Quality inspections of ice roads using GPR

Description of problem

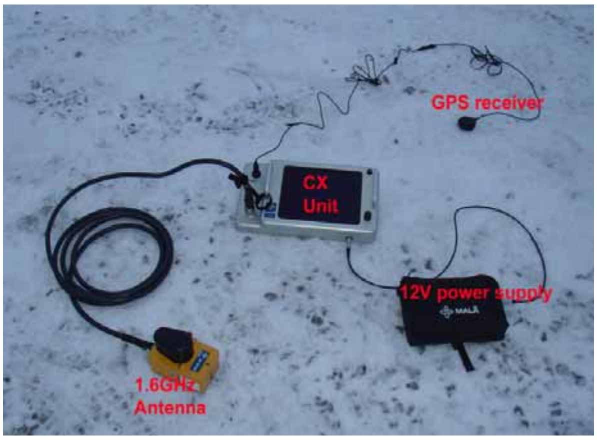
This application note will show an example of ice road thickness and quality investigations. The majority of the car and tyre industry in Europe uses companies in northern Sweden for winter tests, where test tracks are constructed on lakes during the winter season. In Sweden alone, the amount of ice roads (3 m wide) totals up to 5 000 km. The traditional way of controlling the ice thickness and quality is by manual drilling; a method that is quite slow (and thereby expensive) and will not give enough information to pick up local variations in the ice thickness. It is important to control the ice thickness throughout the whole season, which leads to a need of a quicker investigation method.

Ice thickness (cm)	Vehicle weights (kg)
20	2000
25	3000
30	4000
40	7000
50	12000
60	16000

During the winter this region in Northern Sweden gets 1 to 1.5 meter of snow, so it is desired by the car test industry to use as large machines as possible on the test tracks to move away the snow. Larger machines will move away more snow per hour than smaller ones, but the drawback is the weight.
The table below shows the ice thickness needed for different vehicle weights set by the Swedish road administration.

Equipment used

The measurements made in this application note are carried out with Malå GeoScience CX system, with the 1.6 GHz high frequency antenna. The positioning was governed by a GPS receiver directly connected to the CX main unit.



Investigation method

As the amount of measurements made when investigating the thickness of ice roads is large, it is easiest to attach the GPR system to a snowmobile or car.

The car test industry in Northern Sweden is today using 1.6 GHz antennas but depending on the ice thickness and needed resolution the 1.2 GHz or 2.3 GHz antennas are also suitable.

In the picture above the antenna is attached to a simple wagon, and then to the towing hook of the car. To the left an example is seen how the antenna can be attached to a snowmobile and where the CX main unit is kept in the front of the snowmobile. The GPS antennas are in these cases located in a plastic box on the snowmobile and on the roof of the car.

Critical elements

Most often a lake ice environment is quite suitable for the GPR technique, due to the clear signals received and good depth penetration, however there are some details to consider before and during measurements.

First of all, it is important to use the highest possible antenna frequency to be able to resolve thin layers and to get a proper result of the ice thickness. The 1.6 GHz antenna has a wavelength in ice of approximately 11 cm, capable to map ice thicknesses from 4-5 cm with a resolution better than +/- 1 cm.

When performing lake ice investigations water on top of the ice in combination with snow can cause a significant ringing of the radar signal. Water lenses in the ice also make it difficult to measure the total thickness of the ice. Most of the radar energy stops at the first water lens or even prevent the radar waves to travel further down and the total thickness of the ice can by that be missed. Using lower frequency antennas will of course reduce this effect but the drawback of a lower frequency antenna is always a lesser resolution. The operator must be aware that the velocity changes dramatically depending on the situation on the ice. Lenses with water and snow on top of the ice complicate the calculation for the ice thickness. In water the velocity is 0.03 m/ns, in ice around 0.175 m/ns and in snow from 0.150 to 0.260 m/ns depending on the moisture content.

As the aim of an ice thickness investigation is to map a certain layer over a large area, the GPR measurements must be logged with a GPS. If the goal is only to produce the ice map the system is trigged by time. However, if there is a need to stop and control the GPR results immediately (manual drilling) while measuring it can be quite convenient to use a measuring wheel as a trigger device to get a correct position when marking interesting areas.

As ice measurements are carried out during the winter period the temperature might be quite low. Therefore it is important to temperature stabilize the system during 20 minutes before starting the measurement. Using car or snowmobile also allows the use of an external 12V power supply.

When using skid plates on the shielded antennas during ice measurements when the temperature is around or higher than 0 degrees Celsius, one should be aware of the risk of getting water between the antenna and the plastic skid plate provided with the antenna. Even a thin water layer may strongly affect the depth penetration and decrease the energy of the radar wave. It is recommended to completely remove the skid plate when mounting the antenna on the used wagon.

