Multi-Parameter Protocol for Geocryological Test Site: A Case Study Applied for the European North of Russia

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GLOBAL TERRISTRIAL NETWORK FOR PERMAFROST (GTN-P) - SET OF CONTROLLED PARAMETERS:

Active Layer Thickness(ALT): Length (unit: Centimeter, Meter).
Air Temperature: Temperature (unit: Degree Celsius, Degree Fahrenheit, Degree Kelvin, Degree Rankine).
Ground Temperature: Temperature below the ground (unit: Degree Celsius, Degree Fahrenheit, Degree Kelvin, Degree Rankine).
Snow Density: Concentration (unit: Gramm per Square Centimeter).
Snow Depth: Length (unit: Centimeter, Meter).
Snow Temperature: Temperature (unit: Degree Celsius, Degree Fahrenheit, Degree Kelvin, Degree Rankine).
Soil Moisture: Percentage (unit: Percentage).
Surface Soil Moisture (Satellite): Percentage (unit: Percentage).
Surface Temperature: Temperature (unit: Degree Celsius, Degree Fahrenheit, Degree Kelvin, Degree Rankine).
Surface Temperature (Satellite): Temperature (unit: Degree Celsius, Degree Fahrenheit, Degree Kelvin, Degree Rankine).

https://gtnp.arcticportal.org/component/content/article/15-data/database/9-control-vocabulary

GLOBAL TERRISTRIAL NETWORK FOR PERMAFROST (GTN-P) - METHODS:

Frost/Thaw Tubes: Measurements of position of ice in the tube.
(Applies to Active Layer Thickness.)
Ground Subsidence: Measurements of surface elevation (optical leveling, DGPS, thaw tubes).
(Applies to Active Layer Thickness.)
Mechanical Probing: Measurements by gradual metal rod collected manually.
(Applies to Active Layer Thickness.)
Thermistor Automated: Measurements from a thermistor that are collected with a datalogger or other recording device.
(Applies to Air Temperature, Ground Temperature, Snow Temperature, and Surface Temperature.)
Thermistor Manual: Measurements from a thermistor that are collected manually.
(Applies to Air Temperature, Ground Temperature, Snow Temperature, and Surface Temperature.)
Thermocouple Automated: Measurements from a thermocouple that are collected with a datalogger or other recording device.
(Applies to Air Temperature, Ground Temperature, Snow Temperature, and Surface Temperature.)
Thermocouple Manual: Measurements from a thermocouple that are collected manually.
(Applies to Air Temperature, Ground Temperature, Snow Temperature, and Surface Temperature.)
Thermometer: Measurements taken with a mercury or alcohol thermometer.
(Applies to Air Temperature, Ground Temperature, Snow Temperature, and Surface Temperature.)
Temperature Interpolation: Interpolation of depth corresponding to o C degree isoterm.
(Applies to Ground Temperature.)
Mechanical Probing:
(Applies to Snow Depth.)
Gravimetric Soil Sampling:
(Applies to Soil Moisture.)
Spatial Measurements:
(Applies to Soil Moisture.)
Stationary Measurements:
(Applies to Soil Moisture.)
Metop ASCAT (Satellite):
(Applies to Surface Soil Moisture (satellite)).
AATSR (Satellite):
(Applies to Surface Temperature (satellite)).
MODIS (Satellite):
(Applies to Surface Temperature (satellite)).

https://gtnp.arcticportal.org/component/content/article/15-data/database/9-control-vocabulary

A NOVEL MULTI-PARAMETER MONITORING PROTOCOL - SET OF CONTROLLED PARAMETERS:

Air temperature;

Ground temperature;

Snow cover
(thickness, density, thermal conductivity);

Vegetation cover
(classification, thickness, thermal conductivity);

Soil properties
(classification, grain size, water content, density, Attenberg limits, the relative content of organic matter, salinity, freezing point);

Permafrost and active layer spatial distribution;

Amplitude of surface temperature fluctuations;

Thickness of the active layer ;

Type of cryogenic processes;

Cryological mapping in GIS

Isaev, V.; Kioka, A.; Kotov, P.; Sergeev, D.O.; Uvarova, A.; Koshurnikov, A.; Komarov, O.
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A NOVEL MULTI-PARAMETER MONITORING PROTOCOL - METHODS:

Thermometry of air

(Applies to modelling of active layer, permafrost and unfrozen ground structure and spatial dimensions)

Thermometry in boreholes

(Applies to active layer, permafrost and unfrozen ground structure and spatial dimensions)

Light Detection and Ranging (LiDAR)

(Applies to processes – frost heave, coastal retreat , thermokarst et ctr.)

Differential global positioning system (DGPS)

(Applies to processes – frost heave, coastal retreat , thermokarst et ctr.)

An unmanned aerial vehicle (UAV) mapping

(Applies to processes – frost heave, coastal retreat , thermokarst et ctr.)

Electric resistivity tomography (ERT)

(Applies to permafrost and unfrozen ground structure and dimensions)

Route studies with ground and vegetation sampling

(Applies to modelling of active layer, permafrost and unfrozen ground structure and spatial dimensions)

Laboratory studies of the physical and thermal properties of rocks

(Applies to modelling of active layer, permafrost and unfrozen ground structure and spatial dimensions)

Engineering boreholes drillings

(Applies to validation of ERT data and thermometry in boreholes and for active layer, permafrost and unfrozen ground structure and spatial dimensions)

Landscape zoning mapping on the base of GIS

(Applies to system analysis of collected and calculated data)

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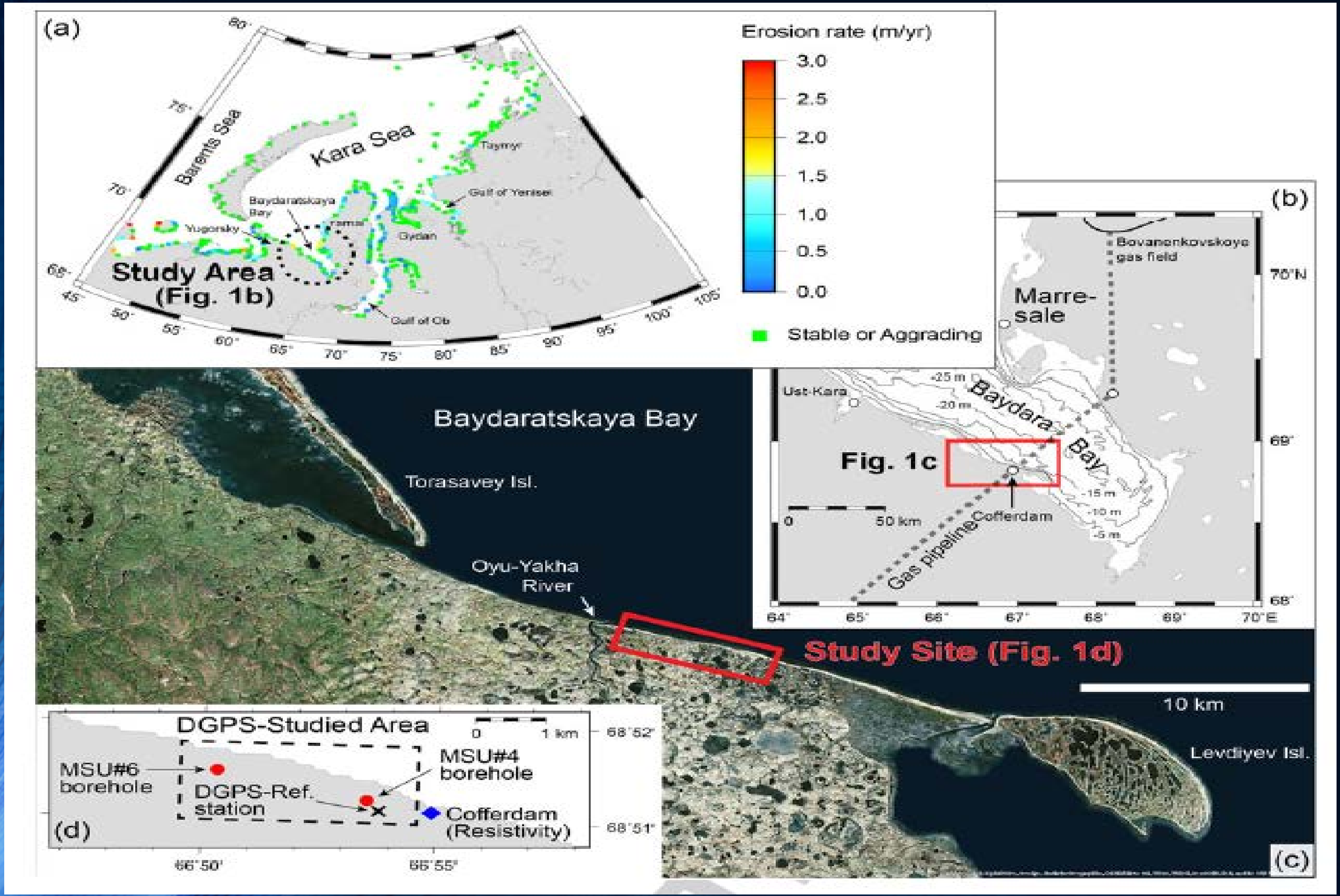
Geotest site "Baydaratskaya Bay"



(a) Mean annual rates of coastal erosion (m/yr) along the Kara Sea coast before 2005. Data are from the Arctic coastal dynamics (ACD) project database.

(b) map of Baydaratskaya Bay in the Kara Sea. Bathymetric contours are from Ogorodov et al.25

(c) satellite imagery of the study area. The imagery data from earthstar Geographics/Esri.

(d) Differential GPS (DGPS)-surveyed area and locations of the boreholes (red circles), reference station for DGPS survey (black cross) and resistivity measurement (blue diamond; Cofferdam).

Coastlines are from the global self-consistent, hierarchical, high-resolution geography database (GSHHG) version 2.3.6.

Cliff retreat of permafrost coast in south-west Baydaratskaya Bay, Kara Sea, during 2005–2016
V.S. Isaev, A.Kioka, A.V. Koshurnikov, A. Pogorelov, R.M. Amangurov, O. Podchasov, D.O. Sergeev, S.N. Buldovich, 2019. Permafrost and Periglacial processes, V30, Issue 1, pp. 35-47
https://doi.org/10.1002/ppp.1993

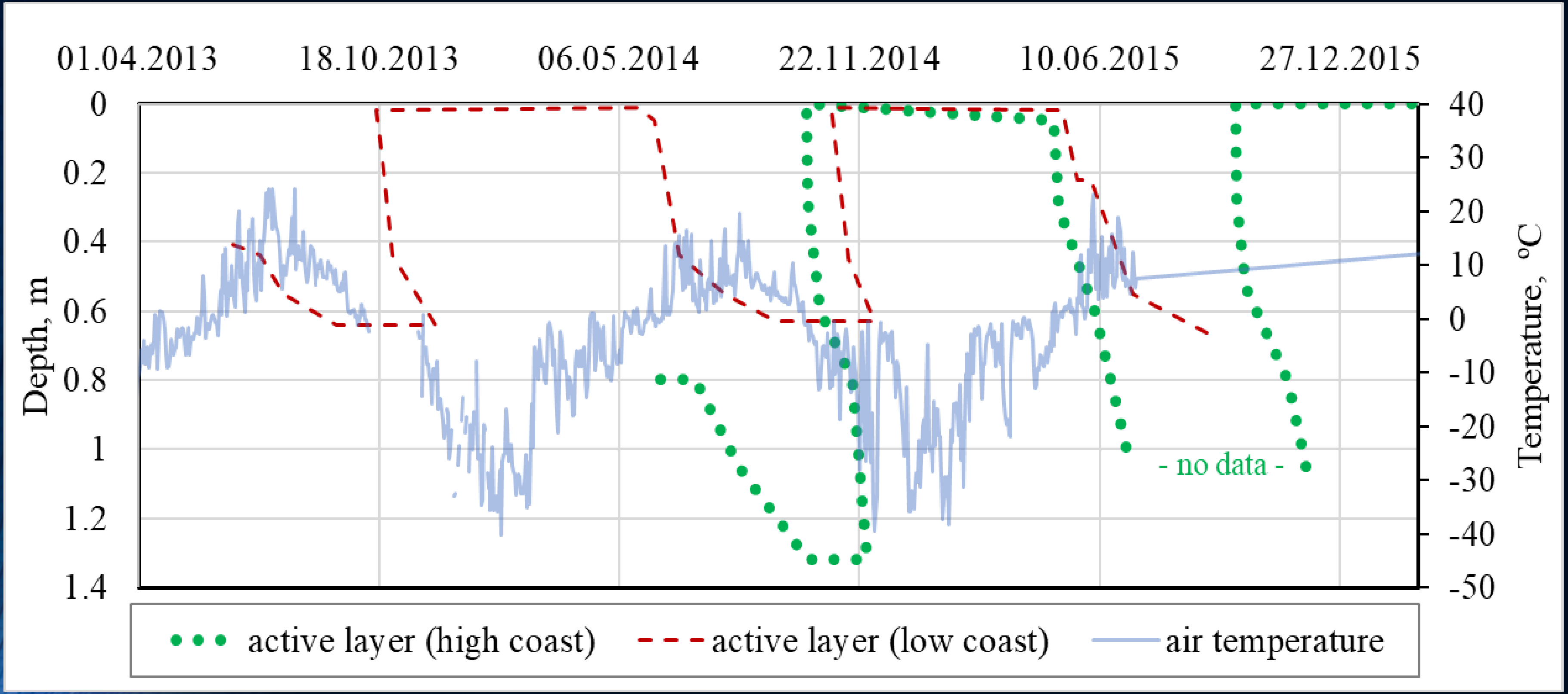
Таблица 2.2.2.1. Измерение глубины сезонного оттаивания на полигоне Байдара

