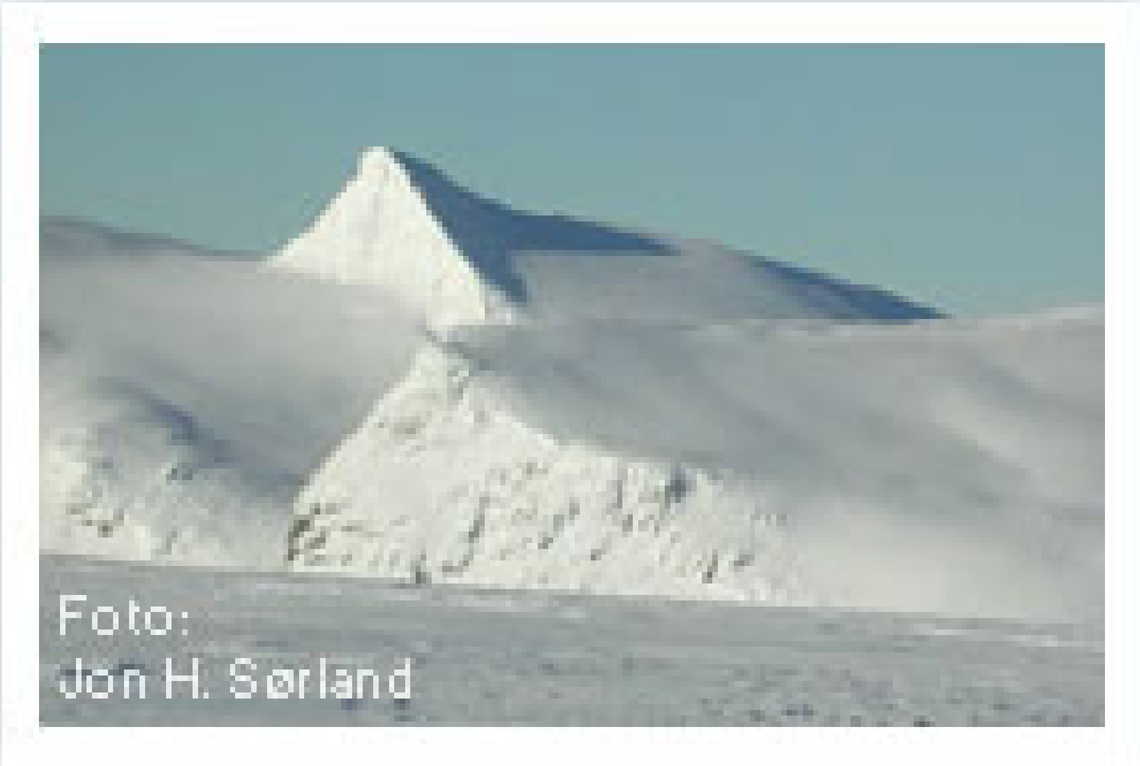
Report on a Ground Penetrating Radar survey of Longyearbreen



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Abstract:

Ground Penetration Radar was used to determine snow depths and ice depths across Longyearbreen, central Svalbard. By use of a 450 Mhz antennae and 50 Mhz antennae, the snow-ice and ice-ground transitions were easily seen within the radar profiles as sharp reflections. In order to best extract the necessary information, post-processing was performed to remove unwanted noise. By applying a variety of filters and gain functions, the necessary information was extracted. Through velocity analysis and Normal Move-Out Corrections, the time scale was easily converted to depths.

Introduction

A ground penetrating radar (GPR) profile was driven along a glacier, Longyearbreenn located directly behind Longyearbyen, in order to require information about ice depth, annual layering and large stones or boulders embedded in the glacier. Furthermore, it is expected that from this survey, information upon ice temperature could be retrieved (i.e. whether the glacier is warm or cold based).

In addition, using a varying frequency with the GPR instrument, one can retrieve snow depth, that if calibrated correctly with snow\ice density, can determine a water equivalent snow depth across the glacier useful for incorporation into mass balance studies.

In conjuction with the GPR profiling, GPS was used to determine exact positions of each of cross-transects. This information is included in a second report containing methods and results to the retrieved GPS positions.

Methodology (Experimental Design)

As the survey was performed on a glacier in the field, the cold conditions must be considered to ensure that the equipment can operate properly, and the survey can be conducted successfully. The equipment consisted of a GPS device for measuring positions, the ground penetrating radar (receiver, antennae, etc.), and a snow mobile with a sledge for equipment transport.

For measuring exact positions, a Leica GPS system 500 was used, where a basis station was set up at the front of the glacier where the survey was beginning. The rover was placed on the sledge which carried the GPR instruments. The coordinates were measured continuously for one crossing of the glacier.

The GPR was configured optimally to fulfil the task of either measuring snow depth or ice depth depending upon which survey was being performed. The transmitter and receiver were installed on a sledge behind the vehicle while the computer unit that receives and saves the data was in the vehicle itself. This ensures that the electronics do not introduce too much noise that the receiver will pick up.

Furthermore, the GPR instruments (transmitter) needs to be set up with a shooting time interval. For our survey, a distance wheel was used such that the transmitter outputs a signal every meter. In contrast, time can also be used to determine a shot interval, but results in a varying spatial scale across the image which makes radar image interpretation difficult. Lastly, fiber optic cables are used to transfer data from the receiver to the computer, in order to minimize time required to send and save the data. In summary, the GPR settings used to retrieve snow depths across the glacier are as follows:

- step size 1 m
- antenna separation 0.25 m
- frequency 450 MHz
- time window 50 ns
- voltage 200 V
- stacks 8
- sampling interval 200 ps

To get good resolution of the signals for such a shallow depth, a high frequency is used. Since only snow depth is desired from this survey, a high frequency allows for higher resolution through a shallower depth. Also a time window of 50 ns is sufficient, such that all data can be received.

To determine ice thickness, the setup of the GPR was changed to the following configuration:

- step size 1 m
- antenna separation 2 m
- frequency 50 MHz
- time window 1800 ns
- voltage 400 V
- stacks 4
- sampling interval 1600 ps

To see the bottom of the ice, a low frequency is used to ensure that the signal can penetrate deep enough through the ice medium. Also the time window has to be enlarged to ensure that all return signals will be received (i.e. the receiver waits long enough to receive the returning radar signal). The enlarging of the time window has also the effect that the size of the data is becoming so big, that the computer cannot handle this and the measuring points may overlap. To compensate for this, the sampling interval is increased to 1600 ps and also reduced the amount of stacks to 4. Stacking, or the number of stacks, in the number of repeated measurements at one point such that the return signals can be summer to generate a larger amplitude, and minimize noise. In summary, this means that the resolution of the traces is reduced and that the measuring signal is repeated only four times at each point.

The crew has only to observe the incoming data during the runs over the glacier. It is useful to begin a new file at the turning points, so it is easier to differentiate the runs later. The wheel for giving the step signal can break when the vehicle is turning. Therefore it is important to lift up the wheel during the turning. These procedures of driving the lines and turning to anther line can be retried as often as desired. We performed only two runs in each direction for snow and two runs for ice.

Filtering snow data

The objective of sounding the top layer of the glacier is to find the depth of the winter snow layer. We retrieved two profiles depicting the snow layer, profile 11 and 12. the same filters are used on these two profiles with the exception of changing the orientation in profile 11. Therefore only a step by step description is given for the processing of profile 11, where profile 12 will be merely presented.

First the raw data in profile 11 is shown in Figure 1. Since the data is unprocessed, little useful information can be obtained from it.

