Results of data processing of the experiment to determine the snow cover thickness using a ground-penetrating radar and a laser rangefinder

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Abstract. This article presents the results of processing the experimental data to determine the thickness of the snow cover in an area with a relatively flat terrain using a ground penetrating radar (GPR) and a laser rangefinder. It is shown that the GPR determines the thickness of the snow cover with an accuracy of 10-15 cm even in places under vegetation, however, in areas with sharp drops in the snow level, the error can be about 1 m due to the wide directional pattern of the antenna. The laser rangefinder is not suitable for measuring the thickness of the snow cover under vegetation, however, it detects local maxima and minima well, which can significantly supplement the GPR data in identifying critical zones. For surfaces that have a small area free from snow, it is possible to determine the thickness of the snow cover relative to this area with a laser rangefinder accuracy of ~ 1 cm, but it is necessary that this surface be free of vegetation. This criterion is met, for example, the roof surfaces of large structures, such as water parks. In the case of using only a GPR, sharp drops in snow level are averaged and inaccuracies in measurements at local sites are possible. When using both instruments, it is possible to determine the snow cover with an accuracy of ~ 10-15 cm on surfaces with vegetation and ~ 1 cm without vegetation, which is the basis for the joint use of instruments. This work is a continuation of a series of experiments started last year.

1. Introduction

Measuring the thickness of snow cover over large areas using a non-contact remote method is still considered an urgent task due to a number of factors, namely: preventing roof collapse in supermarkets and water parks, determining the degree of danger of spring floods, predicting crop yields, to prevent the danger of avalanches in mountainous areas, to establish the meteorological laws of the formation of climate in a certain area.

A method for measuring the thickness of snow on optical waves is known, for example [1], but it requires scanning the Earth's surface both in summer and winter in the presence of reference points; moreover, it is necessary that changes on the Earth's surface during the off-season period between scans was as small as possible.

The method for measuring the thickness of snow on optical and radio waves is also known [2], however, the characteristics and any experimental results on its implementation are not given, and the frequency ranges of sounding are indicated rather approximately. This method is attractive due to its efficiency, because in a short period of time of the order of ten minutes it is possible to obtain data on the thickness of snow over a sufficiently large area [3-6],

The dielectric permittivity of snow in the radio range can vary widely depending on its looseness and humidity: from ~ 1.2 in dry frosty weather for freshly fallen snow to ~ 5 in wet weather for heavy snow [7-10]. When the dielectric constant approaches to 1, the reflection coefficient at the air-snow boundary tends to zero, making it difficult to obtain accurate data using a GPR. Due to this, to clarify the position of the upper edge of the snow, along with a GPR operating in the radio range, which has a consistently high reflection coefficient from the Earth's surface and an unstable reflection coefficient from the snow surface, it is proposed to use a laser rangefinder, the light carrier of which has a reflection coefficient from snow of more than ~ 0.7 [11].

The aim of the work is to obtain operational data on the thickness of the snow cover using a GPR and a laser rangefinder on an area of about 100 x 100 m, to identify shortcomings in the technique used, as well as to formulate recommendations for the application of the technique for a specific application. The described experiment is a continuation of a series of experiments started last year [6].

2. Polygon and Equipment used in experiment

For the experiment, a polygon was chosen between the two outbuilding with a variable snow height from 0 to ~ 1000 mm and with a fairly flat surface of the terrain (Fig. 1). The measurement track passed over two rose hips that grow on this site. Through the center of the landfill there is a path to the building, on which there is no snow, and along its edges you can see large drifts resulting from clearing snow.

