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Science and Innovation Day: New Approaches and Techniques for Permafrost Field Studies

V. S. Isaev[a], A. I. Tyurin[a], D. O. Sergeev[b], E. I. Gorshkov[a], N. G. Volkov[c], and S. M. Stefanov[d]

[a]Department of Geology, Moscow State University, Moscow, 119991 Russia
[b]Sergeev Institute of Environmental Geosciences, Russian Academy of Sciences, Moscow, Russia
[c]LLC Geoinzhservis, Moscow, Russia
[d]LLC Solid, Moscow, Russia
e-mail: tpomed@ramblcr.ru, tjurin_alex@mail.ru, sergueevdo@mail.ru, e.i.gorshkov@yandex.ru, ngv@fugro.ru, solidair2005@gmail.com

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Abstract—This paper discusses the use of innovative field techniques in permafrost investigations. The methods were tested during Science and Innovation Day within the framework of the Zvenigorod-based field course in geocryology.

Keywords: permafrost survey, aerial photography, permafrost mapping, static penetration testing of frozen soils

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INTRODUCTION

Permafrost is found in 65% of the territory of Russia (Balobaev et al., 1973). The thickness of the cryolithozone varies from hundreds of meters in the polar regions of Russia to thousands of meters in the highest mountain regions in Eurasia.

The Subdepartment of Geocryology of the Department of Geology at Moscow State University (MSU) has recently been working on a number of applied research projects that cover the following topics: the reliability management of geotechnical systems in the permafrost; analysis of the interaction of organic pollutants with seasonally freezing soils and permafrost; the creation of protective barriers around underground radioactive and toxic waste disposal facilities using natural and artificial cold (Fundamentals of Geocryology, 1999).

Now that the Northern Economic Development Program has been adopted in Russia, the study of the polar regions is attracting increasing interest, especially with regard for the engineering and geological assessment for construction projects that are under way or planned (e.g., the Yamal megaproject, the Yamal LNG project, the construction of the Northern Latitudinal Railway, reconstruction and re-equipment of the northern airfields, etc.). New requirements for geotechnical surveys (especially, shorter terms for the surveying of vast areas) and the necessity to provide the real-time in-situ monitoring of frozen soils necessitate the use of innovative high-efficiency techniques in addition to the traditional ones.

All of these problems require an integrated approach that combines geotechnical and geocryological aspects. The fundamentals of such an approach have traditionally been taught as part of the course Permafrost Investigations in the Field for the third year geological engineering students of the Department of Geology at Moscow State University (Field ... 1986). The field course includes the study of the cryogenic structure of the permafrost and ice (Associate Professor E.M. Chuvilin); frost heave processes (I.A. Komarov and V.S. Isaev); and geophysical methods for studying seasonally frozen soils (A.V. Koshurnikov).

The course includes geocryological monitoring methods: snow-cover monitoring, snow-survey techniques (S.N. Buldovich), and evaluation of the depth of seasonal freezing by using different techniques (V.E. Tumskoi).

The 2015 Science and Innovation Day significantly improved the field-based course in geocryology that reflect new requirements for permafrost investigations. The purpose of the event was to acquaint students with the state-of-the-art aerial photo- and video surveying techniques and new tricks for traditional static penetration testing in relation to frozen soils. The Science and Innovation Day was attended by the representatives of the leading geosciences companies and research centers that specialize in aerial photography to study the properties of frozen soils, scientists of the Department of Geology, and all those who were interested in the latest achievements in permafrost investigations.

Fig. 1. A quadcopter taking off (*a*) and a photo taken by the quadcopter camera (*b*)

AERIAL MAPPING OF PERMAFROST LANDSCAPES USING UNMANNED AERIAL VEHICLES

Ground-based surveying methods are traditionally used for the purposes of landscape microzoning, identifying cryogenic phenomena, estimating the dimensions of permafrost-related topographic features, evaluating the snow depth, etc. However, aerial photography remains the preferred method for permafrost investigations in inaccessible and impassable areas. On the other hand, it is not always possible to distinguish cryogenic features of a landscape in aerial photographs, as well as to mark reference points for landscape microzoning.

