Geophysical studies of the structure and properties of snow cover at Elbrus region

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Abstract. The paper presents an approach to the study of the structure and properties of snow cover, as well as its quantitative reserves and heterogeneities. Conclusions are drawn and recommendations are given on the possibility of using the geo-radar method in the study of ski slopes.

1 Introduction

The use of non-destructive geophysical methods for studying snow cover has become widespread in glaciology, as they have a number of advantages over traditional pitting methods. In particular, they make it possible to cover a much larger area in comparable periods of time, as well as to explore dangerous and hard-to-reach areas where the laying of a pit is not possible, which is especially important for snow avalanche observations.

As part of the winter expedition of the Department of Cryolithology and Glaciology in the Elbrus region, a georadar study of the snow cover was carried out. The goal was to obtain information about the thickness and stratigraphy of the snow cover in natural conditions and in the conditions of the Elbrus ski resort, where for safety reasons it is impossible to drill. The data obtained were used to determine the snow reserves on the route of the Elbrus ski resort and the costs of the resort for artificial snowmaking in the conditions of a little snowy winter of 2022-23. An attempt was also made to determine the possibilities of using georadar to identify stratigraphic horizons in the thickness of natural snow cover.

In the work, a multifunctional control and indication device was used - a measuring device for the thickness of ice and snow “Picor –Led” (Fig. 1). The principle of its operation is based on the method of radar: radiation of electromagnetic pulses into the probed medium and registration of reflected signals from inhomogeneities and objects in the thickness of the medium. Table 1 shows the main performance characteristics of the device.

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Fig. 1. Multifunctional control and indication device - ice and snow thickness gauge "Picor –Ice" (Operating manual, 2022) ([1]).

Table 1. Operating characteristics of the device "Picor –led" (Operating manual, 2022).

Characteristic	Meaning
Measured snow thickness	5 - 300 cm
Operating frequency	1600 MHz
Accuracy of measurements	1 - 2 cm
Resolution (Vertical)	3 cm
Number of samples per second	50
Operating temperature range	-40…+50 ℃
Field of view (diameter of the examination area at a height of separation of the antenna from the surface of 50 cm)	50 cm

2 Materials and methods

Garabashi -Mir ski slope, which is composed of compacted snow of natural origin. 1 profile - on the section of the ski slope Krugozor - Azau, which is composed of compacted artificial snow. 9 profiles were laid in the roll-out zone from the tracks of the Elbrus ski resort. Another 3 profiles were made on the moraine of the Garabashi glacier, in the area of snow pit No. 1, and 9 profiles in the area of pit No. 2 in the tongue of the Maly Azau glacier. A large number of profiles on the outcrop and near pit No. 2 is due to attempts to find the optimal ratio of measurement parameters to obtain the best result when measuring the thickness and stratigraphy of the snow cover [2, 3].

To determine the thickness of the snow cover within the route, three sections were selected: Garabashi -Mir (3850 - 3500 m) with natural snow, Krugozor- Azau (3000 - 2350 m) with artificial snow and the run-out zone at Azau station (2350 m) with artificial snow. In the rollout zone, profiling was carried out on foot (Fig. 2.), in other areas - using mountain skis to move along the slope from top to bottom. The measurement parameters were set taking into account that the thickness of the snow cover on the track does not exceed 1.4 m (gain=3, size = 0, spike = 1). The layer material is snow.

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Fig. 2. Left - georadar profiling of the left part of the rollout in the area of Azau station (2350 m). Top-down movement. Photo by Zhukova E.D. On the right - georadar profiling in the area of pit No. 2 (Small Azau) using ski equipment to move along the snow cover. Photo Lisachenko E.S.

3 Results and discussion

On the section Garabashi (3850 m) - Mir (3500) several measurements were carried out to determine the optimal number of defined boundaries in the snow mass (Fig. 3.). As a result, it was found that within the path, the georadar detects only two clear interfaces: air-snow and snow-underlying rock, without capturing heterogeneities inside the snow cover. Probably, within the limits of the ski slope, all snow is subjected to compaction when exposed to snow groomers , as a result of which it has a profile that is uniform in density.

