MAPPING OF ARCTIC LANDSCAPES USING MULTI-TEMPORAL SENTINEL-1 IMAGERY: A CASE STUDY OF KOTELNY ISLAND

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Abstract
Radar data is of primary importance for Arctic regions study and mapping. Kotelny Island was selected as an area of interest due to well-defined landscapes diversity and abundance of Sentinel-1 radar data. The study based on multi-temporal and multi-polarization images acquired by Sentinel-1A at a period from October 2015 to September 2016. The ways of modified radar images creation are proposed, which aimed at their adaptation for visual and automated interpretation. The main factors influencing the backscatter values and its dynamics are revealed based on additional data sources. The main result of the research is a map of natural landscapes of Kotelny Island at a scale 1:750 000. Spatial and temporal variations of backscattering coefficient allowed semi-automatic delineating the boundaries of landscapes which are characterized by different combination of the relief, vegetation and soils. Table legend of the map contains information both on landscapes features and respective annual backscatter behavior.

Keywords: Satellite radar images, Sentinel-1, Time series, Backscatter dynamics, Seasonal changes, Kotelny Island, Permafrost, Thematic mapping, Natural landscapes

INTRODUCTION

Satellite synthetic aperture radar (SAR) remote sensing and SAR data processing are actively developing during the last several decades. Both the amount of satellites and acquired data volumes have rapidly grown in recent years. Several decades of engineering and practical use of SAR systems revealed the benefits of acquired data for different fields of earth sciences: geology, hydrology, oceanology, agriculture, forestry, natural disaster monitoring, etc. [Ouchi, 2013]. One of the earliest application of radar images was mapping of tropical rainforests which are especially often covered by clouds; later this data source was used for forest biomass estimation and mapping. Currently SAR data is often used for operational sea ice, water pollution and flood maps creation. Digital elevation models and displacement maps creation based on radar interferometry methods was also actively developed recently.

Such property of satellite radar remote sensing as possibility of all-weather, day-and-night observation of the Earth surface is very important for investigation and mapping of polar regions with long polar night during several winter months, while a persistent cloud cover is typical for a short summer, that restricts the use of optical remote sensing data. The appearance of free-access actual (since 2014) SAR data from Sentinel-1 with the high temporal frequency [Sentinel Online…] together with a processing software open new opportunities for geographical research. During the first years of Sentinel-1 imaging system operation a large amount of SAR data was acquired. Time series of Sentinel-1 images have already been used for investigation and monitoring of agricultural [Myshlyakov, 2016] and forest vegetation [Rodionova, 2016], for surface displacements revealing [Crosetto et al., 2016].

The paper concerns the ways of multi-polarization and multi-temporal Sentinel-1 radar data use for mapping of Arctic natural landscapes.
STUDY AREA

Our study is focused on Kotelny Island, the New Siberian Islands archipelago (Fig. 1). It consists of three parts – Kotelny Island, Bunge Land and Faddeevsky Island – which characterized by different evolution and surface properties.

Figure 1. Kotelny Island (Sentinel-1A scene location is shown by thick frame)

The western part of Kotelny Island is the largest one with an area of 11,7 thousand km². It is rocky and rather elevated in comparison with two other parts. The lower hypsometric level of this island is a coastal plain with average heights of 20-40 m, about half of the area is occupied by plateau with the average height of 80-120 m, and some areas at the south are hilly, rising up to 200-360 m. Bunge Land is a vast empty and almost barren intermediate zone with an area of 6,200 km². Most part of it is a flat sandy desert with heights of 5-8 m above sea level. In its center there is Evsekyu-Bulgunnyakh hill with an elevation of more than 10 m, composed of strong pre-Quaternary rocks with signs of erosion, and in the southeast, there is the upland of the Bunge Land that rises to an elevation of 11 to 21 m above sea level, where the thermokarst dismemberment can be observed. Faddeevsky Island is an eastern part of the island with an area of 5,300 km². It represents a dismembered lowland plain with average heights of 20-30 m, up to 65 m in the very north. Faddeevsky is covered with tundra vegetation and abounds in depressions and lakes of different size. The whole island lies within the zone of continuous permafrost, so its surface is complicated by various forms of cryogenic microrelief.