The level of detail of an aerial photography and video survey depends on the objective of research. There are no all-purpose devices for the entire range of research objectives. A high level of detail is only possible when surveying small areas with the use of relatively low cost equipment in a cost-effective way. The surveying of large areas requires more expensive hardware and software and highly qualified personnel, which means higher costs for the processing of the survey results.

Local problems of landscape microzoning can be solved by using small quadcopters with a small area coverage range.

Within the framework of the Science and Innovation Day, a representative of the Institute of Environmental Geosciences, Project Manager D.O. Sergeev, presented the Assessment of Microlandscape Heterogeneity by means of Aerial Photography and Video Surveying by Small Airborne Apparatuses program (Fig. 1). Quadcopters can repeatedly fly along the right-of-ways of long linear objects such as roads, railways, and pipelines at a height of 50 to 100 m to obtain georeferenced visual images and aerial photographs in the visible and infrared ranges. Based on the data, landscape microzoning can be carried out and permafrost phenomena and exogenous geological processes can be identified (landslides, mudflows, landslides, avalanches, rock falls, etc.).

The participants of the program learned to plan and carry out an aerial photography and video survey and acquired the basic skills of operating a small radio-controlled flying apparatus within sight distance (Fig. 1a). As well, they learned to process the survey data in order to produce a landscape microzoning map, recognize cryogenic phenomena, and assess the sizes of different topographic irregularities and snow depth, etc., which influence the process of hear exchange.

S.M. Stefanov, a representative of LLC Solid, suggested a substantially different model of geocryological mapping. He demonstrated an aero lifting complex (ALC), which is an airborne wind-powered vehicle for lifting and transporting loads. This remote control vehicle is characterized by high reliability, low cost, and low cost-per-flight-hour.

The range of applications of the ALC is substantially different from that of quadcopters. It provides long-term continuous monitoring at different heights to reveal regularities of geoecological processes; visual observations at different heights to study geological irregularities with various levels of detail; the evaluation of background electromagnetic, thermal, and radiation fields; study of atmospheric transparency at low heights using LIDAR sounding; geocryological reconnaissance and geological engineering mapping of coastal strips in the Arctic and in the South; and the study of the processes of erosion along the banks of lowland rivers.

E.I. Gorshkov, a scientist of the Subdepartment of Geocryology of the Department of Geology of MSU, together with K.G. Shermazanyan, a MIIGAIK graduate, presented GATEWING XI00, an unmanned aerial vehicle (UAV) (Figs. 2a and 2b), and a software package for processing aerial photography data to create a three dimensional terrain model.

The advantages of the UAV are as follows: fast and easy deployment and the accompanying software for automated digital image processing. The final products can be readily imported into any standard geographic information system (GIS) or a computer-aided design system (CAD) or any other software. Moreover, the resulting maps are characterized by high accuracy (decimeter accuracy or higher) and high grid density (1 m and more dense); the ground coverage area reaches 20 km^2. Due to the high scan rate, multiple overlapping photos of the ground are taken as the UAV flies along a flight path, thus providing the most complete information about the land surface. The technique is most expedient when conducting applied permafrost research: data processing takes several days or possibly even several hours and the cost is approximately the same as that of the creation of a rough digital terrain model based on conventional ground-based surveying.