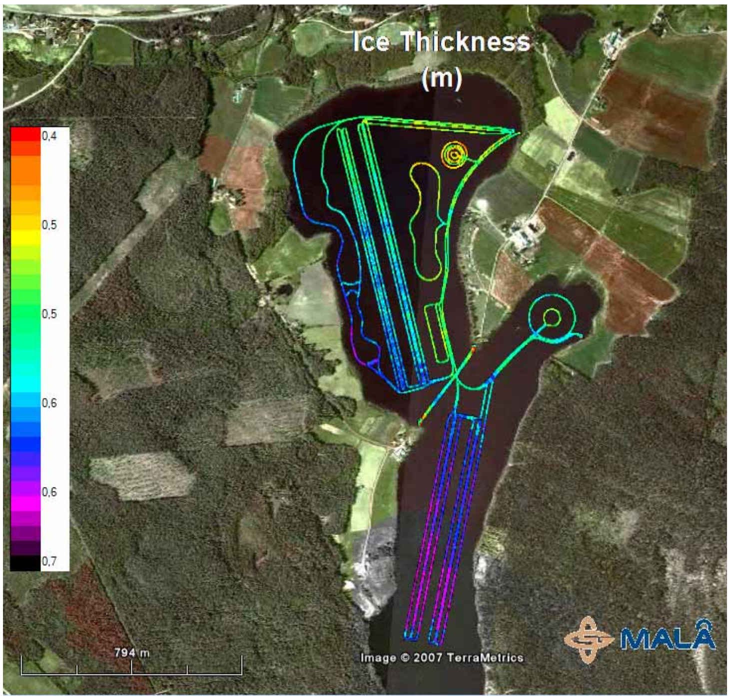
Results

For the lake ice thickness investigations the following standard settings are used; 390 samples, 37 000 MHz sampling frequency, 10.5 ns time window, 1 stack and 0.25 m point interval. When using cars the speed of investigation is kept approximately round 50-70 km/h. During the measurement a GPS is connected to the system to simultaneously log position data for each measured trace.

The result from these ice measurements is processed in the software package Reflex 2DQuick. The software reads the .cor file with the position data and combines it with the radar data. The ice layer is picked (most often this can be done in an automatic way in the processing software used, as the signal from the ice bottom is very clear).

The exported text file from Reflex includes the latitude and longitude position for every pick of the ice thickness. The result is then easily converted in to a readable Google Earth file by the GPS MAPPER software. The result is presented by different colours that represent the ice thickness at actual position.

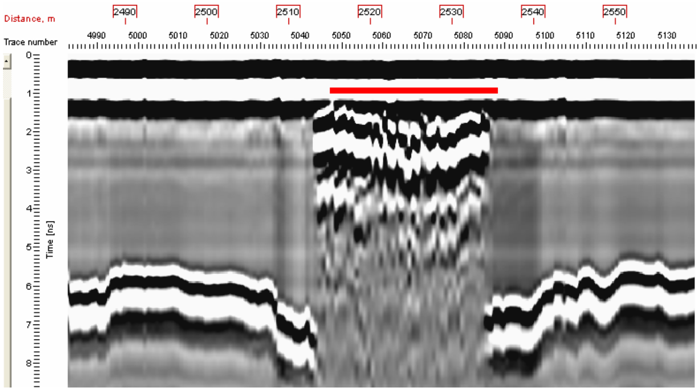
The picture at right is from one of the tracks investigated. As seen the parts with red and orange should be observed more carefully, as the lake ice are a bit thin.



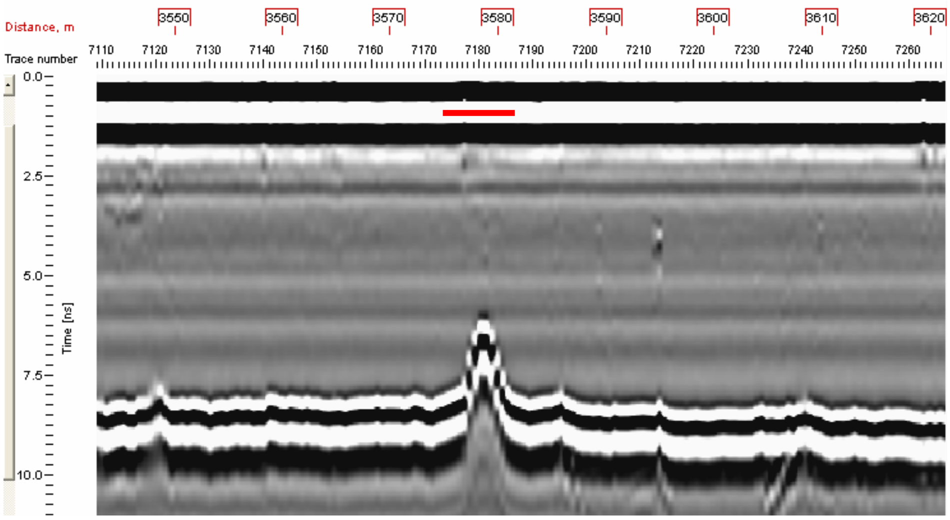
During the test season the lake ice tracks is scanned regularly with GPR. In this example the total measuring length was 25 km and takes around 2 hours from start of the measurements until the final map is produced and distributed. This is very cost- and time-saving compared with conventional drilling and measuring. The measurements and production of ice thickness maps is performed by one person only and no special expertise is needed.

Except for the ice thickness investigations the GPR can also detect and locate quality problems in the ice.

The radargram at right shows a part where the ice quality is relatively poor (the part marked red in the picture). The structure seen in the radargram is due to a water-filled layer quite close to the ice surface, and by that giving a weak area of the ice.



The next example clearly shows the radar ability to detect even small-scale changes in the ice. In this case a part of the ice, approximately 3 m along the measured profile (marked red), indicates an area with thinner ice.



Conclusions

As seen in the presented examples, GPR measurements in lake ice environments give quick, clear and straightforward results. Needed drilling will be reduced to calibration points on thick and thin parts along the investigated track. If the operator is aware of the difficulties that may occur with snow on top of the ice, multiple ice layers and changing velocities due to quality changes in the ice, the GPR measurements will give the wanted information in a much more cost-effective way compared with manual drilling.

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