This region is characterized by a harsh Arctic climate with low air temperatures and low level of precipitation (130-140 mm a year) with its uneven distribution during the year (maximal amount is in July and August). Temperatures reach above freezing values briefly in the short summer months. Snow cover lasts at least 9 months, snowfalls occur sometimes even in summer.

Well-developed river network and abundance of lakes are peculiar to Kotelny and Faddeevsky Islands. Flat depressions within lowlands are boggy. Bunge Land is devoid of constant streams, but the meltwater and storm surges form wide and shallow valleys there in summer.

The vegetation cover of the island is uneven and rather scarce, it is represented mainly by prostrate shrubs, grasses, mosses and lichens whose height does not exceed 10-15 cm. The growing season lasts no more than two months. The density of vegetation is largely depending on snow cover, i.e. vegetation is absent or extremely rarefied at plots devoid of snow in the cold period of the year. And the most abundant vegetation can be found in river valleys and alasess protected from winds [The New Siberian…, 1963; The New Siberian…, 1967; Soviet Arctic…, 1970; The materials of a complex…, 2015].

Relatively large for high latitudes landscapes diversity of Kotelny Island allows to estimate the potential of radar images for mapping of northern polar territories in general.

DATA AND METHODS

SAR data

The European Space Agency provides free access to Sentinel-1 data via Copernicus Open Access Hub [Open Access…]. The SAR dataset for this work included 19 amplitude images acquired by Sentinel-1A/C-band SAR between 7 October 2015 and 19 September 2016 at ~21:37 UTC (~07:37 local time of the next day). All data were obtained from
repeat-pass orbits with identical geometric parameters (incidence angle, imaging direction etc.) to exclude the influence of factors not related to the terrain changes while comparing the time series of images. The time interval between acquisitions was 12 days, with several exceptions. The selected Extra-Wide (EW) Swath mode provided simultaneous coverage of the whole island (Fig. 1), the scene size was approximately 400x400 km. The Level-1 Ground Range Detected (GRD) products with medium resolution in use have a range and azimuth pixel spacing of 40 m. The chosen orbit was in descending pass and the radar was right-looking. The acquisition incidence angles were between 19.2° and 45.5° for the whole scene and between 28.6° and 42.9° for the area of interest. The polarization channels were HH and HV for all images in use.

**SAR data pre-processing for visual and automated interpretation**

Interpretation of original SAR images (both visual and automated) is a complicated task due to several reasons (the presence of speckle noise, radiometric and geometric distortions related to side-looking geometry, etc.). This fact necessitates the preliminary radar data processing aimed at creation of modified images with improved properties, suitable for both visual interpretation and for further computer processing including automatic classification. The processing steps may vary depending on the type of original radar data (Fig. 2).

![Figure 2. The flowchart of modified Sentinel-1 radar images creation](image)

The resulting modified images are suitable for interpretation and thematic processing. Images designed for visual interpretation can be represented as color composites of only three channels (multi-polarization or multi-temporal) and they are expressed as brightness units. Images for automated interpretation should be expressed as the values of normalized radar cross-section (NRCS, also called backscattering coefficient); they can contain more than three channels of multi-polarization or multi-temporal images.

**Additional data**

To reveal the factors, influencing the SAR images we used a set of additional data sources: meteorological data, satellite optical images, topographic and thematic maps.

Meteorological data from rp5.ru website was used for interpretation of backscatter intensity seasonal dynamics and revealing of influence of some individual events (for instance rain). Weather information (air temperatures, precipitation) at 07:00 local time (21:00 UTC) was available from “Ostrov Kotelny” and “Proliv Sannikova” meteorological stations which are located on the north-west and south-west coasts of Kotelny Island Respectively.