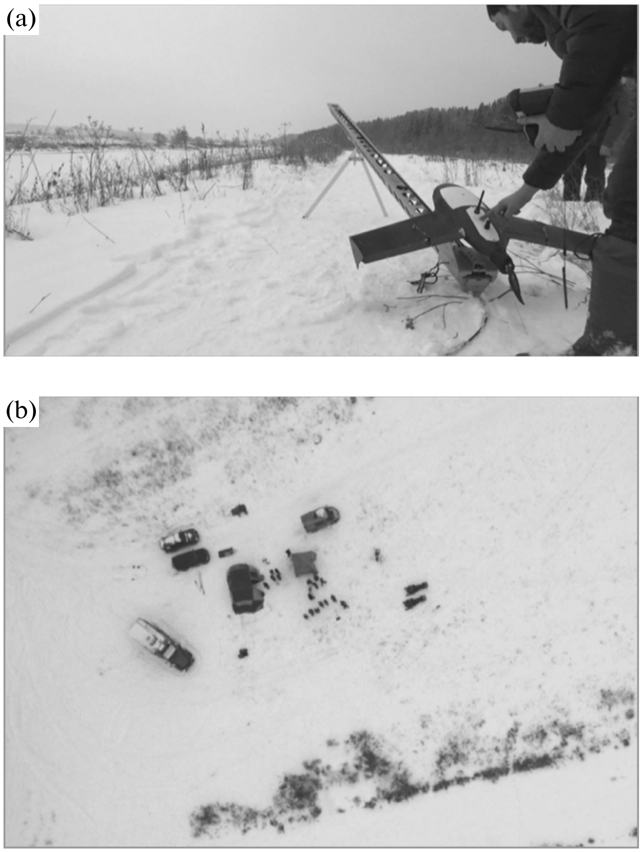

Fig. 2. A GATEWING X100 taking off (*a*) and a photo taken by its camera (*b*)

INNOVATIVE INTEGRATED PERMAFROST PROBING TECHNOLOGIES

The Fugro Geosciences Company presented its innovative integrated technology for probing frozen soils; it includes Cone Penetration Testing (CPT), which allows the mechanical and physical properties of thawed and frozen soils to be evaluated in situ.

Fugro's CPT is used to study plastic frozen soils, together with geotechnical drilling; it partially replaces the latter. It serves as a link between geotechnical drilling, laboratory tests, and geophysical investigations. Soil-temperature profiles can be produced with any depth step. All measurements are carried out in compliance with the requirements of construction regulations (SP, 2012).

Fugro's CPT enables the evaluation of basic parameters of frozen soils, such as cone resistance and sleeve friction. Based on the parameters, the mechanical properties of soils can be calculated/estimated in accordance with construction regulations (SP, 2012), viz., the modulus of deformation Ef (MPa) and equivalent cohesion Ceq (kPa). The bearing capacity of structural piles can be estimated as per construction regulations (SP, 2012) and engineering–geological elements can be identified.

The CPT method is generally used to study plastic frozen soils (Engineering..., 2011) that are widespread along the coastal permafrost zones that are characterized by high salinity, in the areas where frozen soils are affected by human activities and in permafrost masses with taliks. Hard frozen soils and tabular ground ice are not usually objects of investigation by CPT but their mechanical and physical properties may be estimated: CPT tools are robust enough to penetrate through hard frozen materials. Special resistivity measuring instruments provide continuous soil electrical-resistivity measurements using a single resistivity method (Dipole–Dipole, or Wenner). As well, changes in salinity of permafrost with depth can be evaluated; as well, the position of cryopegs and the boundary between frozen and unfrozen soils can be determined. The methane content can be estimated and the boundaries between free gas (gas pockets) and gas that is entrapped in the ice can be located.

To sum up, Fugro's integrated technology significantly expands the range of field research techniques, enhancing the process of acquiring data on the mechanical properties and temperature of frozen soils. A soil temperature profile is obtained from continuous direct temperature measurements. Temperature monitoring is carried out during a single day, including the construction of thermometric wells without upsetting the thermal regime, direct measurements of soil temperature, and subsequent distant collection of monitoring data (Fig. 3). Fugro also provides other services, including the following: operation check-ups of soil thermal-stabilization systems during direct measure-

