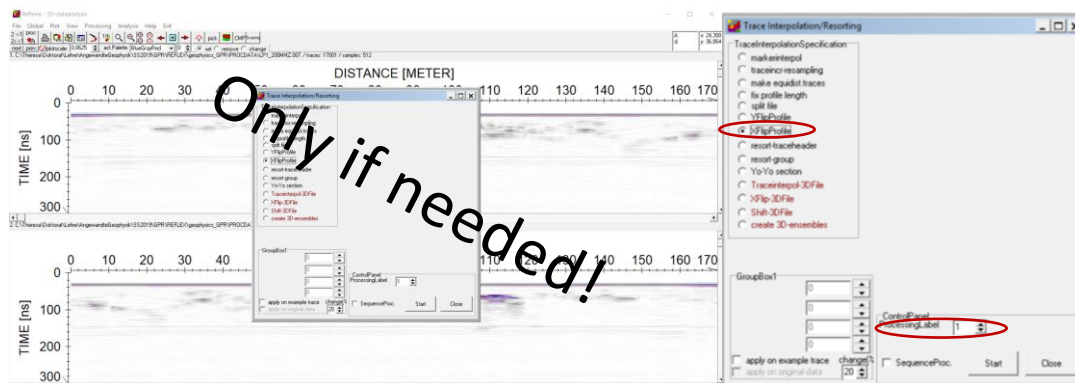
4.) **Edit the geometry:** The next step consists in applying a geometry to the data. The data were acquired along 2D-profiles based on a fixed time base. For a correlation to the distance, during the data acquisition equally spaced markers were placed at distinct intervals (e.g. 10m). To rescale the data from the time base to a distance, within Reflexw this is done using the processing option markerinterpolation under processing/Trace Interpolation. Within this processing step you have to read the markers and define the trace (0,01m) and marker increment for the interpolation. During the field measurements, you have to lead a protocol and note whether a marker was missing or was set at a wrong position. If the profile has to be flipped, use the option “XFlipProfile” under processing/Trace Interpolation.

GPR protocol for the 4 profiles:

- LP1\_200MHz: marker every 10m, first marker has to be deleted, data were collected from 170m to 0m, so the profile has to be flipped, one marker is missing at 160m - has to be set manually (with the option “insert”)
- LP1\_400MHz: marker every 10m, first marker has to be deleted, data were collected from 0m to 170m, so you don't have to flip it
- ST1\_200MHz: marker every 10m, first marker has to be deleted, data were collected from 0m to 178m, so you don't have to flip it, marker distance 5m and 3m at the end of the profile
- ST1\_400MHz: marker every 10m, first marker has to be deleted, data were collected from 0 to 70m, so you don't have to flip it



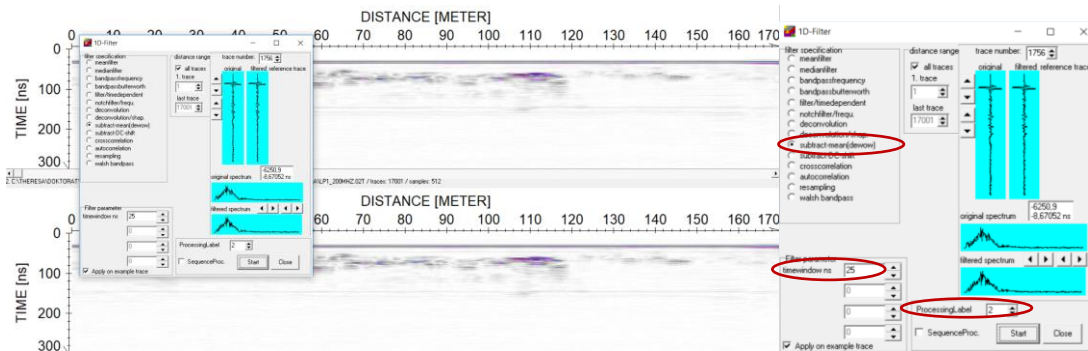
For every processing step, you have to define the processingLabel and increase it. So after the step markerinterpolation (processingLabel 0) you have to load this data set (File >> open procddata>>filename00R) for further processing.