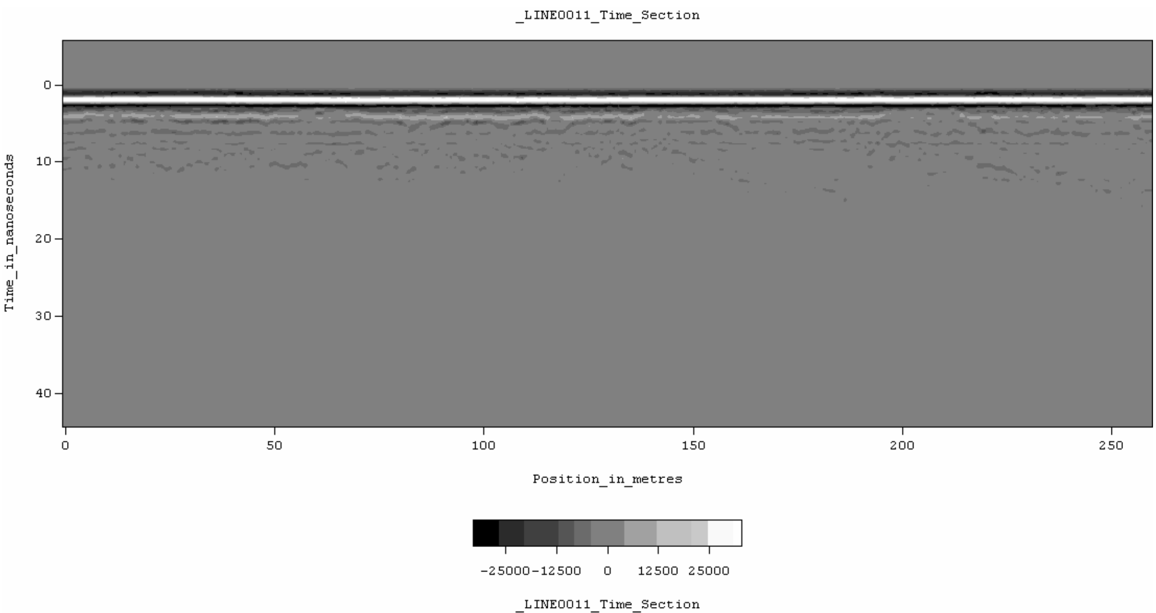


Figure 1: Radar profile before processing

To retrieve a more precise picture of the data we apply an autogain function, which applies a gain automatically to the radar signals. Specifically, it evens out the amplitudes in the profile, by decreasing the amplitude in the upper layers while increasing it in the lower layers. This is because the return signal loses amplitude with depth and thus the signal is stronger in the upper layers and weaker in the lower layers.

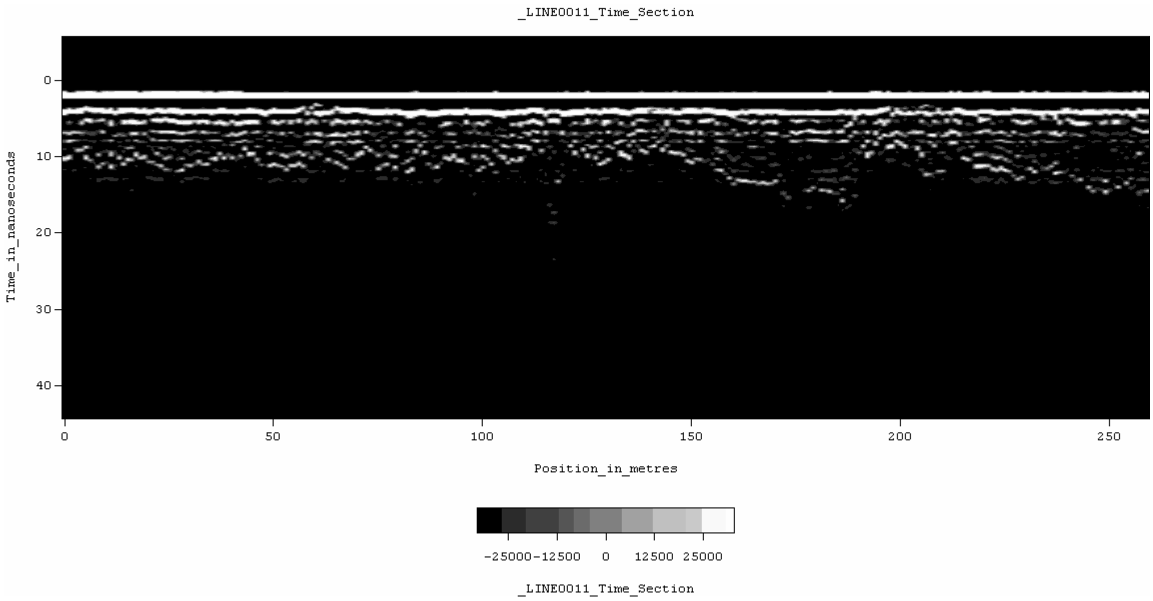


Figure 2: Radar profile after applying autogain

By using the dewow filter, low frequencies noise is removed (figure 3). The filter is applied on the time signal such that the return amplitudes are centered around 0 rather than exhibiting a low frequency wave with time (depth).

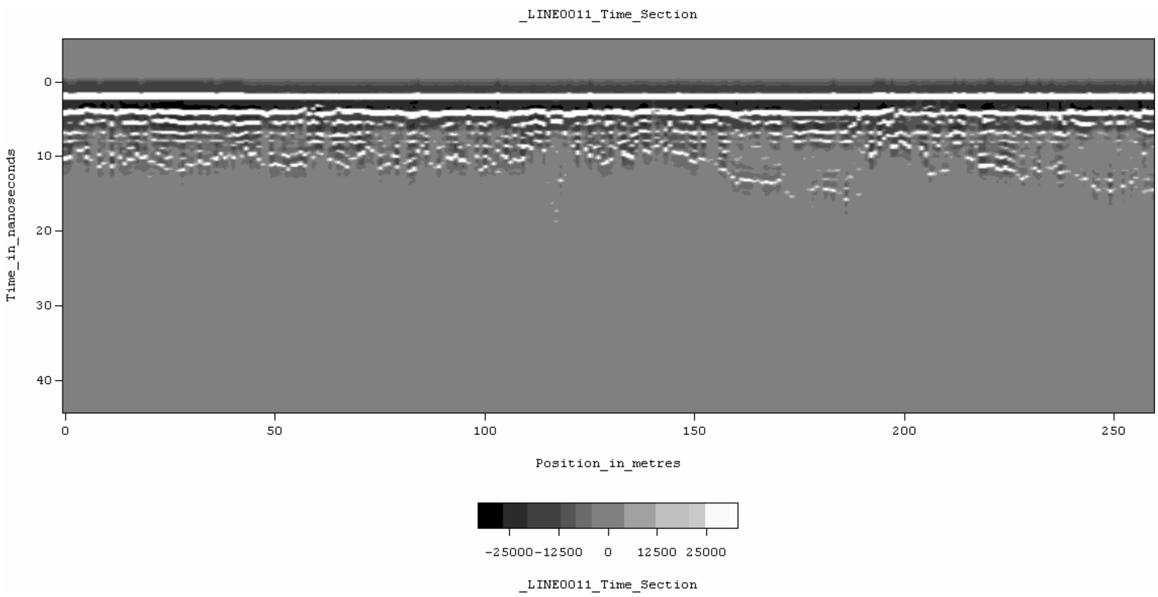


Figure 3: Radar profile after applying dewow

Since we are only interested in the depth of the snow layer, deeper layers are unwanted and thus the time (depth) window is shortened for presentation purposes (figure 4).

