Hydrographic and erosional dissection pattern as an indicator of landform type of the Malozemelskaya and Bolshezemelskaya Tundra

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Abstract. The paper describes the methodology and presents the results of the calculation of the spectral characteristics of the terrain for the territory of the Bolshezemelskaya and Malozemelskaya Tundra (the north of the European part of Russia). There are nine terrain clusters, differing in the topographic dissection pattern. Their geomorphological interpretation is given. Three clusters characterize mountainous and coarsely hilly terrain with the depth of dissection from 150 m and more. The others are low and elevated terrains with much lower depths of dissection (up to 50 m) and different patterns of interposition of landforms.

1 Introduction

Landform and hydrographic pattern analysis and classification might be produced using the focal terrain characteristics such as topographic position indices [1] or others. Focal variables depend on density and magnitude of dissection for different types of the landforms. We develop the technique of spectral terrain variables or characteristics (STC) computing [2]. These variables are aimed to describe the topographic pattern type by one numeric value. Each spectral characteristic of the terrain characterizes different features of topographic drawing, and together they allow distinguishing the areas with a homogeneous character of the terrain (and possibly its origin).

2 Study area

The study area is located at the northeast of the European part of the Russia. It covers about 400 000 km^2 from Kanin Peninsula at the west to Polar Ural Mountains at the east. Although the main interest of the study is focused on the territories of natural and historical regions of the Malozemelskaya and Bolshezemelskaya Tundra, we use more wide boundaries for the analysis, which cover the part of Arkhangelsk Oblast (25 600 km^2), almost whole Nenets Autonomous Okrug (167 500 km^2), Komi Republic (122 700 km^2), Yamalo-Nenets Autonomous Okrug (39 800 km^2) and small northwest part of Khanty-

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Mansi Autonomous Okrug – Yugra (1 200 km^2). The sum area is approximately 360 000 km^2. Overview of the studied territory is presented at the Fig. 1. The boundary between two tundra's is Pechora – the largest river on the territory.
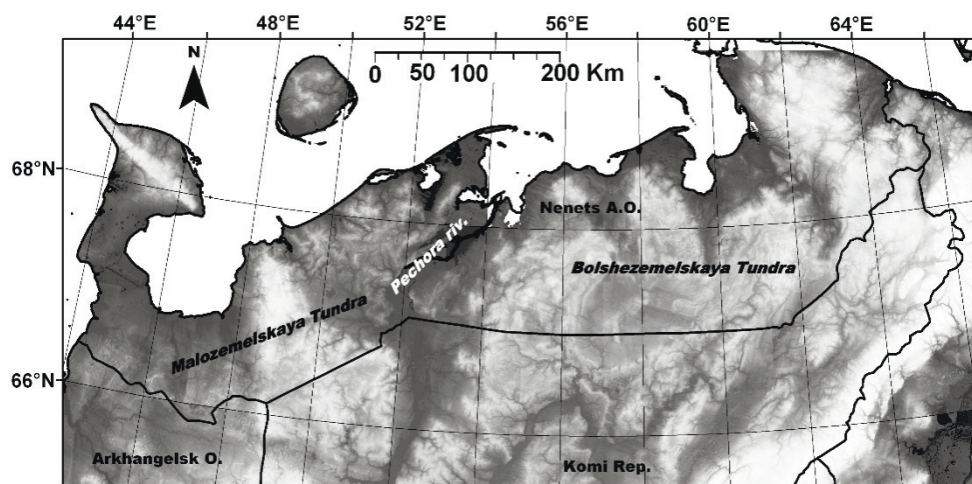

Fig 1. Topography, administrative boundaries and positions of the Tundra on the study area.

Geological settings depend from the site's position on the territory of the four provinces (in the west – east direction): Mesen Basin, Timan High, Timan-Pechora Basin and Ural-Novaya Zemlya Foldbelt (Table 1). In the plain part, mainly Devonian, Permian and Cretaceous deposits (sands and sandstones, siltstones, clays, claystone) are common, and in the Ural Mountains – Ordovician rocks. Quaternary deposits cover almost the entire area with a depth from 0 to 250 m. Glacial, fluvial, lake and slope deposits are distinguished.