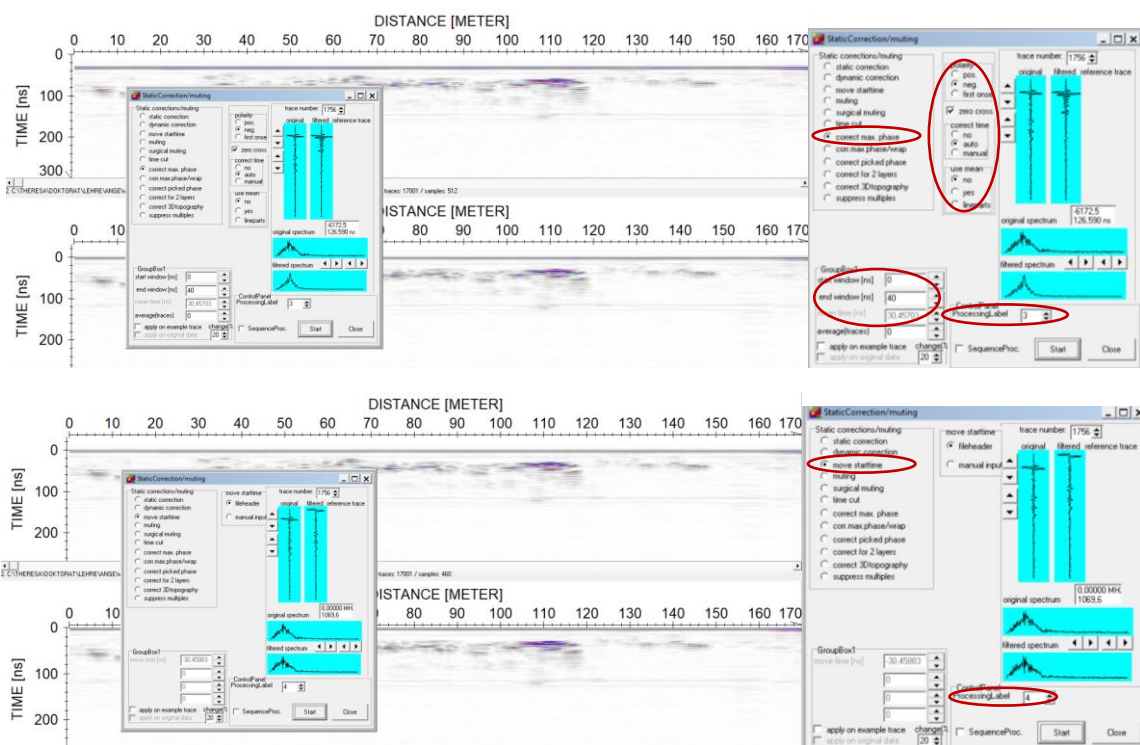
5.) **Dewow filter:** Many GPR data show a significantly low frequency component either due to inductive phenomena or possible instrumentation restrictions. This low frequency range must be removed before applying any other digital filter algorithms. The processing step can be found in



processing/1D-filter/subtract mean-dewow. You have to enter as filter parameter the time range for the calculation of the running mean value. Try different time windows, do you see any difference?



