Preliminary Results of an Experiment to Determine the Thickness of Snow Cover Using Ground Penetrating Radar and a Laser Rangefinder

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Abstract. The article discusses the combination of a ground penetrating radar (GPR) with a laser rangefinder to determine the snow cover thickness, an experiment is described in accordance with the proposed methodology and a comparative analysis of the data obtained is carried out. The purpose of the proposed development of the combined method is to improve the accuracy of snow cover depth determination. Many tasks require high spatial resolution both in the horizontal coordinate and in the depth of the snow cover, since local excess of its critical level can lead to irreversible consequences. Such a situation can arise, for example, when avalanches come down in mountainous areas or when roofs of a large area collapse when snow accumulates on them. The accuracy of the snow depth determination obtained in the experiment is ~ 10 cm and the resolution along the horizontal coordinate is ~ 5 cm. The predicted distance based on the equipment used is about 500 meters. The proposed method can be used for determining the amount of snow on roofs of buildings and structures, as well as in predicting the descent of avalanches, and in search for hidden objects under the snow in emergency situations.

1. Introduction
Remote determination of snow cover thickness is still considered an actual task for solving a number of important economic tasks, namely: preventing roof collapses in hypermarkets and water parks, forecasting crop yields, determining the degree of danger of spring floods and floods, assessing the risk of avalanches in mountainous areas, establishing meteorological laws of climate formation in a certain area, etc.

The dielectric permittivity of snow can vary widely depending on its friability and humidity: from 1.2 in dry frosty weather for freshly fallen snow to 5 in wet weather for heavy snow [1-3]. The reflection coefficient at the interface between air and snow tends to zero when the dielectric constant of snow approaches 1. Because of this, to clarify the position of the upper edge of the snow, it is proposed to use a laser rangefinder, the optical signal of which has a reflection coefficient from the snow of more than ~0.7 [4] together with a GPR working in the radio range, which has a high reflection coefficient from the Ground surface. The use of radar methods for measuring ice thickness has been developed and applied for quite a long time [5-9]. The method of measuring snow thickness on optical and radio waves is also known and described in [9], but the characteristics and any experimental results for its implementation are not given, and the frequency ranges of sounding are specified rather conditionally.
The aim of this work is to obtain preliminary experimental results on the accuracy of determining the thickness of snow cover using a GPR and a laser rangefinder. A polygon with a variable snow height from 100 to 500 mm was selected for the experiment (Fig.1).

2. Equipment used in comparative tests
A working model of the GPR “Gerad 2200” was used as a radar sounding device (Fig.2). The ultra-wide-band GPR signal consists of a single oscillation period (the distance between the minima is 0.5 NS), the pulse duration is about 1 NS. The operating frequency band is in the region from 1.5 to 2.5 GHz, the spectrum width $\Delta f = 1$GHz. Power consumption less than 150 mW, output power -45 dBm per 1 MHz. The results of tests of this GPR are given in the work [10].

The appearance of the laser rangefinder is shown in Fig.3. It has the following characteristics: accuracy of measuring distances 1-10 mm, range up to 500 m, wavelength range – visible or infrared (IR), light output in the visible range ~ 10 mW, in the eye-safe IR range of 1550 nm ~ 500 mW, power consumption ~ 15 W.

Figure 1. Appearance of the test site.
Figure 2. Appearance of the GPR "Gerad-2200" (a), the shape of its radiated signal (b) and spectrum (c).

Figure 3. Appearance of the laser rangefinder
3. Description of experiments and analysis of the results
Measurements were made from a height of 1000 mm above the ground surface. The radarogram obtained after processing the geo-radar data is shown in Fig.4. Control measurements made with a ruler at the most characteristic points of the polygon confirmed the reliability of the results obtained. The green color in the drawing shows the terrain (Ground level), and the blue color shows the snow level according to GPR data. Data obtained with a laser range finder, shown on the radiogram in yellow circles. Discrepancies in measurement results of laser range finder and GPR are caused by the features of the devices used: the spatial resolution of the laser rangefinder is 1-3 cm, and the GPR is tens of centimetres. Thus the local peaks measured by the rangefinder are more accurate and have a greater value, while the GPR averaged the height values in this area. This is most clearly seen in the right half of Fig. 4, where relatively high areas of snow with sharp changes in height were interspersed with dips. It can be seen that the discrepancy between the results on the thickness of snow obtained using only the GPR and the GPR together with the rangefinder can be up to ~10 cm and this, as already mentioned, is mainly due to the mismatch of the width of the directional diagram of the GPR and rangefinder antennas. At the same time, the reflection of radio waves from the Earth's surface gives a fairly clear reference line of the terrain of the earth's surface, and a laser rangefinder with a good spatial resolution accurately determines the height of the snow cover. Further improvement of measurement accuracy can be obtained by optimizing the parameters of the equipment for specific tasks, as well as improving the methods of processing the received data.

![Figure 4](image)

**Figure 4.** A comparison of the results of the experiments. The green and blue lines represent the ground level and the upper level of snow cover, respectively, obtained from GPR data. Yellow dots display the results of snow level measurements with a laser rangefinder.

4. Conclusions
Thus, as a result of this work, data were obtained to determine the depth of the snow cover at a site of ~10 meters using a ground penetrating radar and a laser rangefinder. This method provides more accurate data for determining the height of snow cover than using only one GPR. The accuracy of the determination is ~10 cm and can be improved up to 3-5 cm by improving the equipment and methods of processing the received data. Particularly promising, in our opinion, is the use of the described
method when placing equipment on Board aircraft, which allows you to survey large areas in a fairly short period of time.

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