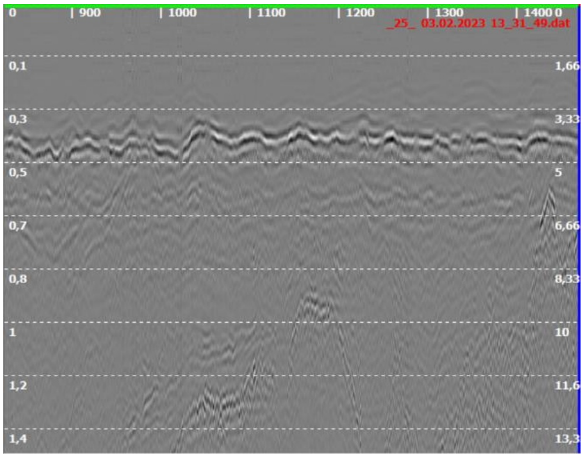

Fig. 3. An example of a fragment of a radargram from the Garabashi -Mir section. The scale on the right is the vertical distance in meters, on the left is in nanoseconds, and on the top is the number of measurements. At a depth of 0.3-0.4 m from the antenna, a wavy air-snow boundary is clearly distinguished. Below it are two weaker boundaries, probably its multiple or incomplete reflections. And only below, at depths from 0.9 to 1.3 m, a second relatively clear, but discontinuous, boundary is observed, which marks the separation of snow and underlying rocks.

Thus, only 2 boundaries were identified on the profiles within the route. Initially, the selection was carried out automatically, after which it was corrected manually (sharp outliers were cut off) (Fig. 4).

Since there was no single end-to-end profiling for the Garabashi -Mir section, three profiles were selected (top, middle and bottom of the section), on which the boundaries were most clearly displayed (Fig. 5).

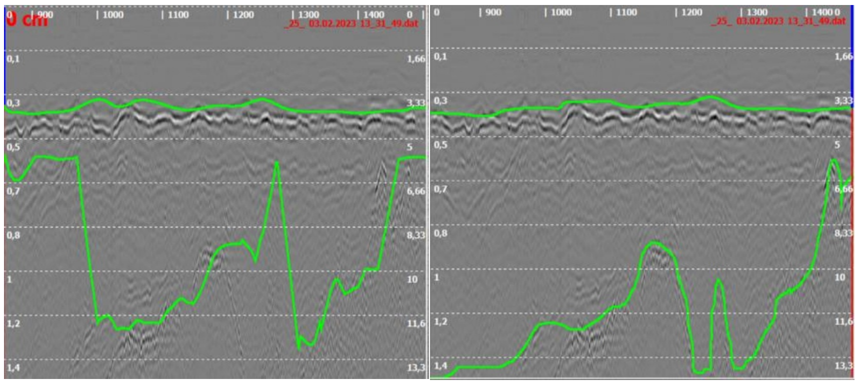

Fig. 4. A fragment of a radargram from the Garabashi - World section with highlighted boundaries: on the left - in automatic mode, on the right - manually corrected.

