НОВЫЕ МЕТОДЫ И РЕЗУЛЬТАТЫ ИССЛЕДОВАНИЙ ЛАНДШАФТОВ В ЕВРОПЕ, ЦЕНТРАЛЬНОЙ АЗИИ И СИБИРИ

Монография в 5 томах

Том I  Ландшафты в XXI веке: анализ состояния, основные процессы и концепции исследований

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NOVEL METHODS AND RESULTS OF LANDSCAPE RESEARCH IN EUROPE, CENTRAL ASIA AND SIBERIA

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This monograph shall inform you about up to date methodologies and recent results in landscape research. It is intended as a guide for researchers, teachers, students, decision makers, stakeholders interested in the topic of landscape science and related disciplines. It provides information basis for decision makers at various levels, from local up to international decision bodies, representing the top level of landscape science in a very short form.

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Chapter I/27: EVALUATION OF THERMOSTATISTICAL PARAMETERS OF RELIEF

Глава 71: Оценка термостатических параметров рельефа

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ABSTRACT. For the first time the method for estimating parameters of non-extensive statistical mechanics for the relief is considered. The relief is considered as a thermostat system, described through 3 coordinates. The object of the study is the south of the Valdai upland. The territory is characterized by an alternation of moraine ridges and periglacial lake plains. For relief, the thermostat parameters are evaluated - entropy, Kulbak information, total energy, bound and free energy, measure of organization. The possibility to estimate deviation of the real relief surface from the stationary model is approved. The parameters obtained are well interpreted and confirmed by field data. It is shown that the moraine ridges are in exceptionally steady state, while the lake plains in non-equilibrium and are actively evolving. The possibility of development of the proposed method of macroscopic analysis is briefly discussed.

ABSTRACT. Для впервые рассмотривается метод оценки параметров нежесткостной статистической механики для рельефа. Рельеф рассматривается как терmostatическая система, описываемая через 3 координаты. Объект исследования – юг Валдайской возвышенности. Территория характеризуется чередованием моренных гряд и перигляциальных озерных равнин. Для рельефа измерены термостатические параметры - энтропия, информация Кульбака, общая энергия, связанныя и свободная энергия, мера организованности. Показана возможность оценки отклонения реальной поверхности от стационарной модели. Полученные параметры хорошо интерпретируются и подтверждаются полевыми данными. Показано, что моренные гряды характеризуются исключительно стационарным состоянием, в то время как озерные равнины неравновесны и активно эволюционируют. Кратко рассматриваются возможности развития предлагаемого метода макроскопического анализа.

KEYWORDS: relief, landscape, non-extensive statistical mechanics, thermodynamics, rank distribution, entropy, free energy, exergy, information, earth sciences.

Ключевые слова: рельеф, ландшафт, нежесткостная статистическая механика, термодинамика, ранг распределение, энтропия, свободная энергия, информация, экология, география, земные науки, ландшафт.
INTRODUCTION
Relief has the leading role in the formation of the landscape spatial structure, providing a redistribution of heat and moisture. Relief can be considered as a geometrical locus of points in the three coordinate system. Coordinates of each point can be considered as a complex system measured by GPS [1,2]. These conditions are the result of crustal movements, glacial and periglacial processes, aeolian processes, erosion and denudation processes [3]. These mechanisms give rise to complex structures, the formation of which is considered in the independent models [4].
Recent studies show that the development of the river network [5,6], denudation structures, the formation of glacial deposits [7], structures generated by geodynamics are subject to mechanisms of self-organized criticality, which give rise to rank distributions (power law).
Self-organized criticality generates fractal structure that on a macroscopic level can be described in terms of thermodynamics. All these structures are described by power rank distributions (power law) and are consistent with models of non-extensive statistical mechanics [8,9]. The parameter q of extensive statistical mechanics provides information on the nature of interaction between system elements and allows to assess the potential direction of their dynamics.
According to general ideas of thermodynamics, the evolution of landscape relief is aimed to formation of an equilibrium system with a minimum dissipation of energy in the transport of liquid and solid runoff in the hillslope and river network [10]. Real landscapes are usually more or less remote from this ideal state [11]. Such systems at each step of its evolution remain thermostatically nonequilibrium and therefore it is useful to have a methods for determining the direction of their evolution. Which methods at the macroscopic level could be described by non-extensive statistical mechanics of Tsallis.