The climate in this area is subarctic. Total solar radiation reaches only 2 kcal/cm^2 from December to February. Winters are cold (in January the average temperature is -16°C in the southwest and -21°C in the northeast) and summers are short and cool (in July the average temperature is 10–12°C). Annual precipitation ranges from 550 mm in the south to 350 mm in the north.

The terrain is a low erosion-denudation and accumulative plain. Glacial processes created the interfluves in the Quaternary. It is a gentle hilly surface with valleys of small watercourses 10-20 m deep, as well as flat, weakly drained watersheds with a height difference of 2-3 m and numerous lakes. The main modern geomorphological processes here are solifluction, thermokarst and erosion. Median elevation is 92 m. The Ural Mountain tops have max elevations – up to 1435 m in the border of study area.

3 Data and methods

The initial data for the calculation of the spectral characteristics of the terrain on a small scale was a digital elevation model GMTED 2010 [3] with a resolution of 200 m per cell.

The calculation method consists in 2-dimensional Fourier transform applied to DEM on a moving window of different sizes. The resulting Fourier-image is used to extract various texture characteristics of the terrain dissection (individual harmonic wave's parameters which sum gives real surface topography on site). In total, 8 values are calculated:

1) maximum magnitude of height oscillations (magnitude of the largest harmonic wave, meters);

2) importance of 1% of the main harmonic waves (fraction of the dispersion of the height described by several most important waves, from the total dispersion in the area – from 0 to 1, non-dimensional);

3) length of the wave having the largest magnitude (the wavelength of the main "rhythm of terrain dissection" at the site, meters);

4) general direction of the height field oscillations at the site (from 0 to 180 degrees);

5) importance of this direction (from 0 to 1, non-dimensional);

6-8) parameters of approximation of dependence of harmonic wave amplitude on its frequency by exponential equation: A0 (meters), L (non-dimensional) and R^2 (non-dimensional) fitting quality. The view of equation: $M = A0 \times e^{(-L*f)}$, where M – magnitudes of waves, e – exponent, f – spatial frequency (waves / window), A0 and L – fitted coefficients.

Table 1. Percentages of geological provinces area by age of the Pre-Quaternary sediments.

Geological age	Geological provinces (area in thous. km^2)			
	Mezen Basin (48)	Timan High (31)	Timan-Pechora Basin (216)	Ural-Novaya Zemlya Foldbelt (69)
Quaternary	17.5	15.0	5.9	2.2
Cretaceous	0.7		46.9	12.2
Jurassic	6.8	1.4	16	4.7
Triassic	23.4	2.3	9	
Permian	46.9	9.5	15.3	7.4
Carboniferous	1.1	9.7	1.8	3.6
Devonian	3.5	49.7	1.1	5.7
Devonian and Silurian			2.4	6.5
O - Ordovician			0.0	29.9
Cambrian - Proterozoic			0.0	11.9
Palaeozoic			34.9	0.6
Upper Proterozoic	0.1	9.0		
Basic, Ultrabasic and Alkaline intrusive rocks of unknown age		0.5		6.8
Other		3.1	1.6	8.5
Sum	100	100	100	100

The listed parameters were calculated on 17 different scales (moving window sizes) from 20 to 100 km with 5 km steps (20, 25, 30, ..., 100 km). The final data table for terrain classification contained 136 (17*8) data columns. As different variables varied over a wide range, centring, scaling, and Box-Cox transformation [4] were applied to the data.

The transformed data were transferred to the input of the self-organizing Kohonen neural network [5]. This method allows finding natural groupings of objects in the characteristic space, i.e. it is essentially a clustering method. The result of creating a neural network for generalization was subjected to hierarchical clustering by the Ward method [6]. The final optimal number of clusters was defined as 9.