Topographic and thematic (geological, quaternary sediments, geomorphological, geobotanical) maps and schemas as well as Landsat-8/OLI images covering the warm period (June-September) of 2016 was used for information on the surface peculiarities. Satellite optical imagery was also used for retrieval the Normalized Difference Vegetation Index (NDVI = \((\text{Near Infrared} - \text{Red}) / (\text{Near Infrared} + \text{Red})\)) which characterizes the abundance of vegetation. It is worth noting that the most detailed maps of Kotelny Island are topographic and geological maps at scale 1:200 000, created at 1980s. The most of thematic maps that were created at different years from 1960s to 2000s, contain too generalized characteristics of the territory at scales about 1:2 500 000.
RESULTS AND DISCUSSIONS

Backscatter analysis for regions of interest

At first, we compared time series of backscatter for the different regions of interest, located within the typical landscapes of the island [Troshko, Baldina, 2018]. Integration of radiometrically calibrated multi-temporal radar images and the co-registered spatial data (optical images, maps and schemas) with the weather information allowed revealing the following main factors influencing the backscatter values and its dynamics:

- for the most part of the test sites, the winter backscatter values are lower than summer ones. This can be explained mainly by the changes of the surface dielectric properties related to active layer freezing (low dielectric constant values) and thawing (increased values);
- surface topography significantly influences to the backscattered signal. Usually, the sites with high degree of erosional dismemberment have higher NRCS values than flat areas. The abundance of microforms of cryogenic relief (such as baidzheraks) also leads to backscatter intensity increase;
- for areas almost devoid of vegetation the type of loose deposits plays an important role in the formation of backscattered signal. Flat and dry sandy surfaces have low backscatter intensity due to the low dielectric constant values. The presence of coarse clastic material leads to increase of surface roughness and, as a result, rise of backscatter intensity;
- the sites with tundra or wetland vegetation commonly have higher NRCS values than areas with arctic desert vegetation or devoid of vegetation;
- despite the presence of rather abundant vegetation, which is identified by higher NDVI values (up to 0.4-0.5 in summer) the boggy areas are characterized by lower NRCS values than other sites with similar vegetation index values. This fact can be explained both by the specular reflection of microwaves from the surface of standing water spots and by the fact that short vegetation does not prevent the propagation of microwaves to the smooth water surface;
- lakes are characterized by highly variable NRCS values in summer depending on the state of water surface. Calm water surface gives low backscatter intensity due to the specular reflection of microwaves while wavy surface gives higher backscattering coefficient values owing to increased roughness. NRCS temporal signatures of lakes in winter depend on their depth [Antonova et al., 2016]. Parts of lakes not freezing to the ground (i.e. covered with floating ice) are characterized by high NRCS values due to strong dielectric contrast between ice and water and strong signal scattering from the “ice-water” boundary. Lakes frozen to the ground give low NRCS values owing to the low dielectric contrast of ice and frozen ground and, as a result, weak scattering of the microwaves;
- the consequences of individual events, such as rainfalls and storm surges were also detected based on backscattering coefficient signatures. The increase of backscatter intensity due to surface wetting was more obvious in case of sand deposits;
- the presence of wet snow on the ground or lake ice leads to significant decrease of backscatter due to absorption of microwaves [Woodhouse, 2005].

It should be noted that NRCS temporal signatures have similar character in both polarization channels with lower values in HV-polarization (the difference achieves 7-12 dB depending on the surface type). Moreover, in some cases HV-polarization appeared to be insensitive to NRCS temporal variations, especially in areas with low backscatter intensity, such as sandy desert.