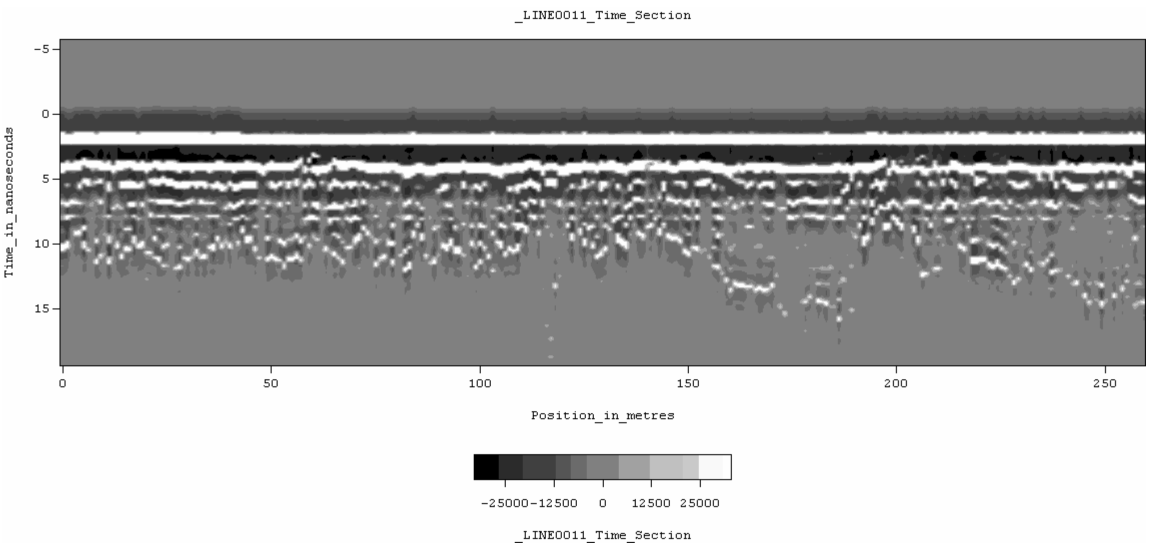


Figure 4: After changing the time window

The orientation on profile 11 is the opposite of profile 12. We therefore change the orientation of profile 11 to go from west to east using a REVERSE function available through the software (Figure 5).

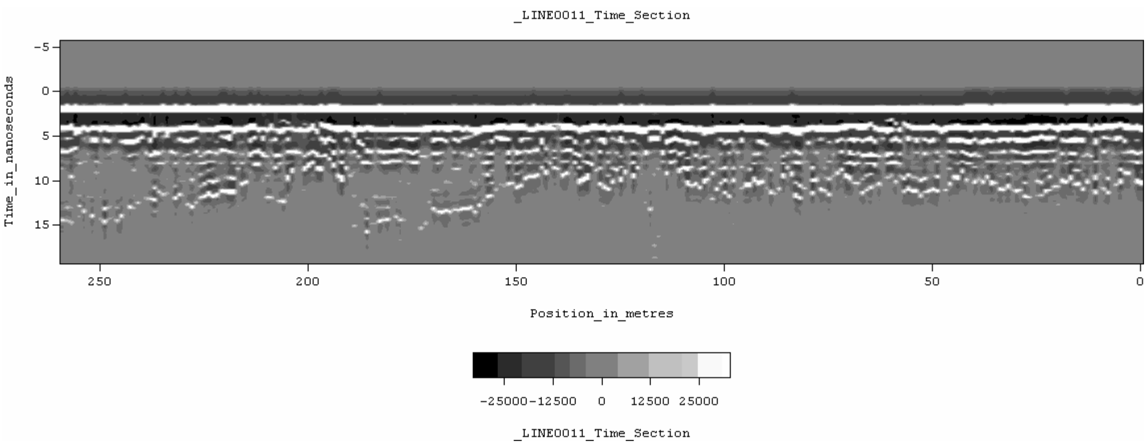


Figure 5: After changing the orientation

By analyzing at the spectrum of the response signal, it can be clearly seen that a great deal of noise exists in the data. The emitted frequency was 450MHz, so we would expect to receive the highest response around this frequency. Therefore, the apparent peak around 800MHz, can be considered general noise from the numerous instruments on the bandwagon.

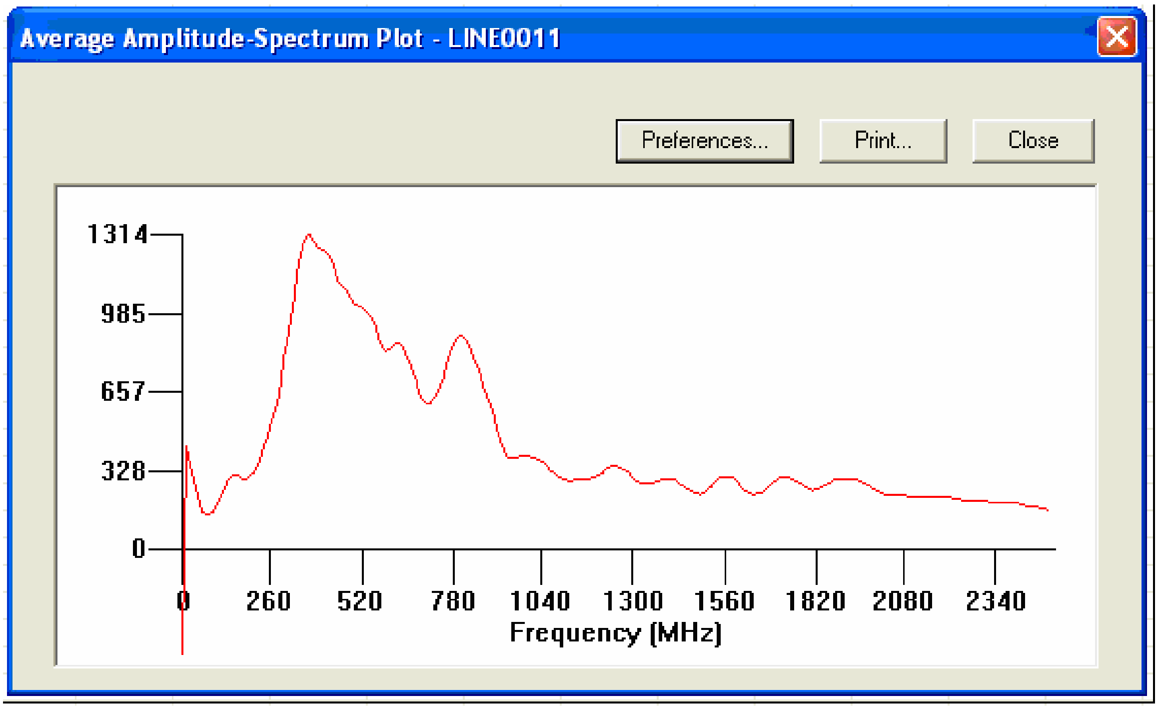


Figure 6: Spectrum of the response signal

To remove this unwanted noice, a bandpass filter is applied that limits (or removes) unwanted frequencies based upon a custom user setting By using bandpass, we filter out frequencies outside the following frequency band. We chose the band so start at 200MHz and increase linearly to 350MHz, for then to incline linearly from 550MHz to 700MHz.