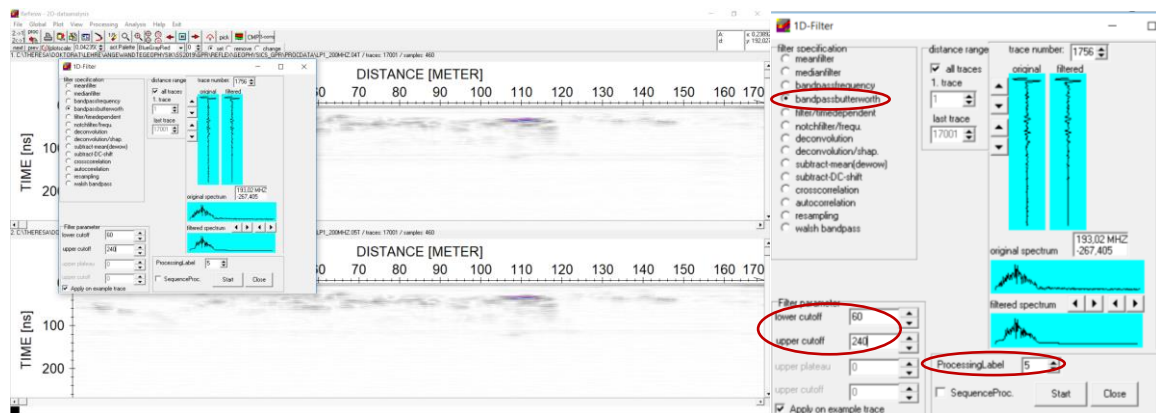
**6.) Time Zero Correction:** Thermal drift, electronic instability, and variations in the antenna airgap can cause jumps in the air/ground wavelet first arrival time. This has an effect on the position of the ground interface in the section. Therefore, traces require adjusting to a common time-zero position before processing methods can be applied. This can be done by searching for the air wave first break point or first negative peak of the trace. Within Reflexw, you can find this processing step under Processing/StaticCorrection/correct max. phase. You have to set a start and end window and define the polarity (negative or positive) of the first wavelet. After defining the air wave first break point, the option “move start time” helps you to remove all data in front of the zero crossing.



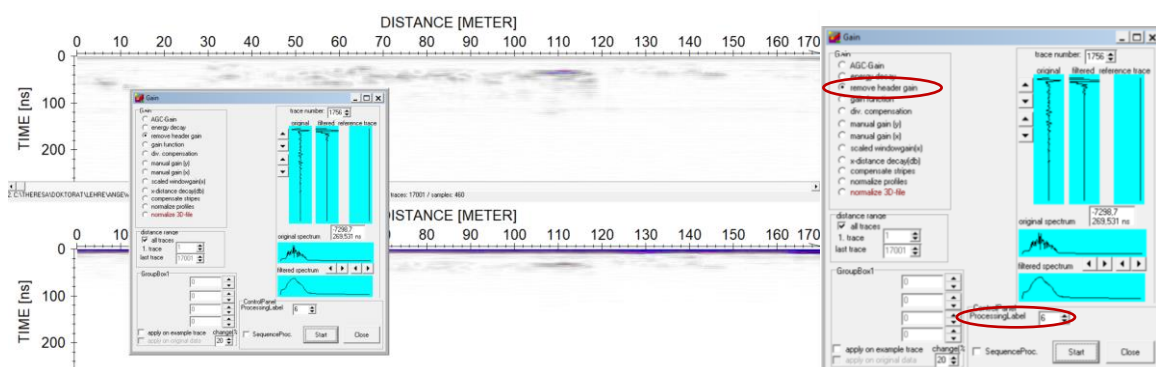
## 7.) Frequency filter: The GPR response

A GPR antenna receives a distribution of different frequencies. So most of the response will be symmetrically distributed around the center frequency, but some response that the GPR receives will actually be at the higher end and some at the lower end of the spectrum (instrument drifts over time, background noise). To adjust for the drift and the noise, you have to apply a high and a low-pass filter -> bandpass filter.

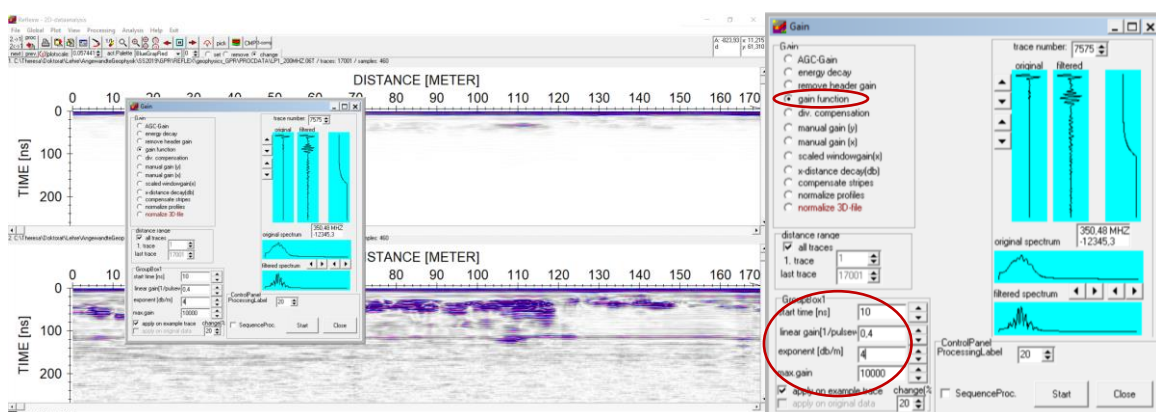
For the bandpass filter, use the option Processing/1D-Filter/bandpassbutterworth, which is specified by the setting of the two frequency values lower cutoff and upper cutoff to apply both a highpass and a lowpass butterworth filter on the data. Choose your pass region as  $0.5\text{--}2 \times$  of the peak frequency of your signal.