Точка	Дата	Время	Тип ландшафта	Характер рельефа	Обводненность поверхности	Растительный покров	Глубина сезонно-талого слоя, м
Т-1-Байд	13.09.2021	10:00:00	Высокая лайда	Выположенная поверхность, локальные повышения на 0,5 м	Сухая	Травянистый, обедненный	1,27
Т-2-Байд	13.09.2021	10:29:00	Высокая лайда	Выположенный, выше на 0,5 м точки Т-1-Байд. Локальные понижения до 0,3 м	Сухая	Мохово-травянистый	0,45
Т-3-Байд	13.09.2021	11:07:00	Низкая морская терраса	Бугристо-западинный, перепад до 1 м	Сухая в повышениях, увлажненная и обводнённая в понижениях	Мохово-травянистый, в западинах нет ерника.	0,43 только мхом, 0,65 на повышениях, 0,75 в понижениях, 0,85 понижения заболоченные
Т-4-Байд	13.09.2021	11:58:00	Низкая морская терраса	Повторно-жильный. Понижение по жиле	Увлажненная	Травянистый	1,2 по жилам, 0,4 на буграх
Т-5-Байд	13.09.2021	12:15:00	Низкая морская терраса	Полигонально-жильный, полигоны 6-9 м, между полигонами 1-1,5 м	Сухая	Травянисто е разнотравье	>1,5
Т-6-Байд	13.09.2021	13:01:00	Низкая лайда	Полигонально-жильный	Увлажненная	Мохово-травянистый	0,5 0,45 0,44 0,42
Т-7-Байд	13.09.2021	14:05:00	Низкая морская терраса	Полигонально-жильный 5-10 м шириной	Увлажненная	Мохово-травянистый покров, появляется ерник	0,45 0,6
Т-8-Байд	13.09.2021	14:32:00	Высокая морская терраса	Пологий	Сухая	Разнотравье, мхи	0,85
Т-9-Байд	13.09.2021	14:43:00	Высокая морская терраса	Хасырей	Сухая	Разнотравье, мхи	>1,5

Route studies

- The probe and pit methods fix the thickness of the active layer
- Lab researches of density and moisture of ground samples
- Vegetation cover classification
- Cryological phenomena survey and its location
- An analysis of the obtained data was made and hypotheses about the reasons for the revealed causes of the active layer distribution for each key landscapes were formed.

Thermometric monitoring



- Changes of active layer thickness and depth of permafrost at the boreholes on low and high coast of Baydara geotest site on the base of thermometry in boreholes on low and high coasts by GeoPrecision logger thermistor strings

Isaev, V.; Kioka, A.; Kotov, P.; Sergeev, D.O.; Uvarova, A.; Koshurnikov, A.; Komarov, O.
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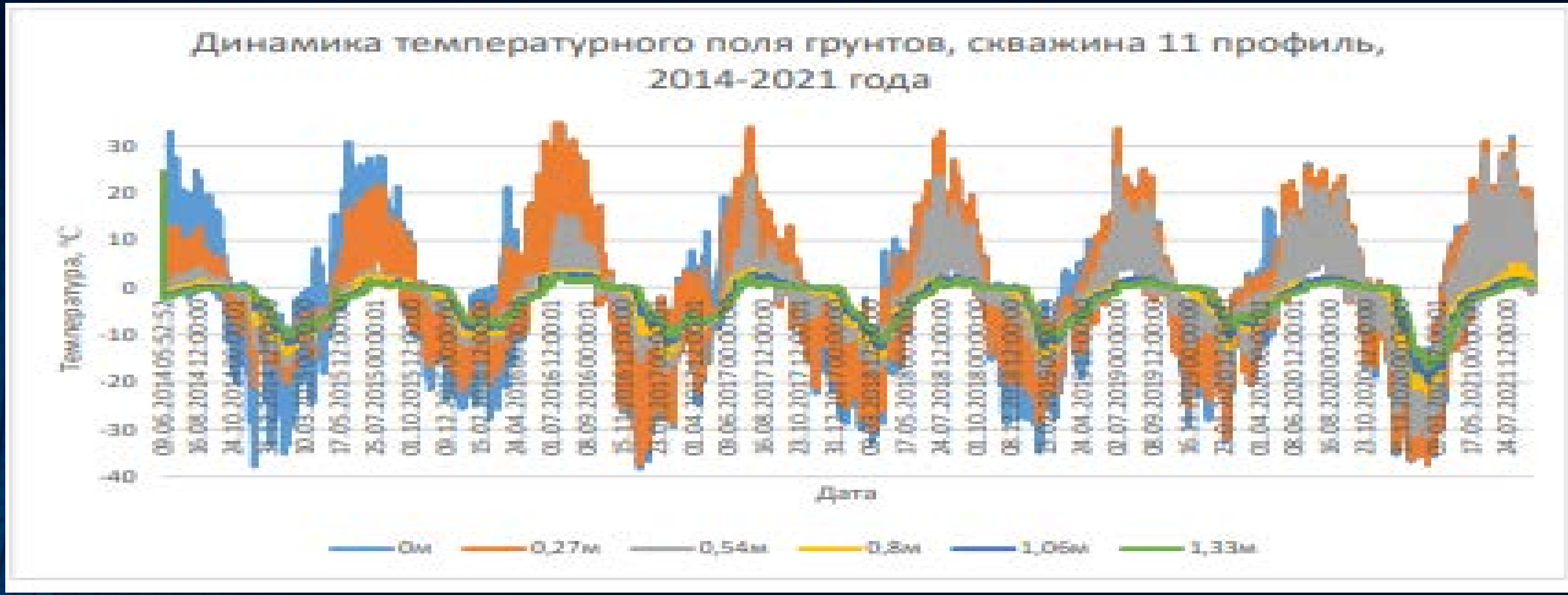
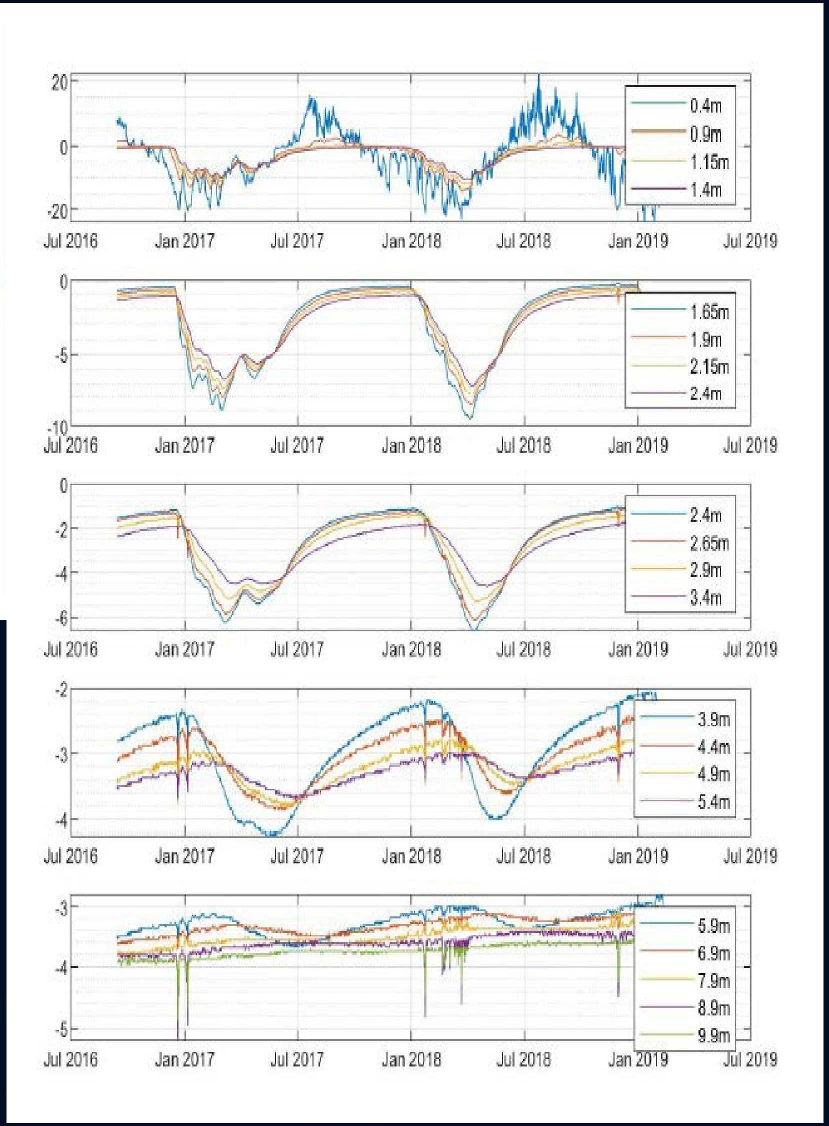
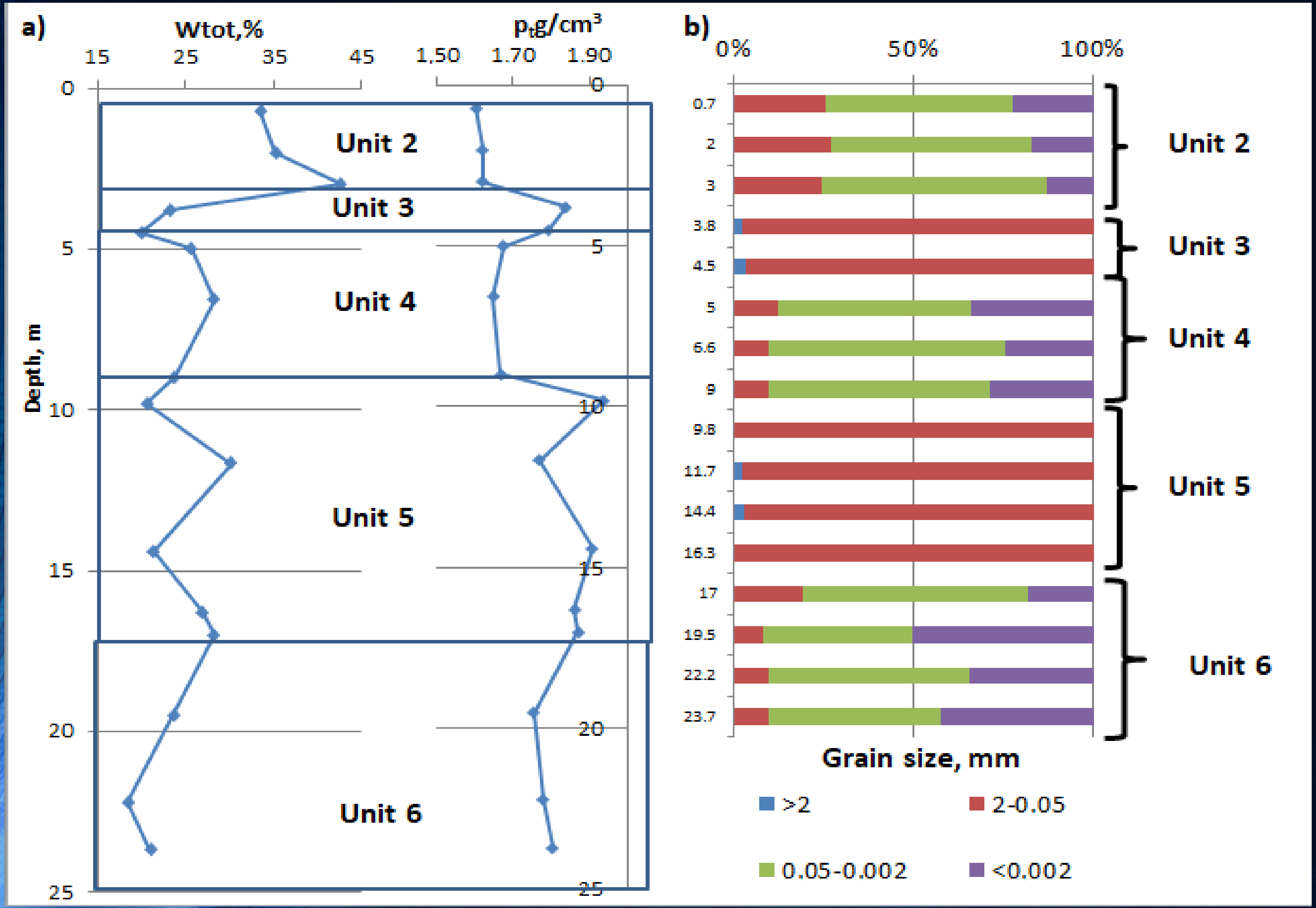
Thermometric monitoring





- The dynamics of changes in temperature fields
- Long-term data on soil temperature dynamics at depths up to 25 m are analyzed and the depths of zero annual amplitudes are determined.
- Observed temperature data formed the basis for numerical modeling of seasonal fluctuations in soil temperatures on the coast of the Arctic seas*
- * Mohammad Akhsanul Islam, Raed Lubbad, Seyed Ali Ghoreishian Amiri, Vladislav Isaev, Yaroslav Shevchuk, Alexandra Vladimirovna Uvarova, Mohammad Saud Afzal, Avinash Kumar, Modelling the seasonal variations of soil temperatures in the Arctic coasts, Polar Science, 2021, 100732, ISSN 1873-9652, https://doi.org/10.1016/j.polar.2021.100732. (https://www.sciencedirect.com/science/article/pii/S1873965221001201)