Visual analysis of multi-polarization color composites

Modified multi-polarization radar images, obtained at different seasons and comprised as RGB composites can be extremely useful for revealing the terrain typical properties. Figures 3 and 4 show the SAR images which characterize the typical summer (Fig. 3 – August 2, 2016), winter (Fig. 4a – February 4, 2016) and early spring (Fig. 4b – June 6, 2016) conditions of the territory on study. The images of all the periods clearly show the differences in the three parts of the island, that is the Kotelny and Faddeevsky Islands, which are more diverse in relief and vegetation cover, have a relatively high brightness and are displayed by a wide variety of colors, while the monotonous sandy desert of Bunge Land, practically devoid of vegetation, has a low brightness and is depicted mainly in black and dark blue colors.

The summer image (Fig. 3) is characterized by the most variability of colors that are correspond with the island features. For the western part - Kotelny Island - the most diverse relief is typical. The inner portion of this part is
represented by an elevated plateau (number 1 at Figure 3). The plateau has a sharp edge in the northeast, that is clearly visible in the form of a bright yellow strip (2). The increase of brightness here is explained by the scattering of the most radio signal by slopes facing the radar. Due to the same peculiarity of radar imaging, some sites of the plateau with strong erosional dismemberment (3) and some slopes of the table-top mountains (4) located in the southern part of the island can be discerned by high brightness. The eastern part of Kotelný Island is a lowland with numerous river valleys that are clearly visible by dark tones (5) (the darkness can be explained by the decrease of the backscattering that takes place probably due to the waterlogging and flatness of these areas) and thermokarst basins (both with standing water and drained), which are usually round (6). Bunge Land is a flat sandy surface without any vegetation, it has a black color (7) due to the equally weak backscattered signal in both polarizations and thus low brightness in the blue channel. Narrow sandy spits (8) are clearly visible by the same dark tone against a fairly bright background of the sea and sea ice. Pebble spits (9), which complicate the western shore of Kotelný Island, have high brightness due to greater roughness. Areas with a lot of eolian hills (10), the Evsekyu-Bulgunnyakh Hill (11), and rugged thermoabrasive shores (12) are clearly distinguished against a dark background of the sandy desert, since surfaces with a higher degree of dismemberment have a higher backscattering. The blue color of these areas at the composite image is explained by their increased brightness at the ratio (HH/HV) channel, due to enhancing of HH component contribution. Wide “valleys” occurred after storm surge (13) are also colored in blue that is related to the backscatter intensity increase due to surface wetting, especially in HH-polarization. Faddeevsky Island is a plain with a large number of river valleys (5) and thermokarst basins (6), in the southeast part of which there is a site with a very high degree of erosion (14) causing the high brightness of the image. It should be noted that the vegetation cover makes a certain contribution to the backscattering of the signal and, correspondingly, to the total brightness of the image. Tundra and wetland vegetation covers most parts of Kotelný and Faddeevsky Islands, and some sites of the Bunge Land (area to the east of Evsekyu-Bulgunnyakh Hill and area of Bunge Land Hill).

*Figure 3. The summer (02.08.2016) color composite created from multi-polarization Sentinel-1A images (color synthesis: R – HH, G – HV, B – HH/HV) (the numbers are explained in the text)*

The most distinctive objects at the winter image (Fig. 4a) are the plateau in the central part and low mountains in the southern part of Kotelný island (yellow), whereas their boundaries are hardly visible at the summer image. Other bright spots (yellow and green) correspond to the parts of lakes not frozen to the ground at the moment of a radar image acquisition. Shallow lakes or parts of lakes frozen to the ground have low brightness in winter image. At the early spring image (Fig. 4b), plateau and low mountains within the Kotelný Island, river valleys and thermokarst depressions are distinguished as intensive blue areas, due to wet snow, which absorbs microwaves that leads to decrease of image brightness [Woodhouse, 2005].
Figure 4. Winter and early spring color composites from multi-polarization Sentinel-1A images (color synthesis: R – HH, G – HV, B – HH/HV): a – 04.02.2016; b – 03.06.2016

It should be noted that each multi-polarization RGB-composite contains some noise as bright stripes. These regular stripes which are perpendicular to spacecraft flight direction (blue arrows at Fig. 5) and to imaging direction (red arrows at Fig. 5) are inherent to cross-polarization (HV) images and can be explained by TOPSAR imaging technique peculiarities. These radiometric distortions are more typical for surfaces with low backscatter intensity level (sea surface, sand flatlands). The presence of these noises limits the application of cross-polarization images for automated classification purposes.