8.) **Gain correction:** The time gain function compensates for spherical spreading losses and exponential ohmic dissipation of the wave amplitude. In the case of the GSSI GPR system, an automatic gain function is applied during the measurements. If we would like to compare data files of different years acquired with different gain, you first have to remove the header gain (Processing/Gain/remove header gain) from the file

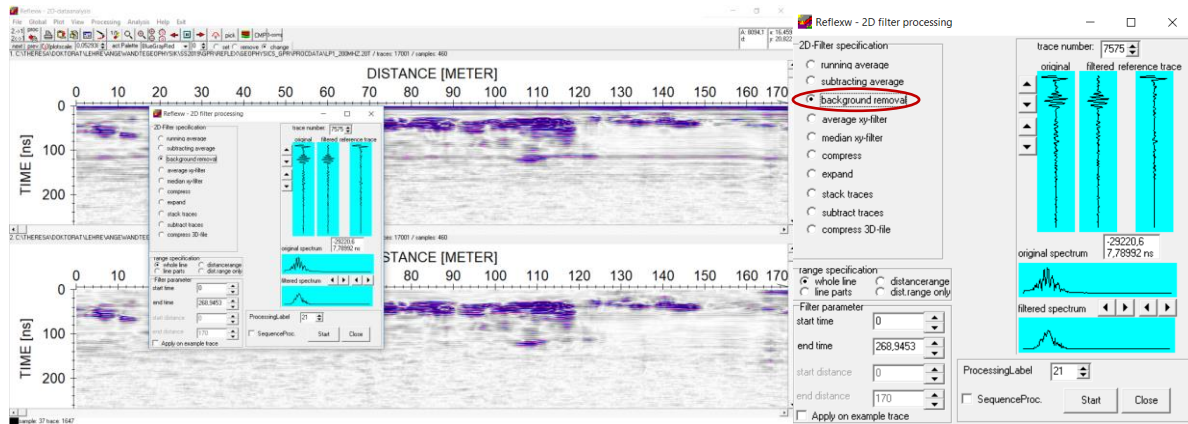


and apply a gain function (Processing/Gain/gain function) to all profiles. The gain function consists of a linear and an exponential part which is defined by the start time, the pulse width and the attenuation of the medium. Here, you have to know the pulse width of the signal and estimate an attenuation for the subsurface (the subsurface material is silty, sandy and clayey; you can find values in the literature).





9.) **Clutter reduction:** GPR data are often contaminated by clutter. The clutter mainly consists of the GPR system noise, ground bounce, soil roughness scattering and reflection signals from external anomalies. The clutter mostly appears as nearly horizontal and periodic ringing. One of the most common operations applied to GPR data is the use of a background removal (average trace removal) filter (Processing/2D-filter/background removal). Try this filter algorithm and decide whether this filtering step is necessary for a better understanding of the subsurface? Do you lose important information or even remove a relevant signal?