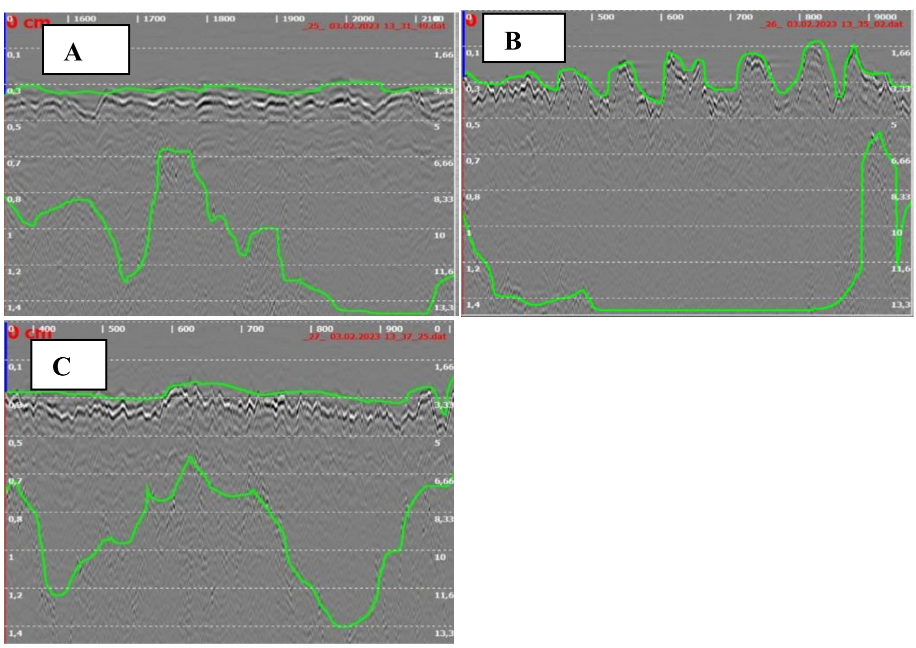

Fig. 5. Fragments of radargrams from the Garabashi-Mir section. *A* is the top. *B* is middle (large slope of the surface). The wavy upper boundary is the result of tacking due to the steepness of the section and the impossibility of moving straight ahead without maneuvering. The flat lower boundary is the result of the absence of the lower snow-soil boundary on the radargram. *C* is bottom (relatively flat roll-out).

A cursory analysis of the received radargrams shows that on relatively flattened areas where smooth forward movement on skis is possible, the upper boundary (air - snow) remains smooth throughout the entire profile. On steep sections (Fig. 5.B.), due to the impossibility of translational movement, the upper boundary acquires a wavy shape - reflecting the movement of the operator "tacks" on alpine skis. In this case, another difficulty arises: in some places on There is no lower boundary (snow-soil) in the radargram. This can be explained by several reasons. Firstly, the thickness of the snow cover on the site can indeed exceed the sounding limits (1.4 m). However, this is unlikely for steep sections of the track, where the snow is especially intensively carried away by resort visitors. Another reason, the most probable one, is the operator's too high speed on a steep slope, exceeding the allowable limit for the PicoR -Led device (40 km/h). Those the wave reflected from the boundary does not have time to reach the antenna, as a result of which the lower boundary is not displayed on the radargram.

The section Krugozor - Azau was traversed by a single profile with two boundaries identified (Fig. 6). It is characterized by the same problem of "waviness" of the upper and lower boundaries, associated with the movement of the operator "tacks" on steep slopes. However, unlike the steep slopes in the Garabashi -Mir section, on this radargram the lower boundary, although wavy, is always quite clearly displayed.

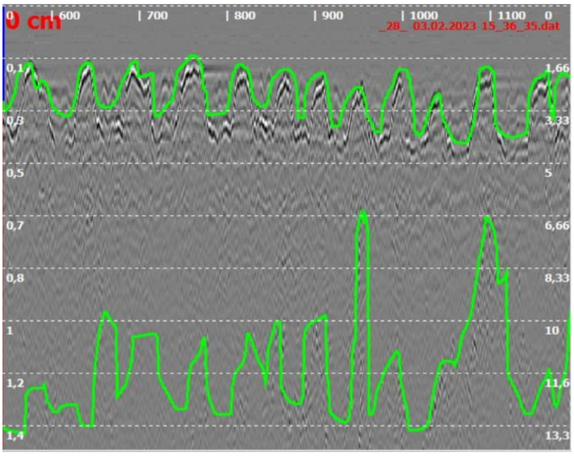

Fig. 6. A fragment of a radargram from the Krugozor-Azau section. In general, no differences were found from the radargrams from the Garabashi -Mir section, i.e. the internal structure of the snow cover of trails made up of natural and artificial snow cannot be distinguished using GPR.

In the run-out area at the Azau station, profiling was carried out without the use of ski equipment. Of the 9 profiles for the analysis of the thickness of the snow cover, three profiles were selected with the clearest air-snow and snow-ground boundaries (7).

