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საქართველოს გეოფიზიკური საზოგადოების ჟურნალი

სერია ბ. ატმოსფეროს, ოკეანისა და კოსმოსური პლაზმის ფიზიკა

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Impact of the Zonal Flows on the Relative Short-Scale ULF Electromagnetic Waves in the Shear Flow Driven Ionosphere

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ABSTRACT

Influence of the large-scale zonal flows and magnetic fields on the relative short-scale ULF electromagnetic waves in the dissipative ionosphere in the presence of a smooth inhomogeneous zonal wind (shear flow) is studied. A broad spectrum of Alfvenic-like electromagnetic fluctuations appears from electromagnetic drift turbulence and evidence of the existence of magnetic fluctuations in the shear flow region is shown in the experiments. In present work one possible theoretical explanation of the generation of electromagnetic fluctuations in DW-ZF systems is given. For shear flows, the operators of the linear problem are non-selfconjugate and therefore the eigenfunctions of the problem are non-normal. The non-normality results in linear transient growth with bursts of the perturbations and the mode coupling, which causes the generation of electromagnetic waves from the drift wave–shear flow system. We show that the transient growth substantially exceeds the growth of the classical dissipative trapped-particle instability of the system. Excitation of electromagnetic fluctuations in DW-ZF systems leads to the Attenuation-suppression of the short-scale turbulence.

Key Words: ULF electromagnetic waves, short-scale turbulence

1. Introduction

In recent years, special attention has been paid to the study of the generation of large-scale spatial-inhomogeneous (shear) zonal flows and magnetic field turbulence in the magnetized plasma medium in laboratory devices, as well as in space conditions (Diamond et al., 2005). Such interest firstly is caused by the fact that the excitement of the zonal flows and large-scale magnetic field can lead to noticeable weakening of anomalous processes, stipulated by relatively small-scale turbulence and by passage to the modes with improved property of adaptation to the equilibrium state (Diamond et al., 2005; Kamide and Chian, 2007). Specifically, the experiments indicate that drift turbulence gives rise to a broadband spectrum of electromagnetic waves, which is the subject of the present study. The zonal flow is different from externally imposed shear flow in that the zonal flow is a self-organized turbulence driven phenomena. The fluctuation data show a broad spectrum of electromagnetic waves in the presence of large scale zonal flows. Alfvenic-like fluctuations appear from electromagnetic drift flow driven turbulence in experiments (Horton, 2005; 2009). Generation of broadband electromagnetic fluctuations in drift wave – zonal flow systems is a significant phenomenon because electromagnetic fluctuations can modify the anomalous transport. In addition, the characteristics of these fluctuations indirectly give information about the dynamics of this system. The reported Alfvenic-like fluctuations occur at high shear rates. The fluctuations in flows with high shear rates are strongly non-normal. The strong nonnormality results in linear transient growth with bursts of the perturbations and mode coupling, which indicates the generation of the electromagnetic waves at interaction of the drift waves with the large scale zonal flows.

However, many-year observations (Gekelman, 1999; Grzesiak, 2000; Guzdar et al, 2001) show that at the atmospheric and ionospheric layers the spatially inhomogeneous shear flows permanently exist and are produced by a nonuniform heating of the atmospheric layers by solar radiation. In this connection, it becomes important to investigate the problem at the presence of inhomogeneous shear winds.

The interest in shear flows exist, generally speaking, due to their occurrence both in the near-earth space (as has been mentioned above) and astrophysical objects (galaxies, stars, jet outbursts, the world ocean and so on) and in the laboratory and engineering equipment (oil and gas pipelines, plasma magnetic traps, magnetodynamic generators and so on). A flow velocity shear is a powerful source of various energy-consuming processes in a solid medium. Though these processes have been studied in the course of many years, their theoretical interpretation is difficult even in terms of linear approximation. The canonical (modal) investigation of linear wave processes (spectral expansion disturbances with respect to time followed by analysis of the eigenvalues) in shear flows does not take into account a highly important physical process, namely, the mutual transformation of wave modes (Chagelishvili et al, 1996; Gogoberidze et al, 2004).

Nonmodal approach correctly describes transient exchange of energy between basic shear flow and perturbations. The energy transfer channel is resonant by nature and leads to energy exchange between different wave modes (chagelishvili et al, 1996; Gogoberidze et al, 2004). The mutual transformation of different kinds of waves is studied numerically and analytically in (Aburjania et al, 2006; Aburjania, 2006) in detail for the ULF electromagneic Rossby type waves. The mutual transformation occurs at small shear rates if the dispersion curves of the wave branches have pieces nearby one another. Other possibility of energy transfer channel is nonresonant vortex and wave mode characteristic times are significantly different and nonsymmetric a vortex mode is able to generate a wave mode but not vice versa. This channel leads to energy exchange between vortex and wave modes, as well as between different wave modes. We concentrate on this channel of mode coupling because it is important at high shear rates.

2. Model Equations

We describe the dynamics of the drift Alfven waves by the following theoretical model –fluid equations (Aburjania et al. 2006):

$$\frac{d_0}{dt}\left(\frac{1}{\delta}\Delta_\perp A - A\right) - \frac{\partial \varphi}{\partial z} - \chi\frac{\partial A}{\partial y} + \nabla_\parallel A = 0, \tag{1}$$

$$\frac{d_0}{dt}(\Delta_\perp\varphi - 0.5\sigma\Delta_\perp^2\varphi) + \nabla_\parallel\Delta_\perp A = 0, \tag{2}$$

$$\frac{d_0 N}{dt} - \chi\frac{d\varphi}{dy} + \nabla_\parallel\Delta_\perp A = 0. \tag{3}$$

Here the density perturbation, N, is normalized to the reference value of the background density value, n_0 - $N = \ln(n_0/n)$, the electrostatic potential, φ, to T_e/e , the parallel component of the vector potential, A, to $(c/c_A)(T_e/e)$; c_A is the Alfven velocity. Time derivative d_0/dt and space derivative along the total magnetic field, $\nabla_\parallel$, imply

$$\frac{d_0}{dt} = \frac{\partial}{\partial t} + V_{oz}(x)\nabla, \qquad \nabla_\parallel = \frac{\partial}{\partial z} - \mathbf{e_z}[\nabla A\times\nabla]_z\,. \tag{4}$$

In this model the ion and electron temperatures are assumed to be uniform ($\nabla T_e\ ,\nabla T_i = 0;\ T_e \ge T_i$) and the temperature gradients are neglected. The perturbations are considered to be quasi-neutral, $N_e \sim N_i = N$.

Electric and magnetic fields are given as:

$$\mathbf{E} = -\nabla\boldsymbol{\varphi} - \frac{1}{c}\frac{\partial A_z}{\partial t}\mathbf{e_z}\ ,\ \mathbf{B}_\perp = [\nabla A_z\times\mathbf{e_z}], \tag{5}$$

$B_z \gg B_\perp$ at $\beta \ll 1$.

We got:

$$\left(\frac{\partial}{\partial t} + V_0(x)\frac{\partial}{\partial z}\right)(\Delta_\perp\varphi + \sigma\Delta_\perp N - \frac{\sigma}{2}\Delta_\perp^2\varphi) + \frac{\partial}{\partial z}\Delta_\perp A + \Delta_\perp\varphi + \sigma\Delta_\perp N - 0.3\sigma D_2\Delta_\perp^2\varphi = 0, \tag{6}$$

$$\left(\frac{\partial}{\partial t} + V_0(x)\frac{\partial}{\partial z}\right)A + \left(\frac{\partial}{\partial z} + S\frac{\partial}{\partial y}\right)\varphi - \chi\frac{\partial A}{\partial y} - \frac{\partial N}{\partial z} = 0. \tag{7}$$

$$\left(\frac{\partial}{\partial t}+V_0(x)\frac{\partial}{\partial z}\right)N+\frac{\partial\Delta_\perp A}{\partial z}-\chi\frac{\partial\varphi}{\partial y}+V'\frac{\partial A}{\partial y}+\Delta_\perp(\varphi-N)=0. \qquad (8)$$

Here, φ, A, N are perturbations of the scalar electrostatic potential, vector potential of the magnetic field and the density, respectively.

Hereafter, we use nondimensional variables and physical quantities. Spatial scales are normalized to the length scale of perturbations along the magnetic field $L_{\parallel} \sim 1/k_{\parallel}$ and time is normalized to the Alfvén wave time $\tau_A \sim 1/k_{\parallel}V_A$, shear flow is given as following:

$$\mathbf{V}_0(z)=v_0(z)\,\mathbf{e_x}\;=A\cdot z\cdot\mathbf{e_x},$$

$$x_1=x-azt,\quad y_1=y,\quad t_1=t, \qquad (9)$$

or

$$\frac{\partial}{\partial t}=\frac{\partial}{\partial t_1}-az\frac{\partial}{\partial x_1},\quad \frac{\partial}{\partial x}=\frac{\partial}{\partial x_1},\quad \frac{\partial}{\partial z}=\frac{\partial}{\partial z_1}-at_1\frac{\partial}{\partial x_1}. \qquad (10)$$

$$\tau\Rightarrow\omega_g t_1;\quad V_{x,z}\Rightarrow\frac{\tilde{V}_{x,z}}{\omega_g H};\quad \rho\Rightarrow\frac{\tilde{\rho}}{\rho_0};\quad P\Rightarrow\frac{-i\tilde{P}}{\rho_0\omega_g^2H^2};$$

$$(x,z)\Rightarrow\frac{(x_1,z_1)}{H};\;\; S\Rightarrow\frac{A}{\omega_g};\;\; k_{x,z}\Rightarrow k_{x_1,z_1}H;\;\; k_z=k_z(0)-k_xS\tau;$$

$$k^2(\tau)=(k_x^2+k_z^2(\tau));\; b_0\Rightarrow\frac{\sigma_P B_0^2}{\rho_0\omega_g};\;\; b_y\Rightarrow\frac{\sigma_P B_y^2}{\rho_0\omega_g};$$

We present the following perturbations in a linear approximation:

$$\begin{Bmatrix}\varphi\left(k_{x_1},k_{y_1},t_1\right)\\ A\left(k_{x_1},k_{y_1},t_1\right)\\ N\left(k_{x_1},k_{y_1},t_1\right)\end{Bmatrix}=\begin{Bmatrix}\varphi_k(\tau)\\ A_k(\tau)\\ N_k(\tau)\end{Bmatrix}\times e^{(ik_{x_1}x_1+ik_{y_1}z_1+iy_1)} \qquad (11)$$

with

$$k_{\mathbf{x}}(\tau)=k_{\mathbf{x}}(0)-S\cdot k_{\mathbf{z}}\cdot t,$$

The wavenumbers of the SFH modes vary in time along the flow shear. In the linear approximation, SFH “drift” in the **K**-space in wavenumber space.

For each Fourier harmonics we will have:

$$\begin{aligned}&(1+\frac{\sigma}{2}k_\perp^2)\frac{\partial\varphi}{\partial\tau}=-i\sigma\chi k_y\phi-ik_z(1+\sigma k_\perp^2),\\ &\frac{\partial A}{\partial\tau}=-ik_z\phi+i\chi k_yA+ik_zN,\\ &\frac{\partial N}{\partial\tau}=-i\chi k_y\phi+ik_zk_y^2A,\end{aligned} \qquad (12)$$

With $k_\perp^2(\tau)=k_{\mathbf{x}}^2(\tau)-k_{\mathbf{z}}^2$,

This system of equations corresponds to spectrally stable DWs. In fact, low frequency DWs are subject to the trapped-particle instability.

In the simulations below, the quadratic form of (spectral energy density) for a separate SFH as a measure of its intensity is

$$E(\tau)=E_A(\tau)+E_\phi(\tau)+E_n(\tau) \qquad (13)$$

In the present analysis, this stretching physics is contained in the wave-number vector **K** time dependence induced by the shear flow parameter *S*. The effect is relatively easy to understand: convection of the initial structures stretches them in the direction of the sheared flow. This occurs for structures of all three fields:

vorticity, density, and magnetic flux. This time-dependent stretching induces a coupling between the three fields.