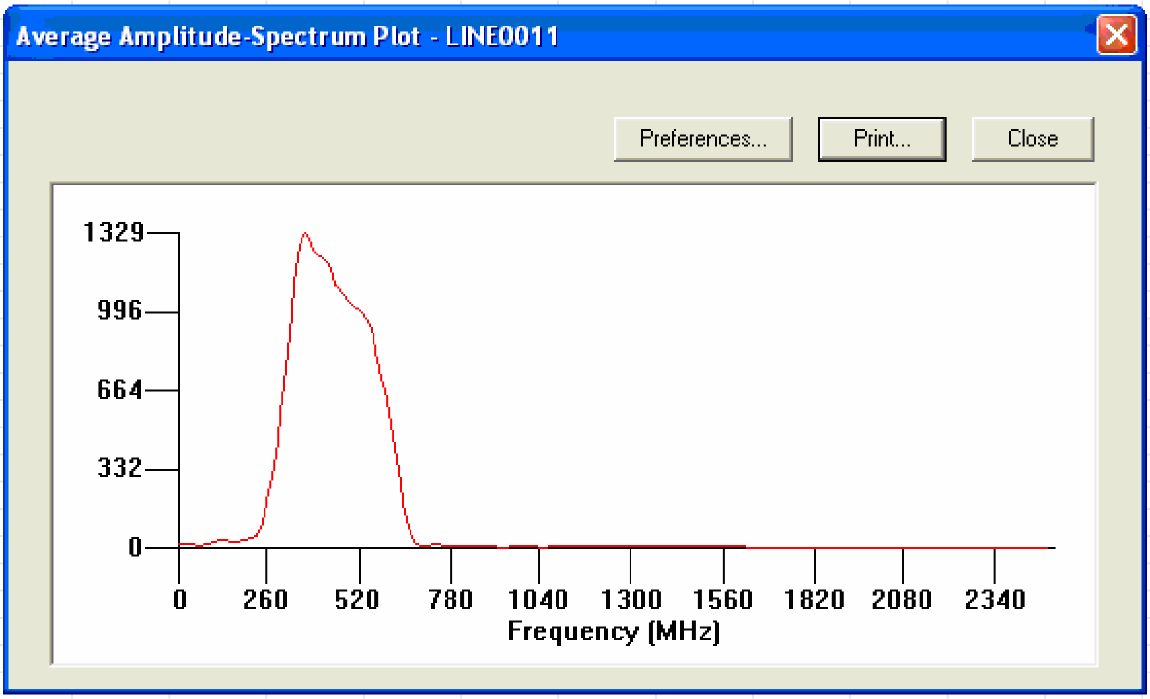


Figure 7: Spectrum of the response signal after bandpass filtering

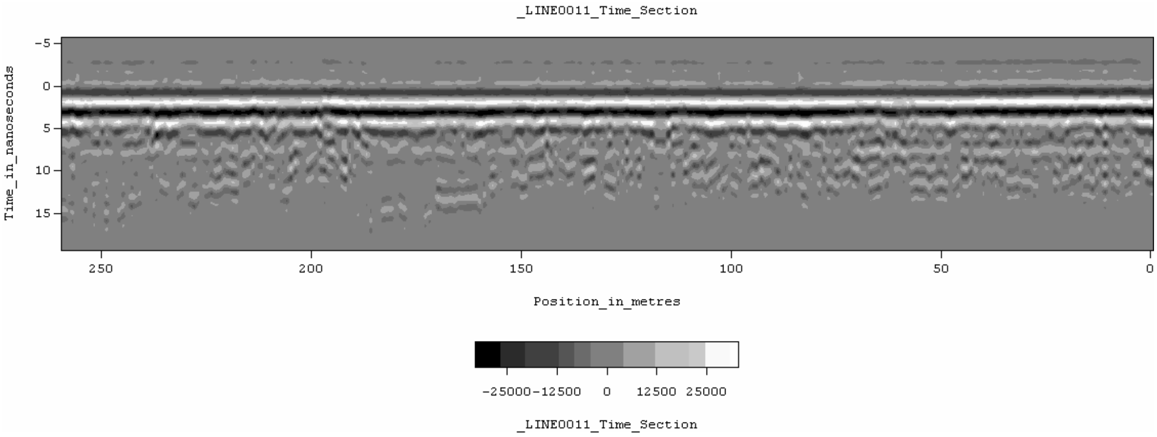


Figure 8: After applying the bandpass

Noise in the upper layer of the profile can be seen as black lines near the surface. This noise (reflections) are due to the frequencies that travel from the receiver through the air and near the surface to the receiver. By using the filter trace difference, we subtract adjacent traces to remove flat-lying reflectors. We applied the background subtraction filter in attempts to remove any more noise, but this did not give better results.

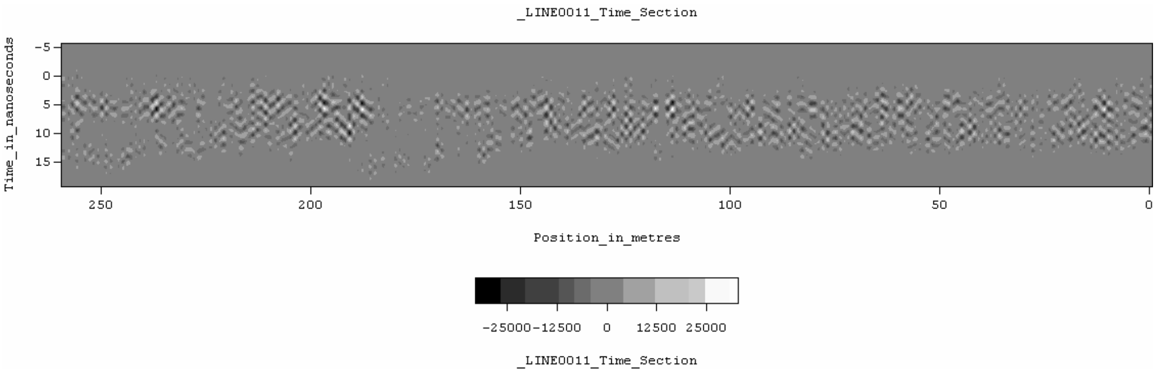


Figure 9: After applying trace difference

In order to read the snow depth out of the figure, time is converted to depth in meters by applying a constant velocity.

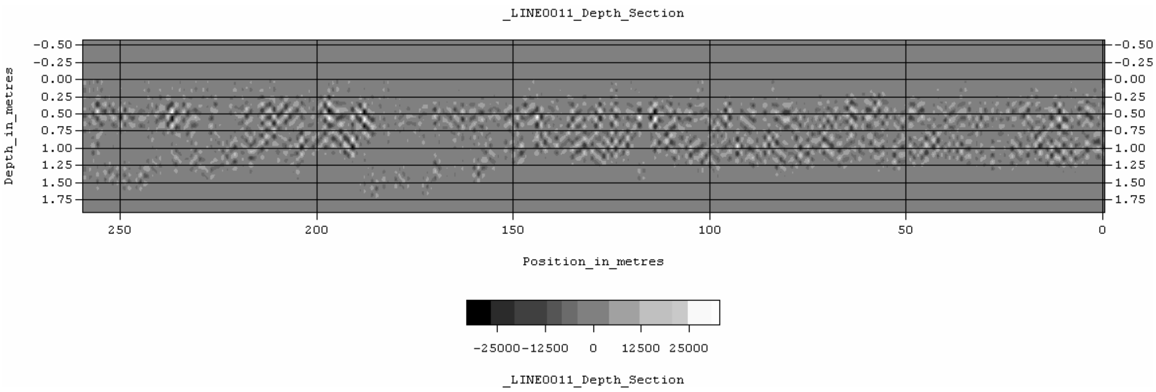


Figure 10: After applying axis

The depth of the snow layer can now be easily read in Figure 10. The snow depth ranges from 1.25 to 1.75 meters.