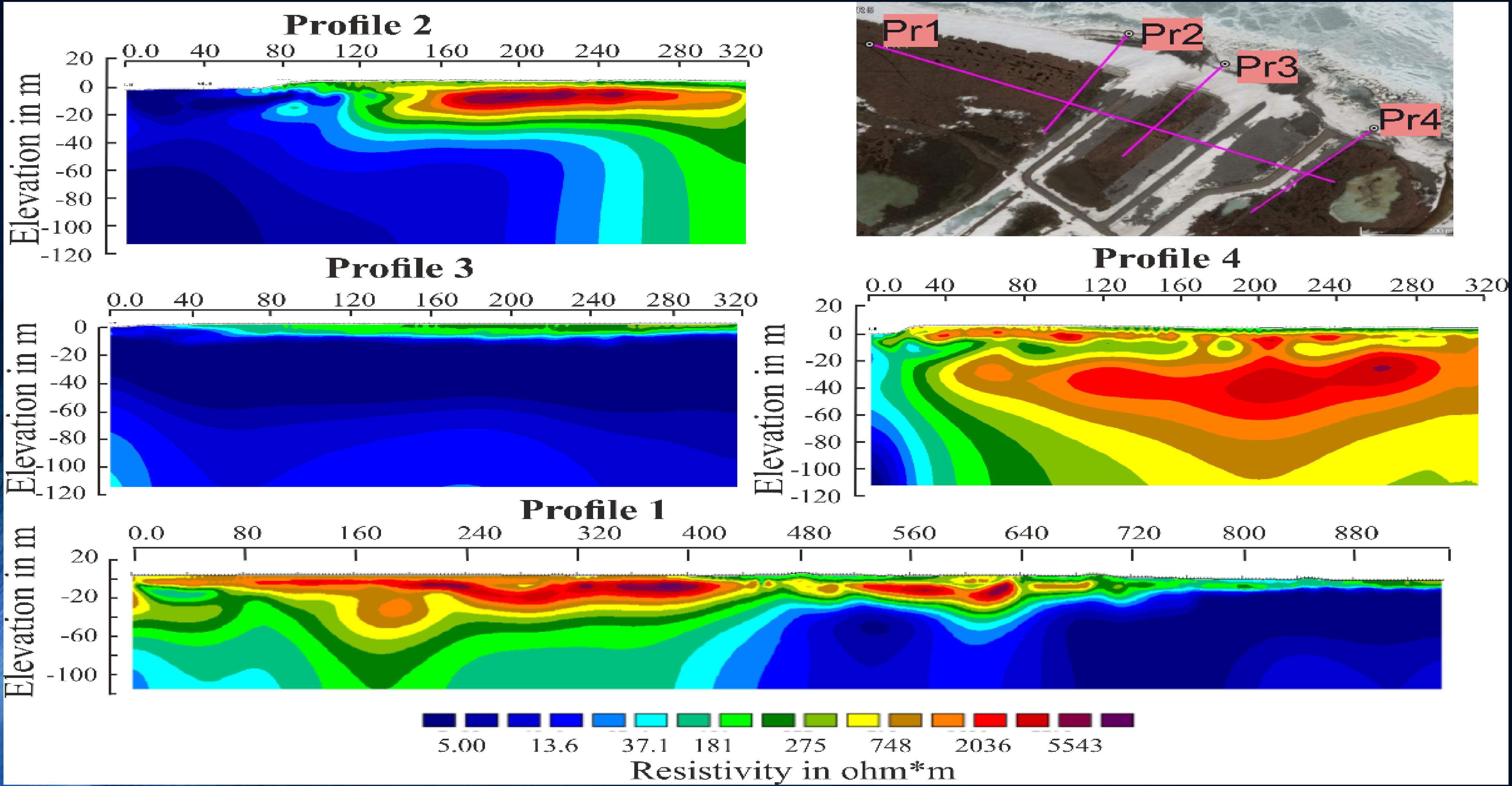
Laboratory studies of physical and thermophysical properties of rocks



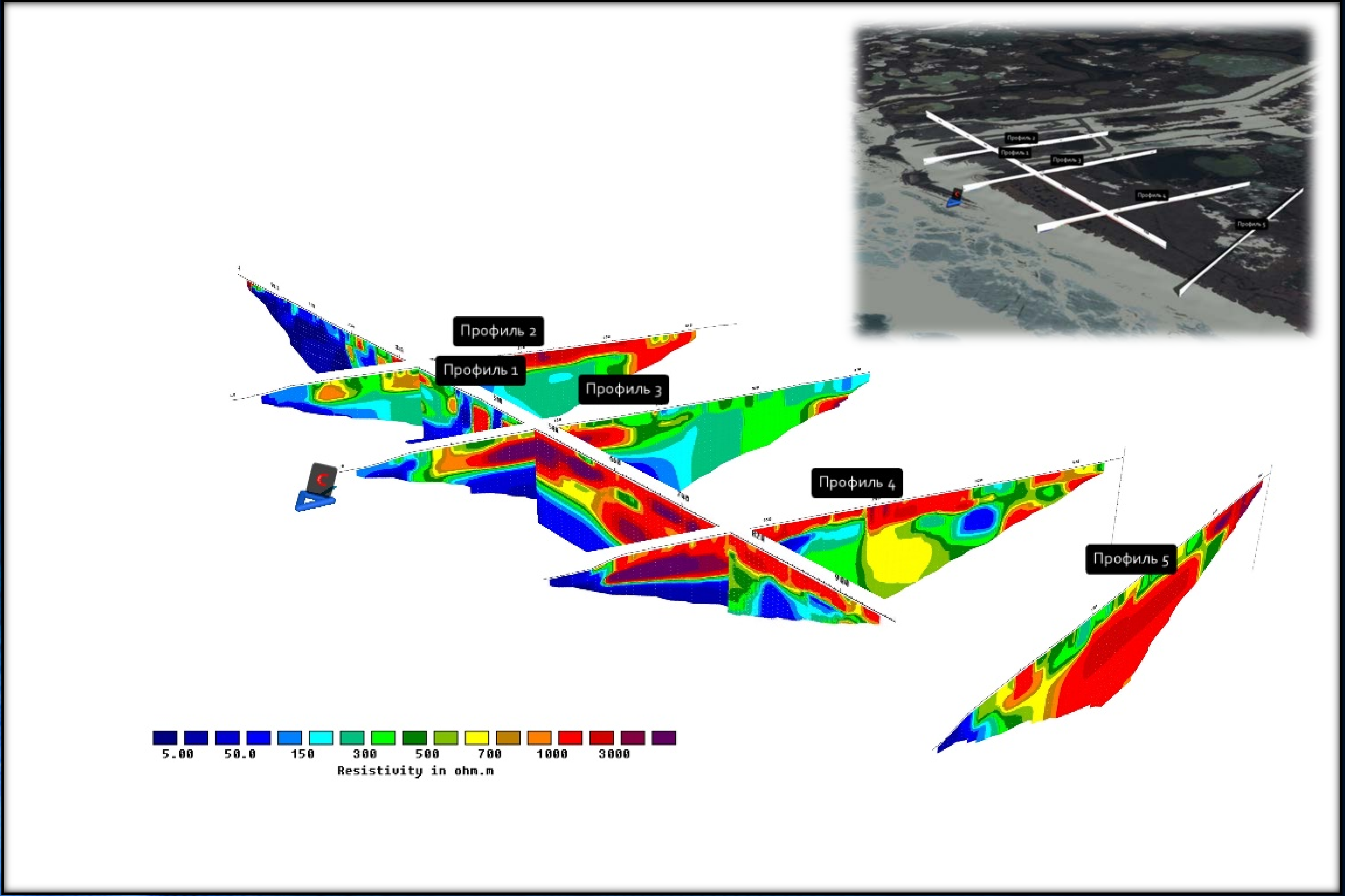
- In the field laboratory, data were obtained on density, moisture, consistency (for fine soils) in accordance with GOST (state standard of Russia) 5180-2015.
- Field results of thermal conductivity measurements, together with laboratory data on the physical properties of the rocks, were used to interpretation of the geophysical data.

a) water content W_{tot} and soil density ρ_t vs. depths,
b) grain size vs. depth.

Electrical resistivity tomography (ERT) 2019

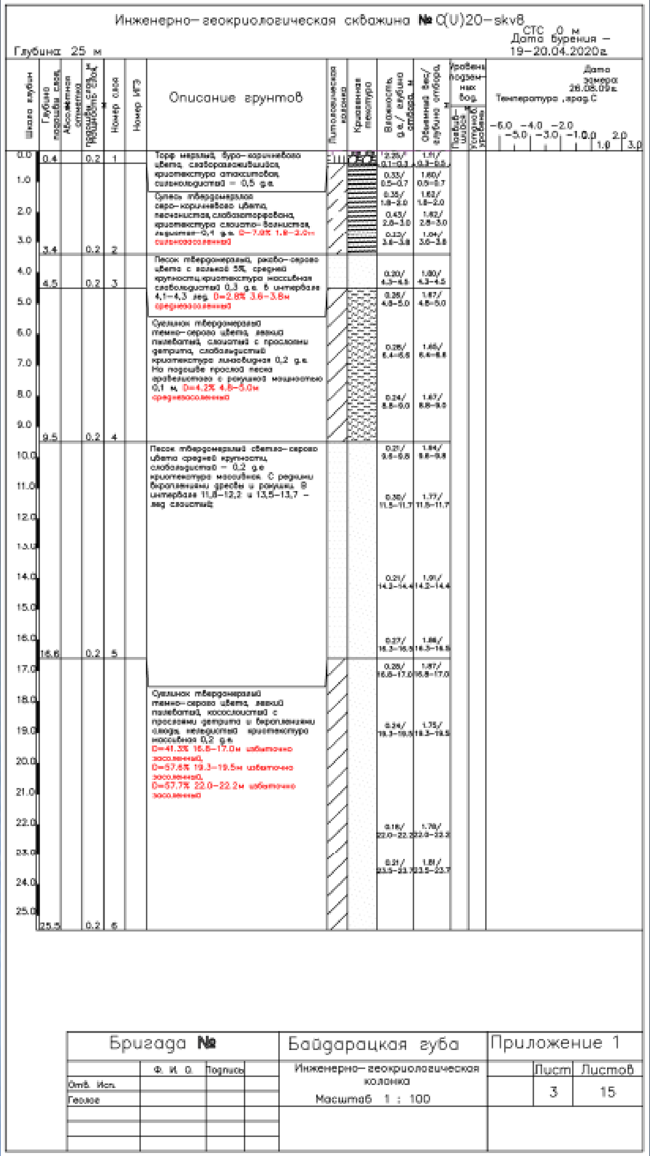


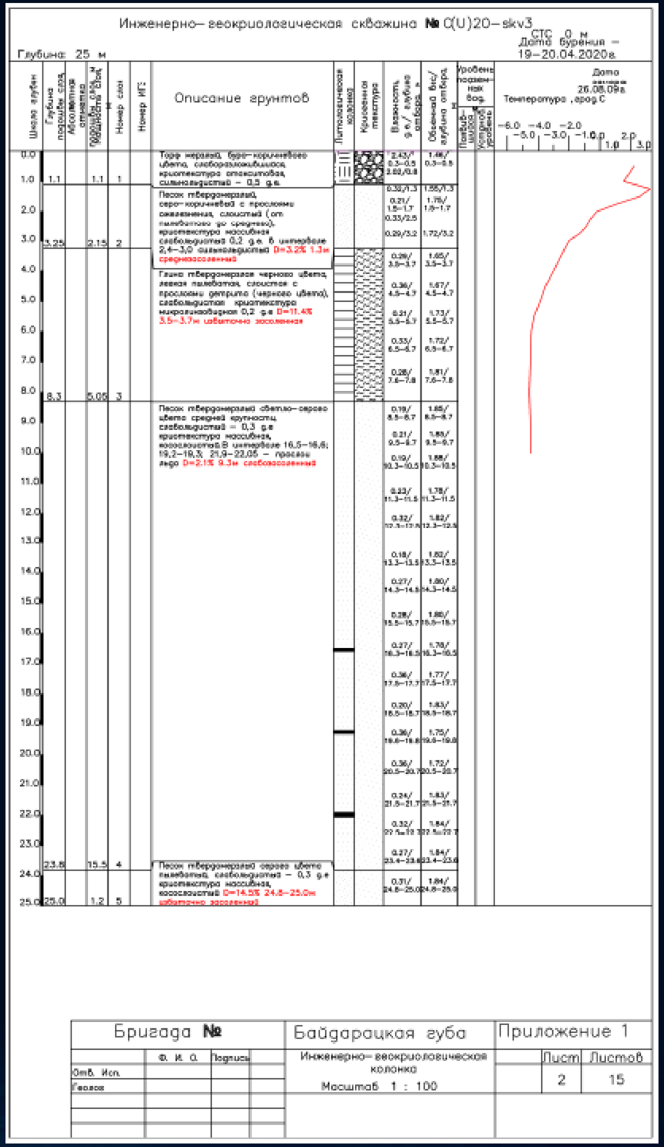
Electrical resistivity tomography (ERT) 2021

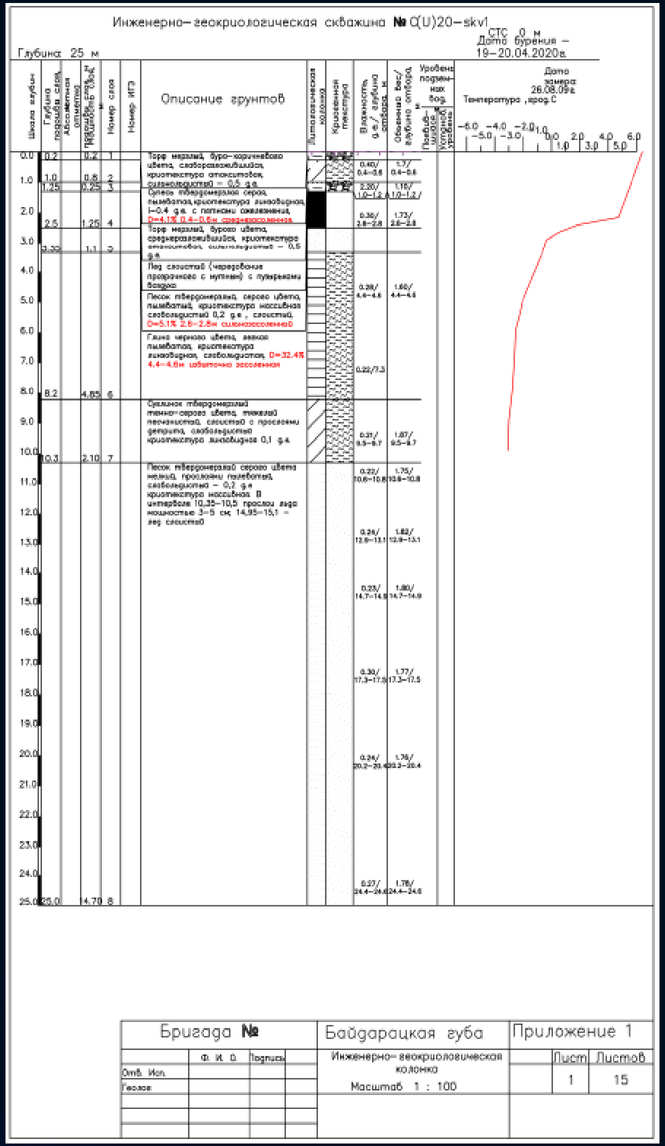


- ERT carried out using the SYSCAL Pro 48 electric tomography made it possible to substantiate the identification of landscapes, as well as to trace a number of patterns in the spatial position of the permafrost boundaries associated with the presence of icy layers and saline soil horizons, and in following repeated studies - to determine the dynamics of changes in the permafrost boundaries.