3. Linear Spectrum of the perturbations

The dispersion equation of our system may be obtained in the shearless limit *S*=0 using the full Fourier expansion of the variables, including time (Horton et al, 2009). Although the roots of the dispersion equation obtained in the shearless limit do not adequately describe the mode behavior in the shear case, we use this limit to understand the basic spectrum of the considered system. Hence, using Fourier expansion of the field vector we derive for the shearless limit the cubic dispersion relation:

$$(1+\frac{\sigma}{2}k_\perp^2)\omega^3+(k_y(1+\frac{\sigma}{2}k_\perp^2)-\sigma\chi k_y)\omega^2+(k_z^2(1+\sigma k_\perp^2)-\chi^2\sigma k_y^2-k_z^2k_y^2(1+\frac{\sigma}{2}k_\perp^2))\omega+ \\ -\chi k_y k_z^2(1+\sigma k_\perp^2)+\sigma\chi k_y k_z^2 k_\perp^2=0, \tag{14}$$

This third order dispersion equation describes three different modes of perturbations: two high frequency kinetic Alfvén waves and a low frequency DW. Due to the nonzero electron skin depth scale the Alfvénic-like fluctuations are dispersive with ω dependent on K_x. This fact is very important for mode coupling since K_x is time dependent in nonuniform flow, which, in turn, makes ω also time dependent. The dispersion equation is solved numerically for the parameters taking *S*=0 and the real parts of the dispersive curves, respectively, are plotted in Fig. 1.The plots show that the magnitude of the frequencies of Alfvénic-like fluctuations differ substantially from the DW frequency for all values of K_x. Consequently, the Alfvénic-like and DWs are linearly coupled solely by the nonresonant channel at sizeable shear flow rates.

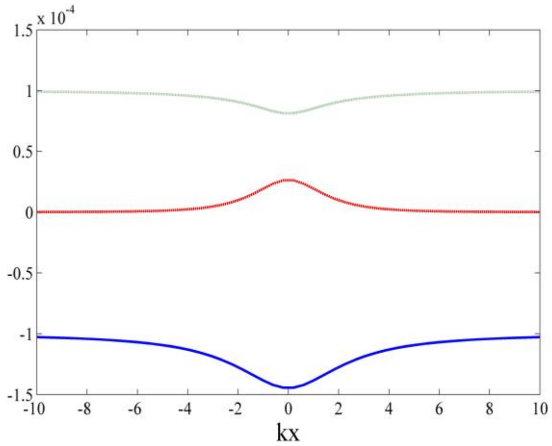

Fig. 1. Dispersion Curves.

Figure 1 shows that maximum values of frequency for the least stable DW mode are achieved at $K_X / K_Z \sim 1$. Thus, and the trapped-particle instability has no significant influence on the dynamical phenomena.

According to Eq. 14 in the shearless limit, when the axial vector potential is comparable to the electrostatic potential i.e., at $K_X / K_Z >> 1$, DWs have a small electromagnetic component that arises from the parallel plasma current. However, as K_X / K_Z, $R_d \to 0$, DWs become electrostatic. As to the other two modes, they are Alfvénic-like with high frequency and have dominant magnetic fluctuations for all K_X. Next we will analyze the coupling of the DW mode with these Alfvénic-like modes.

4. TRANSIENT GROWTH AND MODE COUPLING

Spectral Fourier harmonics dynamics are studied by numerically solving the three complex time evolution equations 8, 9, and 10. Separation of the fields into the real and imaginary parts is made in the following way (Aburjania et al, 2006):

$$\varphi_k=\varphi_1+i\varphi_2,\quad A_k=A_1+iA_2,\quad N_k=N_1+iN_2, \tag{15}$$

For each Fourier harmonics we will have:

$$(1+\frac{\sigma}{2}k_{\perp}^2)\frac{\partial\varphi}{\partial\tau} = -i\sigma\chi k_y\phi - ik_z(1+\sigma k_{\perp}^2), \tag{16}$$

$$\frac{\partial A}{\partial\tau} = -ik_z\phi + i\chi k_y A + ik_z N, \tag{17}$$

$$\frac{\partial N}{\partial\tau} = -i\chi k_y\phi + ik_z k_y^2 A \tag{18}$$

Equations 16–18, together with the appropriate initial values, pose the initial value problem describing the dynamics of a perturbation SFH. The character of the dynamics depends on which mode SFH is initially imposed in the equations: pure DW SFH, one of the Alfvénic wave SFH or, or a mixture of these wave SFHs. Let us concentrate on the linear dynamics when we initially insert in Eqs. 16–18 a SFH nearly corresponding to a DW perturbation with wavenumbers satisfying the condition $K_X(0)/K_Z >> 1$. The numerical simulations are performed using the MATLAB numerical ordinary differential equation solver. Note that the action of the flow shear on the dynamics of DW SFH at wavenumbers $K_X(0)/K_Z >> 1$ is negligible.

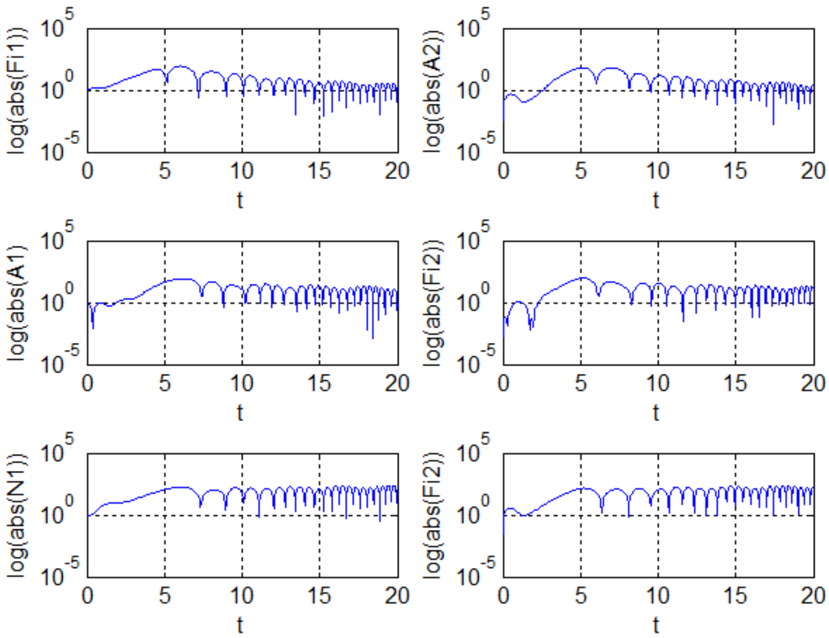

Fig. 2. The evolution of a single SFH

The simulations reveal a novel linear effect - the excitation of Alfvénic-like fluctuations - that accompanies the linear evolution of DW mode perturbations in the ZF. Mathematically, the problem is equivalent to time-dependent scattering theory in quantum mechanics. By using a 3x3 matrix representation of the system, formal solutions can be written in terms of the time ordering operator and exponentials of matrices.

The evolution of the initial DW SFH according to the dynamic equations (12) for the ionospheric parameters is presented in Fig. 2. Recall that K_X changes in time according to Eq. 14: the shear flow sweeps K_X to low values and then back to high values but with negative K_X/K_Z. While $K_X/K_Z >> 1$, the DW SFH undergoes substantial transient growth without any oscillations and the magnetic fluctuations are small. Significant magnetic field fluctuations appear when $K_X/K_Z = 1$. While $K_X/K_Z = 1 < 0$, the DW SFH generates the related SFH of Alfvénic-like wave modes through the second channel of the mode coupling. This generation of Alfvénic-like wave modes is especially prominent, where significantly higher frequency oscillations of all the fields are clearly seen at times when $K_X/K_Z = 1 < 0$. A substantial transient burst of the electron thermal energy, electron density of fluctuations is evident and an appearance of Alfvénic like fluctuations.

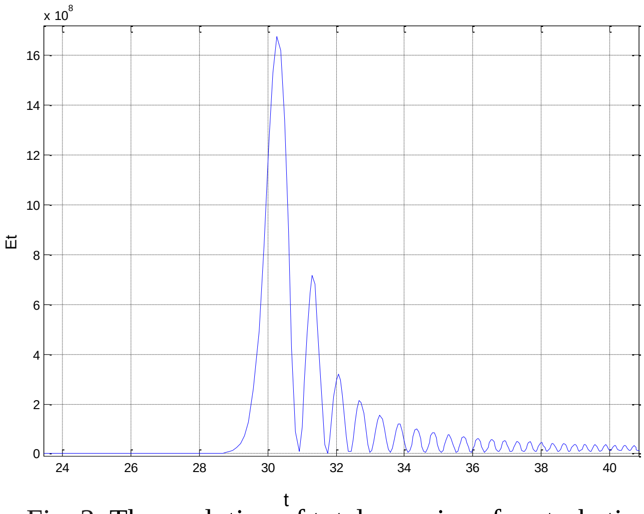

Fig. 3. The evolution of total energies of perturbation SFH

Figure 3 shows the related dynamics of the different energies. It indicates a substantial transient burst of the electron thermal energy of fluctuations and an appearance of Alfvénic like fluctuations.

4. CONCLUSIONS AND DISCUSSION

Drift-Alfvén waves are investigated in plasma with a significant level of background sheared flow. Magnetically confined plasmas in laboratory experiments, space physics, and coronal loops are examples where sheared flows occur.

We show that the linear dynamics of DWs are qualitatively changed by the presence of sheared flows when the shear normalized parameter *S* approaches unity and, consequently, there is strong excitation of magnetic fluctuations by the drift wave–shear flow system. The shear flow induces transient growth/bursts along with complex temporal wave forms and generates Alfvénic-like fluctuations from DWs. We show that the trapped-particle or any classical DW instability is far slower than these transient bursts and has no notable influence on the dynamic processes for the ionospheric parameter values. The frequency of the bursts is determined by the frequency of the generated Alfvénic-like waves Fig. 1. The frequency of the bursts depends only on the value of velocity shear parameter.

The complex linear dynamics are a result of the shear flow continually sweeping the wavenumber of the DW SFH K_X to low values and then back to high values. In this time-dependent sweeping of K_X, the DW SFH undergoes substantial transient growth and, when $K_X / K_Z < 0$, it generates the related SFH of Alfvénic-like wave modes illustrated in Fig. 2. The linear mode coupling channel universally leads to energy exchange between different perturbation modes at high shear rates. Flow non-normality induced mode coupling is related to the abrupt changes in magnetic turbulence during *L-H* transitions.

The energy evolution is easily produced by integrating the linear system of coupled field equations (see fig. 3). For sufficiently low values of the shear flow, the coupling becomes weak and the usual Doppler-shifted, well-separated modes of the linear system are recovered.

In space physics the effect is associated with sheared Earthward flows in the nightside plasma sheet that are driven by enhanced solar winds with southward embedded solar magnetic field components. Spacecraft in the plasma sheet measure high speed sheared flows driven by the convection electric field. Enhanced magnetic fluctuations associated with these flows are also observed. It remains to make a quantitative analysis of the magnetospheric problem. Finally, note that nonlinear simulations showing the growth of vortex structures out of the linear transients. Further nonlinear studies are being planned for the laboratory and space physics settings of this qualitatively new phenomenon.

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დიდმასშტაბიანი ზონალური დინებების ზეგავლენა შედარებით მცირემასშტაბიანი ულტრა დაბალი სიხშირის ელექტრომაგნიტურ ტალღებზე წანაცვლებით დინებიან იონოსფეროში

ხ. ჩარგაზია

რეზიუმე

ნაშრომში შესწავლილია დიდმასშტაბიანი ზონალური დინებებისა და მაგნიტური ველებს გავლენა შედარებით მცირემასშტაბიანი ულტრა დაბალი სიხშირის ელექტრომაგნიტურ ტალღებზე წანაცვლებით დინებიან დისიპაციურ იონოსფეროში. გამოვლენილია ალფენის მსგავსი ელექტრომაგნიტური ფლუქტუაციების ფართო სპექტრი, რომლებიც დაიმზირება ექსპერიმენტებში. წარმოდგენილ ნაშრომში წარმოდგენილია ელექტრომაგნიტური ფლუქტუაციების გენერაციის თეორიული ახსნა დრეიფულ ტალღა - ზონალური დინების სისტემაში. წანაცვლებითი დინებისათვის წრფივ ამოცანაში შემავალი ოპერატორები არარიან

თვით-შეუღლებადი და ამასთან, საკუთარი ფუნქციებიც - -არაორთოგონალური. აღნიშნული არაორთოგონალურობა განაპირობებს ფლუქტუაციების იმპულსურობას და მოდების ურთიერთკავშირს, რაც თავის მხრივ იწვევს ელექტორმაგნიტური ტალღების გენერაციას დრეიფული ტალღა - წანაცვლებითი დინების სისტემაში. ჩვენ ვაჩვენეთ, რომ მოდების ტრანზიენტული ზრდა მნიშვნელოვნად აღემატება სისტემის კლასიკურ დისიპაციურ წარტაცებული ნაწილაკების არამდგრადობას. ელექტრომაგნიტური ფლუქტუაციების გენერაცია აღნიშნულ სისტემაში იწვევს მცირე მასშტაბიანი ტურბულენტობის მილევას.