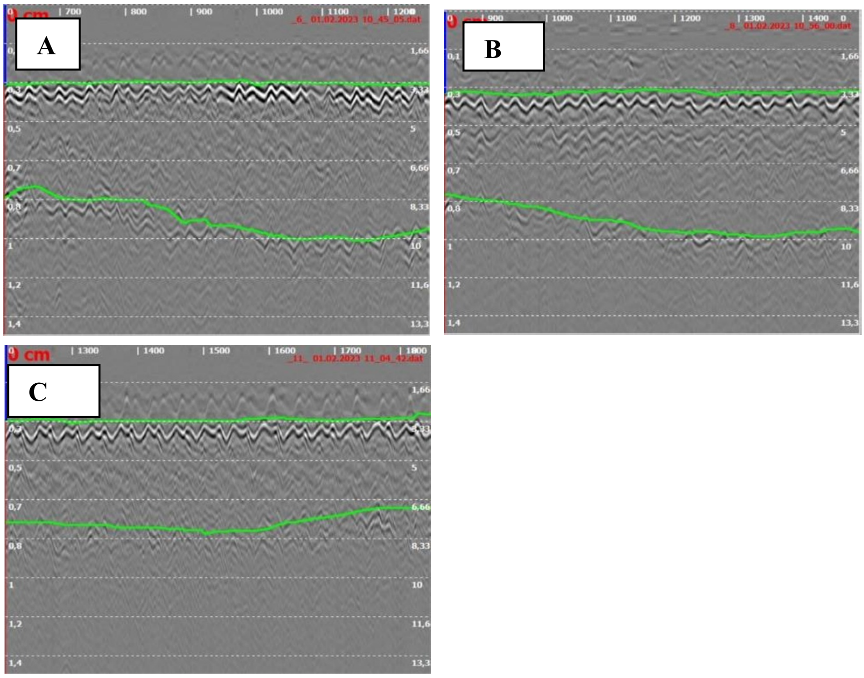

Fig. 7. Fragments of radargrams from the rollout at the Azau station. *A* is a flat roll-out area. *B* is orographically the left edge of the track. *C* is orographically right edge of the track.

It is noted that the Pikor - Led georadar better displays the lower boundary of the snow cover on a flat area, when it is underlain by asphalt (Fig. 7.A), compared to areas where the snow cover is underlain by soil. Also, clearer boundaries of the snow cover are displayed on the radargrams of those profiles, which were surveyed from bottom to top, i.e. over a longer period of time (Fig. 8).

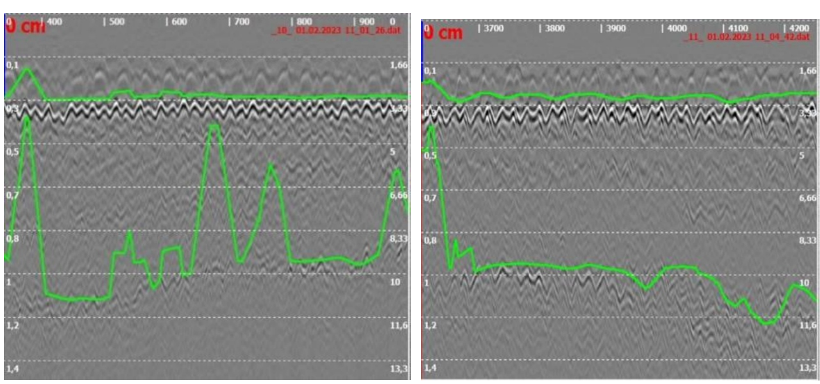

Fig. 8. Fragments of radargrams from profiles laid in the orographically right part of the rollout zone near Azau station. The boundaries of the snow cover are determined automatically . On the left is a profile taken while moving from top to bottom. On the right is a profile taken while moving from bottom to top. On the right profile, the lower boundary of the snow cover is more clearly visible and more reliably deciphered automatically.

Thus, the data obtained during the georadar survey were used to determine the thickness of the snow cover on various sections of the route of the Elbrus ski resort.

Georadar profiling of snow cover in natural occurrence was carried out in the area of pits on the moraine of the Garabashi glacier and on the tongue of the Maly Azau glacier.

During measurements on the pit No. 1 (the moraine of the Garabashi glacier, height is about 3850 m), a significant slowdown in the work of the georadar was noted, probably associated with hypothermia of the computer. Therefore, it was not possible to shoot a full-fledged profile at this point (Fig. 9). However, even on the obtained radargram, several boundaries located inside the snow cover can be distinguished.