Figure 5. Radiometric distortions (shown by the arrows) at the Sentinel-1A HV-polarization image

Automated classification of SAR images

Automated extraction of objects with the similar backscatter intensity values was carried out using unsupervised classification (clustering) of a dataset consisting of 19 co-registered multi-temporal co-polarization (HH) images. In this case the extracted classes have similar character of NRCS temporal dynamics. For example, Figure 6a illustrates the result of clustering of modified multi-temporal SAR image by 5 classes. Figure 6b shows temporal NRCS signatures of each class. The classes interpretation was implemented using previously revealed regularities of microwaves interaction with different types of terrain and surface features:

- **class 1** (red) has the lowest (< -20 dB) average backscatter intensity values during the whole year with higher values in winter. This class corresponds to the relatively smooth surface of sandy desert almost devoid of vegetation occupying the largest part of Bunge Land. Low NRCS values of this class can be explained both by low roughness of the surface and low dielectric constant of sand deposits. Decrease of NRCS values in summer is probably related to the drying of sand (dry sand deposits are characterized by very low dielectric constant values, so the microwaves can penetrate through the sand until they meet an object with other dielectric properties [Woodhouse, 2005]);

- **class 2** (green) is characterized by rather low (-17…-21 dB) NRCS values during the year, but higher ones than sandy desert has. This class can be observed only at Bunge Land. It unites different types of surfaces, namely areas with the erosional dismemberment within the Evsekyu-Bulgunnyakh Hill and the coastal zone, which is subject to periodic flooding by storm surges phenomena during the warm period. The values of NRCS for this class are higher than for class 1, since these areas are characterized on the one hand by more pronounced degree of surface roughness due to erosional dismemberment, and on the other hand with the...
moistening due to periodic flooding. These areas are almost devoid of vegetation that explains the lower values of backscatter intensity in comparison with classes 3 and 4 where the vegetation cover creates the higher level of backscattering;

- class 3 (blue) has average backscatter intensity values varying from -15 dB in winter to -11…-13 dB in summer. It includes such objects as river valleys and thermokarst depressions with wetland vegetation. Lower NRCS values during the cold period can be explained by the low dielectric constant values of frozen ground, while the thawed ground at warm period has a relatively high dielectric constant. It can be noted that the graph of the class 3 is like to that of class 4, but it places below especially at the warm period. Not very high NRCS can be explained by the flatness and waterlogging of these areas;

- class 4 (yellow) is characterized by the moderate NRCS values (about -15 dB) in winter and high ones (more than -10 dB) in summer. It corresponds mainly to the ice complex lowlands of Kotelny and Faddeevsky Islands. As in the case of class 3, seasonal differences of NRCS values are explained predominantly by the changes of surface dielectric properties related to active layer freezing and thawing. Nevertheless, this class is characterized by higher backscatter intensity values in comparison with class 3, due to a higher degree of erosional dismemberment (i.e. roughness) and the presence of tundra vegetation;

- class 5 (cyan) have the highest NRCS values in winter and one of the highest – in summer. This class corresponds mainly to the area represented by the plateau-like uplands. High average backscatter intensity values can be associated both with the large number of slopes inclined towards the radar and with high surface roughness due to the presence of coarse clastic material. NRCS values sharp decrease at 3rd June 2016 is related to the event of wet snow on the plateau surface which leads to the microwaves absorption.