MATERIALS AND METHODS
Let us imagine the relief of a statistical ensemble of elements. Elements described by coordinates and impulses or by mass and velocity and respectively by action and energy (\( \xi \)). Interaction between elements define a model of statistical mechanics. This form is given by the function of the weighted average of Kolmogorov-Nagumo with any function [12]. If the function is linear the model fits the Gibbs-Shannon thermostatics. If the function is exponential – the model fits the thermostatics of Renyi. If the function is a power law (1) the model fits the non-extensive thermostatics of Tsallis.
\[
\frac{dy}{dx} = y^q, \quad \text{Respectively, } y = \left[1 + (1 - q)x\right]^{-\frac{1}{q-1}} \equiv e_x^q (1)
\]
Thus, the linear interaction is defined. Similar to the Boltzmann-Gibbs entropy for a power type of interactions the Tsallis entropy for equiprobable events is
\[
S_q^{\text{max}} = k \ln_q W \frac{1 - W^{(1)}(W)}{1 - q}, \quad (2) \text{ where } W - \text{ is the number of classes}
\]
and q-entropy is
\[
S_q^\tau = k \left( \ln_q (1 / p_i) \right) = k \frac{1 - \sum_i p_i^q}{q - 1} \quad (3),
\]
In the Tsallis model the entropies of independent systems are non-additive. If \( q > 1 \) than the system called subadditive and if \( q < 1 \) the system is called superadditive. If \( q = 1 \), than \( (e \xi)^q = (e \xi) \) which indicates linear relationship. The above statement means that there is always interaction between systems [13]. The smaller the \( q \) the larger the entropy. q-Kullback information
\[
I_q(P^\prime / P^\tau) = \sum_{i=1}^n p_{i}^\prime \left[ \frac{p_{i}^\prime}{p_{i}^\tau} \right]^{q-1} - 1 \quad (4),
\]
can be considered as the real system \( P^\prime \) distance from its steady state limit \( P^\tau \) with a local maximum of entropy. The most complete form of rank distribution of Tsallis for the most common form of action at the macroscopic level will be
\[ p_i^q = \frac{[1 - (1 - q)\beta_i (\varepsilon_i - E_q)]^{1/(1-q)}}{Z_q} \]  

Where (E_q) is the average energy of the system per class, (\beta) is tempera of Gibbs rank distribution, (Z_q) is statistical sum. As in the case of Boltzmann Gibbs model we have the following ratio of the basic thermodynamic variables

\[ F_q = U_q - TS_q = -\frac{1}{\beta} \ln_q Z_q = -T \sum_{i=1}^{n} \varepsilon_i p_i^q \]

Where (U_q) is the energy absorbed from the environment, (F_q) is free energy, (TS_q) is bound energy. Thus, within frames of thermostatics and having empirical rank distributions we can identify all the fundamental variables of a thermodynamic system.

Parameter (q) contains important information about the system. If (q)>0, then there is a correlation (\rho) and it is a self-organizing system (q) = (1/(1-\rho)). If (q)<0 then the information in system decreases and entropy increases, statistical order decreases and disorder in the microstates of the system increases. Such process leads to degradation of the system and to establishment of another stationary state [14]. The system's transition from (q)=1 to (q)>1 can be interpreted as a change in the phase state.

Kullback information allows to estimate the distance of the real system from the hypothetical equilibrium. It can be expected that the further system from equilibrium, the greater the conversion of its structure. Technically, the systems which are far from equilibrium are expected to produce more useful work, such as biomass or the system can be withdrawn from the equilibrium state as a result of destruction, instead of organized structure changes.

A useful addition to the thermodynamic variables discussed above is a measure of organization proposed by Foerster [15].

\[ R = 1 - \frac{S_r}{S_{max}} \]

Where (S_r) is the measured entropy. The system is self-organizing, if d(R)/d(t)>0. Self-organization can go both by reducing the entropy (S_r)/d(t)<0, and the emergence of new classes d(S_{max})/d(t)>0 at constant entropy Sr.

