Improvement of Field Methods for Engineering Geocryological Surveying


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Abstract—Testing of modern innovative field methods of engineering geocryological research, master classes by leading specialists of engineering geocryological surveys, and verification of the measurement equipment for thermal field ground massif research were carried out during the Zvenigorod Winter Educational Scientific Geocryological Field Practice for the fourth-year students and the Day of Science and Innovation at the Zvenigorod Biological Station of Moscow State University. The necessity for integration of innovative methods has been shown.

Keywords: field engineering geocryological research, static probe research of frozen grounds, thermal sensor cable, thermal syphon, aerial photography, laser scanning (LiDAR technology)

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RELEVANCE OF THE RESEARCH

With rare exceptions in the geocryological aspect, the Russian Federation is a research object for geocryology engineers due to the spread of permafrost and seasonally frozen soils over most of its area (Balobaev, 1973). Temperature variations of frozen rocks lead to soil thawing followed by loss of soil strength and, finally, man-made disasters (Osnovy ..., 1999). The complex structure and unstable state of the frozen massif pose the following tasks to the engineering and geological industry:

1. Collection of reliable operational information on soil bodies located in the negative temperature zone;
2. Soil body forecasting to take the climatic trend for the studied region and the technogenic load during the development of this area into account;
3. Substantiated paleoreconstruction of climatic conditions of frozen sequences in the studied area, which is based on the knowledge of laws of the cryosphere.

When training specialists for the solution of these engineering and geocryological problems, the Geocryology section of the Geology Department of Moscow State University holds a practice for its engineering-specialized fourth-year students during the Field Geocryological Studies program (Polevye ..., 1986). The practice is carried out at the Zvenigorod Biological Station of Moscow State University, where platforms for integrated geocryological monitoring have been created in recent years, including:

1. Temperature monitoring of soil bodies in different taxonomic units identified by the students in the course of microzoning;
2. Observation of frost heaving processes in the studied microzones;
3. Engineering drilling with coring to study the frozen ground texture;
4. A wide range of geophysical surveys: electrotomography and high-frequency sounding (HFS).

The field engineering geocryological studies allow students to obtain field engineering geocryological survey data, to forecast the development of cryogenic processes, and to offer the most effective methods of dealing with cryogenic processes and phenomena, based on the traditional methods of field geocryological research.

Due to the changing requirements for engineering surveys, the Practice Program in 2015 was supplemented by the Day of Science and Innovation, which has become a tradition. During this Day of Innovation the students are given the opportunity to study and to test new techniques in geotechnical research, such as:

1. Static sounding of soils as applied to frozen soils;
(2) thermal soil stabilization using seasonal cooling devices (SCUs);

(3) aerial photography using unmanned aerial vehicles (UAVs);

(4) 3D topography using advanced laser scanning technology (LIDAR);

(5) study of seasonally frozen soils with the latest geophysical methods and equipment.

In addition, the measuring equipment from different manufacturers is tested to reveal its advantages and disadvantages. This testing makes it possible to carry out expert evaluation of survey equipment and to improve the quality of engineering surveys. Thermal sensor cables of different manufacturers were tested in 2017.

**COMPARISON OF TEMPERATURE MEASUREMENTS MADE WITH THERMAL SENSOR CABLES FROM DIFFERENT MANUFACTURERS**

The experiment was carried out at the Zvenigorod Biological Station of the Moscow State University in the period from 12:30 p.m. January 23 to 09:30 a.m. January 24, 2017. This comparison involved the following equipment:

(1) a thermal sensor cable and logger by V.Kh. Kir’yakov (Pushkov Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation, Russian Academy of Sciences (IZMIRAN));

(2) a thermal sensor cable and logger by V.A. Dubrovin (All-Russian Research Institute of Hydrogeology and Engineering Geology—Space Research Institute, Russian Academy of Sciences (VSEGINGEO—IKI));

(3) a thermal sensor cable and logger by GeoPrecision (Germany) (http://www.geoprecision.com/);

(4) a thermal sensor cable and logger by HOBO (United States) (http://www.onsetcomp.com/products/data-loggers-sensors/temperature).