Consequent increase of the number of classes allows extracting the natural landscapes of lower hierarchical level. Some areas clearly distinguished during visual images interpretation can be retrieved only applying classification with large number of classes. For instance, the south-eastern part of Faddeevsky Island with high degree of erosional dismemberment and abundance of baidzheraks appears in the clustering result only when more than 20 classes are selected. At the same time the other classes appear to be too fractional that complicates the use of these classification results for the whole studied territory.

**Kotelny Island map creation based on SAR images**

Automated classification of SAR images allows revealing so called «radiogeosystems» [Nekos, 1986] – the areas with similar values of radar backscattering coefficient (in case of multi-temporal image – with similar character of its temporal variability). However, the understanding of these radiogeosystems is complicated for geographers not usually familiar with the peculiarities of microwaves interaction with the surface. That’s why we implemented the matching of radiogeosystems with natural landscapes with the unique combination of the relief, vegetation cover and the other components of the environment.

The boundaries of natural landscapes firstly were defined basing on automatic multi-temporal image processing by clustering, and afterward the lines were manually corrected basing on image visual interpretation. An extensive set of spatially coordinated additional sources played an important role in interpreting the outlined polygons. The need for additional sources is caused by the dependency of the backscattering at different parts of the island from a wide range of
terrain characteristics (namely, the relief, a density of the vegetation cover, the surface wetness, etc.). So, it is insufficient to associate the polygons, revealed from the differences in backscatter intensity, with just the reference to known patterns of radio waves interaction with roughness and dielectric properties differences. Additional cartographic data sources (which are topographic and geological maps of 1:200 000 scale, geomorphological and geobotanic schemes by different authors of 1:2 500 000 scale and some other) allowed to establish the correspondence of the areas which were defined by the multi-temporal radar image processing, to the terrain objects, represented at the already existing maps. Landsat-8/OLI optical images helped to evaluate the contribution to backscatter intensity at some areas of such terrain characteristics as an abundance of vegetation, the type and degree of surface erosional dismemberment, etc. The resulting map at a scale 1:750 000 (Fig. 7 and 8) represents natural landscapes of Kotelný Island. The lands boundaries were outlined from multi-temporal radar image, and the thematic content of polygons is based on information from existing maps and books. The landscapes differ in the patterns of seasonal NRCS variability, which is caused by a unique combination of relief, vegetation cover and soils. Due to the availability of multi-temporal radar data with medium spatial resolution, the final map is characterized by much greater detail and a larger scale in comparison with the used thematic sources.

CONCLUSION

Sentinel-1 satellite radar imaging is a valuable data source for mapping of remote and hard-reaching Arctic regions due to the possibility of data acquisition independently on cloud cover and solar illumination with high frequency. As a result of experiments, general approach of Sentinel-1 images application for mapping of geographical landscapes of these territories was elaborated. At first, original SAR data requires creation of modified multi-polarization and multi-temporal images adapted for visual and automated interpretation. An automatic SAR images interpretation is more effective on using the multi-seasonal image in HH polarization, however the classification results usually require editing, based on images visual analysis. The complexity of SAR images interpretation requires utilization of variable additional data sources – meteorological data, maps and satellite optical images. The medium scale (1:750 000) map of natural landscapes of Kotelný island, which characterizes the peculiarities of the relief; lakes, vegetation cover and soils was created based on the elaborated approach.

The recent appearance of Sentinel-1 data with a higher spatial resolution (20 m) and the placement of high-resolution (1-2 m) summer images of the Arctic regions on the Google Earth opens up new opportunities for correlating radar images with objects of this remote terrain, more detailed mapping and deep understanding of its properties.