Влияние крупномасштабных зональных течений на сравнительно мелкомасштабных ультра низкочастотных (УНЧ) электромагнитных волн в ионосфере в присутствии неоднородных зональных ветров

Х.Чаргазиа

Резюме

Изучена влияние крупномасштабных зонального течения и магнитного поля на сравнительно мелкомасштабного ультра низкочастотных (УНЧ) электромагнитных волн в диссипативной ионосфере в присутствии неоднородных зональных ветров. В экспериментах показана появление широкого спектра Альвеновских флюктуации от электромагнитной дрейфовой турбулентности и возможность магнитных флюктуаций в сдвиговых течениях. В данной работе описана одна теоретическая возможность генерации электромагнитных флюктуации в ЗТ (зональное течение) – ДВ (дрейфовая волна) системе. При сдвиговых течениях операторы линейных задач не являются взаймно сопряженными и в следствии, соответствуюшие собственные функции не являются ортогональным. Неортогональность вызивает линейный транзиентный рост возмущений с пучками и взаймную трансформацию волновых мод, что приводит к генерацию электромагнитных волн в ЗТ– ДВ системе. Показано, что транзиентный рост волновых возмущений существенно превосходит классический диссипативный рост неустойчивости захваченных частиц системы. Излучение электромагнитных флюктуаций в ЗТ– ДВ системе приводит к затуханию мелкомасштабной турбулентности.

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Spatial Distribution of the Local Meteorological Fields and Dust Concentration in Kakheti Atmosphere in Case of the Northern Background Wind

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ABSTRACT

Spatial distribution of meteorological fields and dust concentrations in case of northern background winds is studied by means of the model of mesoscale atmospheric processes evolution at the territory of Kakheti and numerical integration of transfer-diffusion of passive admixtures.

It is shown that the Kakheti terrain has significant impact on formation of meteorological fields in boundary layer. The impact of terrain is substantially weaker in free atmosphere. Influence of regional terrain on background flow causes formation of horizontal and vertical swirls and waves directed along the background flow. There is a wave not only in atmospheric boundary layer, but also in free atmosphere. Vertical vortexes are formed on windward and leeward sides of the Greater and Lesser Caucasus Mountains, some of them are in the vicinity of ranges. Sizes of formed vortexes are depended on ridge width and height or on gorge depth.

Pictures of dust spatial distribution are obtained. Dust dispersion areas in cities are determined. Dust dispersion kinematics is studied. It is obtained, that in 2-100 m atmospheric layer dust dispersion mainly occurs through turbulent diffusion. In layer from 100 meters to 1 km height the processes of diffusive and advective transfer are equal, while above 1 km advective transfer of dust is primary.

***Key words**: numerical modeling, local circulation, meteorological field, air pollution, equation of mass transfer*

1. Introduction

In this article the numerical investigations of the local meteorological fields and the spatial distribution of the dust concentration obtained by the numerical model of the β-mesoscale atmospheric processes in the Kakheti Region made in [1, 2, 3] are continued.

Numerical integration is made on spatial grid comprising of 118×90×31 points. Grid steps are 2 km in horizontal direction, while in vertical it varies from 2 to 15 m in the surface layer, and from 15 to 300 m in the boundary area and free atmosphere. Time step is 10 sec.

Climate conditions corresponding for June are taken. Meteorological situation corresponds with northern stationary winds, when the velocity of geostrophic background winds is 1 m/sec at the height of 10 meters. The speed linearly increases along with height and reaches 23 m/sec at a height of 9 km.

The distributions of the anthropogenic dust emitted in the atmosphere from Tbilisi and Rustavi cities and 19 little towns of Kakheti and 3 towns of Azerbaijan are numerically modeled. The data of National Environment Agency [4] are taken as the initial and boundary values of the monthly average concentrations at the height of 2 m in atmosphere at the territories of Tbilisi and Rustavi, while for territories of other cities, where observations over dust pollution were not conducted, an initial concentration values are calculated according to given methodology [5]. The initial concentration of dust at the points of the network that don’t belong to cities is considered equal to zero. The diameter of dust particle is assumed to be equal to 10 µm.

2. Results of modeling. On Fig. 1-12 are shown patterns of spatial and time distribution of meteorological fields at midnight (t = 0 h) obtained through calculation.

On Fig. 1 is shown wind velocity vector and module at the height of z = 10m – a), b) and z = 100 m – c), d), respectively. It is seen that terrain impact on northern background winds in surface layer of the atmosphere has caused significant change in velocity field at the territory located between the Greater Caucasus Mountains and Trialeti range. Northern wind occurs only on northern slopes of the Greater Caucasus Mountains and part of Trialeti range, which is situated in south-eastern part of modeling area. At the rest of territory north-western, western and south-western weak winds are obtained. Formation of clearly separated air convergence band along the southern slope of the Greater Caucasus Mountains should be noted. This band follows Alazani River valley. At the mentioned territory wind velocity is not big. At the height

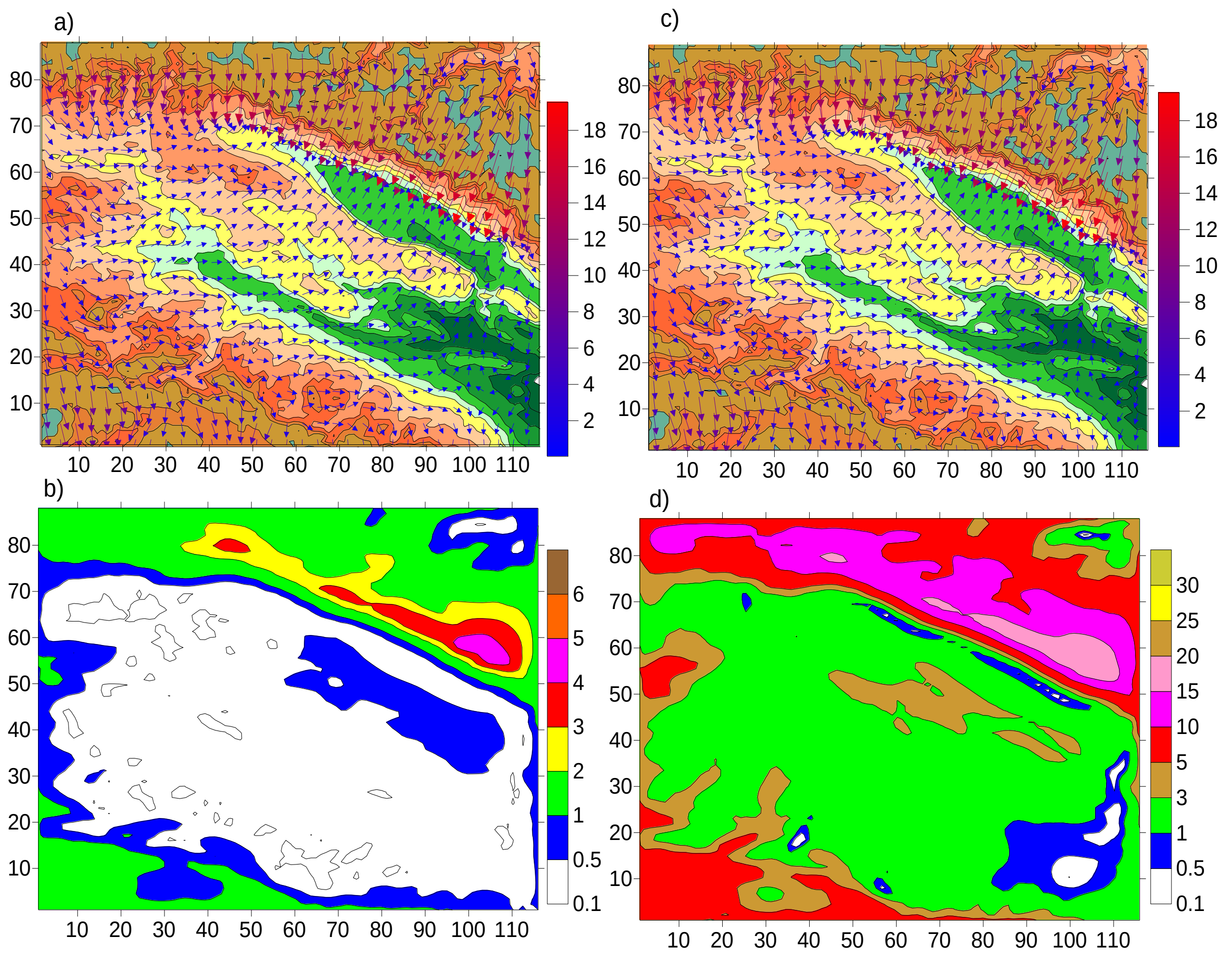

Fig. 1. Wind velocity and sped at height z =10m – a), b) and z =100m – c), d), from earth surface, respectively, when t = 0h.

of 10 meters windless conditions take place basically. At 2 and 100 m height from the earth surface (Fig. 1 ,c) and d) spatial distributions of wind velocity are similar to each other. Change in wind direction and magnitude in surface layer is analogous to changes peculiar to boundary planetary zone. At 100 m height from earth surface windless conditions are obtained only at small territories near Shiraki valley and Eldar lowland.

In the free atmosphere a wind keeps the direction of background wind (Fig. 2). Surface distribution of wind velocity module changes with height increase. At 3 km height wind velocity in the central part of region is less than velocity obtained in northern and southern parts. On the contrary, at 6 km height wind velocity along the Greater Caucasus Mountains is less than velocities of winds existing above lowland and plain territories.

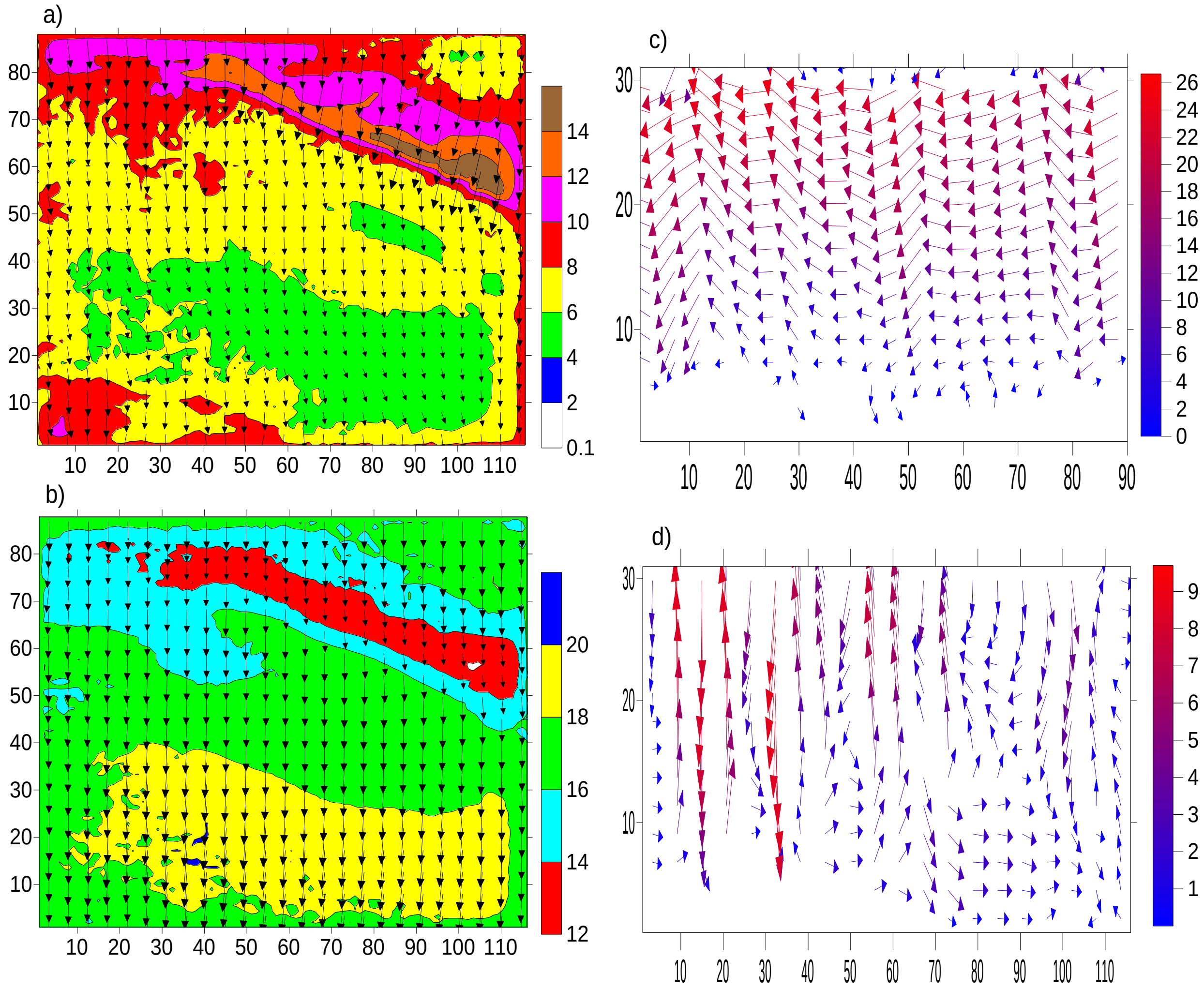

Fig. 2. Wind velocity and sped at height z = 3 km – a) and 6 km – b). The latitudinal projection of wind velocity on XOZ plane when Y = 20 – c), and longitudinal projection of wind sped on YOZ plane when X = 20 – d), when t = 0h.