Engineering-geological drilling 2020

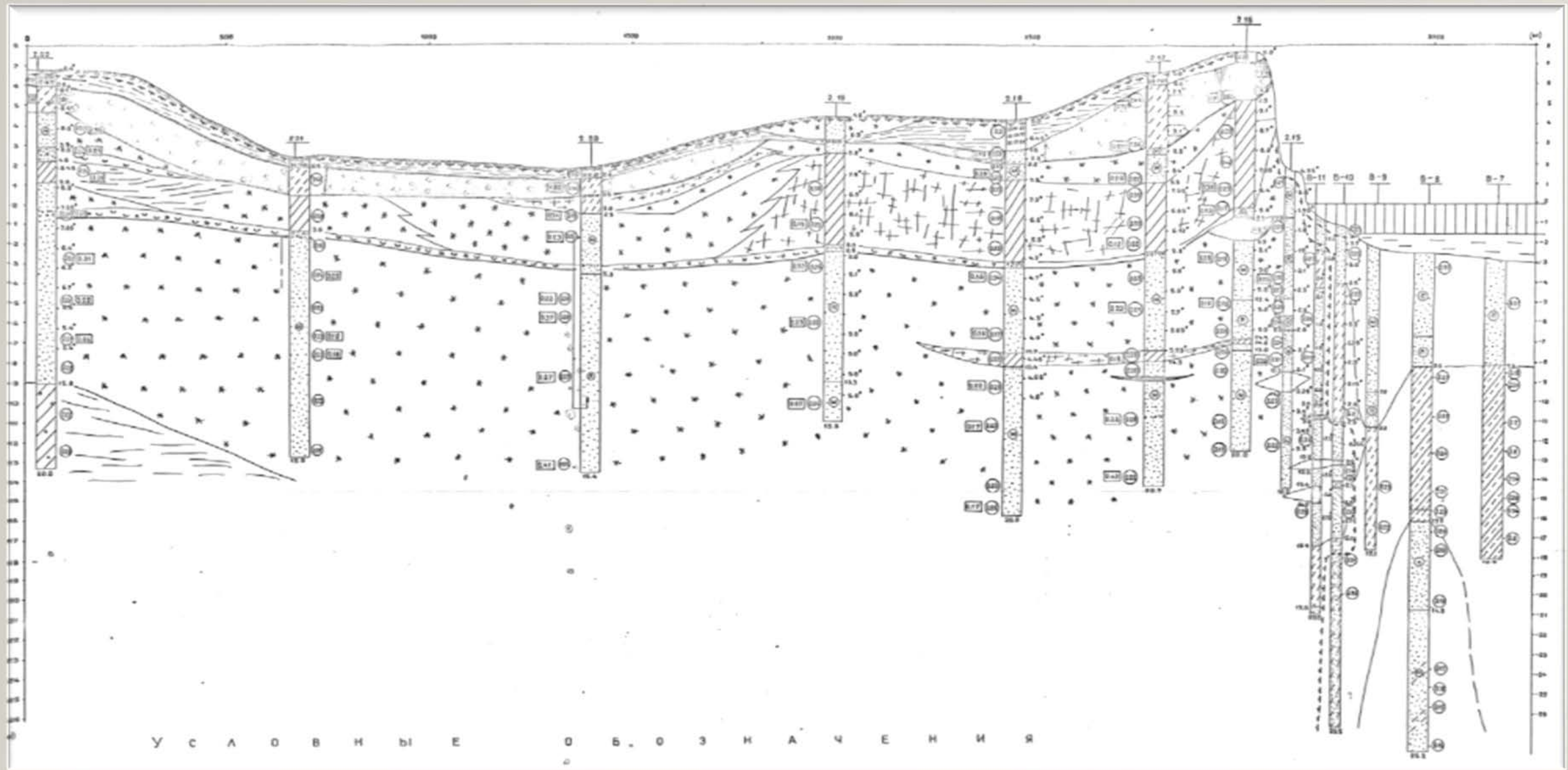






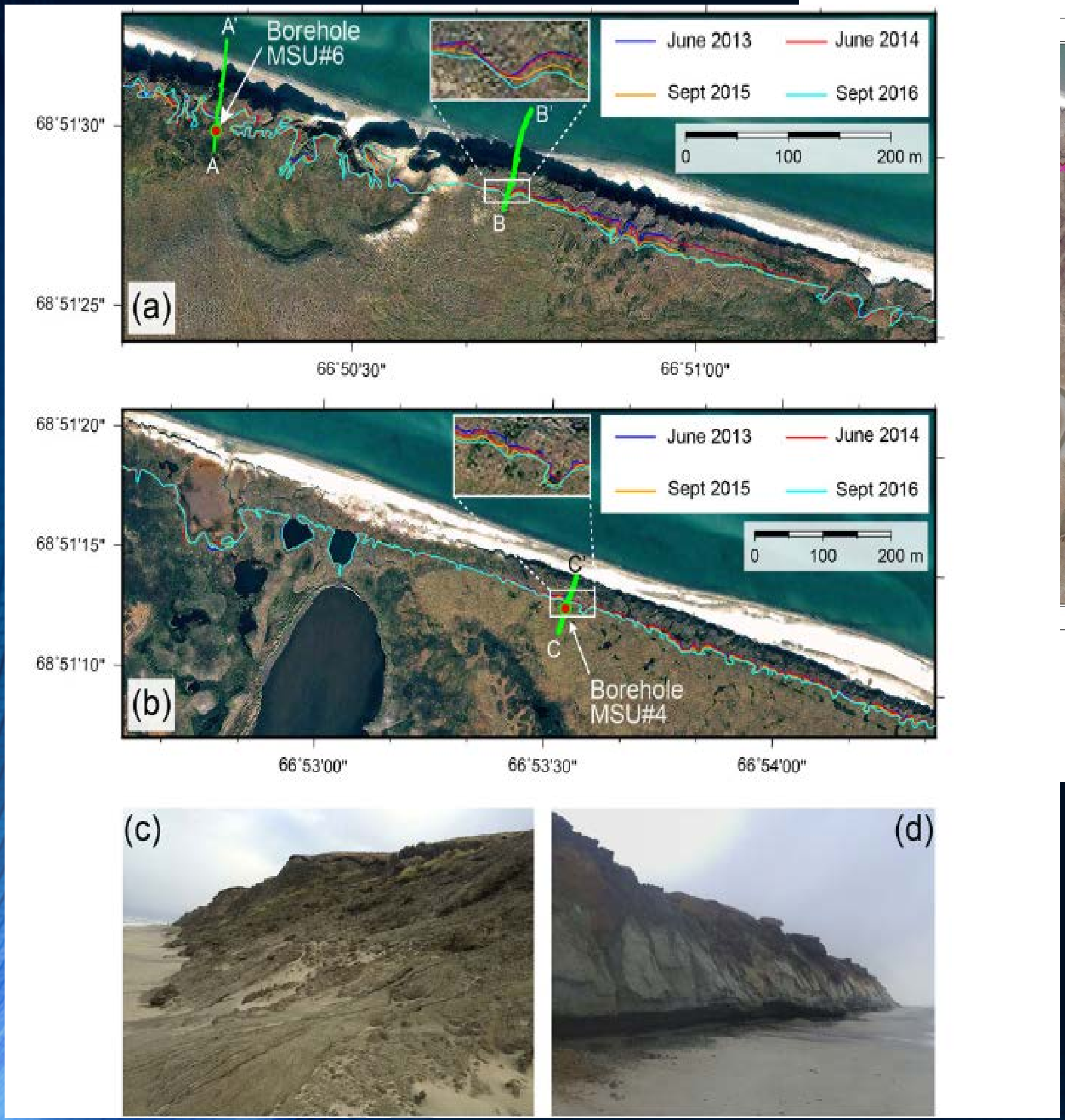
Feishutich, 2020

Engineering-geological drilling 1993



Kalbergenov, 1993

Differential geodetic position system (DGPS) cliff edge survey 2013-2021



Shift in coastal cliffs between June 2013 and September 2016 in (a) the western study area and (b) the eastern study area. Track lines of profiles perpendicular to the coast (green) in Figure 3 and positions of boreholes MSU#4 and MSU#6 are also shown. The satellite image was taken on 31st August 2005 by QB02 spacecraft. Imagery data are from DigitalGlobe. (c) Photo of the area of profile A–A′. (d) Photo of the area of profile B–B′. The photos were taken in September 2015

Cliff retreat of permafrost coast in south-west Baydaratskaya Bay, Kara Sea, during 2005–2016
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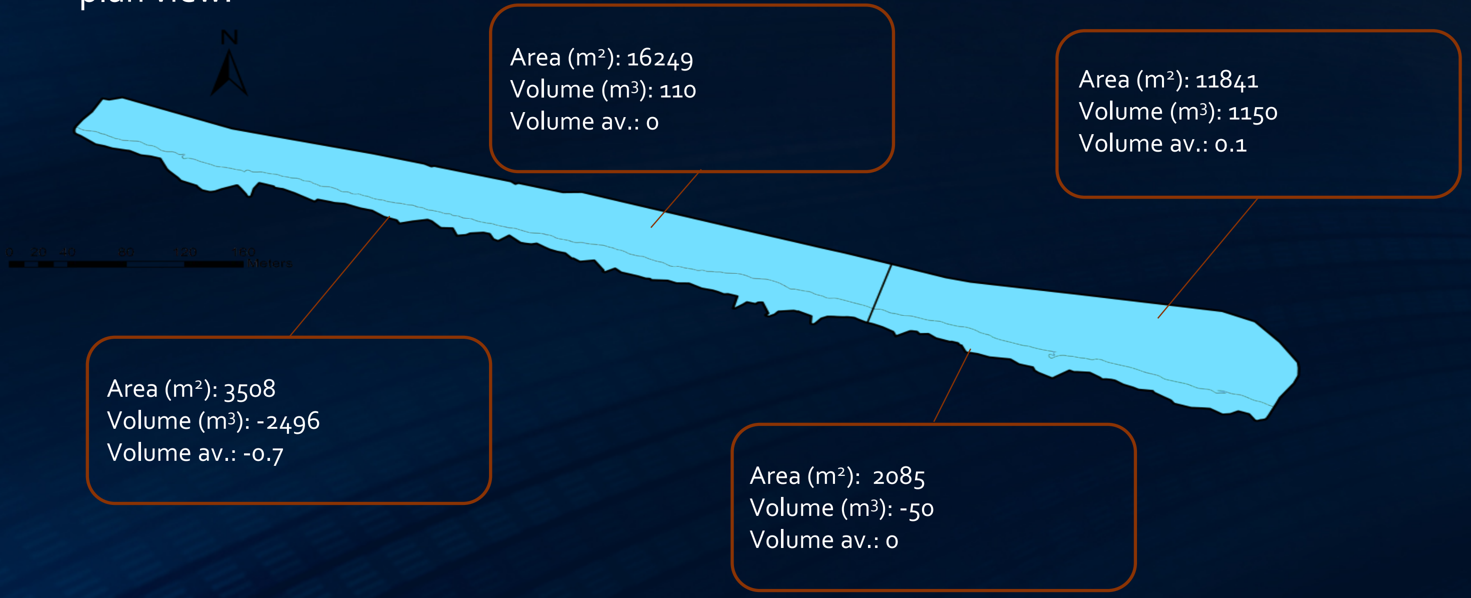
https://doi.org/10.1002/ppp.1993

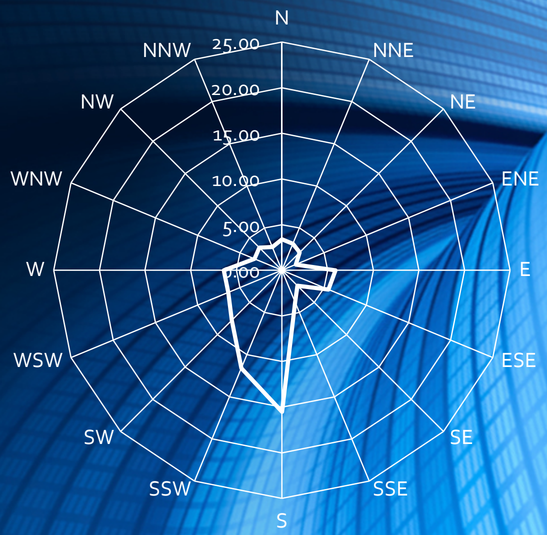
Laser scanning system survey results

summer 2016 | 2017

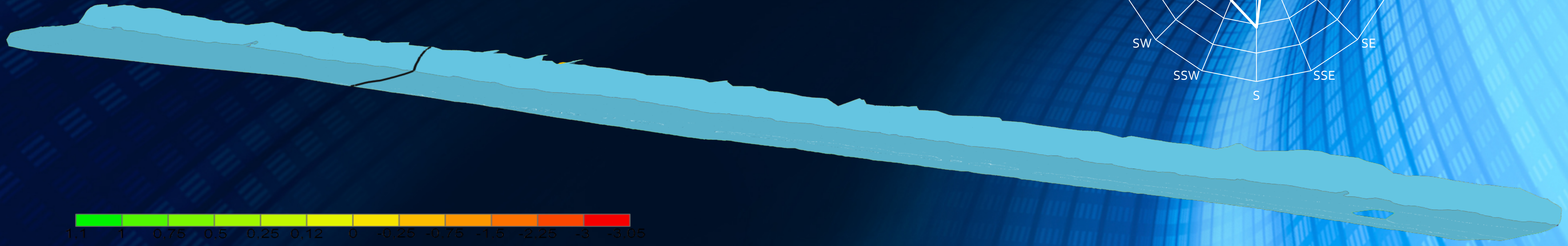
Calculations of the Baydaratskaya bay coastal surface changes | plan view:



main wind direction throughout summer period (days):