ACKNOWLEDGMENTS

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REFERENCES


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Figure 7. The map of natural landscapes of Kotelny Island (see legend in the Fig. 8)
<table>
<thead>
<tr>
<th>Natural landscapes</th>
<th>HH-polarization backscatter intensity in multi-temporal C-band radar images</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mudflats</td>
<td>Moderate (-10...-15 dB) winter and summer</td>
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<tr>
<td>Spits</td>
<td>Sandy</td>
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<tr>
<td></td>
<td>Pebble</td>
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<tr>
<td>Coastal lowland with heights up to 4 m periodically flooded by sea during high tides and surges with tundra vegetation</td>
<td>Moderate (-10...-15 dB) winter and summer</td>
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<tr>
<td></td>
<td>Coarse and fine sand</td>
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<td></td>
<td>Medium to coarse sand</td>
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<td></td>
<td>Fine to silt</td>
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<tr>
<td></td>
<td>Sandy</td>
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<td>Pebble, gravel</td>
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<tr>
<td>First marine terrace with heights up to 10 m with vegetation of sandy arctic deserts</td>
<td>Moderate (-10...-15 dB) winter and summer</td>
</tr>
<tr>
<td></td>
<td>Flat and slightly undulating with eolian microrelief with heights up to 3 m</td>
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<tr>
<td></td>
<td>Flat and slightly undulating with eolian microrelief with heights up to 3 m</td>
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<tr>
<td></td>
<td>Valleys of temporary streams with eolian and eolian microrelief</td>
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<td></td>
<td>Eolian hills</td>
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<tr>
<td>Second marine terrace with heights up to 10-25 m with mainly</td>
<td>Moderate (-10...-15 dB) winter and summer</td>
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<td></td>
<td>Erosional dismemberment and vegetation of sandy arctic deserts</td>
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<td>Erosional dismemberment and tundra vegetation</td>
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<td></td>
<td>Erosional dismemberment and wetland vegetation</td>
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<td>Thermokarst dismemberment and tundra vegetation</td>
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<td>Thermokarst dismemberment and wetland vegetation</td>
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<td>Thermokarst dismemberment and wetland vegetation</td>
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<tr>
<td>Ice complex lowlands with heights up to 50 m with</td>
<td>Moderate level of erosional-thermokarst dismemberment and sparse tundra vegetation</td>
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<tr>
<td></td>
<td>High level of erosional dismemberment and tundra vegetation</td>
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<tr>
<td></td>
<td>River valleys with wetland vegetation</td>
</tr>
<tr>
<td>Bottoms and slopes of thermokarst basins (lasses) with wetland vegetation</td>
<td>Low (&lt;-20 dB), weakly variable winter and strongly variable summer</td>
</tr>
<tr>
<td>Flat and slightly inclined lowlands with heights up to 50-100 m with tundra vegetation</td>
<td>Low (&lt;-20 dB), weakly variable winter and strongly variable summer</td>
</tr>
<tr>
<td>Plateau-like uplands with heights up to 100-300 m with vegetation of mountain arctic deserts</td>
<td>Low (&lt;-20 dB), weakly variable winter and strongly variable summer</td>
</tr>
<tr>
<td>Mountains with heights up to 300-361 m, almost without vegetation</td>
<td>Low (&lt;-20 dB), weakly variable winter and strongly variable summer</td>
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<tr>
<td>Lakes</td>
<td>Shallow, freezing to the ground during winter</td>
</tr>
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<td></td>
<td>Deep, not freezing to the ground during winter</td>
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*Figure 8. The legend of Kotelny Island map*


BIOGRAPHY

Elena Baldina, graduated from Lomonosov Moscow State University, majoring in cartography. PhD in Geographical Sciences. Present position is leading research scientist in Remote Sensing Laboratory of Cartography Department at the Faculty of Geography, Lomonosov Moscow State University. She is a lecturer in the discipline of Aerial and satellite images interpretation. Priority research areas are Remote Sensing Applications for geographical mapping and Earth changes, education in remote sensing, thermal and radar satellite imagery use for mapping.

Ksenia Troshko, graduated from Lomonosov Moscow State University, majoring in cartography. Present position is junior research scientist in the Laboratory of Cartography, Institute of Geography, Russian Academy of Sciences. Priority research area is satellite radar imagery application for thematic mapping. Currently she is preparing PhD thesis in this field.