For orography flow-around phenomenon is characteristic the formation of wave and vortex motions both in boundary layer and in free atmosphere (Fig. 2, c) d), Fig. 3 – Fig. 6). Vertical *vortexes* are more clearly expressed in the surface layers of atmosphere than waves in free atmosphere. Anticyclonic *vortexes* are obtained in planes directed along the background flows (meridian planes). They are formed not only at lowland territories, but also on hill-sides of ridges and highlands with sufficient length. Horizontal scales of swirls are depended on sizes of orography non-uniformities. In boundary layers of atmosphere vortex structures in planes perpendicular to background flows (along the parallel) are not clearly expressed. Flow direction above lowland and plain territories doesn't change with distance from earth surface.

In the surface layer of atmosphere the basic distinguishing feature of temperature field is its increase with distance from earth surface. In Alazani valley and in the vicinity of Iori plateau air temperature at 100 m height is roughly 4°C higher than atmosphere temperature at 2 m height. As to the soil, its temperature is equal or slightly lesser than temperature obtained at 2 m height.

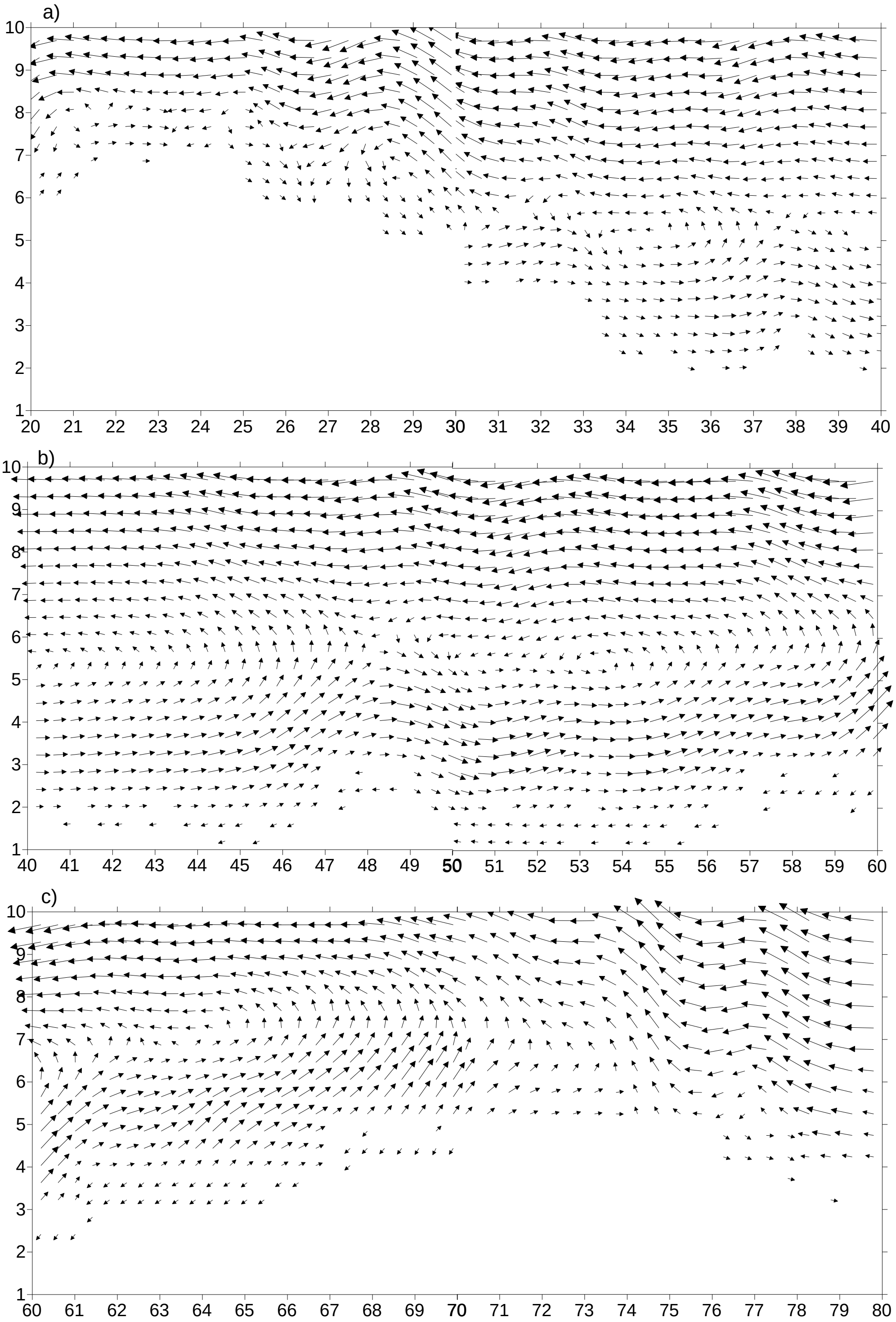

Fig. 3. Longitudinal projection of wind sped on YOZ plane when $z \le 3$, $x = 30$, $20 \le y \le 40$ – a), $40 \le y \le 60$ – b), $60 \le y \le 80$ – c) and $t = 0h$.

Temperature gradient in atmospheric boundary layer and in free atmosphere is mainly directed westward (Fig. 7). In the free atmosphere temperature field is represented by meridionally oriented zones, which are deformed by advective and turbulent heat transfers. Deformation is complicated and its explanation needs additional research (Fig. 8).

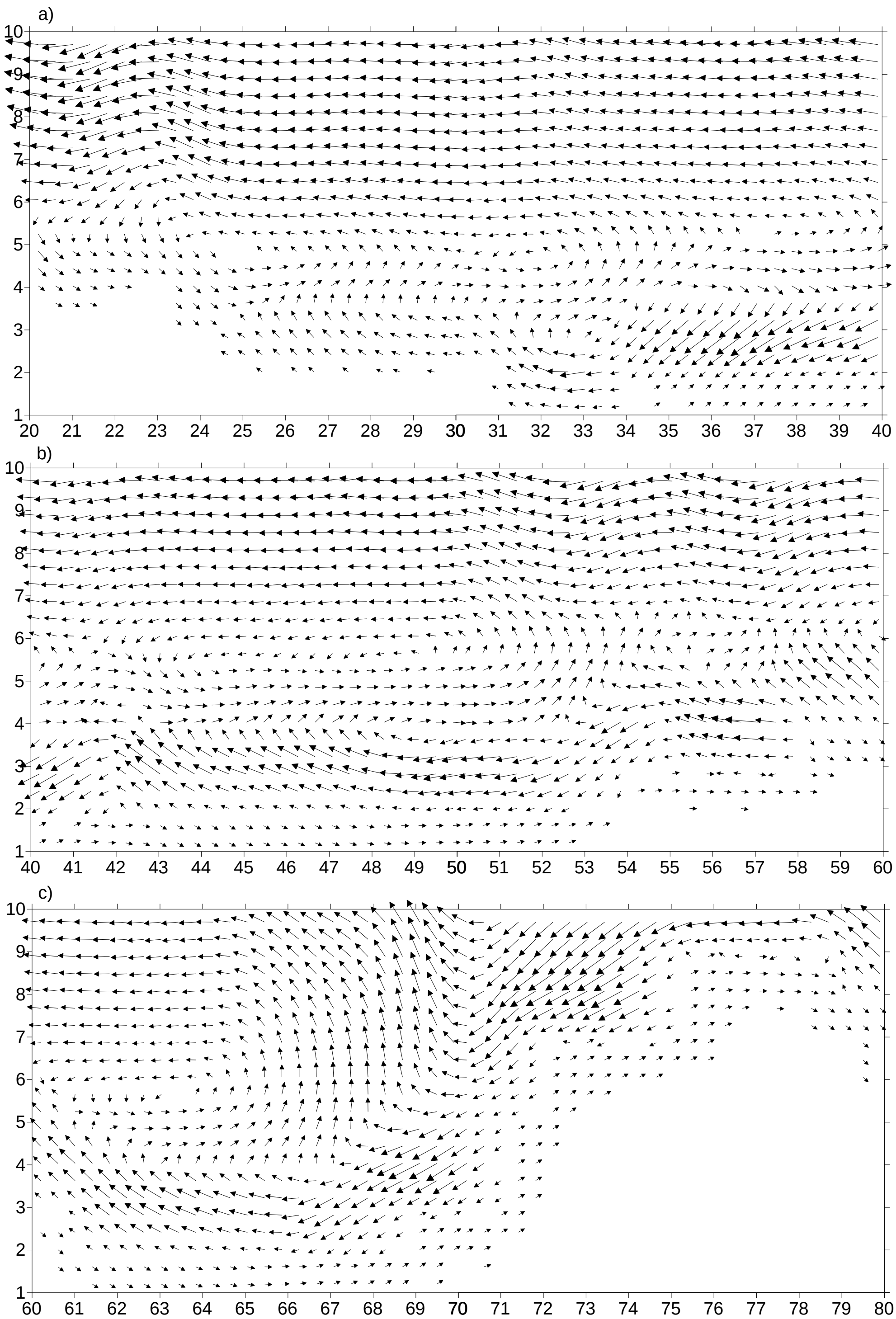

Fig. 4. Longitudinal projection of wind sped on YOZ plane when $z \leq 3$, x = 60, $20 \leq y \leq 40$ – a), $40 \leq y \leq 60$ – b), $60 \leq y \leq 80$ – c) and t = 0h.