4 Results and discussion

The final (after generalization) number of allocated units of the territory was 498. The mesh of contours is shown in Fig. 2. In their essence, these clusters are the areas of territory with a homogeneous pattern of dissection. The procedure for building such a map is fully

automated. The only subjective aspect of the algorithm is that the user selects the scale at which the spectral characteristics of the terrain are calculated and the details of the resulting map (sliding window step and the level of contour generalization). The skills of a professional geomorphologist will be required when interpreting created borders.
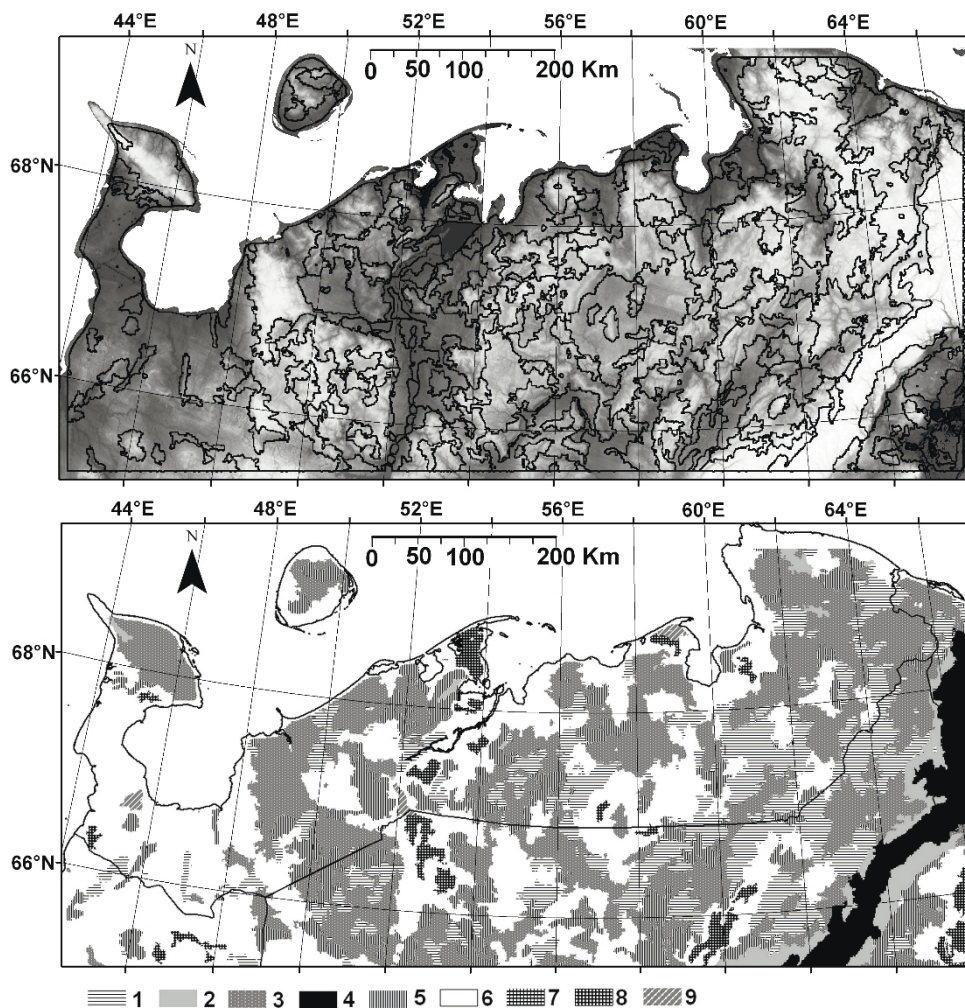

Fig. 2. Cluster boundaries with labels of the clusters.