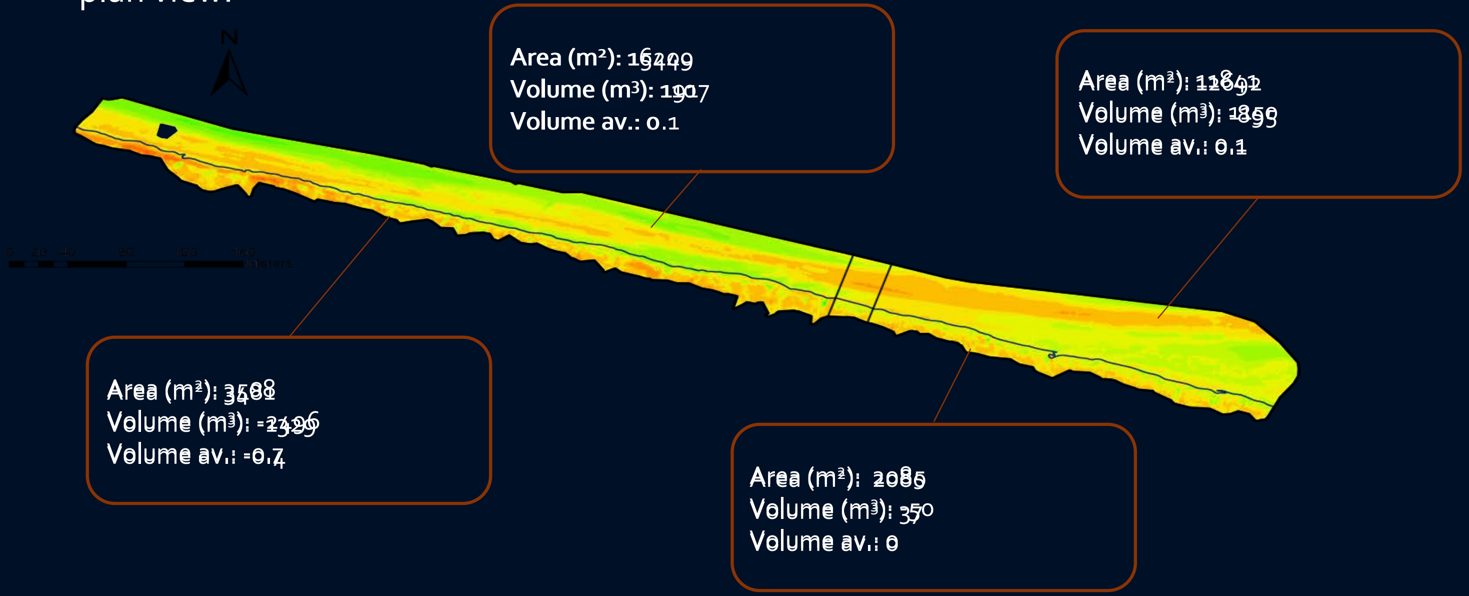


view from the Kara sea:

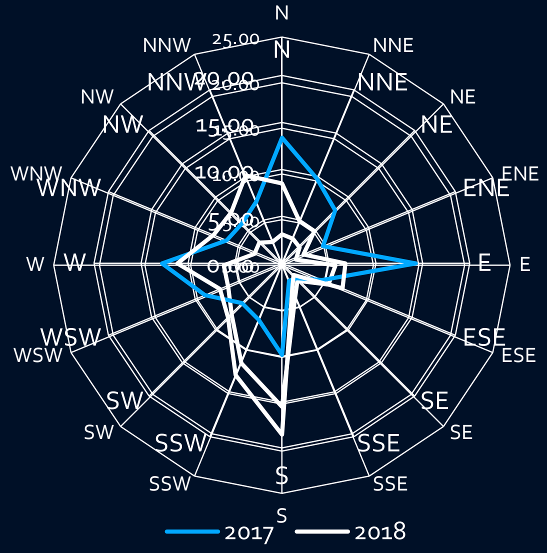


Calculations of the Baydaratskaya bay coastal surface changes | **summer 2017 2018**

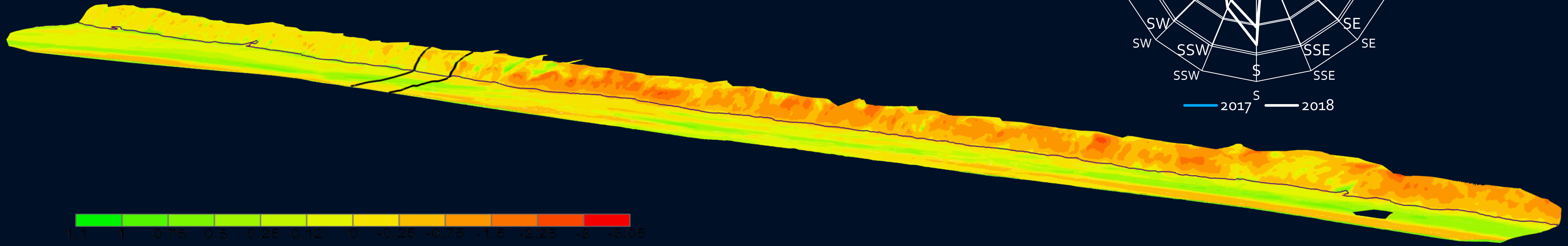
plan view:



main wind direction throughout summer period (days):

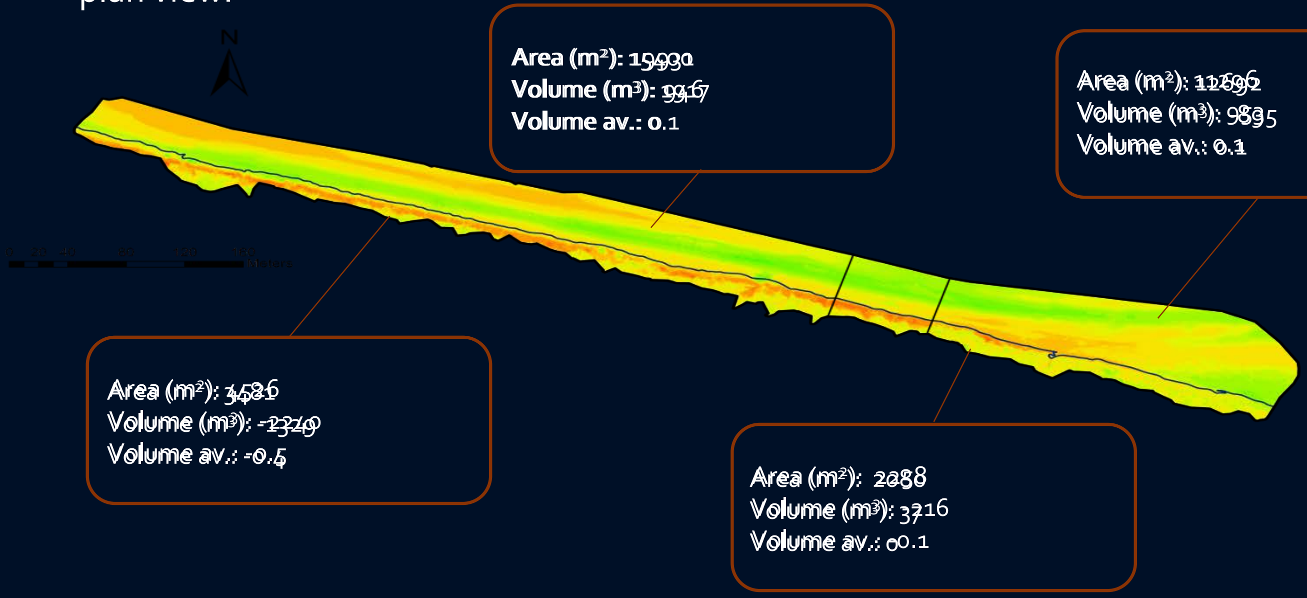


view from the Kara sea:

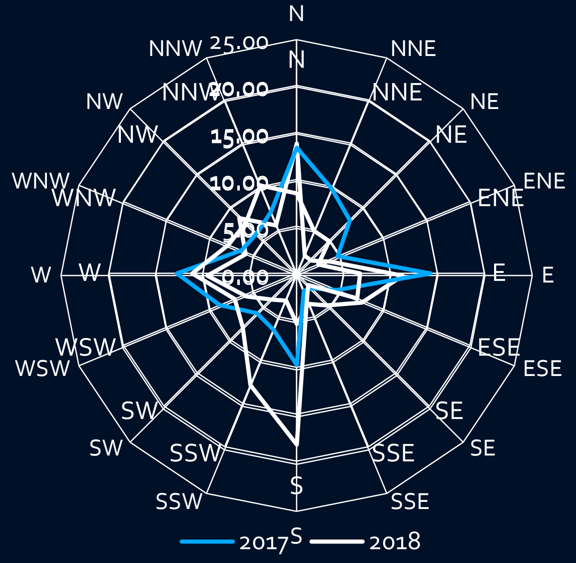


Calculations of the Baydaratskaya bay coastal surface changes | **summer 2018 2019**

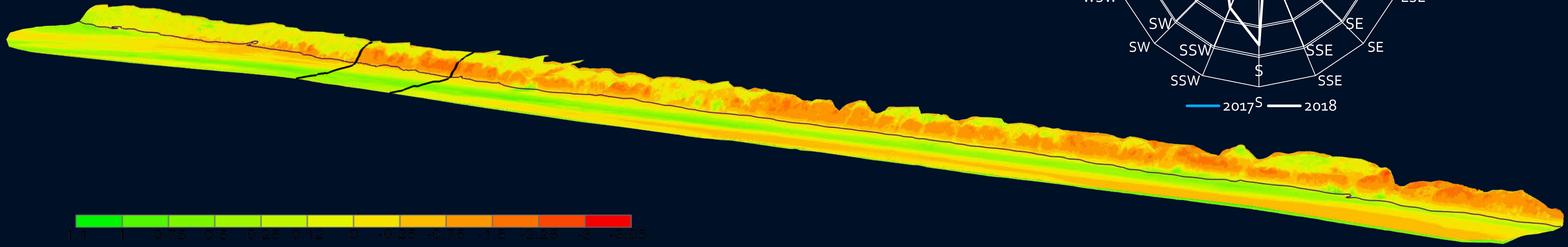
plan view:



main wind direction throughout summer period (days) 2019:



view from the Kara sea:



Landscape zoning mapping on the base of GIS

ISO 19115-1:2014 = GOST P 57668-2017

Field data mapping

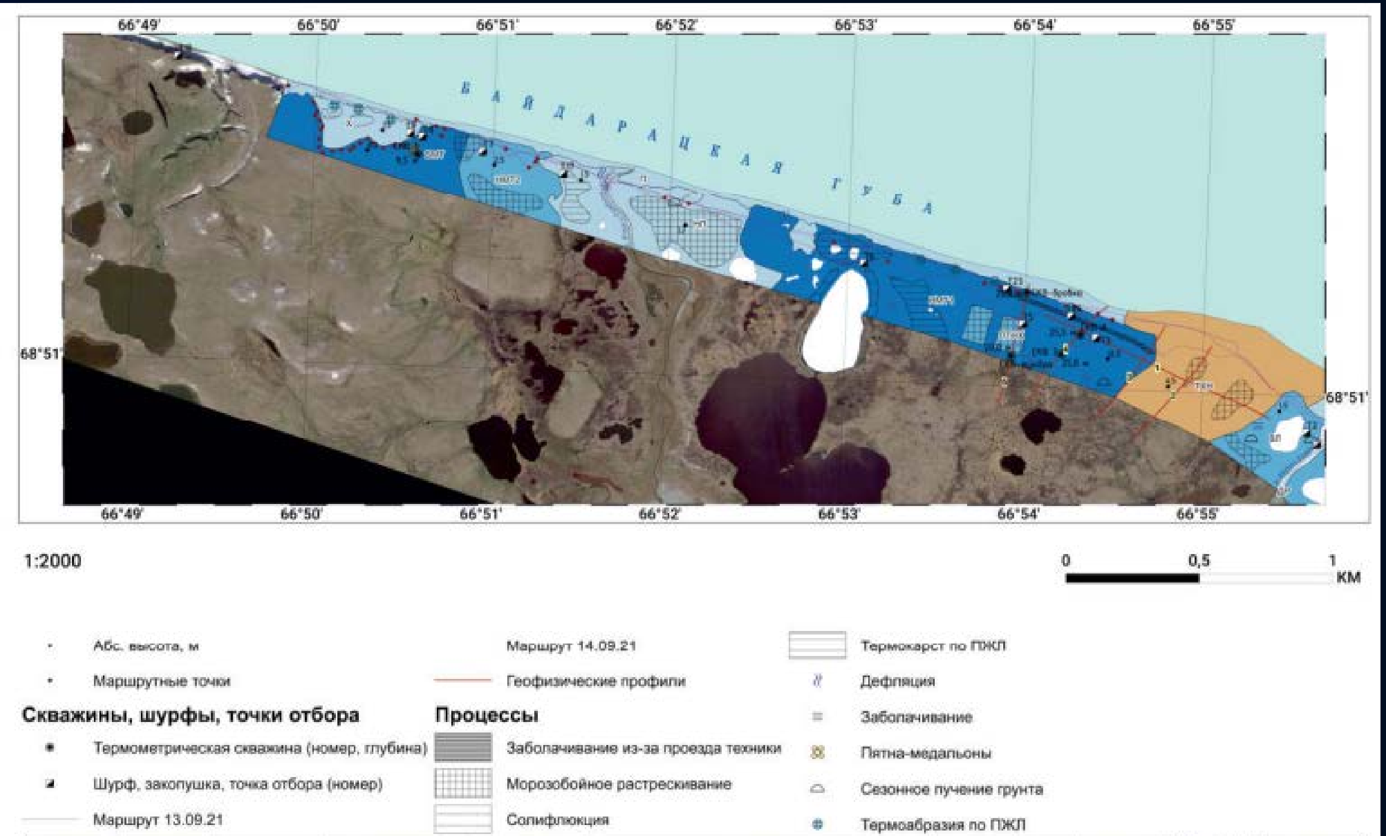
КАРТА ФАКТИЧЕСКОГО МАТЕРИАЛА
участка "БАЙДАРАЦКИЙ"