Parameters of the rank distribution are obtained by nonlinear estimation in Statistica software. A complex system of relief at the macroscopic level can be determined in the following manner. Let us imagine the relief in three-dimensional space in a grid with a linear pixel size corresponding to the selected scale. Then, each pixel can be considered as an element of the system, with energy (\varepsilon_i) proportional to its height above sea level.

**OBJECT OF THE ANALYSIS**

The area in the south of the Valdai Hills with rectangle corners coordinates 32.607781E, 56.682393N, 33.230169E, 56.682798N, 32.611149E, 56.354927N, 33.228192E, 56.355327N. Average elevation 246.2 meters asl (min 200.4 – max 319.047). Total area 6788.8 sq.km. Most part of the area is protected within Central Forest state Biosphere reserve. The whole territory is crossed by the watershed between rivers Zapadnaya Dvina and Volga. It is located on the border of Weichselian glaciation. The central part of the territory is occupied by ridge moraine of longitude stretch (Figure 1). Inter-ridge lowlands are filled with lacustrine sediments of glacial lakes with small islands of moraine. The southernmost part of the territory is formed by periglacial deposits. Most of the rivers of the territory belong to the first to third order. They mainly originate from peatbogs in the lake lowlands or from discharges of groundwater from the moraine ridges.
Figure 1 - Relief of the territory: (a) altitude above sea level, meters; (b) Deviation of real relief from the equilibrium model, meters. Unit X and Y 30 m.

RESULTS
Table 1 shows the evaluation of non-extensive statistical parameters and Figure 2 shows corresponding rank distribution.

Table 1 - Thermostatistical parameters of relief.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Index</th>
<th>Whole territory</th>
<th>Moraine ridge</th>
<th>Lacustrine periglacial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coefficient of determination</td>
<td>$R^2$, %</td>
<td>93.759</td>
<td>92.164</td>
<td>74.288</td>
</tr>
<tr>
<td>$w$</td>
<td></td>
<td>-18.394</td>
<td>-0.044900</td>
<td>-37.5622</td>
</tr>
<tr>
<td>Parameter of exponent</td>
<td>$q$</td>
<td>1.05436</td>
<td>23.2717149</td>
<td>1.02662251</td>
</tr>
<tr>
<td>Tempera</td>
<td>$\beta_q$</td>
<td>0.058352</td>
<td>0.019579</td>
<td>0.063207</td>
</tr>
<tr>
<td></td>
<td>$\beta$</td>
<td>0.0263779877</td>
<td>7.7E-132</td>
<td>0.0433447885</td>
</tr>
<tr>
<td>Temperature</td>
<td>$T$</td>
<td>37.9103976</td>
<td>1.23E+131</td>
<td>23.0708243</td>
</tr>
<tr>
<td>q-average energy</td>
<td>$E_q$</td>
<td>365670</td>
<td>60444</td>
<td>590398.548</td>
</tr>
<tr>
<td>q-entropy model</td>
<td>$S_q$</td>
<td>10.052809</td>
<td>0.04490</td>
<td>11.8035718</td>
</tr>
<tr>
<td>q-entropy according to data</td>
<td>$S'_q$</td>
<td>10.0525786</td>
<td>0.04490</td>
<td>11.74280</td>
</tr>
<tr>
<td>q-maximum entropy</td>
<td>$S_{max}=\ln_a n$</td>
<td>18.39410</td>
<td>0.04490</td>
<td>37.56203</td>
</tr>
<tr>
<td>q-Kullback Information</td>
<td>$I_q$</td>
<td>0.00293350895</td>
<td>0.00176313786</td>
<td>0.043254699</td>
</tr>
<tr>
<td>Statistical sum</td>
<td>$Z_q$</td>
<td>2200618.48</td>
<td>645988.5</td>
<td>1424790.38</td>
</tr>
<tr>
<td>Bound energy</td>
<td>$B_q$</td>
<td>221.591</td>
<td>5.5E+129</td>
<td>271.32</td>
</tr>
<tr>
<td>Free energy</td>
<td>$F_q$</td>
<td>67268087</td>
<td>138615.421</td>
<td>350857774</td>
</tr>
<tr>
<td>Total energy</td>
<td>$U_q$</td>
<td>67268309</td>
<td>350858045</td>
<td></td>
</tr>
<tr>
<td>Proportion of free energy</td>
<td>$F_q,%$</td>
<td>0.999970</td>
<td>0.99999992</td>
<td></td>
</tr>
<tr>
<td>Organization</td>
<td>$R_q$</td>
<td>0.453</td>
<td>0.000</td>
<td>0.68738</td>
</tr>
</tbody>
</table>