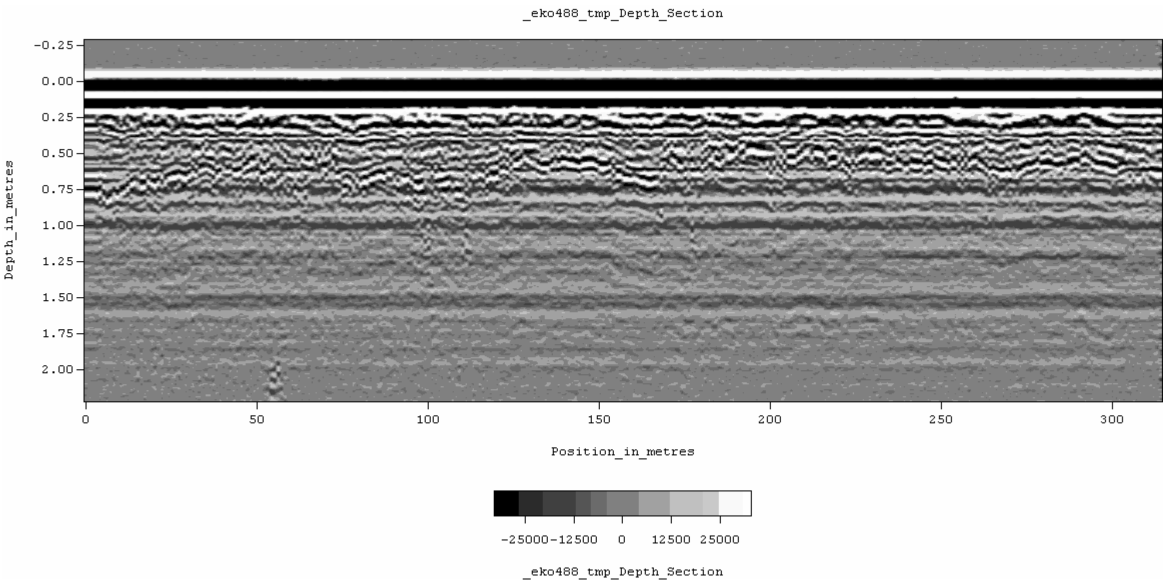


Figure 11: Rawdata from profile 12

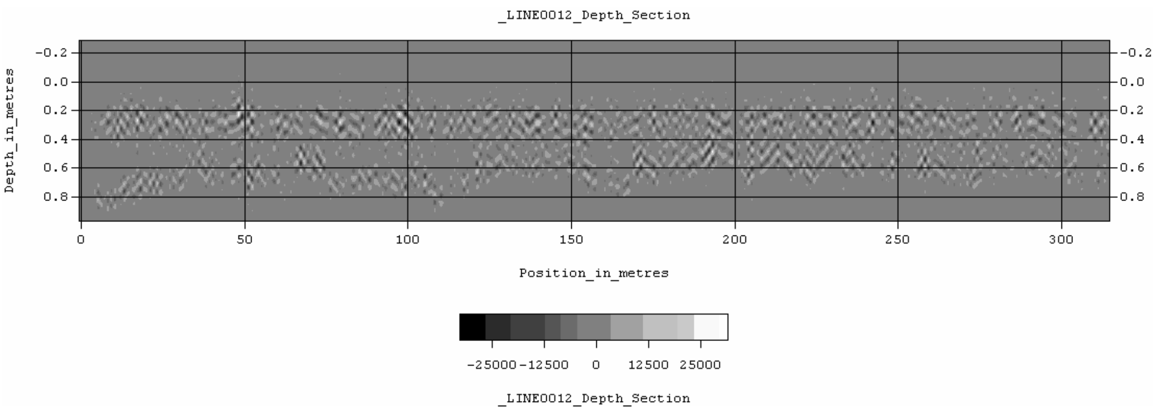


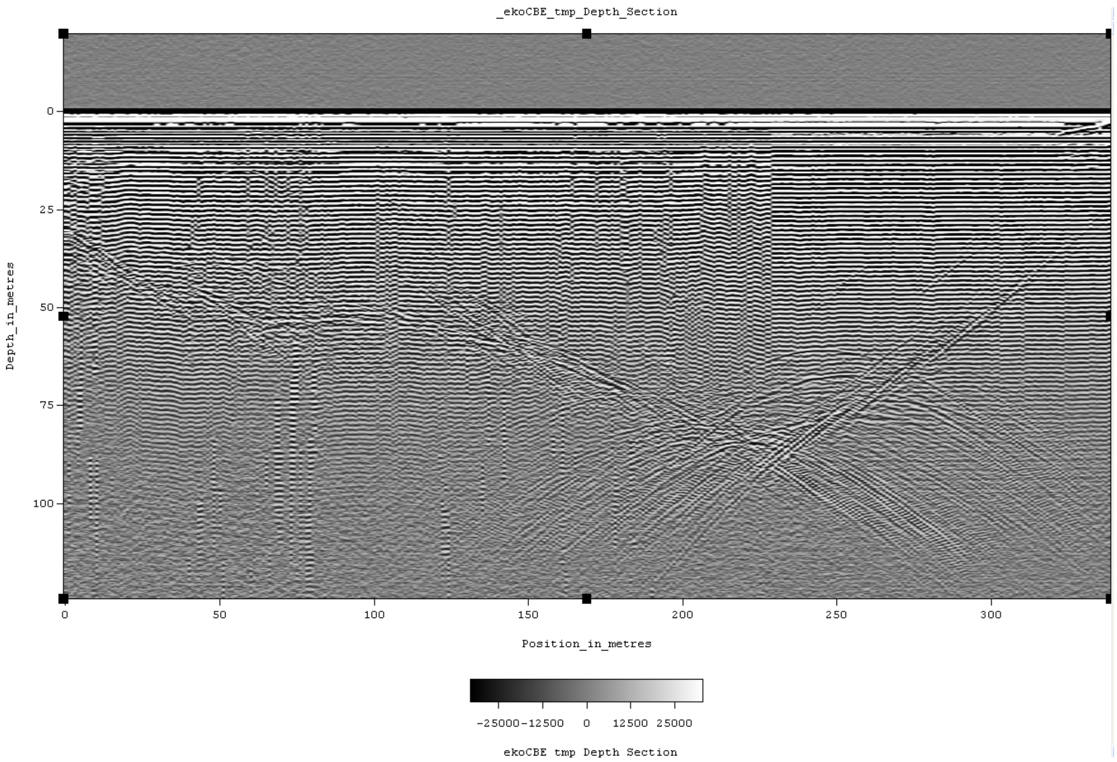
Figure 12: End result of profile 12

The snow depth ranges from 0,6 to 1 meter in Profile 12.