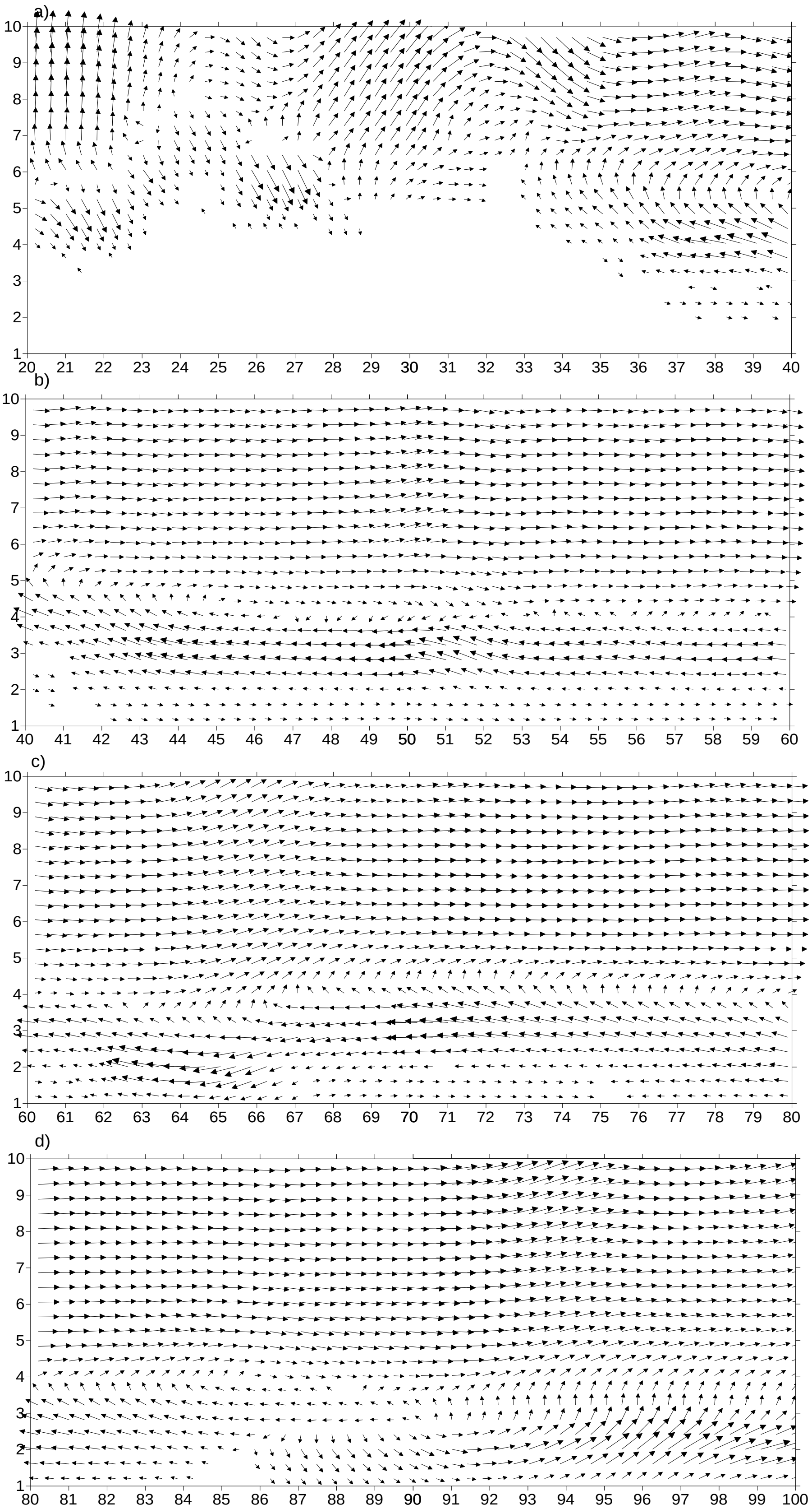

Fig. 5. Latitudinal projection of wind sped on XOZ plane when $z \leq 3$, $y = 30$, $20 \leq x \leq 40$ – a), $40 \leq x \leq 60$ – b), $60 \leq x \leq 80$ – c) and $t = 0$h.

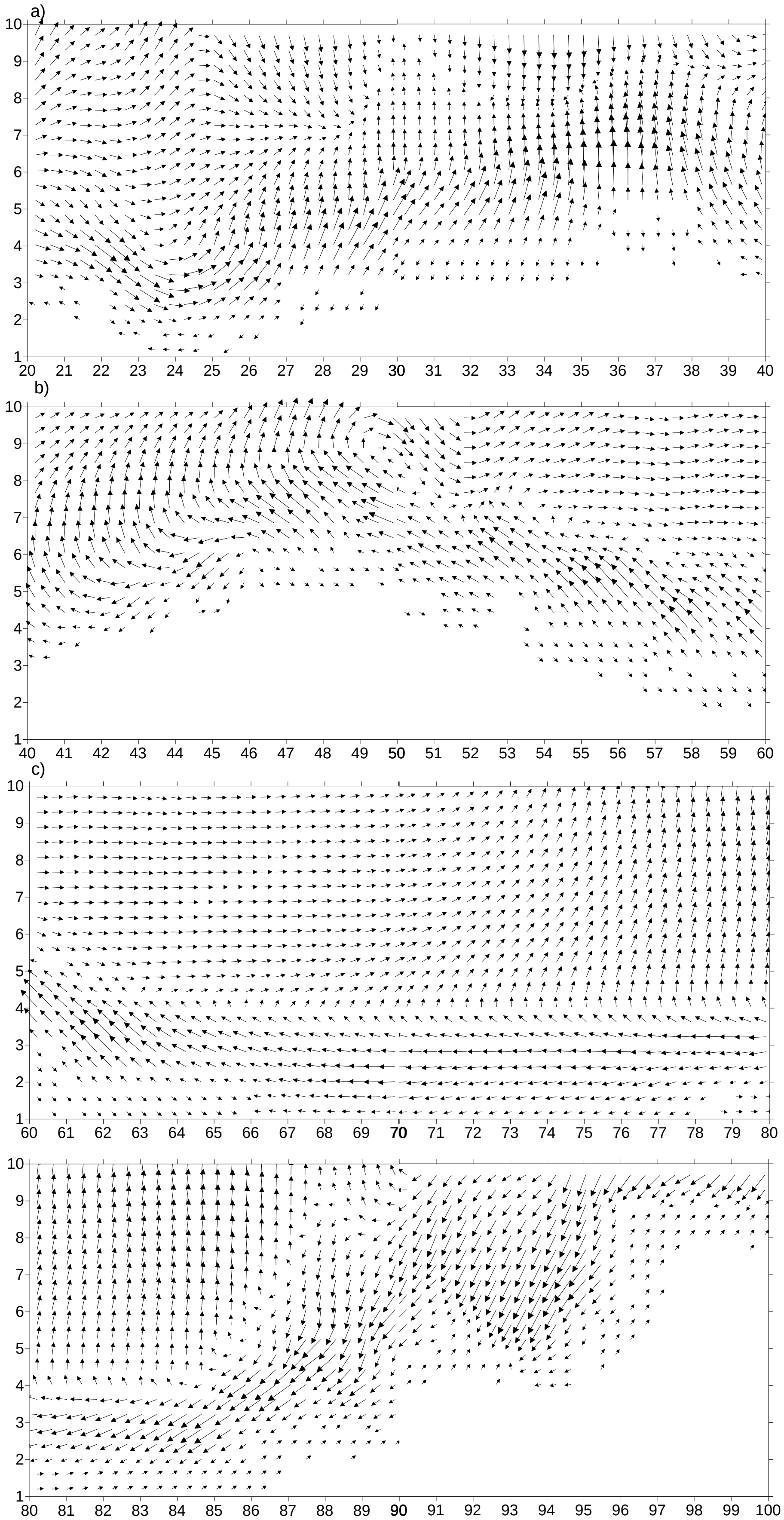

Fig.6. Latitudinal projection of wind sped on XOZ plane when $z \leq 3$, $y = 60$, $20 \leq x \leq 40$ – a), $40 \leq x \leq 60$ – b), $60 \leq x \leq 80$ – c) and $t = 0$h.

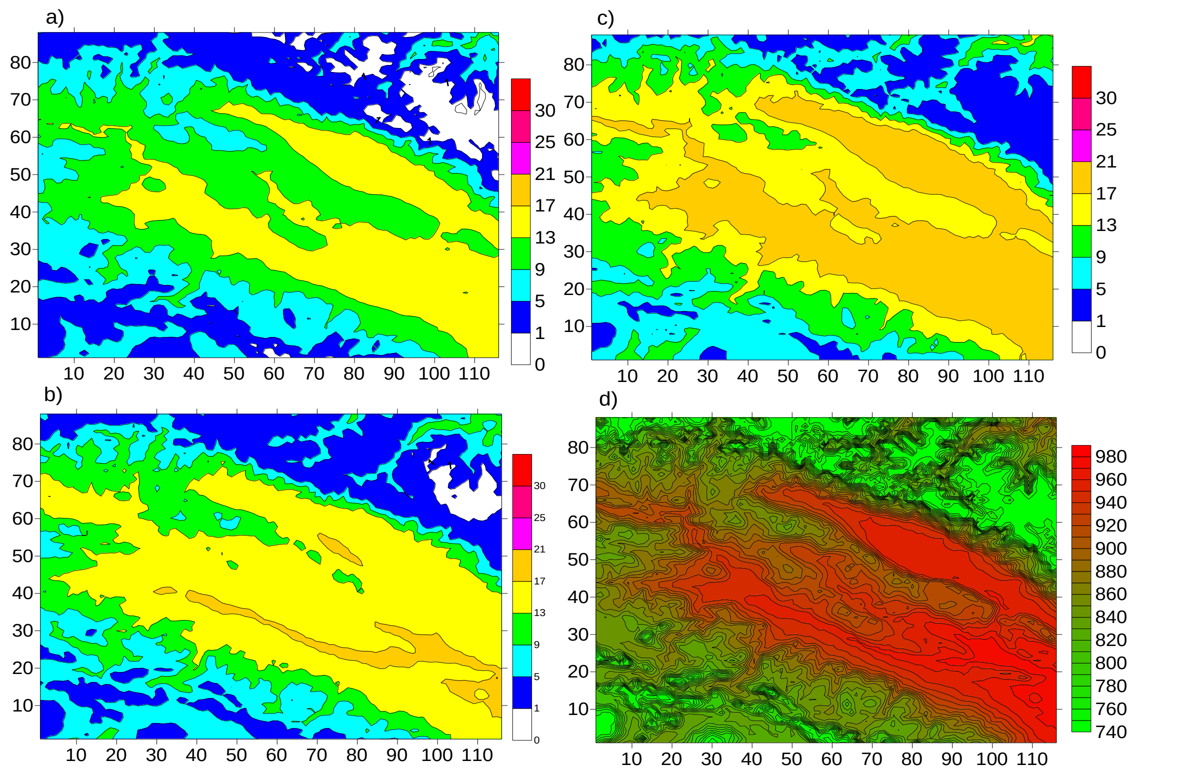

Fig. 7. Temperature (^{o}C) on the earth surface – a), at height from earth surface z = 2m– b), 100m - c) and surface pressure (mb), when t =0h.

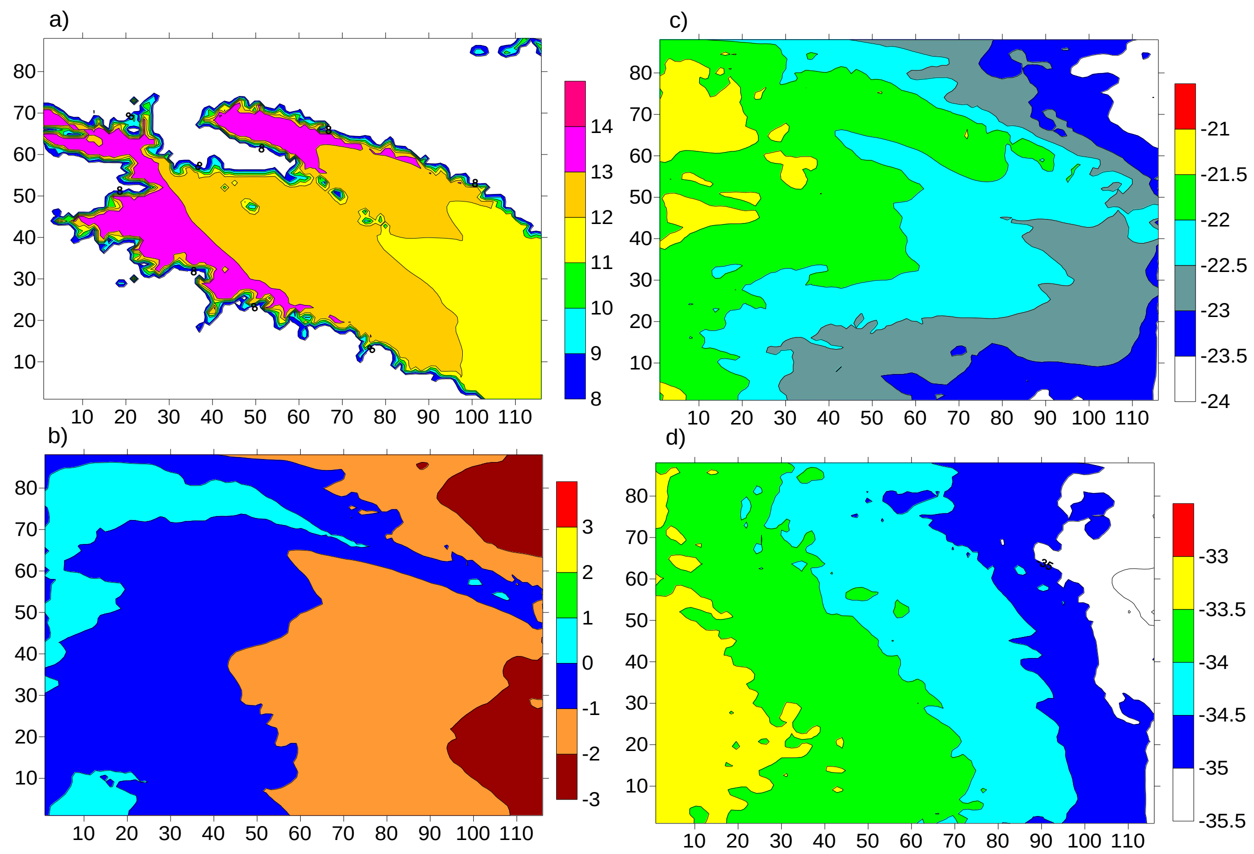

Fig. 8. Temperature (^{o}C) on at heights z = 1, 3, 6. 8km when t =0h.