1:2000

0 0,5 1 КМ

- Абс. высота, м
- Маршрут 13.09.21
- Маршрут 14.09.21
- Геофизические профили
- Точка уточнения границ ландшафтов
- Зачистка
- Точка обследования морского берега
- Термометрическая скважина (номер, глубина)
- Точка отбора торфа
- Закопушка с отбором образцов
- Закопушка без отбора образцов
- Граница ландшафтов

- In the course of route studies, the micro relief, vegetation cover, soils (at key sites) were described, the thermophysical properties of the upper horizons and the thickness of the active layer were measured, and the observed geocryological processes and phenomena were fixed.
- A LiDAR survey of the coast was carried out.
- The thermophysical properties of the upper horizons were measured for each selected landscape using the MIT-1 probe.
- Comprehensive geophysical studies were carried out (electrical tomography (ERT) profiles were placed along the reference thermometric wells)



Тип ландшафта	Возраст и генезис отложений	Классификационный номер	Тип растительности	Тип увлажнения	Микрорельеф	Состав грунтов	Wtot, д. е.	Глубина СТС, м	Среднегодовая температура пород, °С	Процессы
Пляж	amIV	П	Отсутствует	Сухая	Субгоризонтальная поверхность со следами приливно-отливной деятельности моря. В период отлива виден бар. Конуса выноса вблизи термоцирков и оврагов	Песок, супесь	0,25	1,1	-2...-4	Термоабразия, дефляция
Низкая лайда	lmIV	НЛ	Мохово-травянистая	Увлажненная	[illegible]	Суглинок, торф	0,2	0,5-0,7	-1...-4	Термокарст, дефляция, морозобойное растрескивание, сезонное пучение
Высокая лайда	lmIV	ВЛ	[illegible]	[illegible]	Бугристо-западинная поверхность. Отдельные кочки высотой до 0,5 м	Песок, суглинок	0,18-0,36	0,5-1,2	-3...-4	Заболачивание, морозобойное растрескивание, сезонное пучение
Низкая морская терраса-1	mIII	НМТ1	Мохово-травянистая	Увлажненная	[illegible]	Супесь, суглинок	0,21	0,8-1,2	[illegible]	[illegible]
Низкая морская терраса-2	mIII	НМТ2	Мохово-травянисто-кустарничковая	Сухая	Полого-наклонная поверхность с мелкими кочками высотой до 0,2 м и полигональной сетью трещин. Размер полигонов 5-10 м, глубина трещин до 0,2 м	Суглинок	0,22	0,4-0,6	-3...-4	Морозобойное растрескивание
Высокая морская терраса	mIII	ВМТ	[illegible]	Сухая	[illegible]	Песок	0,13	[illegible]	[illegible]	[illegible]
Хасырей	lIIV	Х	Разнотравно-моховая	Сухая	[illegible]	Супесь, торф	0,21	>1,5	-2...-3	Солифлюкция, термоабразия по ПЖЛ
Долина ручья	aIV	ДР	Травянисто-моховая	Увлажненная	Полого-волнистая поверхность с небольшими буграми пучения высотой до 0,4 м и площадью до 2 кв. м	Песок, супесь	0,24	1,1	-1...-1,5	Сезонное пучение
Техногенный	tIV	ТХН	Редкие травы на насыпи. В понижениях - кустарничково-травянистая	Сухая	[illegible]	Щебень	НД	НД	НД	Морозобойное растрескивание
Посттехногенный	tIV	ПТХН	Злаковое разнотравье	Сухая	[illegible]	Суглинок, щебень	0,17	>1,5	-3...-4	Морозобойное растрескивание

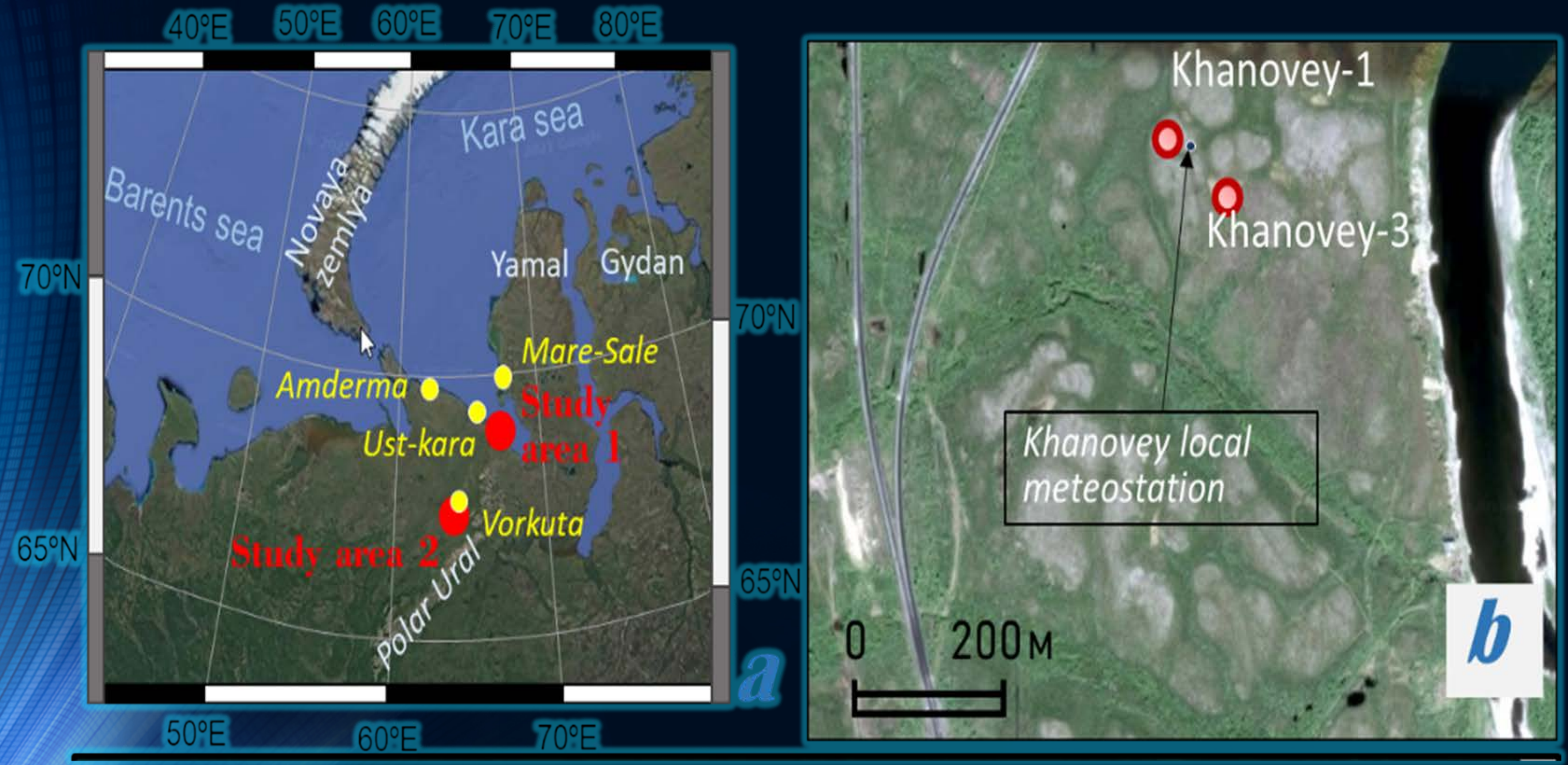
Landscape zoning mapping on the base of GIS

ISO 19115-1:2014 = GOST P 57668-2017

Geocryological mapping

- As a result of comprehensive studies the geocryological map was done. It can later be used for a more detailed study of each of the selected landscapes and for survey of the dynamics of geocryological processes in the coastal zone of the Arctic seas.
- The conducted studies have become the basis for understanding the mechanisms of coastal permafrost transformation, and can also serve as a basis for predicting of coastline retreat rate.

Geotest site "Hanovey"

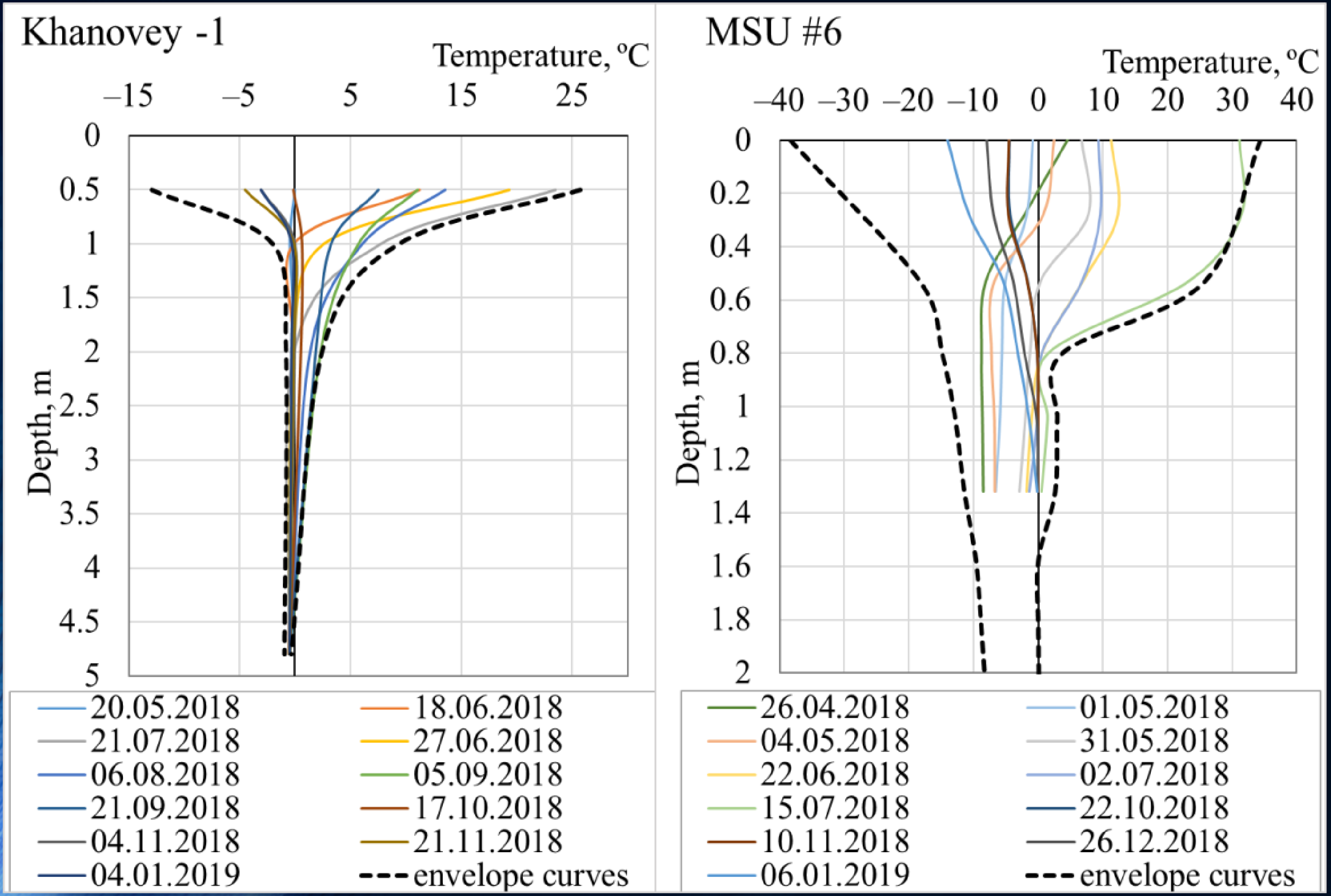


(a) Baydara and Hanovey geotest site location.