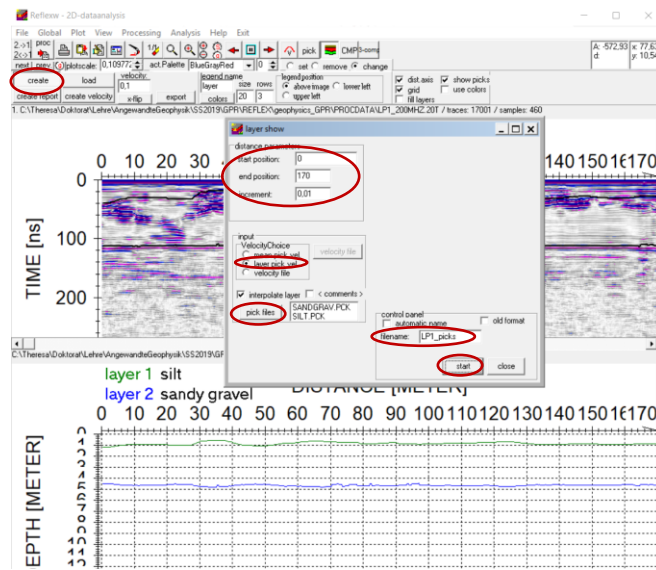
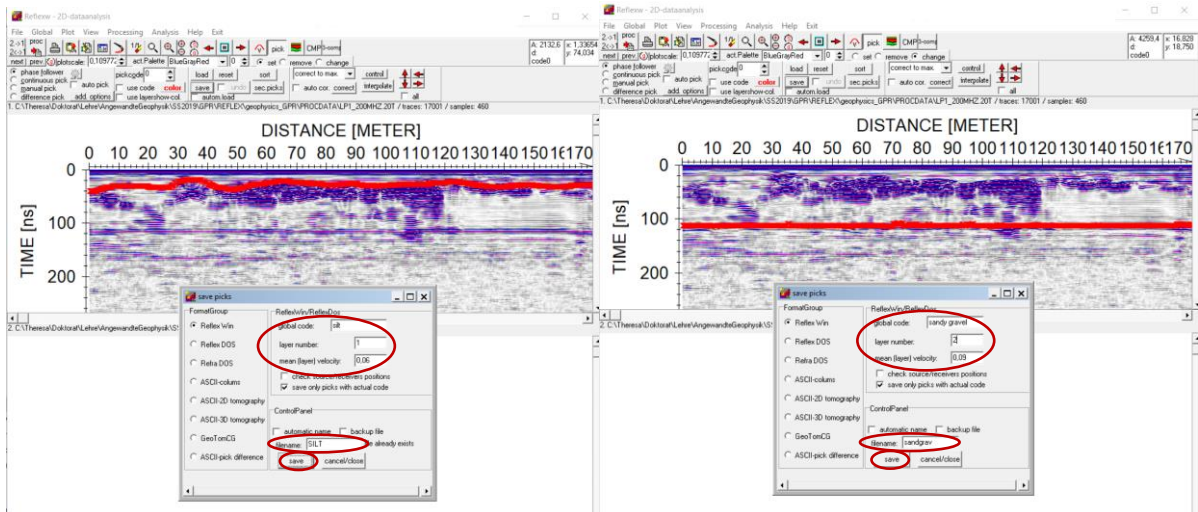
#### 10.) Interpretation of the data (picking interfaces, building a 2D-model):

First of all, you should check the information available for the site: lithological information from boreholes, other geophysical data (ERT/IP)... What do you know about the local physical properties? High/low conductivity? High/low dielectric permittivity? Is the ground dry or saturated (permittivity)? Does the ground contain features which may scatter the signal? What is the operating frequency and the wavelet pulse width (see gain function)? What do you think about the resolution and penetration depth?

Regarding your measured data: When is the latest useful signal you measure? Why can't you see anything after the latest signal? Attenuation? Strong reflector? Is there a reverse in polarity of the wavelet signal? What does that tell you about  $\epsilon_1$  and  $\epsilon_2$  for an interface? Do you notice any hyperbolic features? If yes/no, what does it indicate? Are you able to pick interfaces? What were the challenges? If you compare 200 Mhz and 400 Mhz, what are your observations?