Ice Depth GPR Profiles

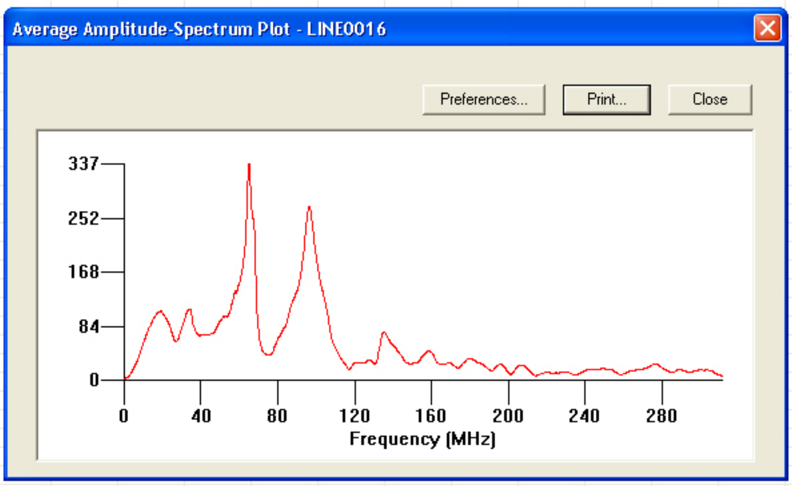
The data consists of two files which contains two profiles across the glacier: Profile15 and 16.

The unprocessed data display some clear reflections related to the ice-ground transition, but also contain much noise. But the results from profile 16 show also in the raw data some clear hyperbolas, but in the raw data of line 15 are no complete hyperbolas. For these reasons the processing of the data will start with line 16.

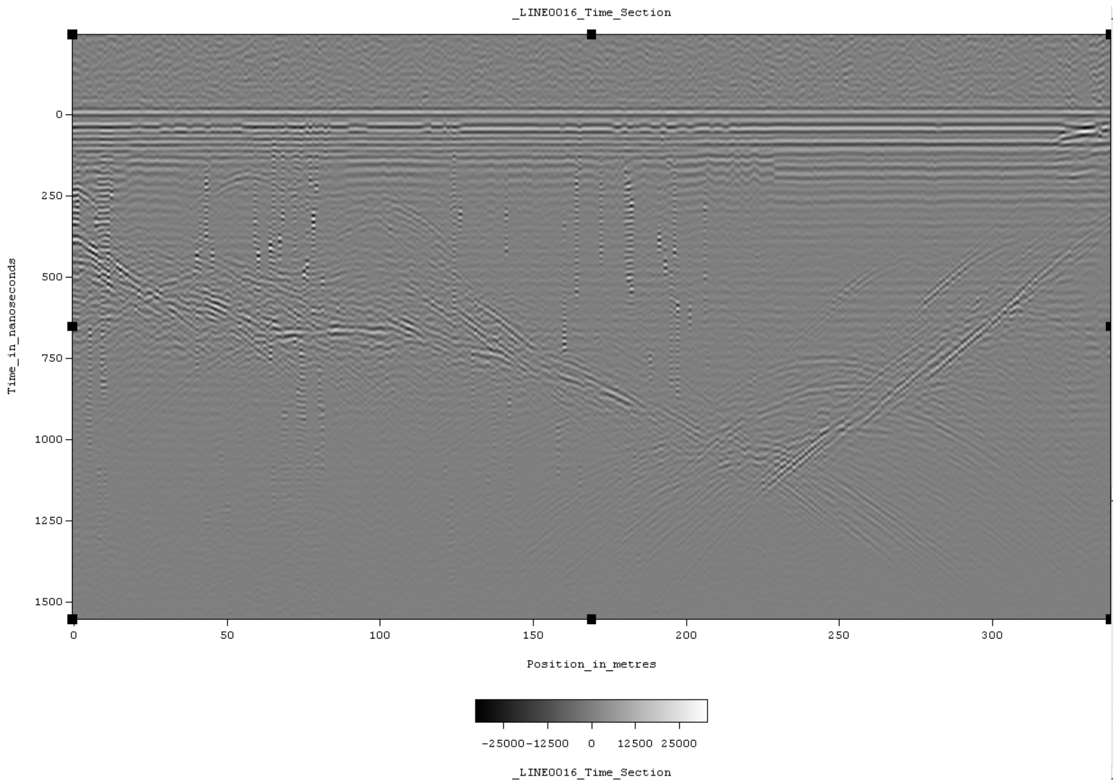


Therefore it is important to filter out the noise to retrieve the desired signals. The data was processed with the program WIN EKKO Pro. The first steps to gain a clear picture of the data are the steps Autogain and Dewow. The low frequencies will be removed from all traces and the low amplitudes on each trace will be amplified. Through this, low frequency noise is removed by DEWOW filtering and weaker signals are enhanced through the Autogaining.

In addition, it is important to analyze the spectrum of the response signal. The recorded data show high peaks in the response frequencies between 60 and 70 MHz.and at approximately 120 MHz. This is really unexpected because the emitted frequency was at 50 MHz and the peak has to be noise from the equipment or the vehicle.



Therefore, we chose to perform a band pass filter on the data with the dimensions 20, 30, 55 and 60 MHz. A linear filtering is performed between 20 and 30 MHz and also between 55 and 60 MHz. The upper border is chosen very close so that the high peak is filtered out. After these processed steps the data changes to a clearer picture and some lines and hyperbolas can be identified in a simple manner. Also the bow tie reflection at the bottom of the narrow valley is visible.



At the basis of this picture the calculation for the velocity of the signals in the ice were performed. For this the top point of one hyperbola and another point of the hyperbola are needed. With the help of these points and with the use of the Normal Moveout (NMO) equation it is possible to calculate the velocity.

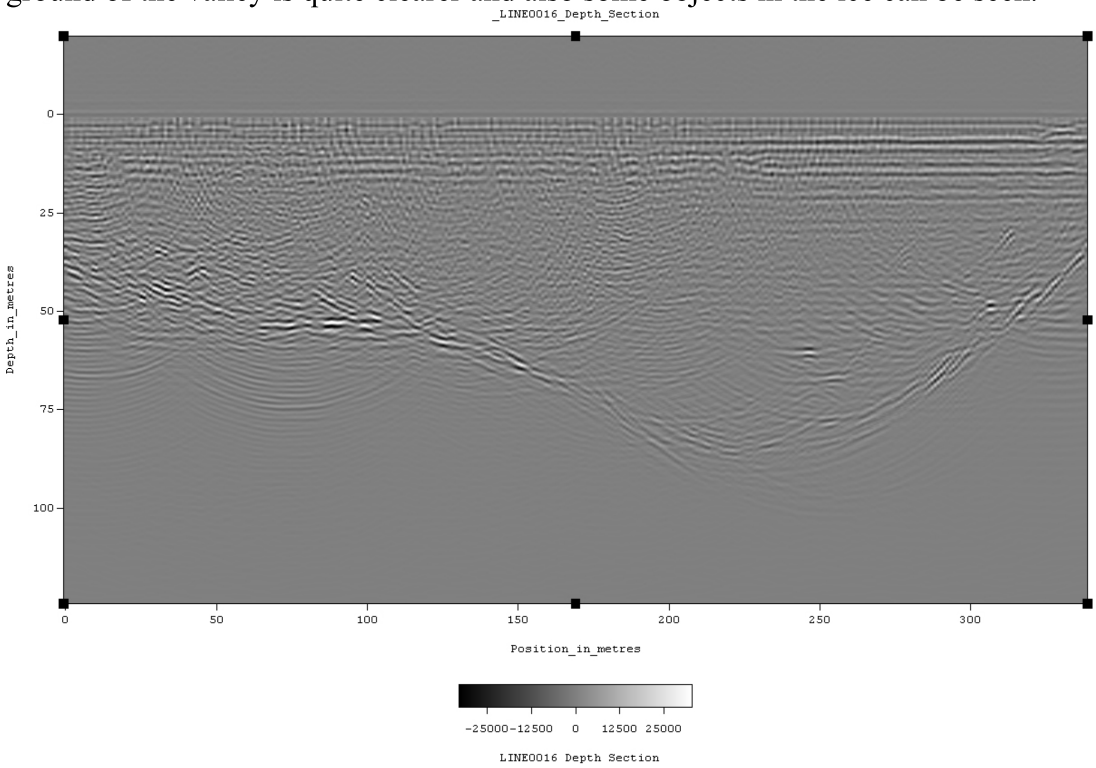
$$\Delta T = x^2 / (2V^2 t_0)$$

Rearranging of the terms in according to v results to:

