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Application of remote sensing and mathematical morphology of landscape for studying thermo-karst processes

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Climatic and technogenic changes render diverse effect on the environment, and it in turn affects economic activities. The area of development of permafrost rocks is one of the most sensitive to changes.

More than 60% of Russia is a permafrost zone. Accordingly problems of permafrost rocks and integrated with them exogenous geological processes are very actual for our country, especially for Siberia, which greater part is within the permafrost area and where the most of mineral deposits of Russia are placed.

As a rule, the frozen ground processes including those in a stage of stabilization or attenuation become more active under technogenic intervention and climatic changes, receiving a new impulse. And even more, they can reach higher degrees of intensity in their development. Besides other processes arise, which were not developed earlier at this territory.

Thermo-karst is one of geocryological processes especially sensitive to climatic changes. Thermo-karst is a process of formation of the closed negative landforms as a result of degradation of the soils containing ice.

Thermo-karst originates when the following conditions are satisfied:

a) Soils contain ice in the form of beds or schlieres;
b) Depth of seasonal thawing exceeds a depth of occurrence of underground ice or the soils containing schlieres of ice;
c) The water formed after ice thawing is filtered off in a thawed zone and due to it sinking of soil occurs.

Thermo-karst depressions much depend on types of underground ice and ground that thaw and on conditions of water flow.

Thermo-karst is mainly associated with loams, sandy loams especially containing big amount of particles of 0.05–0.002 mm, sandy silt and it is frequent within peatland.

Presence of close water-bearing horizons promotes thermo-karst processes, therefore the significant amount of thermo-karst forms is associated with alluvial sediments of ancient and actual river systems (Kachurin 1961).

Rate of thermo-karst processes depends on ice content of sediments: the higher it is, the faster ground destroys. Rate of destruction of walls of an exposure depends on latitude of locality, composition of deposits overlapping ice, ice thickness, exposure of slopes and depth of erosion base level. Persistent thermo-karst destruction and self-development of this process is possible at water body depth of 1,5 m and more. The stable water regime of thermo-karst lake is provided under condition that thawing stocks of underground ice in an ice complex make more than 35% of total volume of ground of an ice complex. At thawing of such amount of underground ice there is a self-development of thermo-karst lake irrespective of weather conditions of the year. In this case the further evolution is limited by underground ice amount and drainage conditions of locality. In case of formation of a drainage canal along which water from thermo-karst lake outflows, the water level drops sharply, leading to temporary stabilization of shores of the lake. Growth of thermo-karst lakes slows down sharply (Are et al. 1974).

One of the important problems is to find out principles of distribution and dynamics of thermo-karst development with the purpose of forecast of environment changes.

Studying regularity of distribution of thermo-karst forms, Romanovsky (1977) specifies their difference in different frost-temperature zones. These differences are caused by:

– genesis, scale of evolution of underground ice and ice content of the ground, which have zone features;
– the beginning of evolution of thermo-karst process, which in the north is connected mainly with alteration of seasonally thawed layer, and in the south in the greater extent with degradation of a permafrost;
– the probability and extent of thawing of underground ice increases in a direction from the north to the south.

Near to southern boundary of permafrost and especially outside its limits all types of ice and grounds containing ice thaw through.

Territories of distribution of sediments with low ice content appear to be hypsometrically above sunk sections (Romanovsky 1977).

In our work we use a method of mathematical morphology of a landscape – a branch of landscape science, investigating quantitative laws of construction of mosaics which are formed on an earth surface by natural units, and methods of the mathematical analysis of these mosaics – landscape patterns (Viktorov 1998).

Canonical initial mathematical models play a special role in mathematical morphology of a landscape. They deal with the patterns developed in uniform conditions, that is, at a constancy of major factors of landscape differentiation. The further combination of such models, in view of interaction of processes allows us to describe all variety of the morphological patterns developed in the diversified combinations of natural conditions. The fact of existence of such possibility to construct the model capable to describe complete variety of geometrical features of morphological patterns of the given genetic type with several equations is quite a real fact, though it is not obvious at first sight. Also, it should be noted, that basic equations do not depend on a lot of particular conditions, for example, a material structure of surface sediments, annual sum of precipitations, etc. Thus, the model allows us to examine the problems in general, i.e., obtaining a solution fair for a broad spectrum of natural geographical conditions.

We have investigated principles of surface change in connection with dynamics of thermo-karst processes. Researches were conducted on several reference sites. The section within West Siberian plain on the Pjakupur River has been taken as the basic, reference one. Additional sections are on Alaska, on Yamal peninsula and in Western Siberia. Aerial photographs and cartographical materials of different time dates were used: 1969, 1980, 1990 and 2000 and of different resolution from the one of more than 1 meter, up to 30 meters. The maps also were of different scale 1:100000 and 1:200000.

Measurement of size, area, and parameters of distribution of thermo-karst lakes was carried out. Various software products have been applied for the measurement: MapInfo Professional 7.5, ERDAS, Vektorizator, GST3, Excel and others.

The equations of the mathematical model of a morphological pattern for thermo-karst lake plains were used for the analysis of data and forecast constructions. They represent combination of the probabilistic mathematical relations reflecting the most essential geometrical features of the pattern. The equations include:
– probabilistic distribution of a number of thermo-karst lakes, which have appeared within a specified site during the given time interval (Poisson process).
– probabilistic distribution of changes of thermo-karst lake diameters (Winer random process relative to logarithms of diameters).

The analysis has shown:
– conformity on the whole of distribution of the centers of lakes to Poisson distribution with certain deviations;
– conformity on the whole of distribution of sizes of lakes to lognormal distribution with certain deviations;
– complex dynamics of similar territories.

The analysis of deviations of data distributions from theoretical model allows to outline influence of the varying factors acting over thermo-karst processes (climate change and the anthropogenous factor).

Literature

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