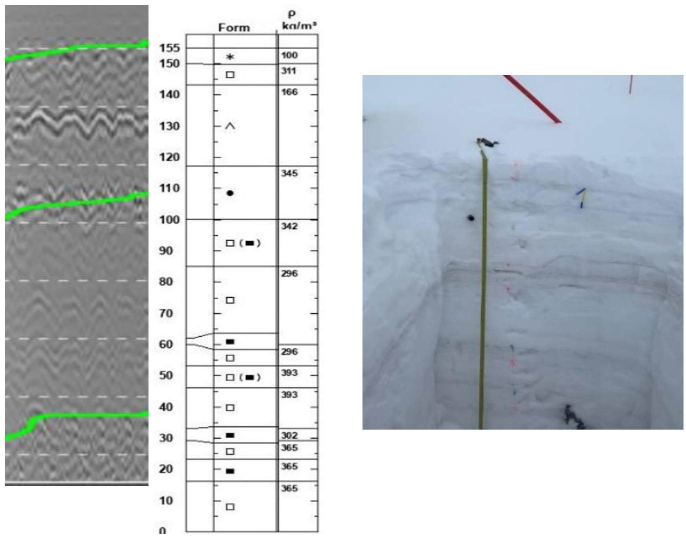

Fig. 9. A fragment of the radargram obtained during measurements in the area of pit No. 1, the structure of the snow cover and the density of snow layers obtained during pitting and a photograph of pit No. 1.

There are 4 borders on the radargram. The top is the border of air and snow. The second boundary (not marked with a green line) probably marks the transition from freshly fallen snow to older, subjected to daigenesis processes , which in the pit is marked by an ice crust at a depth of 140-141 cm (with a pit depth of 155 cm, 0 cm - at ground level) . The third boundary stands out at a depth of about 110 cm (counting from below) and can mark the transition from coarse hoarfrost (117-141 cm along the pit) to denser medium-grained snow (density jump from 166 kg/m 3 to 345 kg/ m^3). After the third boundary, a number of weak reflected signals are observed, which may be reflections from the underlying ice crusts (85-100 cm along the pit), or are multiple and incomplete reflections of the previous boundaries. Finally, the last visible fourth boundary, most likely, is a reflection of the signal from a powerful ice crust located in the pit at a depth of 29-33 cm. Since the depth of the pit on the moraine of the Garabashi glacier is 155 cm, and the depth georadar sounding was chosen as 1.4 m, then, probably, the lower boundary of the snow cover is not reflected on the radargram. Nevertheless, despite the problems with GPR equipment at low temperatures, we managed to get a small radargram, on which it is possible to identify the main horizons identified in the pit No. 1.

GPR, carried out in the area of pit No. 2, was more successful. Sounding was carried out along 9 profiles with different parameters. In particular, the radar depth changed from 1.4 to 3.5 m, which made it possible to display the lower boundary of the snow cover on the radargram (Fig. 10).