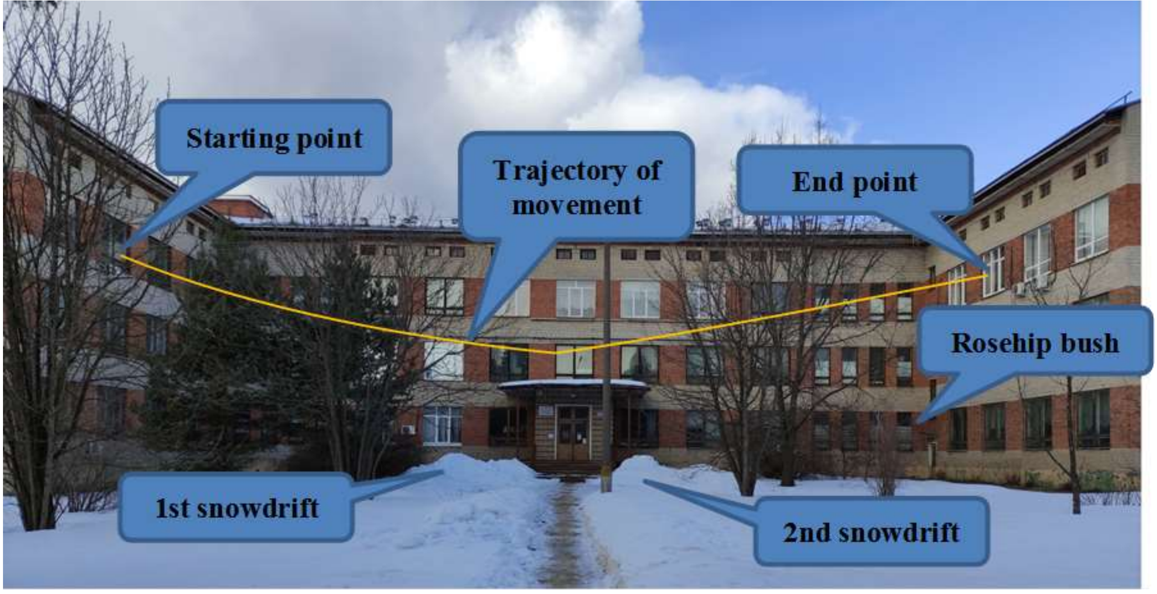

Figure 1. Appearance of the polygon (site for experiments).

The general view of the radio-optical meter is shown in Fig. 2. A working model of the GPR “Gerad 2200” was used as a radar sounding device [12]. The ultra-wideband GPR signal consists of one oscillation period (the distance between the minima is 0.5 ns), the pulse duration is about 1 ns. The working frequency band is in the region from 1.5 to 2.5 GHz, the spectrum width is Δf = 1 GHz. Power consumption less than 150mW, output power -45dBm / MHz.

The GPR consists of an electronics unit, an amplifier of the transmitted signal, transmitting and receiving antennas, a system for collecting and displaying radar data based on a tablet PC. In addition, the complex includes a laser rangefinder, consisting of a laser-optical unit, an electronics and data recording unit, and an autonomous power supply.