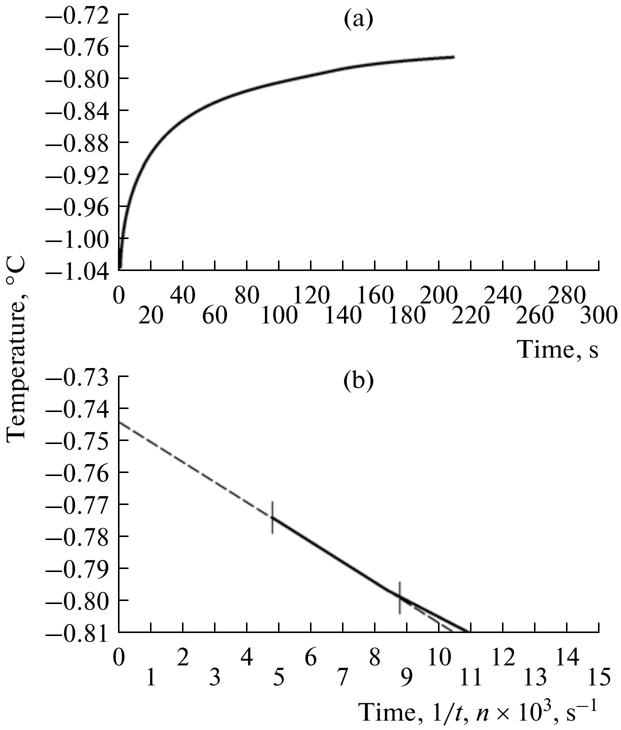

Fig. 3. Processing of temperature measurements made by Fugro's CPT tool: *a*, actual data; *b*, trendline (extrapolation)

ments of soil temperature in the immediate vicinity of a thermal stabilizer; comparison of the measured temperatures with a background temperature that is beyond the zone that is affected by the thermal stabilizer; evaluation of the mechanical properties of frozen soils that are cooled by a thermal stabilizer, which enables the evaluation of the bearing capacity of piles that are located in a zone that is affected by a thermal stabilizer.

CONCLUSIONS

The techniques that were tested during Science and Innovation Day significantly widen the range of field methods for permafrost investigations. UAV-based aerial photography and video surveys considerably facilitate field research.

(1) The acquisition of primary data that is necessary to identify cryogenic processes, carry out permafrost microzoning, and assess potential geohazard risks at construction sites has been substantially enhanced. Aerial surveying fills the gap between ground-based route surveys and satellite observations. Moreover, UAVs can reach remote inaccessible areas, especially where there are rivers and wetlands;

(2) The data that were obtained using Fugro's integrated technology can be verified. Long-term temperature monitoring data of stationary wells that are located near the Zvenigorod Biological Station of MSU show that there is strong agreement between different techniques for measuring soil temperatures. The results of the UAV-based surveys together with the results of ground-based route surveys have allowed improvement of the landscape microzoning map of the area of the Zvenigorod Biological Station. Aerophotography materials serve as the basis for long-term geomorphological monitoring in the area of the Zvenigorod Biological Station.

REFERENCES

Balobayev, V.T., Devyatkin, V.N., and Kutasov, I.M., Contemporary geothermal conditions of the existence and evolution of permafrost, in *II Mezhdunar. Konf. po merzlotovedeniyu. Dokl. i soobshcheniya. Vyp. 1. Teplofizicheskie protsessy formirovaniya i razvitiya kriolitozony* (Proc. 2nd Int. Conf. on Permafrost. "Thermophysical Processes of Formation and Evolution of the Cryolithozone". Iss.1. Yakutsk, July 13–28, 1973), 1973, pp. 11–19. 1

Inzhenernaya geologiya Rossii. T. 1. Grunty Rossii (Engineering Geology of Russia. Vol. 1. Soils of Russia), Trofimov, V.T., Voznesenkii, E.A., and Korolev, V.A., Eds., Moscow: Kn. Dom Univ., 2011.

Osnovy geokriologii. Ch. 5. Inzhenernaya geokriologiya (Principles of Geocryology. Pt. 5. Engineering Geocryology), Ershov, E.D., Ed., Moscow: Mosk. Gos. Univ., 1999.

Polevye metody geokriologicheskikh issledovanii. Metodicheskoe rukovodstvo po uchebnoi praktike studentov geol. fakul'teta MGU (Field Methods of Geocryological Studies. Practical Training for Students of Geology of Faculty, Moscow State University), Ershov, E.D. and Gordeeva, G.I., Eds., Moscow: Mosk. Gos. Univ., 1986.

SP 25.13330.2012. "Osnovaniya i fundamenty na vechnomerzlykh gruntakh". Pril. L. "Opredelenie mekhanicheskikh svoistv i nesushchei sposobnosti osnovanii svai v mnogoletnemerzlykh gruntakh po rezul'tatam staticheskogo zondirovaniya" (Requirements SP 25.13330.2012. Soil Bases and Foundations on Permafrost Soils. Suppl. L. Determination of Mechanical Properties and Bearing Capacity of Permafrost According to Results of Static Sounding). Moscow: Nauchno-Issled. Inst. Osnovanii Podz. Sooruzh., OAO NITs "Stroitel'stvo", 2012.

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