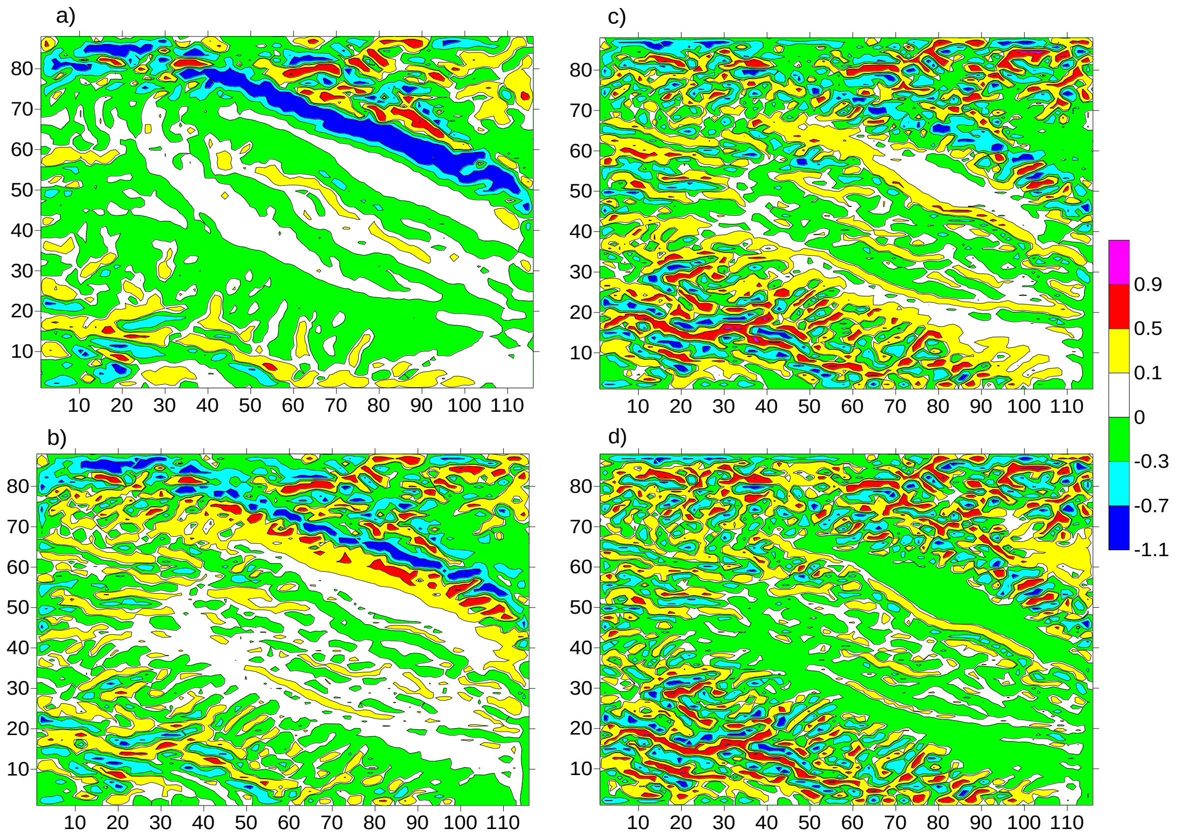

Fig. 9. Vertical velocity field (m/sec) at at height from earth surface z= 100 m – a), 3 km – b), 6 km – c) and 8 km – d) when t = 0h.

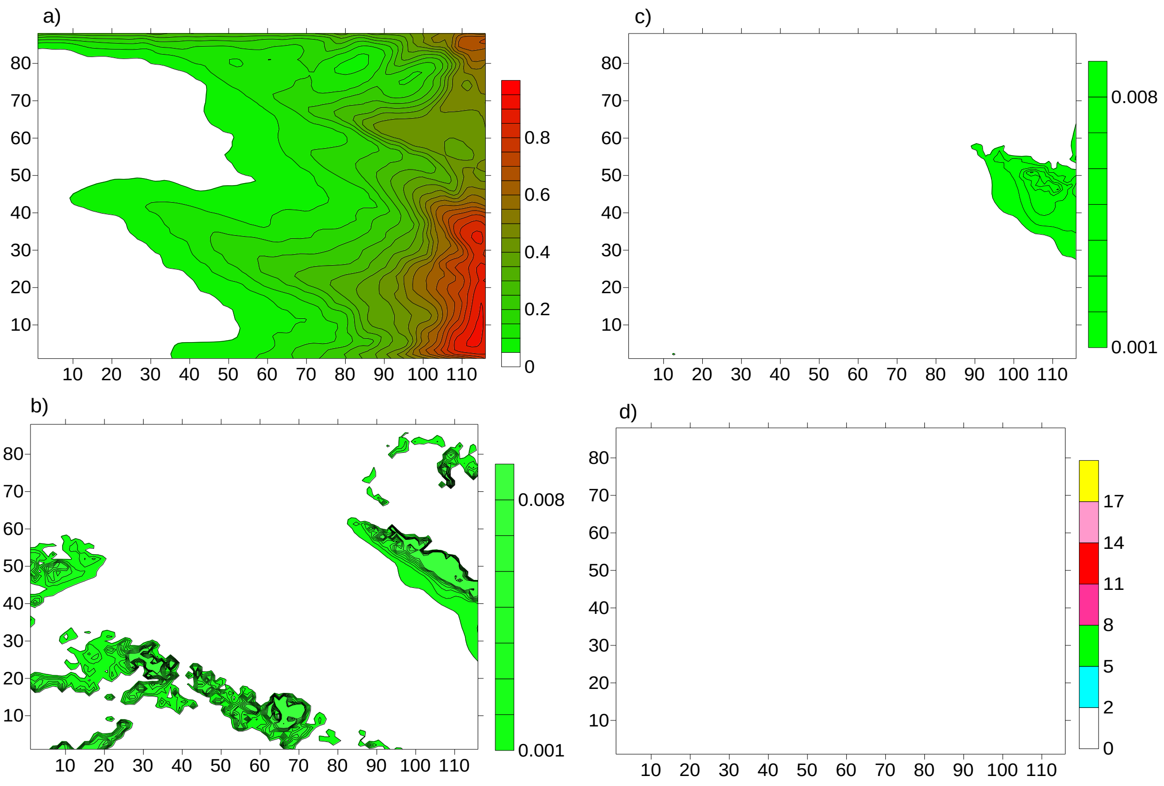

Fig. 10. The mass content of water steam (g/kg) at height z= 3km –a), mass content of water (g/kg) at z= 2km – b), 3 km – c), and precipitate – d), when t=0h.

The value of surface pressure changes from 1000 mb in the vicinity of Mingachevir reservoir to 740 mb in the neighborhood of main peaks of Caucasus Mountains.

On Fig. 9 is shown distribution of isolines vertical of velocity. As is seen from figures, in the central part of the region – Iori plateau, Alazani valley and in the vicinity of Jeiran valley the field of vertical velocity has band structure, in which the value of downward motion velocity changes within 0 – -1m/sec, while the value of upward vertically motion velocity doesn't exceed 0,1 m/sec.

At the 3 km and more height vertical distribution of velocity is typical for region. It consists of small-size cells of upward and downward motions, location of which corresponds with disposition of separate small-size ridges.

Massive content of water steam, cloud water and precipitations fallen obtained by calculations are shown on Fig. 10. As is seen from figure, the cloud is formed in two areas, but water content in them is so small that despite great magnitudes of vertical velocities, water content is not sufficient for rain.

Dust distribution in surface and boundary layers of atmosphere obtained by calculation is shown on Fig. 11 and 12. It is seen from figures that in the neighborhood of Tbilisi, Rustavi, Marneuli and Bolnisi cities dust distributions at 2 and 10 m height are virtually the same and their concentrations insufficiently differ from each other. The mentioned distribution in the vicinity of pollution sources is caused by windless condition and meteorological situation close to windless one. At 100 m height the dust emitted from different sources experiences

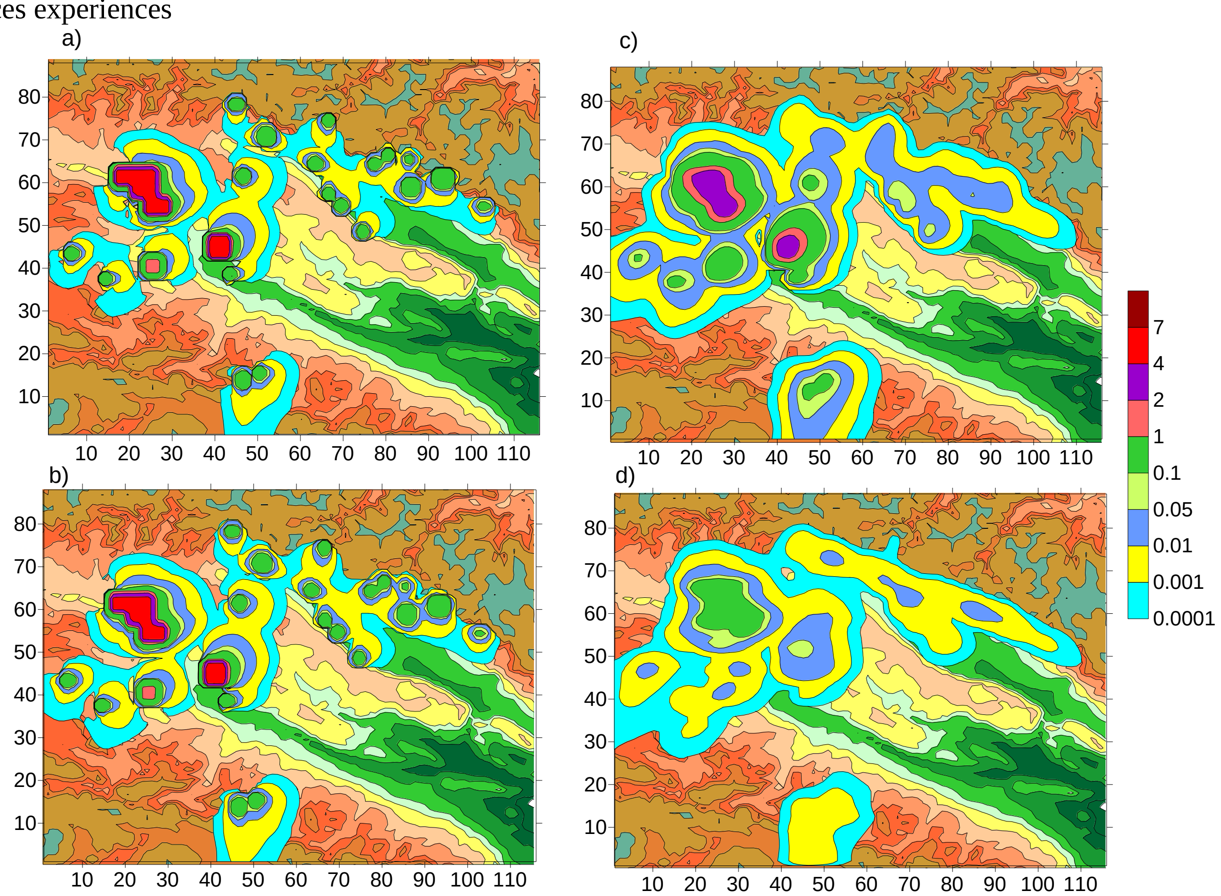

Fig. 10. Dust concentration at heights z = 2, 10, 100 and 600 m when t = 0h.