**Experimental Set up**

Five sensors from each thermal sensor cable (except for the HOBO thermal sensor cable, which has only four sensors) were wound up unit by unit. Each unit was 3–4 cm in diameter and approximately 4 cm in length with account for the sensors. Because of the different sizes of the thermal sensor cable sensors (thermal cables nos. 1 and 2 had the largest sensors), they were placed outside of the winding, while the more compact sensors of the thermal sensor cables nos. 3 and 4 were placed inside the windings. Each winding was fixed with tapes of different colors and wrapped from above with one to two thermal foam insulation layers (a winding thickness of approximately 2 mm) (Fig. 1, left). All thermal sensor cables were placed in a snow pit to a depth of approximately 30 cm at the same level, one next to the other, and covered with slightly compacted snow, while the loggers were placed in a bag next to this pit (Fig. 1, right).

Temperature measurements were carried out every 15 minutes, while the timers of all loggers were
checked before the start to avoid a difference by more than 1–2 minutes.

The air temperature during the experiment was approximately +1°C; thus the snow layer was characterized by a virtually gradient-free temperature field with a temperature near the phase transition; it was a positive factor in the experiment.

**Processing of the Results**

The obtained data were recorded from all loggers, and time–temperature curves were constructed for each unit of sensors using the Grapher program (the numbers of sensors of the V. Kir’yakov thermal sensor cables were taken as file names). Figure 2 shows two graphs for each winding: (1) for the entire time of measurements, including the initial rest (50–100 min); (2) without resting, at an enlarged scale, with account for temperature to follow the operation of temperature sensors of the thermal sensor cables produced by different manufacturers.

**Arrangement of Thermometric Wells in Plastic Pipes in Combination with Static Sounding at the Test Site of Seasonal Cooling Devices (SCDs).**

A new research site where different SCDs are tested has been arranged at the Zvenigorod testing site. It is planned to carry out new testing of year-round SCDs. To assess the effectiveness of SCDs, Fugro has developed a new technique that uses static sounding. The static sounding technology consists in insertion of the cone probe into the soil, which is accompanied by measurement of a number of parameters, such as front indentation resistivity, lateral friction, temperature, pore pressure, and a number of other parameters depending on the selected configuration. Front indentation resistivity, lateral friction, and temperature of soils were measured at the Zvenigorod testing site. Figures 3 and 4 show the test results, which record the reference point for monitoring the soil conditions in the studied area.

Static sounding is a promising method to study the strength and deformation characteristics of frozen soils. This method makes it possible to outline the boundaries of the frozen ground, as well as to map the talik zones and the plastic frozen soil zones. Static sounding using a cone with a temperature sensor is applied to obtain the temperature profile with a given step and with a high measurement accuracy within one day. Static sounding can be used to investigate the state of frozen soils cooled with thermal stabilizers. The major advantage of this method is the ability to measure both an increase in the mechanical characteristics of the frozen ground and a decrease in temperature of this frozen ground in the course of one test process.
Hence, the compiled empirical database makes it possible to assess the necessary decrease in temperature of frozen soils in order to achieve the required mechanical properties of frozen soils. The tests are supposed to be conducted annually in order to track the soil freezing dynamics during SCD operation.

Advantages of this method also include the fact that the temperature data can be obtained by direct measurement throughout the testing at any depth of interest. After the testing, the hole left after insertion of the probe is equipped with a casing and a “thermal cable” for periodic soil temperature measurements.

Fig. 3. Static sounding of soils at the site with thermal stabilizers.

Fig. 4. Frozen soil temperature measurements.
continuous plastic pipe with a diameter of 32 mm is used to arrange a thermometric well based on the static sounding. The pipe is sealed with a plug at the well bottom, it has no joints and other connections to avoid flooding of the well by groundwater. In addition, due to the small diameter of the pipe, the soil temperature error is reduced due to lower air convection in the well and more reliable sealing of the wellhead.

Assembly of the pipe and installation of the thermal sensor cable are carried out within 1 or 2 hours, while the thermal equilibrium time is minimal, that is, a few hours, because the soil body temperature conditions are not interrupted during the static sounding. This method significantly reduces the time needed for construction of a group of thermometric wells at the site compared to the traditional method. In addition, the arrangement of thermometric wells in this manner fully complies with the requirements of GOST 25358-82.

The Fugro Group of Companies also recommends installing stationary thermal sensor cables and periodic remote sensing to minimize the impact of external factors on the wells. Hence, the set of static sounding points equipped for temperature monitoring makes it possible to remotely receive the data and to evaluate changes in the state of the soil massif.