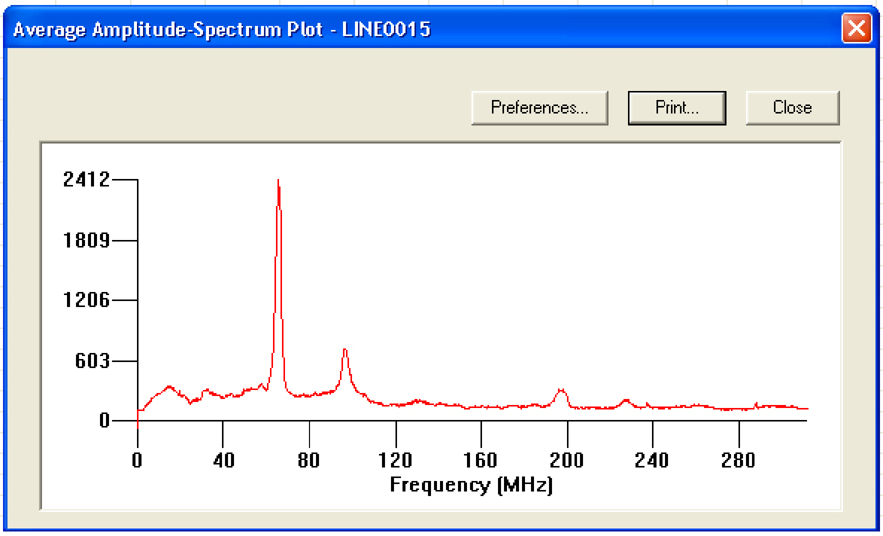
$$V = x / (2t_0 \Delta T)^{1/2}$$

The calculation were performed on the hyperbola with the points t_0=744, x_0=245 and t_1=798.4, x_1=222. Therefore, ΔT = 54.4 and the result for the velocity is
v = 0.1617 m/ns.
We doubled the result with a second hyperbola located much closer to the surface at the points t_0=188.8, x_0=57 and t_1=230.4, x_1=45. Therefore, ΔT = 41.6 and the result for the velocity is
v = 0.19 m/ns.
The results show a significant difference between the velocities. The first hyperbola was near to the ground of the ice and the second near to the top. Therefore is the relative influence of the snow also different. The speed of the signals is higher in the

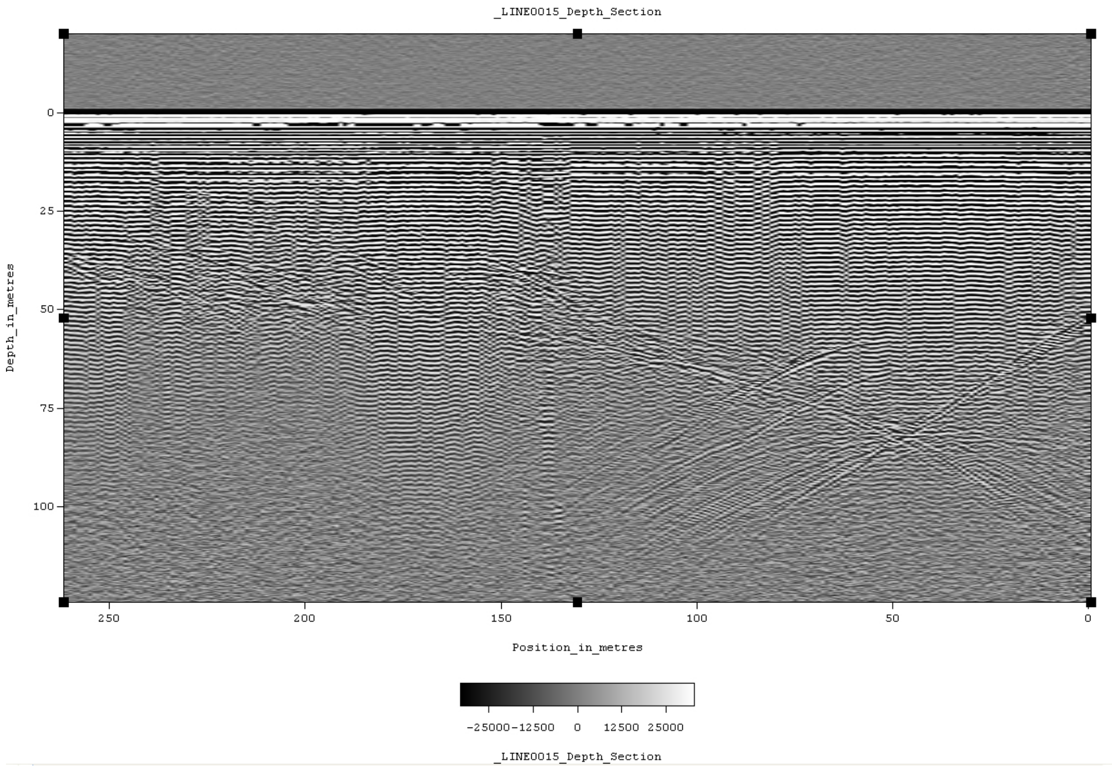
snow and therefore has to be the average velocity higher near to the top, because the snow is more dominating than in the deep section of the ice. The problem is now to find a “good” velocity for the migration of the data. But for a picture of the ground structure of the glacier it is more likely to use the number from the bottom of the glacier. After the performed migration with a velocity of 16 m/ns the picture of the ground of the valley is quite clearer and also some objects in the ice can be seen.