(b) Position of boreholes with logger thermal strings (Khanovey 1 and 3) and local meteo station on Hanovey geotest site

Isaev, V.; Kioka, A.; Kotov, P.; Sergeev, D.O.; Uvarova, A.; Koshurnikov, A.; Komarov, O.
Multi-Parameter Protocol for Geocryological Test Site: A Case Study Applied for the European North of Russia.
Energies **2022**, *15*, 2076. https://doi.org/10.3390/en15062076

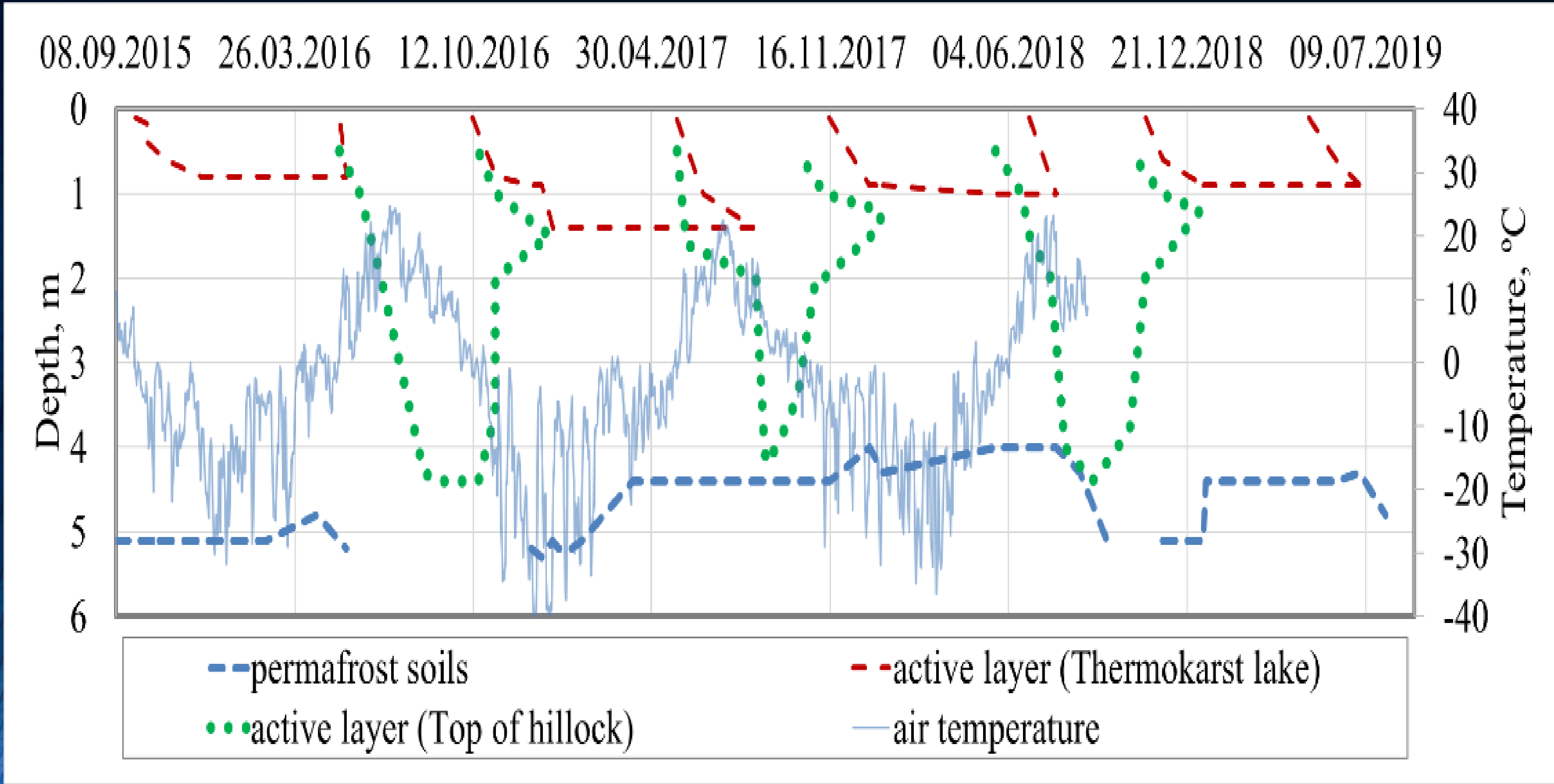
Thermometric monitoring



- The dynamics of changes in temperature fields in the study area was assessed
- Long-term data on soil temperature dynamics at depths up to 2 - 5 m are analyzed and the depths of zero annual amplitudes are determined.
- Temperature data formed the basis for numerical modeling of seasonal fluctuations in soil temperatures on the coast of the Arctic seas*

* Mohammad Akhsanul Islam, Raed Lubbad, Seyed Ali Ghoreishian Amiri, Vladislav Isaev, Yaroslav Shevchuk, Alexandra Vladimirovna Uvarova, Mohammad Saud Afzal, Avinash Kumar, Modelling the seasonal variations of soil temperatures in the Arctic coasts, Polar Science, 2021, 100732, ISSN 1873-9652, https://doi.org/10.1016/j.polar.2021.100732. (https://www.sciencedirect.com/science/article/pii/S1873965221001201)

Thermometric monitoring



- Changes of active layer thickness and depth of permafrost at the boreholes Khanovey-1 and 3 (air temperature was recorded from our local temperature sensor) on the base of thermometry in boreholes.

Isaev, V.; Kioka, A.; Kotov, P.; Sergeev, D.O.; Uvarova, A.; Koshurnikov, A.; Komarov, O.
Multi-Parameter Protocol for Geocryological Test Site: A Case Study Applied for the European North of Russia.
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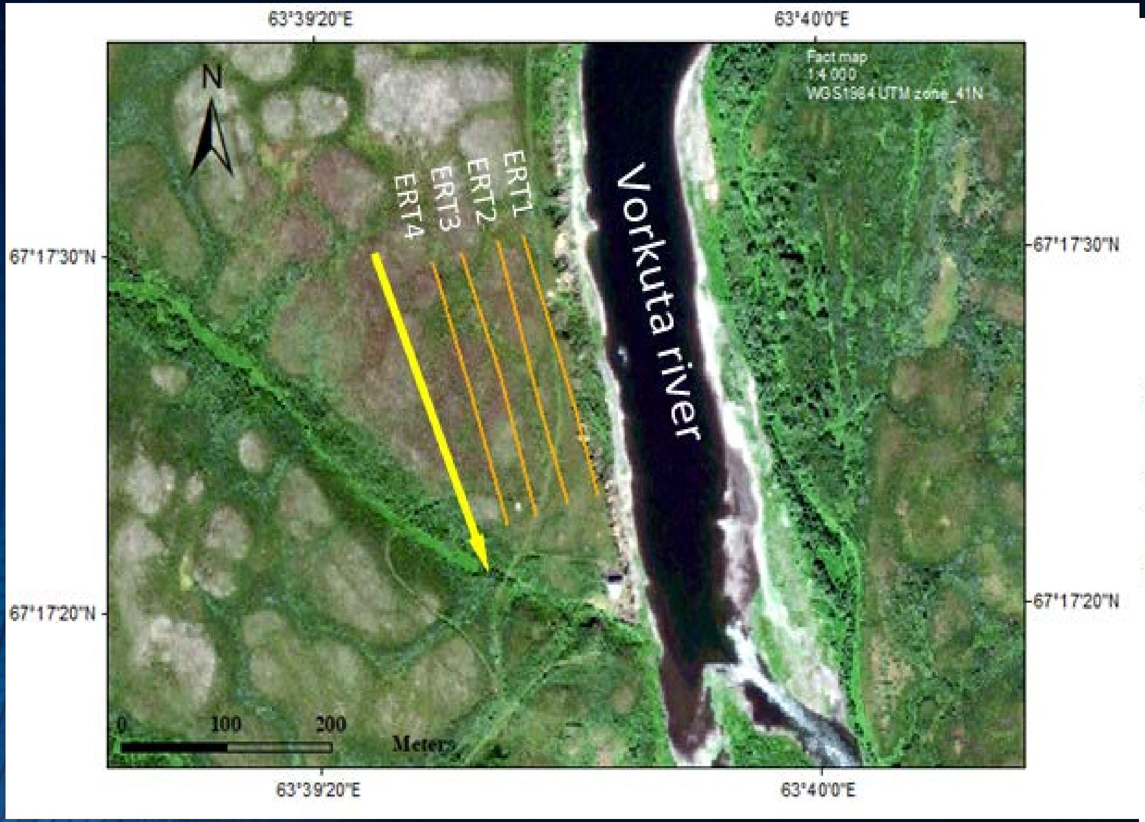
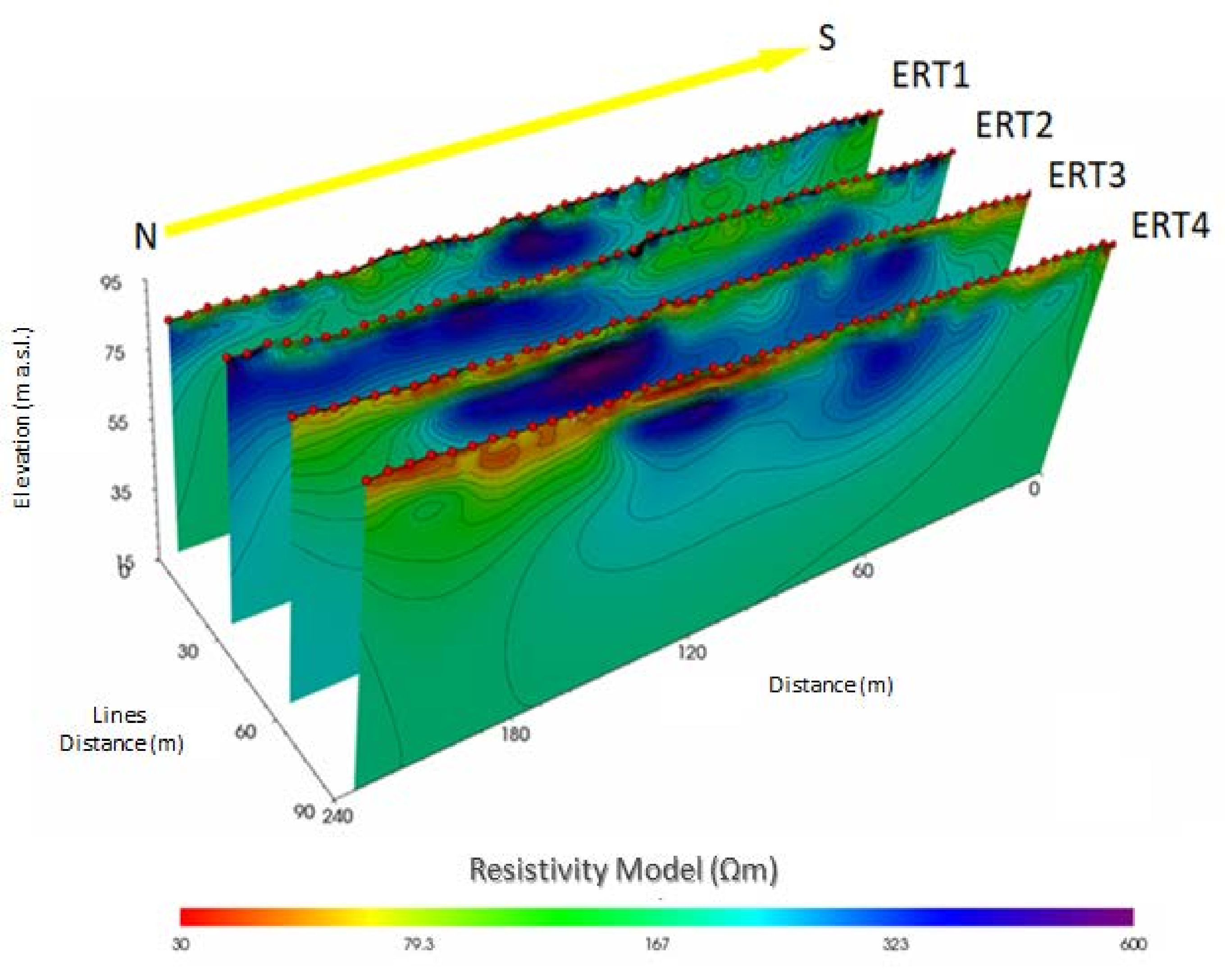
Electrical resistivity tomography (ERT) 2019

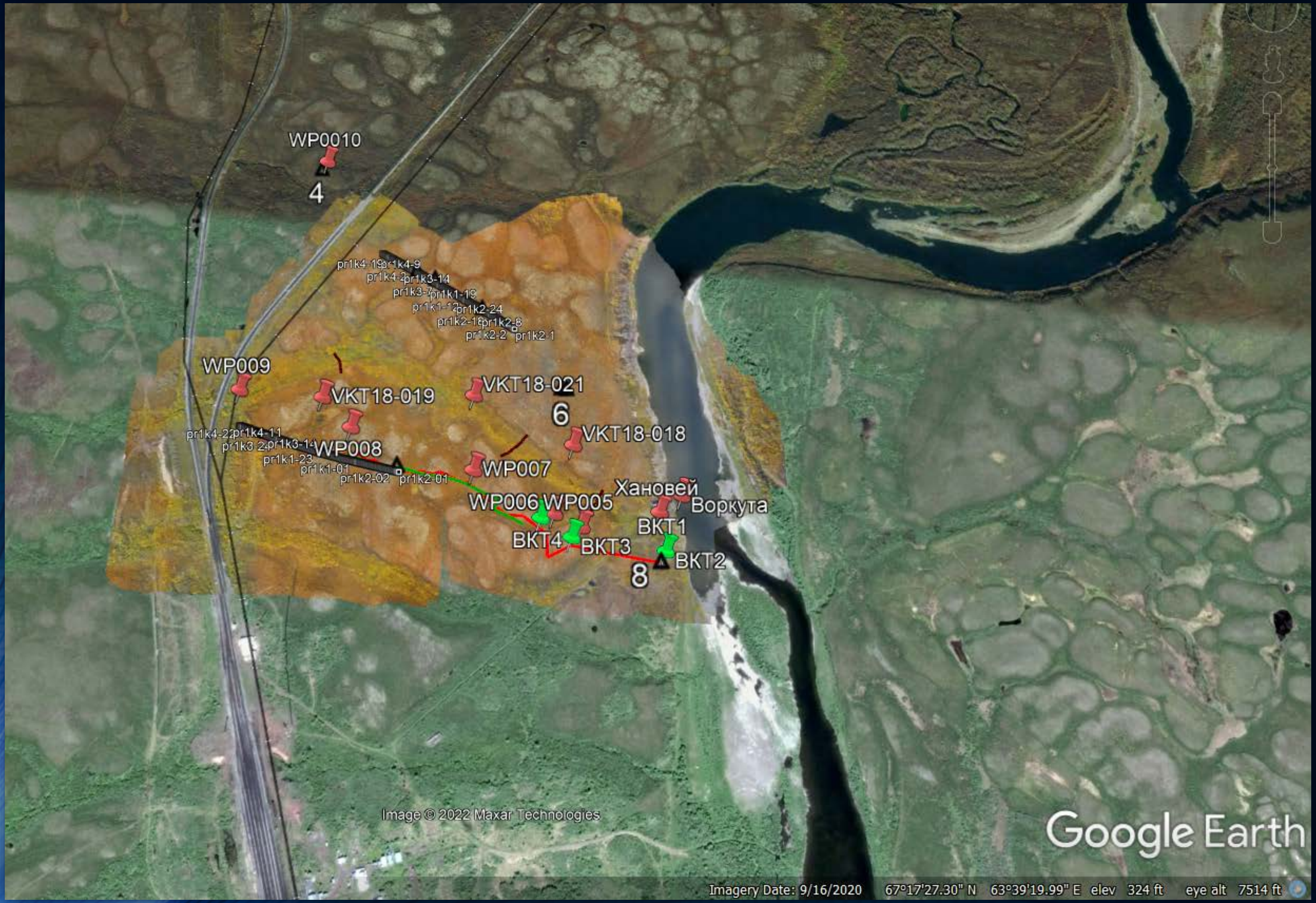




Location map with ERT1, ERT2, ERT3, ERT4 profiles position; orientation of the 3D view is shown by the yellow arrow. On the bottom: north-south 3D view of the four ERT profiles of site 1A (electrodes in red dots). Elevation meters above sea level is expressed in Z axis; distance between lines is represented on the Y axis and electrodes distance is shown on the X axis. Resistivity values of the models are expressed in Ωm referring to the log scale. Iso-resistivity lines are represented by grey contours. Moving to east, towards the Vorkuta river, thickness and spatial distribution of low resistivity layer (< 80 Ωm) decrease.