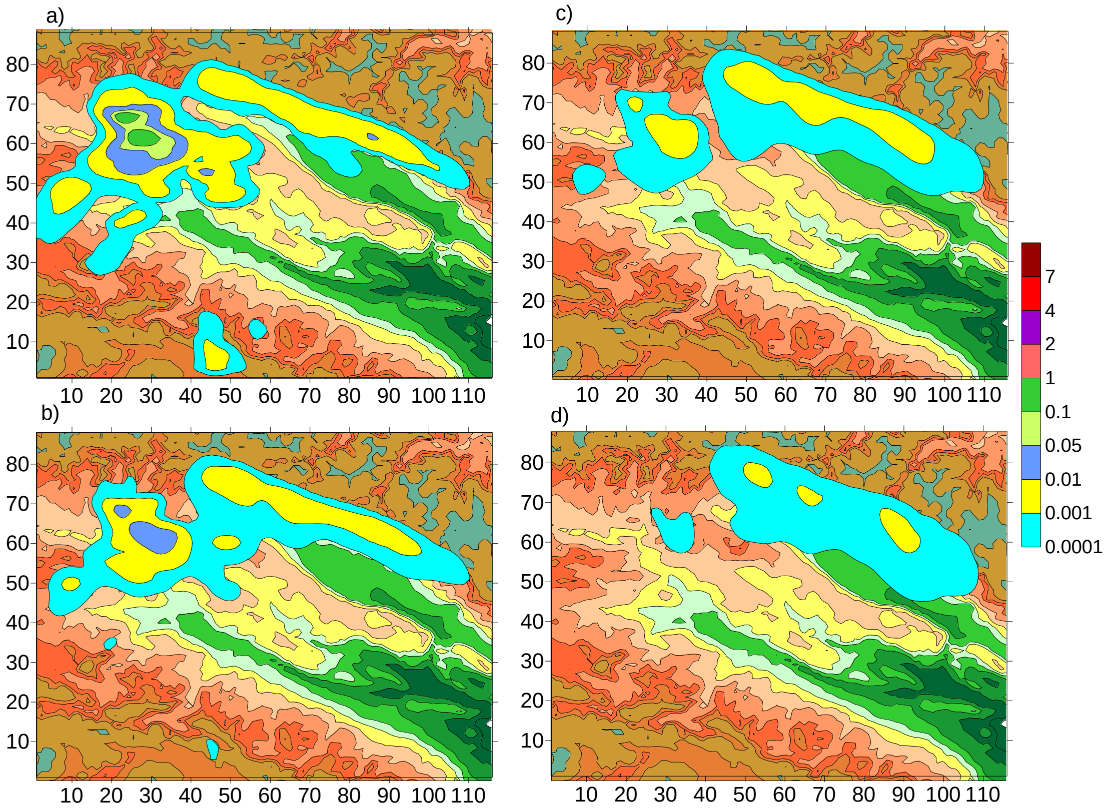

Fig.11.Dust concentration at heights z = 1, 1.5, 2 and 3km when t = 0h.

superposition as a result of horizontal diffusion and pollution area is like unite dust cloud with two clearly expressed centers in the outskirts of Tbilisi and Rustavi. In Sagarejo and Gardabani the dust is dispersed at very large distances that primarily is caused by the processes of advective transfer.

Conclusions

Thus, carried out numerical modeling has manifested the meteorological features, which are peculiar to Kakheti region in case of flow-around of its terrain by northern background winds at midnight (t = 0h). It is shown that terrain impact on background flow causes formation of vertical wind swirls. Horizontal size of swirls is depended on the width of terrain deepening, while vertical size – on the value of wind velocity in atmospheric boundary layer. Formed centers of local circulations are located like sublayers close to surface and also at a remote. Circulating swirls are mainly dominant in meridian plane and they have the direction of anticyclonic rotation. In swirls formed in planes directed along the parallels wind rotation direction is both cyclonic and anticyclonic.

Orographic internal gravitation waves are formed in atmospheric boundary layer and are spread in free atmosphere. Wave amplitudes are directly proportional to orographic resistance, height and wind velocity.

Formation of vertical motion bands with up to 1 m/sec velocity in atmospheric boundary layer is peculiar to flow-around process. These bands are narrow and in the form of several dozen kilometer length areas follow the southern slopes of the Greater Caucasus Mountains and north-eastern hillsides of Tsiv-Gombori range.

Separate multiple cells of vertical convection are formed above regional ridges both in atmospheric boundary layer and in lower and middle tropospheres.

Specific picture of temperature horizontal distribution is peculiar to this process. Temperature field in surface layer of atmosphere is determined by the form of sublayer surface, orography inclination to the horizon and its height. Temperature field in troposphere is represented by vertically oriented bands, which are deformed as a result of impact of thermodynamic heat transfer processes in the region.

Complicated hydrodynamics of the region has an impact on dust dispersion in atmosphere. Vertical diffusive dust transfer is dominant in surface layer of atmosphere, while in atmospheric boundary layer the important role belongs to advective dust transfer and horizontal diffusion. As a consequence, dust is dispersed at large areas in atmospheric boundary layer. Dust pollution zone with more than 0.1 MAC is limited between Tbilisi and Rustavi cities and small-size atmosphere part situated in the vicinity.

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ლოკალური მეტეოროლოგიური ველების და მტვრის კონცენტრაციის სივრცული განაწილება კახეთის ატმოსფეროში ფონური ჩრდილოეთის ქარის დროს

ნ. გიგაური, ა. სურმავა

რეზიუმე

კახეთის ტერიტორიაზე მეზომასშტაბის ატმოსფერული პროცესების ეოლუციის მოდელის და პასიური მინარევის გადატანა - დიფუზიის განტოლების რიცხვითი ინტეგრირების საშუალებით შესწავლილია მეტეოროლოგიური ველების და მტვრის კონცენტრაციის სივრცული განაწილება მსხვილ ჩრდილოეთის ფონური ქარის შემთხვევაში.

ნაჩვენებია, რომ კახეთის რელიეფი მნიშვნელოვან გავლენას ახდენს მეტეოროლოგიური ველების ფორმირებაზე ატმოსფეროს სასაზღვრო ფენაში. რელიეფის გავლენა თავისუფალ ატმოსფეროში მნიშვნელოვნად სუსტია. რეგიონის რელიეფის მოქმედება ფონურ დინებაზე ჰორიზონტალური, ვერტიკალური გრიგალებისა, და ფონური დინების გასწვრივ მიმართული ტალღების წარმოშობას იწვევს. ტალღა არსებობს როგორც ატმოსფეროს სასაზღვრო ფენაში, ასევე თავისუფალ ატმოსფეროში. ვერტკალური გრიგალები ფორმირებული არიან მთავარი მცირე კავკასიონის ქედების ქარპირა და ქარზურგა მხარეს, ზოგიერთი მცირე ქედების მიდამოებში. წარმოშობილი გრიგალის ზომები დამოკიდებულია ქედის სიგანეზე და სიმაღლეზე, ან ხეობის სიღრმეზე.

მიღებულია მტვრის სივრცული განაწილებების სურათები. განსაზღვრულია ქალაქების მტვრის გავრცელების არეები. შესწავლილია მტვრის გავრცელების კინეტიკა. მიღებულია, რომ ატმოსფეროს 2 – 100 მ ფენაში მტვრის გავრცელება უპირატესად ტურბულენტური დიფუზიით ხდება. 100 მ-დან 1 კმ-დე ფენაში დიფუზიური და ადვექციური გადატანის პროცესები ტოლფასია, ხოლო 1კმ-ის ზევით ძირითადია მტვრის ადვექციური გადატანა.

Пространственное распространение метеорологических полей и концентрация пыли в атмосфере Кахети в случае фонового северного ветра

Н.Г Гигаури, А.А. Сурмава

Резюме

С помощью модели эволюции мезометеорологических атмосферных процессов и численного интегрирования уравнения переноса-диффузии примеси на территории Кахети исследованы пространственное распределение метеорологических полей и концентрация пыли в случае фонового северного ветра. Показано, что рельеф Кахети существенно влияет на формирование локальных метеорологических полей в атмосферном пограничном слое. В свободной атмосфере влияние значительно слабее. Воздействие рельефа на фоновое движение воздуха вызывает возникновение мезомасштабных горизонтальных и вертикальных вихрей и волны, направленной вдоль фонового движения воздуха. Волна существует как в пограничном слое, так и в свободной атмосфере. Вертикальные вихри формируются с наветренной и подветренной сторон орографического препятствия. Размеры возникших вихрей зависят от ширины и высоты или глубины горного хребта или ущелья, соответственно.

Получены картины пространственного распределения и определены зоны распространения городской пыли. Изучена кинетика процесса диффузии загрязнения воздуха. Получено, что в нижнем, 2-100 метровом слое атмосферы турбулентная диффузия играет преобладающую роль в процессе распространения пыли. В слое от 100 м до 1 км влияния турбулентной диффузии и адвективного переноса одинаковы, а выше 1км - адвективный перенос преобладает над турбулентной диффузией.

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Statistical Characteristics of the Monthly Average Values of the Air Temperature in the Layer of Atmosphere 0.54-27 km above the Kakheti Territory (Georgia) in 2012-2016

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ABSTRACT

Here is presented the data of statistical analysis of the monthly average values of the air temperature in the atmosphere above the territory of Kakheti at 19 levels in the range of heights from 0.54 to 27 km for the period from 2012 through 2016.

Key words: aerological sounding of atmosphere, air temperature vertical distribution.

Introduction

Information about the vertical distribution of the air temperature in atmosphere has great value for the solution of different problems of meteorology and climatology. In particular - forecast of the dangerous meteorological phenomena (thunderstorm, hail, snow-storm, etc.) [1,2], determination of different microphysical characteristics of clouds according to the data of radar measurements [2-6], weather modification of [2, 7-11], estimation of climate change [12-14], etc.

In the past century in Soviet Georgia the regular aerological sounding of the atmosphere in Tbilisi, Sukhumi and Batumi were carried out [15-17]. In the years with the work of anti-hail service in Kakheti the aerological sounding of the atmosphere in the village of Ruispiri in the Telavi municipality was carried out also [3,7,18]. The aerological sounding of atmosphere is not conducted since 1991 in Georgia.

The necessity of regular obtaining of information about the vertical distribution of meteorological elements in the atmosphere arose after the restoration of anti-hail works in Georgia [19-22].These works were begun in 2015 [23] with use data of https://www.ready.noaa.gov/READYcmet.php. Subsequently it was studied above Kakheti Territory (Georgia) the vertical distribution of the average monthly values of air temperature in 2012-2016 during January, April, July and October in the range of heights from 0.543 to 27 km above sea level [24], they were studied the statistical characteristics of monthly and ten-days average values of freezing level in the atmosphere and hourly values of the height of isotherm -6°C in the atmosphere from April to October [25,26].

Material and methods

For investigating the thermal regime in the free atmosphere above the territory of Kakheti the resources of http://ready.arl.noaa.gov/READYcmet.phpand https://rp5.ru/Weather_in_Georgia were used.

Here is carried out the statistical analysis of hourly (04, 10, 16 and 22 hours on the Tbilisi time) air temperature at the 19 heights about Kakheti territory from January through December 2012-2016. The total quantity of data composes is 138852. As the informational unit the values of average air temperature in the twenty-four hours are used, averaged in five years.

The analysis of data with the use of the standard statistical analysis methods is carried out [27]. The following designations will be used below: Min – minimal values, Max - maximal values, Range - variational scope, St Dev - standard deviation, σ_m – standard error, 95%(+/-) - 95% of confidence interval, mb –millibars, diurnal value – average value for 4, 10, 16 and 22 hours.