DEVELOPMENT OF A METHOD TO CALCULATE THE THERMAL POWER OF THE SCD MODEL

Under the program for testing of different SCDs at the Zvenigorod testing site it was proposed to develop a new procedure for testing the thermal power of SCDs. The existing methods to calculate temperature conditions of the frost soils frozen or cooled with seasonal cooling devices or thermal stabilizers are based on solution of the Fourier problem using computer-aided finite-difference schemes. However, this method still has the unresolved problem of how to set up the temperature conditions at the SCD—soil boundary. The methods differ: some researchers use the monthly average air temperatures and heat transfer coefficient, while others use average heat flow values preliminarily calculated depending on the air temperature and a number of other parameters. However, the selection of these parameters is subjective and depends on the specialist (on his experience, outlook, attitude towards the customer, etc.). A method based on objective setting of temperature boundary conditions has not been developed as yet.

To solve this task, a new SCD model was developed at a small scale (Fig. 5). The pipe is 10 mm in diameter. The thermal stabilizer or heat pipe is 560 mm in length. Finning of the SCD is made in the form of a plate (44 × 137 mm) so that when calculating the heat removal in the SCD finning surface, it would be possible to apply simpler, verified, and reliable empirical formulas that have been used for decades in heat engineering. This SCD is made of aluminum alloy. The heat agent inside the heat pipe is pentane. The heat pipe is two-phase. The amount of heat agent is strictly metered so that inside the heat pipe the agent covers the pipe wall with a thin film and the remaining volume is filled by vapors (the gaseous phase of the agent). However, in order to study and demonstrate the effect of the liquid phase of the heat agent, the agent was pumped in excess into the pipe, so that a liquid agent column of 100 mm in height was accumulated at a temperature of 0°C in the heat pipe at a vertical position in the evaporation zone. The test procedure is relatively simple (Fig. 5). The Inter Hit Pipe used it as early as the 1990s (http://iheatpipe.ru/history_retro.html). The SCD was installed in a freshwater reservoir (Fig. 5) for 18 h 40 min (67 200 s) from 03:00 p.m. January 18 to 09:40 a.m. January 19, 2017. During this period, the air temperature varied from −6 to −8°C (7°C, on average, for the specified period). An ice cylinder with a total weight of 165 g was formed around the SCD. The cylinder diameter was 35 mm at the evaporator pipe diameter of 10 mm. Based on the data we obtained, it is possible to calculate the thermal power of the SCD. To freeze 165 g of water, it is necessary to use

\[
165 \text{g} \times 335 \text{J/g} = 55275 \text{J.}
\]

Neglecting other values of heat transfer during operation of the thermal stabilizer, the thermal power of an SCD under these conditions will reach

\[
55275 \text{J}/67200 \text{s} = 0.82 \text{W.}
\]

This result is of great value because of the clarity and simplicity of the experiment. Each test performed according to this method is easy to verify, because the amount of ice frozen with the SCD in the given period is clearly visible. The shape of the ice cylinder shows the efficiency of the SCD and the temperature gradient. When testing, it is clearly seen that water was not frozen at the end of the evaporative part of the SCD. Below the level to which the agent was poured in excess, the cylinder goes into a cone and disappears completely. This fact clearly confirms that the heat removal at the evaporator, where the agent is in excess (which is now the norm for most manufacturers), is extremely low and freezing and/or cooling does not occur in this zone of the evaporator.

We propose to organize a new task during the Zvenigorod practice, where students would perform short tests related to water freezing in a freshwater reservoir. In the course of testing, they can study the effects of different factors on SCD performance, such as air temperature and wind velocity. The set of empirical data obtained in the course of such testing can be used to develop a new technique for setting up the temperature conditions at the SCD—soil boundary.
USE OF ELECTROTOMOGRAPHY, A MODERN MODIFICATION OF THE RESISTIVITY METHOD, IN WINTER DURING THE DAY OF SCIENCE AND INNOVATION

Electric tomography (electrotomography) is a modification of vertical electric sounding (VES) using multichannel (multielectrode) systems. In this VES modification, a set of electrodes are located at regular intervals along the observation profile. During measurements, electrodes are repeatedly used for both receiving and feeding. The application of electrotomography is specified in regulatory documents (SP 11-105-97, part VI) for detailed study of a 2D inhomogeneous media. According to practical experience, electrical tomography has proven itself in research of complex environments, clarification of the structure of a geological section top and detection of local heterogeneities, study of karst—suffusion processes, mapping of slip planes of landslide bodies, investigation of permafrost visors and sluggish congeation, and in the solution of other problems. An additional advantage of this technology is the potential of the topographic data as a source material along with the measured apparent resistivity for calculation of the geoelectric medium model. Hence, this method can be applied to any relief, even at very significant elevations.