The distribution corresponds to the Gibbs thermostatics $(q) =1.05436$. Entropy of real relief and model differs little from the maximum entropy and the organization is very small. Bound energy is very small, and more than 99% is free energy. According to this estimates it can be assumed that the system has to evolve to the Gibbs distribution and most of the energy goes to the transport of moisture and to denudation. Figure 1b shows the deviation from the equilibrium model areas. Positive deviations are typical for the most elevated parts of the moraine ridges, while the existing ridge lower than that predicted by the equilibrium model. Two genetically distinct forms of relief are presented on the territory: moraine
ridges and flat lowlands on the lake and periglacial sediments. Accordingly, it is logical to assess them separately.

Table 1 shows the thermostatic parameters. The organization of moraine ridges is different from those of relief of the whole territory especially the parameter \( q = 23.27 \). Its value indicates a high level of self-organization. Such high value of \( q = 23.27 \) were not observed for any other territories. From Figure 2 it is evident that most of the surface close to the model except maximum heights.

The Kullback information for the moraine is twice less than for the whole area. Significant q value indicates very high value of bound energy which means that most of the internal energy cannot be used for useful work. In terms of surface flow it means limited surface runoff and water filtering into an underground flow. This interpretation is confirmed by field observations.

CONCLUSIONS
1. The resulting parameters are physically interpretable and method shows high sensitivity to the genesis of relief.
2. The organization of two genetically distinct forms of relief presented on the territory - moraine ridges and flat lowlands on the lake and periglacial sediments differ each from other as well they both differ from the whole territory.
3. Parameter \( q = 23.27 \) for moraine ridges indicates a high level of self-organization which means that the relief of moraine ridges is a stationary thermostatic system.
4. The development of lake and periglacial areas towards equilibrium goes through the development of erosion network with articulated low and high floodplains.

Direct observations show that the lake terraces composed with sands are highly resistant to surface erosion and only valleys of temporary and permanent watercourses transferred into the equilibrium state.

REFERENCES

Chapter I/28: MEASURING DYNAMICS AND POTENTIAL TRANSPORT CHARACTERISTICS OF DUST AEROSOL ORIGINATING FROM THE ARAL SEA BASIN Глава I/28: Измерение динамики и характеристика потенциального переноса пылевых аэрозолей бассейна Аральского моря

Jilili Abuduwalli*1,2,3; Yongxiao Ge1,2,3; Gulnura Issanova1,2,3; Long Ma1,2,3; Dongwei Liu4

ABSTRACT. We studied the inter-annual and intra-annual changes in dust aerosol from the Aral Sea basin and its potentially seasonal transport characteristics from 2005 to 2013 using Ozone Monitoring Instrument (OMI) aerosol data (2005-2013) and the Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model. Results showed that annual mean value of the OMI aerosol index (AI) exhibits a strong increasing trend because of the continuous decrease in the water level since 2005, which increased to 1.47 by 2013. Peak AI values were recorded in spring (March–May) and early winter (November–January of the following year), indicating notifying seasonal differences. The potential distance and height of air parcel trajectories to the northeast are greater than those to the west and south, whereas the air parcel trajectories proportion of the former is lower than that of the latter. The potential transport distance of dust emissions to the northeast is greatest in spring and winter. This transport distance is less in autumn, with the minimum observed in summer.