M. Rossi, M. Dal Cin, S. Picotti, D. Gei, V. Isaev, A. Pogorelov, E. Gorshkov, D. Sergeev, P. Kotov, and M. L. Rainone. Geophysical and geocryological investigation of active layer along the north russian railway (khanovey, russia). In *Engineering and Mining Geophysics 2021*, volume 2021, pages 1–5, Netherlands, 2021. Netherlands. [DOI]

Landscape zoning mapping on the base of GIS



Field data mapping (mosaic UAV image, ERA lines (WP...), key sites centers with vegetation and ground probing (VKT...)

Isaev, V.; Kioka, A.; Kotov, P.; Sergeev, D.O.; Uvarova, A.; Koshurnikov, A.; Komarov, O.
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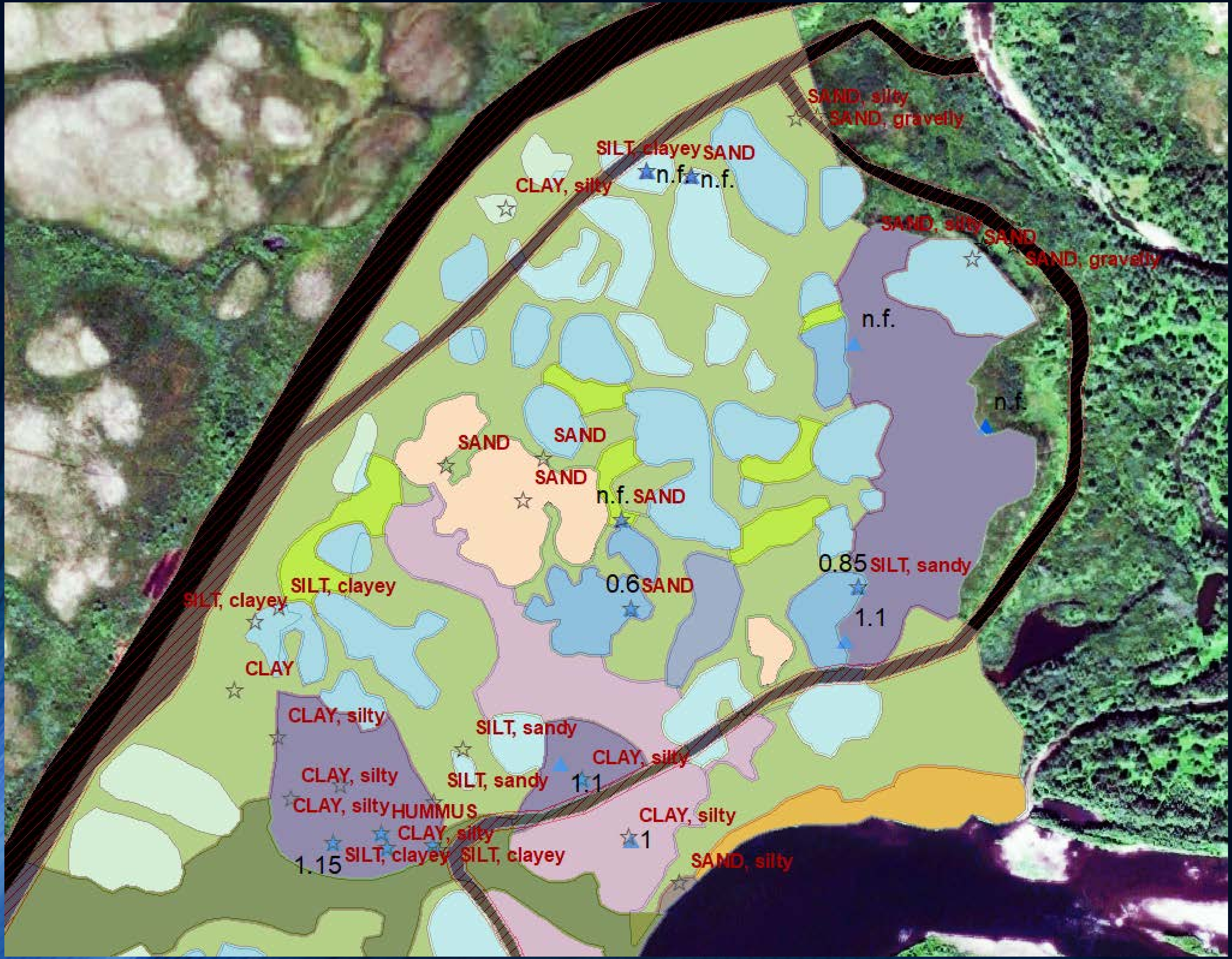
Landscape zoning mapping on the base of GIS

Color	Name of zone	Micro-zone №	Meso- and microrelief, surface characteristics	Surface drainge	Vegetation	Composition of active layer deposits (seasonally-thawed)	Thickness of active layer	Cryogenic processes	Actual field data	Composition of underlying permafrost
	Moundy hilltop	1,1	Meso: None to small relief Micro: 20-50 cm mounds	Dry	Lichen, tall shrubs on mound	SIlT or CLAY	0.85-4	Frostheave	Borehole no. 6	Lean silty clay with massive cryogenic structure observed
	Even hilltop	1,2	Meso: None to small relief Micro: Even	Dry	Lichen, small or none shrubs	SIlT or CLAY	3,6	None	Borehole no. 1 and 5	Lean clay
	Mixed hilltop	1,3	Meso: None to small relief Micro: 0-20 cm mounds	Dry	Lichen, tall shrubs	SIlT or CLAY	4,4	Small activily	None	Lean clay
	Valley	2,1	Meso: U-formed landscape Micro: Even to small bumps	Dry to stream	Tall birch, dwarf shrubs, grass, water grass	Usually SAND, gravelly, with pebbles	n.f.	None	Borehole 4	Lean clay
	Bushy depression	2,2	Meso: In-between hilltop Micro: Flat	Moist with stream	Birch and red shrubs	Coarse	n.f.	Warm area	Borehole no. 2	Lean clay and silt and rocks on bottom
	Swamp/grass depression	2,3	Meso: In-between hilltop Micro: Moundy	Moist to wet	Green moss, grass	SIlT or CLAY	0.4-1	Frostheave or/and thermokarst	Borehole no. 3	Lean clay
	Riverbank (landslide)	3,1	Meso: more than 40 Micro: Even	Very dry	None or little grass and waterplants	SIlT or CLAY	1,8	Ice wedge landslide	Slope digging 2019	Clay and silt composition
	Riverbank (forest)	3,2	Meso: less than 40 Micro: Small bumps	Dry	Trees, birch, grass	Usually coarse-grained deposit	n.f.	Warm area	None	No information
	Moundy hill slope	4,1	Meso: evenly distributed distance Micro: bumpy	Wet	Lichen, moss, grass, dwarf birch	SIlT or CLAY	0.5-1.15	Frostheave	Borehole 7	silty clay
	Even hill slope	4,2	Meso: evenly distributed distance Micro: Even	Dry	Lichen, small or none shrubs	SIlT or CLAY	1-1.5	None	None	No information
	Anthropogenic	5,1	Irrelevant	Varrying	Mostly bare or grass, unnatural forms	Usually sand or gravel filling, if not - compacted	-	Warm area	None	No information

Legend of the geocryological map

Student report, Field work 2019

Landscape zoning mapping on the base of GIS



The geocryological map

Student report, Field work 2019

Conclusions

- **The new way of complex research of arctic areas considerably improve the GTN-P methodology by the ERT, LiDAR technology . The new complex way for each parameters data set is proposed. Considerable input of vegetation cover impact in cryological environment is state. The final analytic geocryological mapping in GIS is accumulating all field, lab and calculated/modelling data and open ability for the forecast calculations.**

- **The field material collected by the authors and the availability of access to archival data in the form of a complex of data from engineering and geological drilling, year-round data on temperature measurements in wells and annual LiDAR surveys of the coastal zone make it possible to quantitatively and qualitatively evaluate the long-term dynamics of geocryological processes.**

- **The data obtained in the course of many years of research served as the basis for substantiating the conclusions about the main reasons for the retreat of the coastline* and for creating a model for changing temperature conditions in the soil mass of the coastal zone**.**

*Cliff retreat of permafrost coast in south-west Baydaratskaya Bay, Kara Sea, during 2005–2016 V.S. Isaev, A.Kioka, A.V. Koshurnikov, A. Pogorelov, R.M. Amangurov, O. Podchasov, D.O. Sergeev, S.N. Buldovich, 2019. Permafrost and Periglacial processes, V30, Issue 1, pp. 35-47 https://doi.org/10.1002/ppp.1993

** Mohammad Akhsanul Islam, Raed Lubbad, Seyed Ali Ghoreishian Amiri, Vladislav Isaev, Yaroslav Shevchuk, Alexandra Vladimirovna Uvarova, Mohammad Saud Afzal, Avinash Kumar, Modelling the seasonal variations of soil temperatures in the Arctic coasts, Polar Science, 2021, 100732, ISSN 1873-9652, https://doi.org/10.1016/j.polar.2021.100732. (https://www.sciencedirect.com/science/article/pii/S1873965221001201)

- **The Baydaratskaya Bay and Hanovey research areas can be used as a geotest sites*** for testing the methods of integrated geotechnical and geocryological monitoring and testing of new technologies (as** Synthetic Aperture Radar Interferometry **InSAR**** apply to frost heave measurement) in a typical areas of the Arctic.**

- ***Jean-Sebastien L'Heureux, Tom Lunne. Characterization and engineering properties of natural soils used for geotesting[J]. AIMS Geosciences, 2020, 6(1): 35-53. doi: 10.3934/geosci.2020004

- **** Rouyet, L., Karjalainen, O., Niittynen, P., Aalto, J., Luoto, M., Lauknes, T. R., et al. (2021). Environmental controls of InSAR-based periglacial ground dynamics in a sub-arctic landscape. *Journal of Geophysical Research: Earth Surface*, *126*, e2021JF006175. https://doi.org/10.1029/2021JF006175

The term **reference site**, or **geotest site*** refers to a site that is well characterized and that can be used to compare measurements or observations made by different techniques or methods. This means that a test site must be well defined in terms of geological history, soil classification parameters and strength, deformation and flow parameters. Other requirements or specification for a test site usually include, but are not necessarily limited to:

- Representative soil conditions for an area or project type.
- Ease of access.
- Availability.
- Size—e.g. large enough for model testing.
- Relevant infrastructure is in place; e.g. access road, water supply and electricity.

*Jean-Sebastien L'Heureux, Tom Lunne. Characterization and engineering properties of natural soils used for geotesting[J]. AIMS Geosciences, 2020, 6(1): 35-53. doi: 10.3934/geosci.2020004

Future

- **The new way of frost heave monitoring by multi-geometry Sentinel-1 Synthetic Aperture Radar Interferometry (InSAR)***
- * Rouyet, L., Karjalainen, O., Niittynen,P., Aalto, J., Luoto, M., Lauknes, T. R.,et al. (2021). Environmental controls of InSAR-based periglacial ground dynamics in a sub-arctic landscape. *Journal of Geophysical Research: Earth Surface*, *126*, e2021JF006175. https://doi.org/10.1029/2021JF006175
- **Hydrological aspect of permafrost research.** "Isotopic evidence supports upward subpermafrost groundwater migration through open taliks under water tracks and fens/bogs/depressions and its supply to streams via shallow subsurface compartment. Temporal variability of isotopic composition and dissolved organic carbon (DOC) in water track and a major river system, the Vorkuta River, evidence the widespread occurrence of the described processes in the large river basin. Water tracks effectively drain the tundra terrain and maintain xeric vegetation over the elevated intertrack tundra" ****.**
- * * Hydrological connectivity in a permafrost tundra landscape near vorkuta, north-european arctic russia / N. Tananaev, V. Isaev, D. Sergeev et al. // *Hydrology*. — 2021. — Vol. 8, no. 3. — P. 106–116. DOI 10.3390/hydrology8030106
- **Machine learning technics for typical landscape recognition** and mapping**. Base on the UAV images collection and is the final stage of area survey. *****
- ***Applications of permafrost_CCI _time series, Bartsch A.[1] , Pointner G. [1], [1]b.geos, Korneuburg, Austria, annett.bartsch@bgeos.com   Report on International conference CTGS'21 ISBN 978-5-6046108-4-8. URL: Электронный ресурс (PDF)