Operation of the Russian 16-channel 64-electrode Scala 64 electrotomographic station (OOO Electrometry Design Bureau, Novosibirsk) was demonstrated during the Day of Science and Innovation. This station works under different electric survey protocols, including Wenner, Schlumberger, dipole axial, three-electrode (direct and reverse), and two-electrode systems.

The demonstration was carried out on a profile located along the central road of the Zvenigorod testing site (Fig. 6). Electrodes were spaced at 3-m intervals along the profile. The work was carried out according to the protocol of the AMN–MNB counter (combined) three-electrode setup, which provides the maximum depth and detail of the research. The level of detail in terms of physical observation points reached 64 VES points with a 3-m step along the profile in two directions (AMN and MNB). The profile length was 189 m at a maximum AO spacing of 90 m. The infinity electrode was installed opposite the central part of the profile at a distance of 400 m.

Electric exploration using the resistivity method in winter is distinguished by a certain specificity, because the quality of the obtained field data is greatly depen-
dent on transition resistivities between the soil and the electrodes. The modern electrotomographic stations make it possible to estimate transition resistivities immediately before the measurements.

In our case, the transition resistivity values between the soil and the electrodes driven into the frozen ground with a punch and a sledge hammer were too high and varied from 30 to 100 kOhm. As an experiment, we measured the apparent resistivity at such high values of transition resistivity (Fig. 7).

To improve the grounding quality and to reduce transition resistivities, we applied a technical solution that was proposed by O.I. Komarov in 2010 and tested in many works. A hole with a depth of 0.6–0.7 was drilled in the soil for each electrode with a mobile generator and a perforator with a long drill (Fig. 8). Brine was poured into the drilled hole, and the electrode was immersed and put through in it. This electrode installation method makes it possible to considerably reduce the transition resistivity in winter. In our case, after the

Fig. 6. The site location of the electrotomography profile and infinity electrode.

Fig. 7. A poor quality of field materials measured at a high transition resistivity. At the top, AMN pseudosection; in the middle, MNB; and at the bottom, resulting AMNB.
measures taken to improve the grounding quality, the transition resistivity values did not exceed 5 kOhm (mostly 0.7–1.5 kOhm) (Fig. 9).

The conducted research yielded high-quality field data (Fig. 10) that were suitable for further processing and interpretation.

As a result of primary processing, the data file was prepared for construction of a geoelectric model. The electrotomography data were interpreted for 2D models using special software. The geoelectric medium model was selected using the procedure for a 2D automatic inversion of the measured apparent resistivity field. The 2D inversion is an algorithm that converts the observed electric field into the corresponding 2D distribution of specific resistivity. With this approach, the search for a solution takes the entire set of measured data into account.

When changing the model selection parameters, introducing a priori information into the base model, using various filtering and smoothing algorithms, the operator influences the result. After entering the necessary parameters, the program automatically calculates the mathematical model of the medium and builds a geoelectric section. Since this problem is
incorrect, the solution is regularized using models with gradual variations in resistivity. Due to the integral nature of the resistivity method, the resulting solution, as a rule, simplifies and smoothes real components of a geological structure of the section. In addition, false anomalies related to objects located near the observation profile and to inversion instability can occur in the section. Very contrasting objects of anthropogenic origin (for example, water supply and sewage pipelines, etc.) are a special problem. Depth values obtained by surface geophysical surveys are determined using judgment due to equivalent relationships between resistivity and thickness of the soil. The interpretation yielded the geoelectric section along the research profile (Fig. 11).

The resulting geoelectric section has a complex structure. In the upper part, up to a depth of 3–4 m, in PK 42–69, PK 99–129, and PK 144–189, well-defined lenticular zones are characterized by a high specific electric resistivity (SER) varying in the range of 1500–5000 Ohm m, which lithologically correspond to drained sands. In PK 0–42 and PK 69–99, near the surface, soils are characterized by moderate electrical resistivity values varying in the range of 100–300 Ohm m and that most likely correspond to sandy wet soils. In the range of PK 99–189, at a depth of 7–12 m, a low-resistivity layer with a soil resistivity of 10–30 Ohm m apparently corresponds to water-rich eluvial deposits as limestone eluvium and sandy–loamy soils. In addition, near PK 27–48, at a depth of 7 m and deeper, a low-resistivity (100–200 Ohm m) is recorded; poorly preserved fractured limestones are likely confined to it. We also should particularly note an anomalous zone in PK 78–102 at a depth of 12–15 m, which is characterized by a low resistivity (10–30 Ohm m). The loamy/clay soil zone as well as the broken limestone zone can correspond to this anomaly. The anomaly can be explained by other factors; such well-defined anomalous zones in the geoelectric sections are often caused by the location of communications lines and commonly by leaks. Therefore, in order to clarify the nature of this anomaly, it is necessary to conduct a verification drilling.