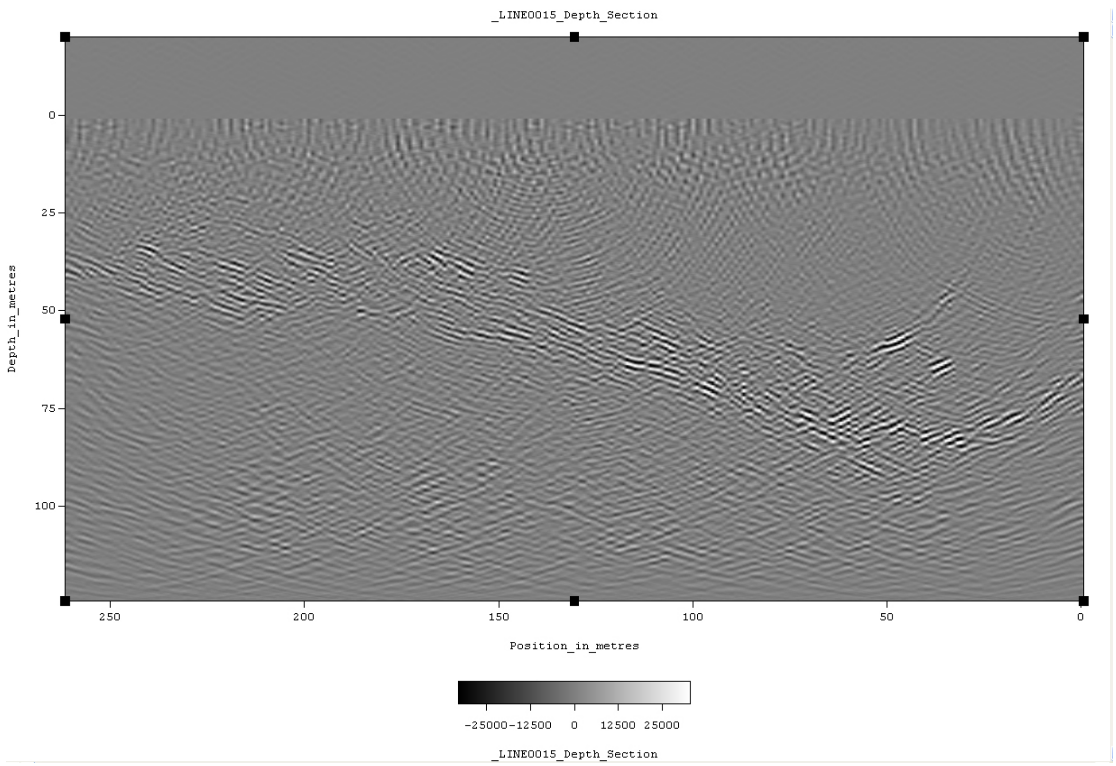
The same steps were performed for line 15 too. The band pass is chosen in the same manner even though only one peak is shown in the spectrum of the received signals.



The direction of the stored traces has to be changed because the record of the traces took in place in a reversed route. The raw data with reversed direction show this picture. No clear hyperbolas can be seen, but the bow tie at the bottom of the valley are very clear.

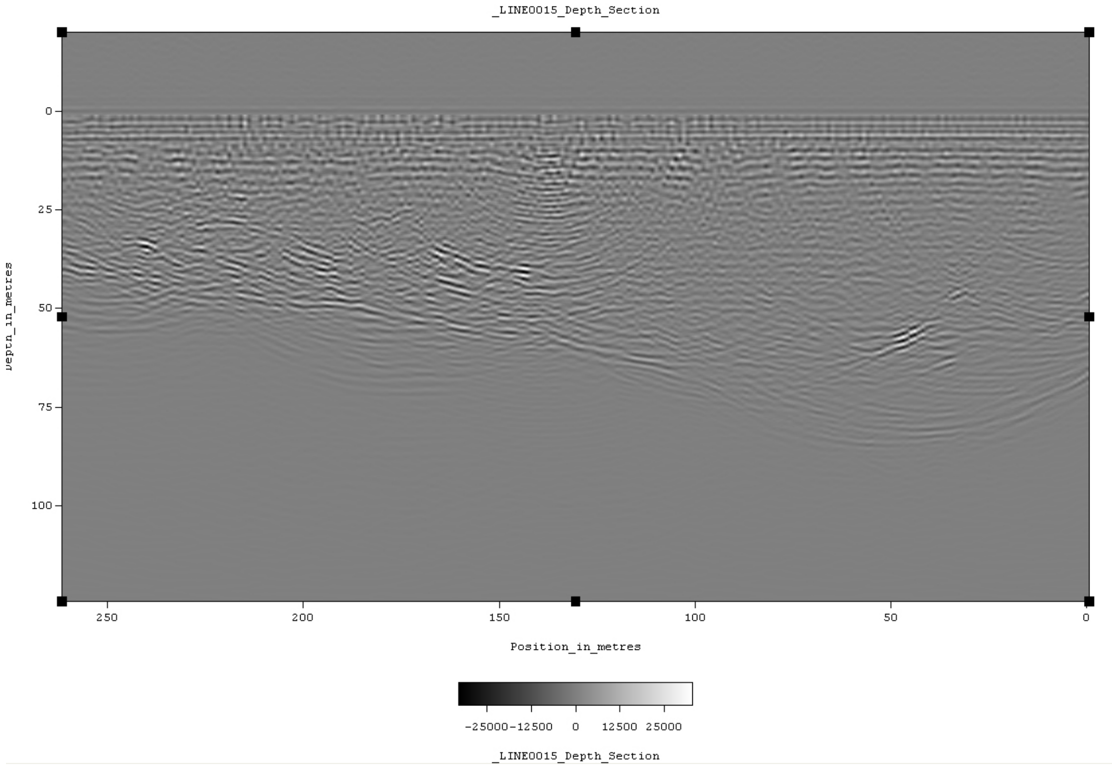


As usual, the steps Autogain, Dewow, and Bandpass with 20, 30, 55 and 60 MHz were performed. The migration is executed with the same velocity as for line 16. That means with 16 m/ns. As a new step the background subtraction were applied to obtain a better picture. This step reduces the background noise by subtracting the average signal picture from the original picture. The result of these performed steps is shown in the next figure.



The data representation is not as clear as for line 16, although the ground of the ice can be defined very easy. Also the appearance of some objects is without question.

An interesting outcome of this exercise is that the order of the processing steps is quite important. The changing of the direction is performed on the next picture in the last step, and as you can see the differences of the pictures are quite large.



7 Discussion

- **Recommendations for future work**

A lot of noise was present on the first radar profile. One of the reason was that we used a "walky talky" to communicate between the driver and the passenger in the snowmobile. After stopping this radio communication, much noise was removed.

It was no use trying a higher frequency than 50 MHz, because we barely retrieved a clear enough pictures with this frequency. An alternative could be to use higher energy. We used 400 V but we understand that Unis also had a 1000 V apparatus.

We used a step size at 1 m. Errors can be encounted on the spatial scale in places where the wheel skips over the surface.

Because of the extremely cold weather it was easy to destroy cables. It would be smart to bring with some extra in case of emergencies such that all data is not lost or destroyed.

We would recommend using a bandwagon to generate radar profile as it is easier to get a functioning computer in the warm cabin rather than outside. It is also more comfortable for the researcher. The drawback in this approach lies in the amount of noise that results from the numerous instruments on the vehicle.

8 Conclusion:

In conclusion, Ground Penetration Radar profiles were retrieved over Longyearbreen using two frequencies, 450 Mhz and 50 Mhz. The objectives to retrieve snow depth and ice depth were both completed successfully using these two frequencies. Moreover, although much noise was attained during the retrieval of the profiles, it was apparent that post-processing techniques can be very useful to extract only the desired information. Nonetheless, the quality of the data is ultimately dependent upon the raw data retrieved in the field.

Through radar profiling, we were able to determine an average, or range of snow depths, as well as the depth of the glacier. Snow depths upon longyearbreen ranged from 0.5 to 1.5 meters. The depth of the glacier varied from east to west with the shallowest ice located along the western edge of the glacier (approximately 50 meters). The deepest ice on longyearbreen is on the eastern edge which reaches down to approximately 80 meters. Although the specifics of the ice densities and permittivities were not known, it was possible to attain accurate velocities by performing a velocity analysis and subsequent Normal MoveOut (NMO) correction of various hyperbolas present in the profiles. Moreover, by perfoming the velocity analysis on two hyperboles located relatively close to the surface, and deeper in the ice, it is possible to see that the average wave velocity varies with depth, and is certainly not constant through the glacier ice medium.