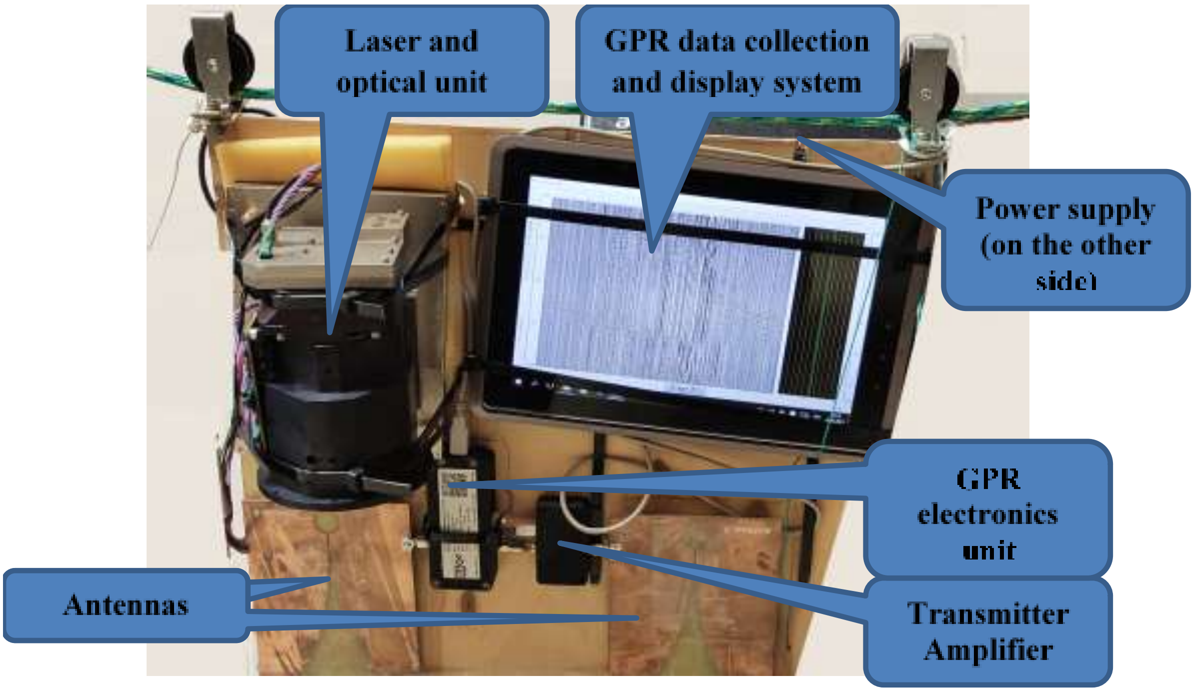

Figure 2. The general view of the radio-optical meter

The characteristics of the laser rangefinder are as follows: distance measurement accuracy ~ 1-10 mm, operating range up to ~ 100 m, wavelength range ~ 700 nm (red spectral region), light radiation power ~ 15 mW, power consumption ~ 15 W.

3. Description of experiments and analysis of the results

The measurements were made by moving the radio-optical meter along a cable stretched at the level of the third floor of the building. The trajectory of the device in height had a parabolic appearance, because the cable sagged under the influence of the weight of the device. The measurements were carried out from a height of ~ 7-10 m above the ground surface with a time interval of 0.5 seconds. Due to the complexity and laboriousness of the experiment at negative temperatures, measurements were carried out along one path only, but this was quite enough to determine the accuracy of measurements, identify the shortcomings of the method used, and develop some recommendations for its implementation. The measurement results are shown in Fig. 3.

Control measurements at the most characteristic points of the landfill, carried out with a measuring ruler, confirmed the reliability of the results obtained. Some discrepancies in the measurement results are caused by the characteristics of the instruments used. The spatial resolution of the device is determined by several factors: the speed of its movement along the route, swinging of the device from wind and mechanical loads, directional patterns, geometry features, and in our case it was ~ 0.1 m for laser measurements and ~ 1 m for GPR data. The accuracy of measuring the distance by the rangefinder for these conditions was ~ 10 mm, and the GPR - tens of centimetres, therefore the local peaks measured by the rangefinder are more accurate and have greater significance, while the GPR averaged the heights in areas with sharp differences in range. This is most clearly seen near the central path to the building, Fig. 1 and Fig. 3, where relatively high snowdrifts with sharp changes in height were interspersed with an almost zero level on the path itself.

The terrain relief measured by GPR (ground level) was more homogeneous. It can be seen that the discrepancy between the results on the thickness of the snow, obtained using the GPR and the rangefinder, is significant in areas with vegetation (under a rose hip bush). This is because the size of the laser spot ~ 0.5-1 cm did not allow to accurately measure the height of the snow with a range finder under the rose hips. The laser spot hit the bush branches, the reflection height at these points is chaotic and this can be seen both on the right and left of the central track sections of the route, Fig. 3, where the height of the laser radiation reflection changes randomly depending on the impact on the bushes branches rose hips. At the same time, the height of snow in these areas, measured by GPR, coincides with the readings of the measuring ruler with an accuracy of ~ 15 cm.

The discrepancy between the thickness of the snow cover along the route in local places, measured by the GPR, with the rangefinder data can be about 0.5 m, and this is the main argument in favor of supplementing the GPR data with the data of the rangefinder measurements. Despite the indicated discrepancies, the characteristic features of the snow cover on the measurement route were identified. For example, it was determined that the snow height is significantly higher on the north side of the building (left side of Fig. 3) than on the south side (right side of Fig. 3), where the snow thickness tends to zero. This, naturally, correlates with the time of solar irradiation of the snow cover in both areas of the test site.