Cluster No. 4 is most clearly distinguished; these are the mountainous areas of the Urals – a belt 20-50 km wide within the area under consideration (Table 2). These are the surfaces at altitudes up to 1400 m, separated by deep river valleys. The orthogonal pattern of the river network predetermining by tectonic faults. Clusters 3 and 2 are hilly and plateau-like interfluves, and low mountains and foothill areas of the Urals. Their coarsely shaped terrain character with great depth of dissection unites them. All other clusters differ greatly from clusters Nos. 4, 3 and 2 (as well as 7). These are flat areas with different topographic patterns and shallow negative landforms. Clusters Nos. 1 and 5 are hilly areas with different size of hills. The largest areas are occupied by cluster No. 6, usually confined to the extensions of large river valleys and coastal plains. These are practically flat vast surfaces. Clusters Nos. 8 and 9 differ from it. While a shallow depth of dissection also

characterizes both of them, these are areas with an abundance of concentric negative landforms, as a rule, these are the depressions of thermokarst lakes. Their difference is that the first one is purely thermokarst terrain, and the second one is complicated by erosion.

Table 2. Characteristics of the territory clusters based on the terrain periodicity.

Cluster lable	Area, thous. km^2	Features of topography
1	47,7	Weakly dissected lowlands (dissection depth about 20-30 m) on the moraine interfluves
2	9,9	Weakly dissected low mountains and foothills (dissection depth about 150 m)
3	93	Flat plateaus and hills (≈200 m), dissected by deeply cut river systems.
4	16	The middle and upper levels of the mountains, with a depth of topographic dissection of about 500-600 m and a characteristic distance between watersheds or valleys of about 4-5 km.
5	36	Concentric hilly dissection type with large hills (wavelength is 5-10 km, elevation range – 50-60 m)
6	106,5	Very weakly dissected lowlands (dissection depth about 5-20 m) in the wide of the large river valleys bottoms and sea coasts.
7	0,1	*A non-representative cluster from one object.* It's closest to cluster number 3.
8	9,5	Chaotic small-depth (around 5 m) dissection on the thermokarst plains and floodplains.
9	1,2	Ordered small-depth (around 5 m) dissection on the erosional and thermokarst plains

The degree of statistical proximity of the selected types of terrain is shown at the dendrograph (Fig. 3). The statistical distance in conditional units is presented by the axis of abscissa. If, for example, two sites of territory at all 136 parameters have values -1 (the first site) and 1 (the second site) then statistical distance according to Pythagoras' theorem will make about 23 units.
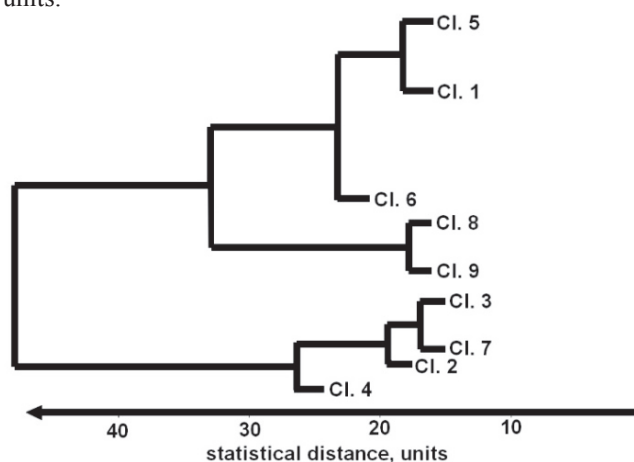

Fig. 3. The cluster's dendrograph.

5 Conclusion

Spectral characteristics of the terrain allow selecting areas with different types of topographic decomposition patterns. The result of their calculation for the territory of the Bolshezemelskaya and Malozemelskayatundra allowed for the clustering of the terrain by the nature of the topographic periodicity. There are 8 large classes and 1 small class, represented by only one object. A meaningful geomorphological interpretation of the allocated classes is given. The main criteria that predetermined the differentiation of the terrain were the depth and density of dissection, the shape of the interfluve profile, orderliness or randomness of the location of the positive and negative landforms. A final map of clusters and a dendrograph illustrating the degree of their closeness to each other was drawn up.

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