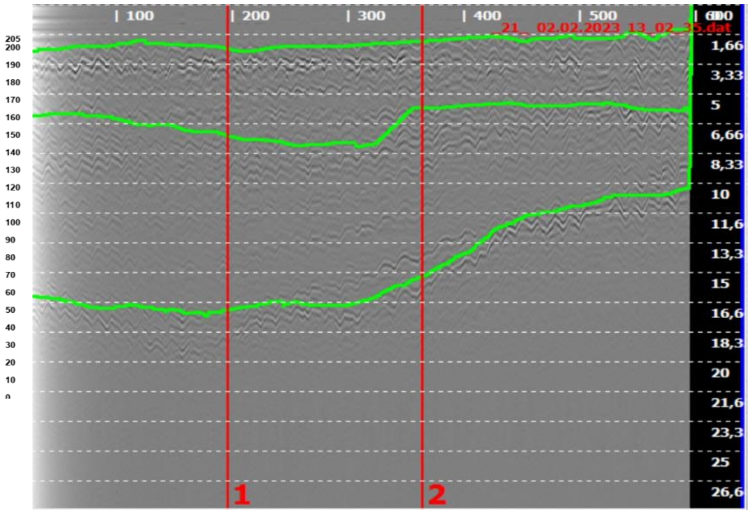

Fig. 10. Profile radargram in the area of pit No. 2 (tongue of the Maly Azau glacier). The red lines show the marks placed during the survey. The total depth reflected on the radargram is 3.5 m (the left scale of depths is not displayed). The lower boundary is the lower boundary of the snow cover, the depth of which varies from 90 to 170 cm on the profile. The difference with the depth of the laid pit - 205 cm) is explained by the laying of the profile 5 m above the pit and significant variations in the thickness of the snow cover in space.

You can also try to compare the radargram obtained in the area of pit No. 2 and the line of pit No. 2 (Fig. 11).

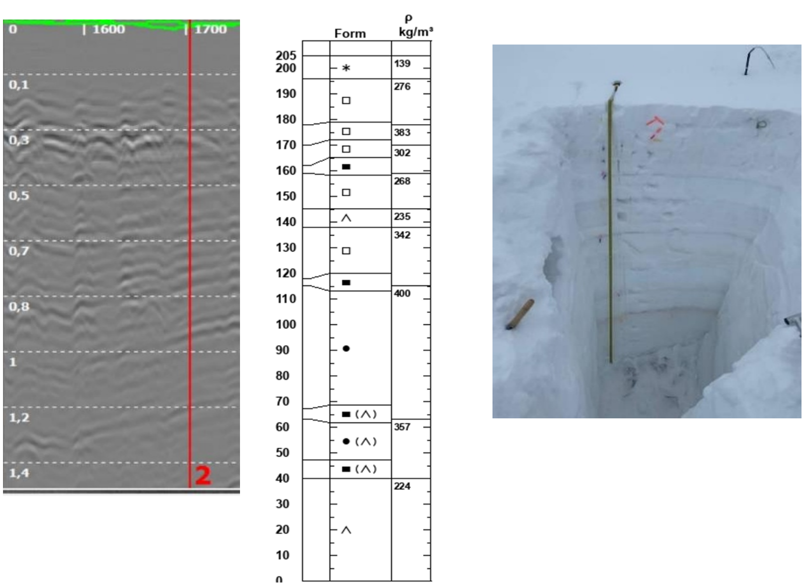

Fig. 11. A fragment of the radargram obtained during measurements in the area of pit No. 2, the structure of the snow cover and the density of snow layers obtained during pitting and a photograph of pit No. 2.

When comparing the radargram and the structure of the snow mass in pit No. 2, one can notice that the boundaries of the layers on the radargram are poorly distinguished. We can confidently distinguish the upper air-snow boundary. Then, at a depth of 0.7 m from the surface, a weak reflection of the signal is observed, which can be correlated with the ice crust, opened in the pit at a height of 159-162 cm from the ice surface. Moreover, below 0.7 m, weak signals are observed similar in shape to the signal at 0.7 m, and, probably, being its re-reflection . In this connection, deeper boundaries within the snow cover are not visible on the radargram.

4 Conclusion

Thus, summarizing the above information, we can draw a number of conclusions regarding the use of the Pikor - Led georadar when conducting snow cover research:

The use of geophysical methods, in particular the georadar method , in the study of snow cover, can significantly expand the observation area and speed up the process of collecting field data.

Profiling with the use of ski equipment, especially on steep slopes where smooth forward movement is impossible, gives a lower quality result than profiling without using it.

On the ski slopes, the snow has a homogeneous structure (without isolated horizons), which is reflected in radargrams , which show only two boundaries: air-snow and snow-underlying surface. The absence of horizons is associated with the regular compaction of the snow cover by snowcats and the suppression of diagenesis processes.

Georadar "Pikor -led" can be used to determine the thickness of the snow cover in natural occurrence, provided there are field observations (pit or snow survey) and sufficient sounding depth.

Also, the Pikor - Led georadar can be used to identify stratigraphic horizons in the snow cover, if they have noticeably different density properties. Ice crusts and boundaries between loose and dense snow stand out especially clearly on the radargrams.

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