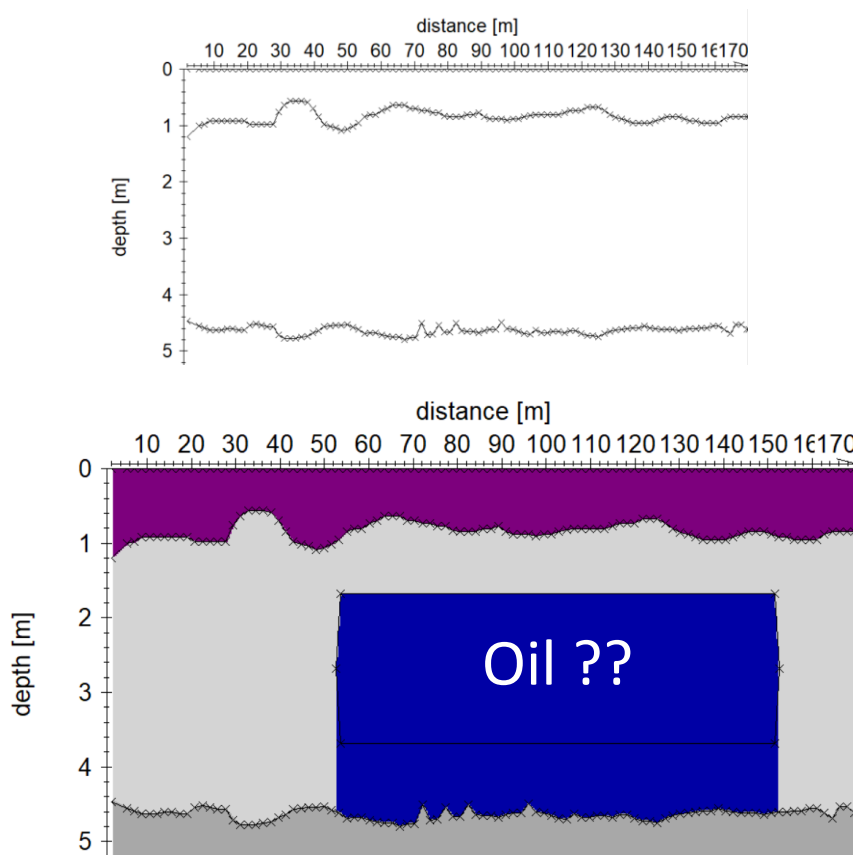
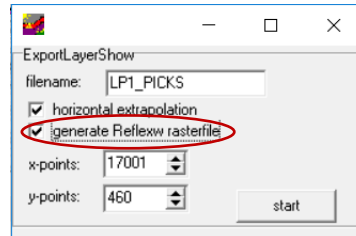
We expect tar oil within the subsurface. What are the electrical properties for oil? What did you learn from the processing of the ERT and IP data? You can find attached the result of the ERT and IP data from the same profile measured in 2017 together with GPR. Where would you expect oil within the subsurface? Can you see any change in the reflection amplitude within the radargram?

Steps for picking interfaces in Reflexw: Use the option "pick" and "phase follower or continuous pick" for defining an interface. After picking an interface, save it, define a global code (layer name), layer number, mean layer velocity (take expected velocities from literature) and a filename. Then save the picks for this layer, reset the picked layer and pick the second/third layer (same procedure). The next step is to define a 2D-model of the subsurface, where you have to activate the layer show, and create a layer model as shown in the last figure.



### Exercise 3: Calculation of the synthetic response of your model and comparison with measured data

Now the question is, how reliable is your interpretation? Where do you expect the oil within the radar section? For validation, you can calculate the synthetic response of your layer model and compare it with the measured data. How comparable are they? What is your conclusion?



Therefore, you have to export your layer model by using the option “export” and import the model in the modules “Modelling” – “File/load from ASCII” (Attention: the wavetype must be set to electromagnetic before importing the ASCII-file). Then the velocities within the ASCII file are automatically converted into epsilon values. You only have to define a sigma for each layer (you can use the values from the ERT result or take values from the literature) and add a rectangle (with electrical properties of oil) to your model where you expect the contamination. Then calculate the synthetic response and compare it to your measured data. (Task: synthetic data for profile LP1 200 MHz antenna, for every additional profile you will get additional points)