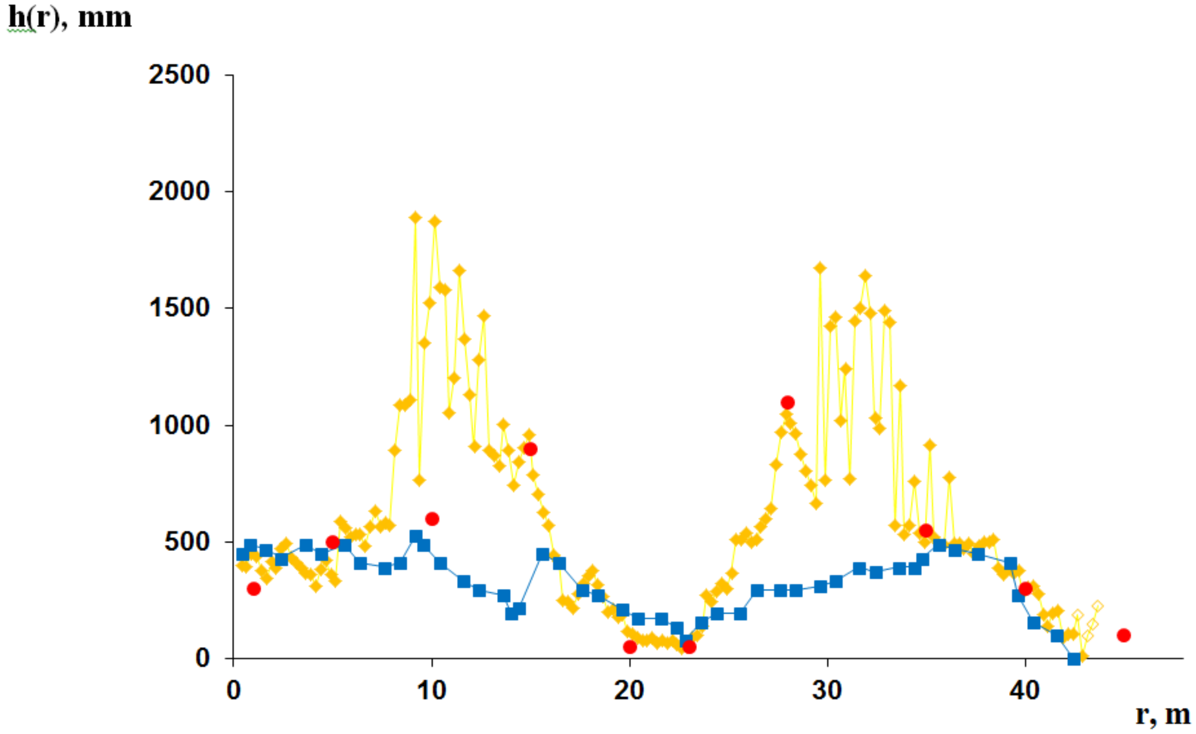

Figure 3. Change in the thickness of the snow cover along the measurement route: blue curve according to GPR data, yellow - laser rangefinder, red points - control measurements with a measuring ruler.

4. Conclusions

Thus, the following conclusions can be drawn.

1. GPR determines the height of the snow cover with an accuracy of ~ 10-15 cm at the selected polygon, even in areas with vegetation. The only exceptions are small areas with high snowfalls, where peaks and valleys are smoothed (averaged) due to the wide antenna pattern.

2. The laser rangefinder in the used version with a narrow radiation pattern is completely unsuitable for measuring the height of the snow cover under the branches of vegetation, but it accurately determines the local maxima and minima, which can significantly supplement the GPR data in identifying the critical zones of the surveyed landfill.
3. For flat areas of surfaces with a small flat area free of snow, determining the ground level, it is possible to determine the snow level with the accuracy of a laser rangefinder. It is sufficient that the surveyed area is free of vegetation. This criterion is met, for example, on the roof surfaces of large structures, such as water parks. When using only one GPR, sharp snow peaks are averaged and inaccuracies in forecasting the snow height in local areas are possible.
4. When using both devices, it is possible to determine the snow cover with an accuracy of a laser rangefinder of ~ 1 cm in areas without vegetation and with an accuracy of 10-15 cm in areas with vegetation, which is the basis for their joint practical application.

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