In conclusion, it should be noted that the elecrotomography is characterized by highly detailed studies; simple technical solutions make it possible to use it on the frozen ground in winter.

LASER SCANNING

Laser scanning is an effective technology to obtain spatial data at a high accuracy and velocity, which is based on measurements of the distance and two angles to an object using a variety of low-power laser pulses. These measurements are carried out using 3D laser scanners. As a result of measurements carried out using scanners, specialists obtain laser reflection points for which spatial coordinates \((x, y, z)\), as well, as the reflected signal shape and rate, are calculated. The obtained data are used to construct spatial digital models of measured objects. Laser scanning is a survey method which has already firmly filled its niche in the objective spatial data market. Compared with the traditional measurement methods that provide only discrete point measurements in selected locations, laser scanning devices make it possible to measure surfaces of objects as a whole with complete covering of these objects by laser reflection points (measurements).

By analogy to office copiers that use light to copy a document line by line, laser scanners “copy” the surrounding world using laser pulses. Laser scanning can be supplemented with photogrammetric information on the survey object. After scanning, real colors will be applied to laser reflection points. Laser scanning, in contrast to photogrammetric surveys, measures the distance to an object directly without calculations; in addition, it does not depend on external factors such as illuminance that affects the ability to perform measurements in photogrammetry. During the Day of Science and Innovation, we carried out laser scanning of the Zvenigorod Biological Station with temperature monitoring areas and the SCD study site (Fig. 12).

GEOCRYOLOGICAL MAPPING USING UNMANNED AERIAL VEHICLES

Ground survey methods are commonly used for solution of geocryological problems such as land microzoning, identification of cryogenic phenomena, estimations of characteristic inhomogeneities of relief,
snow accumulation, etc. However, due to the inaccessibility and obstruction of many research areas, preference is given to the interpretation of aerial photographs (APGs). However, due to the low resolution of APGs it is impossible to interpret the manifestations of cryogenic processes and to outline the reference land microzoning areas. Small quadrocopters with a short-range coverage area are preferable in solution of local tasks related to land microzoning.

During the Day of Science and Innovation, a representative of the Sergeev Institute of Environmental Geoscience of the Russian Academy of Sciences, project leader D.O. Sergeev presented the Assessment of Microlandscape Heterogeneity by Aerial, Photo, and Video Survey from Small Aerial Vehicles program. The use of quadrocopters makes it possible to carry out repeated surveying of land with extended linear engineering facilities (motor roads, railways, and pipelines) from a height of 50–100 m in order to obtain topographically referenced visual images and aerial photographs in the visible and infrared ranges. These data can be used in land microzoning and identification of geocryological phenomena and exogenic geological processes (landslides, mudflows, landfalls, avalanches, rockfalls, etc.) (Sergeev et al., 2007).

During the Day of Science and Innovation, the participants acquired the skills to plan and perform a perspective aerial photographic and video survey (Fig. 13) and to process its results to solve geocryological problems (land microzoning, identification of cryogenic phenomena, estimations of characteristic terrain heterogeneities, snow accumulation etc., that affect heat transfer conditions).

**FREQUENCY SOUNDING (FS)**

This method belongs electromagnetic methods of geophysical research. Geophysical studies by electromagnetic methods are performed in the areas where work based on direct current (electrical profiling and vertical electrical sounding) is impossible or difficult due to the lack of galvanic communication of the measuring line with the surface, for example, if the section contains soils with a high level of electrical resistivity, as in the case with a seasonally frozen layer.

The FS technology (as a type of electromagnetic sounding) is based on the use of variable electromagnetic fields. Advantages of this technology include the noncontact excitation and reception of the electromagnetic field; this is the reason that it is often used in rocky and frozen soils. FS uses an artificial electromagnetic field in the frequency range from 4 to 1024 kHz to study the section top. The field is excited and measured at the same frequency using antennas (multiturn frames) located horizontally at a certain distance from one another (Fig. 14).

The maximum research depth does not exceed the distance from the source to the receiver. Frequency sounding is carried out using HF–EM equipment (Fig. 15) (OOO MGU–Geophisika, Moscow).

The FS method was demonstrated in the area from the teaching house to the road out from the Zvenigorod Biological Station of the Moscow State University (Fig. 16).

The measurements were carried out under continuous operation conditions; generating and measuring antennas were mounted on plastic nonconductive sleds that were carried using a snowmobile at low speed.

Fig. 12. Laser scanning of the Zvenigorod Biological Station, Moscow State University, with temperature monitoring areas and a thermal stabilization testing site.
The measurement data analysis yielded the geo-electric section of the apparent soil resistivity along the studied profile. The section contains higher-electric resistivity zones. At the section top, the high-resistivity anomalies are related to seasonally frozen soils. As an example, a well-defined anomaly of high electrical resistivity of soils was identified in the profile center. This anomaly is probably related to snow clearing at the gate of the station and, as a result, to deeper seasonal freezing of soils in this area. In addition, going from the exit road to the Lutsinskoe highway, rocks with a lower electrical resistivity begin to occur at the section bottom; this may be due to more dispersed rocks in the section.

STUDY OF SEASONAL COOLING DEVICES AT THE NEW EDUCATIONAL AND SCIENTIFIC GEOCRYOLOGICAL TESTING SITE

During the Day of Science and Innovation, the students visited a new educational and scientific geocryological testing site. Four seasonal cooling devices (SCDs) are being operated there. These devices are often used for thermal stabilization of soil foundations in the construction and operation of facilities in permafrost areas (Vyalov, 1981). Their functioning is related to the use of the cooling potential of atmospheric air in the winter period. In Russia, SCDs are manufactured by OAO Fundamentproekt, OOO NewFrost, FSA FundamentStroiArkos, ZAO Hit Pipe, OOO Rivmash, and other manufacturers. The SCD...
installation depth is commonly limited to 10–15 m. The characteristic size (diameter) is 33.7–57 mm. The temperature level is –2 to –10°C at the contact. The cooling agents are: a) R404a freon gas (ozone-safe) with a medium pressure $P_{\text{med.}} = 4.67–3.55$ atm and a heat removal of 10–15 W/m; b) R717 ammonia with $P_{\text{med.}} = 4–2.9$ atm, which is the most effective cooling agent in terms of heat release, heat removal of 25–30 W/m; and c) R744 carbon dioxide with $P_{\text{med.}} = 33–26$ atm and heat removal of 12–18 W/m.

Ten-meter vertical SCDs of natural circulation (Fig. 8) are installed at the Zvenigorod testing site, with two thermal stabilizers using ammonia as a coolant; one is filled with freon, another is filled with carbon dioxide. To monitor and control the operation of the SCDs, 10-meter temperature wells are drilled near the thermal stabilizers, where semiconductor resistivity sensors are used as thermal sensors. Readings of these sensors are recorded with a logger.

The disadvantages of SCDs include the seasonal dependence of the operation and time of installation in the rock, a relatively low freezing rate, and problems with freezing of highly saline rocks; advantages include the absence of energy costs or the need to maintain the system during its operation.

CONCLUSIONS

Modern technologies tested on the Day of Science and Innovation have made a considerable contribution to the traditional field geocryological research.

Field materials collected during the Day of Science and Innovation substantially supplemented the engineering and geocryological database that is used in the engineering and geocryological practice for students of the Department of Geology of Moscow State University.

Testing of thermal sensor cables from different manufacturers on the Day of Science and Innovation made it possible to carry out the independent assessment of the technical characteristics of the manufac-
The work of the geocryological testing site at the Zvenigorod Biological Station of Moscow State University made it possible to conduct field experiments with seasonal cooling devices (OOO RivsMash). This program is aimed at studying temperature fields around a thermal stabilizer, assessment of different agents used as heat-exchange fluids, investigation of phase transitions inside pipes, and the effect of phase transitions on the thermal stabilizer operation at depth.

Mapping using UAV makes a great contribution to obtaining the primary data for interpretation of cryogenic processes, permafrost micрозoning, and identification of areas that are at risk in the course of construction. This method makes it possible to fill the gap between route field surveys and satellite imagery.

REFERENCES