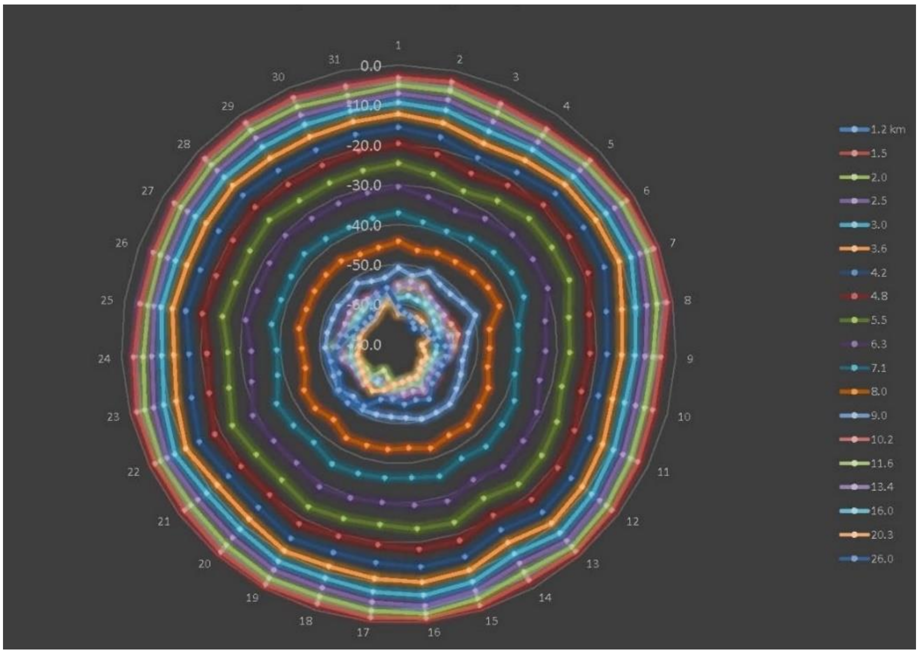

Fig. 1.Example of the vertical distribution of diurnal average values of air temperature above Kakheti territory in January 2012-2016

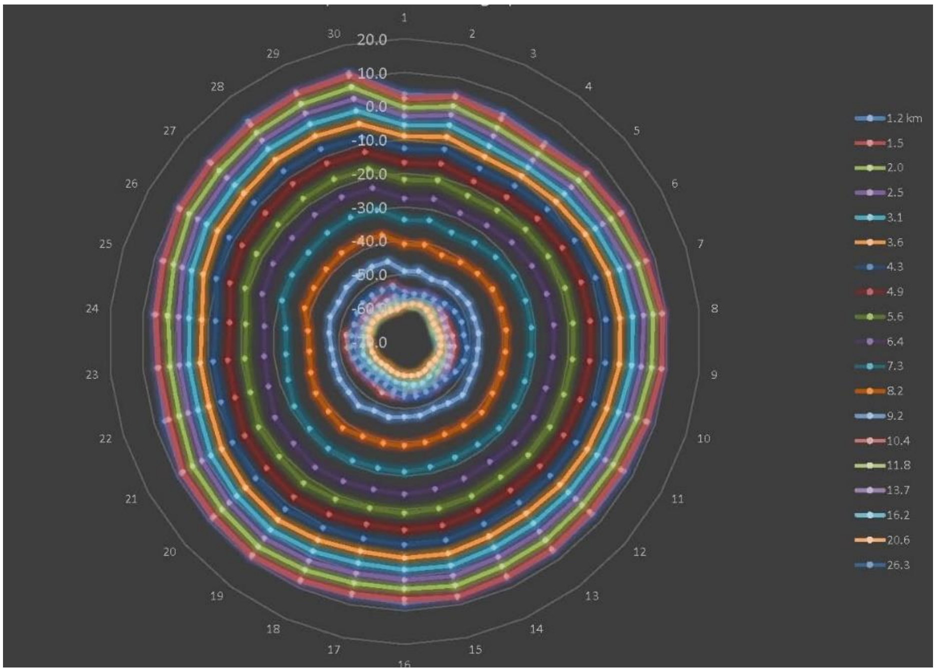

Fig.2. Example of the vertical distribution of diurnal average values of air temperature above Kakheti territory in April 2012-2016

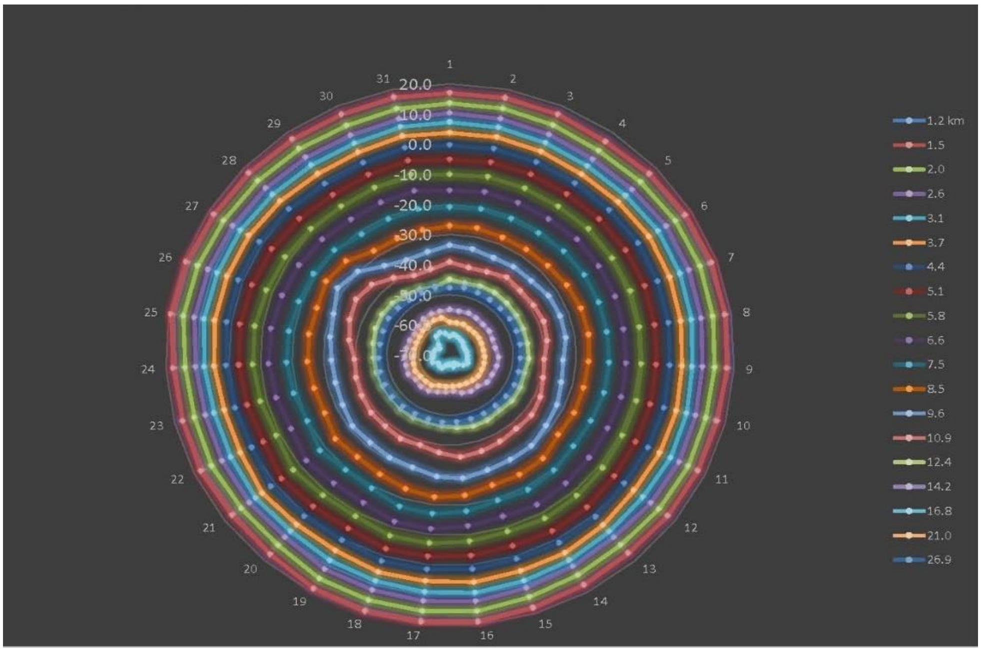

Fig.3. Example of the vertical distribution of diurnal average values of air temperature above Kakheti territory in July 2012-2016

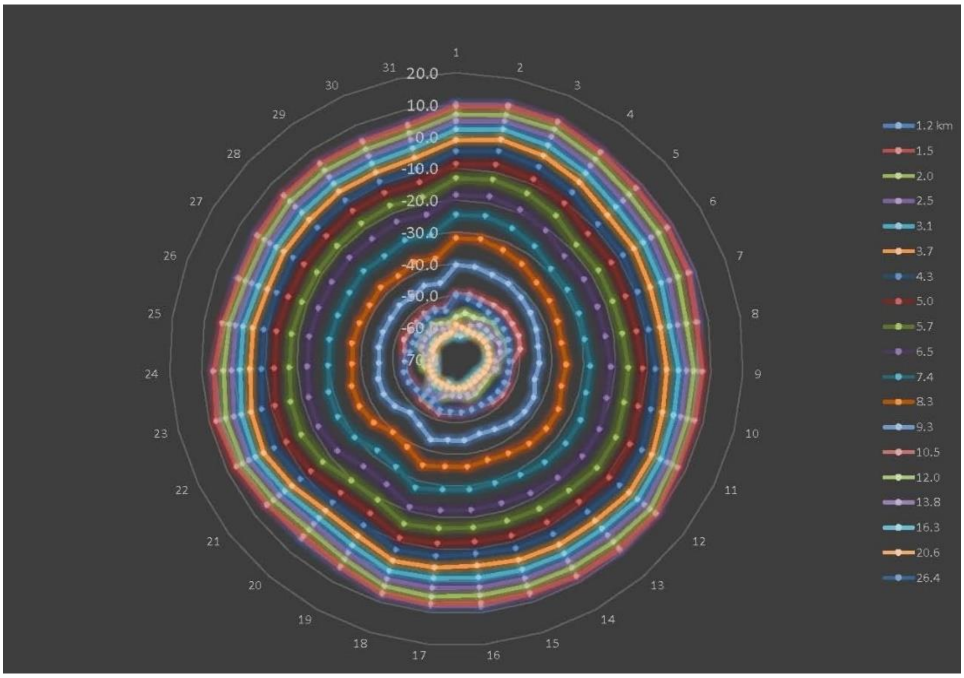

Fig.4. Example of the vertical distribution of diurnal average values of air temperature above Kakheti territory in October 2012-2016

Fig. 1 - 4, as an example, 2D pictures of the vertical diurnal average distribution values of air temperature above Kakheti territory in January, April, July and October 2012-2016are demonstrated.

The statistical data about the monthly average values of the air temperature are represented below above the investigated region.

Results and discussion

The results of studies are presented in tables 1-12 and figures 5-19.

There is represented the statistical structure the monthly average values of the air temperature of the vertical distribution above the territory of Kakheti from January through December 2012-2016 in tables 1-12 and in Fig. 5-16.

Table 1

Statistical characteristics of the five years mean of diurnal air temperature values on the different heights above Kakheti during January

Km	Mean	Min	Max	Range	St Dev	σ_m	95% (+/-)
0.543	2.5	-14.5	15.7	30.2	4.30	0.17	0.34
1.478	-2.5	-13.4	6.9	20.3	3.36	0.13	0.26
1.957	-4.5	-16.4	3.9	20.3	3.47	0.14	0.27
2.463	-6.6	-18.9	0.8	19.7	3.55	0.14	0.28
3.000	-9.1	-21.8	-2.3	19.5	3.63	0.15	0.29
3.570	-12.3	-25.7	-5.5	20.2	3.73	0.15	0.29
4.177	-16.0	-30.4	-9.0	21.4	3.83	0.15	0.30
4.827	-20.2	-35.5	-12.7	22.8	3.89	0.16	0.31
5.526	-25.2	-40.8	-17.4	23.4	3.90	0.16	0.31
6.282	-31.0	-45.0	-23.0	22.0	3.87	0.16	0.30
7.106	-37.4	-47.7	-27.5	20.2	3.74	0.15	0.29
8.013	-44.6	-54.8	-33.5	21.3	3.40	0.14	0.27
9.028	-51.7	-58.9	-41.8	17.1	2.74	0.11	0.22
10.194	-57.1	-64.6	-47.0	17.6	3.21	0.13	0.25
11.600	-57.9	-69.7	-44.5	25.2	4.85	0.19	0.38
13.421	-56.7	-68.3	-45.5	22.8	3.53	0.14	0.28
15.981	-58.9	-66.4	-49.8	16.6	2.77	0.11	0.22
20.298	-60.8	-70.6	-46.4	24.2	4.14	0.17	0.33
26.003	-57.5	-75.9	-38.5	37.4	7.14	0.29	0.57

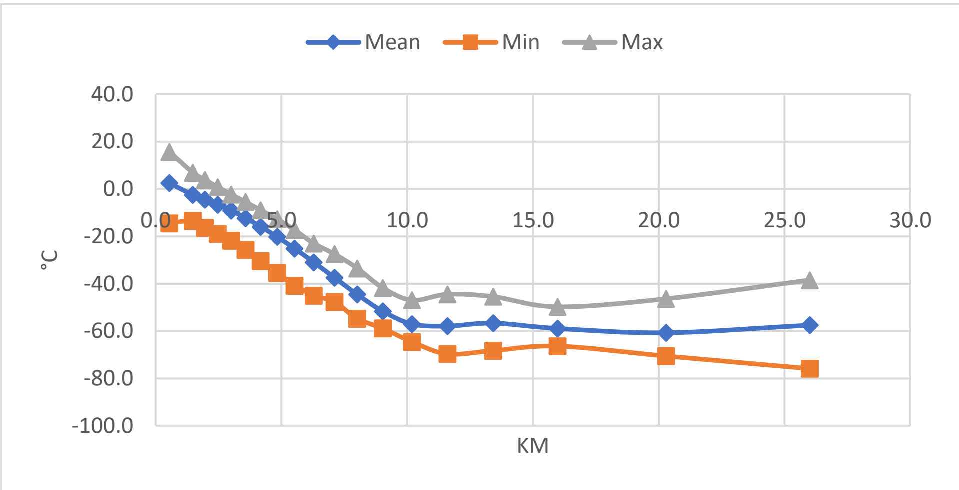

Fig.5.Vertical distribution of mean monthly, maximum and minimum air temperature over territory of Kakheti in January

As it follows from Table 1 and Fig.5, during January the average monthly air temperature (T) approximately linearly decreases with 2.5 °C (amplitude of hours values from -14.5 °C to 15.7 °C) on the earth's surface to -57.1 °C (Range: -64.6÷-47.0 °C) at the height of 10.2 km (lower boundary of tropopause), then little change to the height of 26 km (T = -57.5 °C, the range: -75.9÷ 38.5 °C). Limits of a change of the values T in the layer 11.6 - 26.0 km: from -60.8 °C (height of 20.3 km) to -56.7 °C (height of 13.4 km). The greatest variations are observed in the air temperature on the earth's surface, and also at heights 11.6 and 26.0 km (Range > 25.0 °C).

Table 2

Statistical characteristics of the five years mean of diurnal air temperature values on the different heights above Kakheti during February

Km	Mean	Min	Max	Range	St Dev	σ_m	95%(+/-)
0.543	3.5	-13.5	18.5	32.0	5.06	0.21	0.42
1.488	-1.4	-16.5	8.3	24.8	4.64	0.20	0.38
1.969	-3.6	-17.5	6.0	23.5	4.44	0.19	0.37
2.477	-5.7	-19.0	3.9	22.9	4.33	0.18	0.36
3.015	-8.1	-19.4	1.6	21.0	4.25	0.18	0.35
3.589	-11.2	-22.0	-1.6	20.4	4.16	0.18	0.34
4.200	-14.8	-24.7	-5.2	19.5	4.10	0.17	0.34
4.852	-19.2	-29.0	-9.9	19.1	4.04	0.17	0.33
5.554	-24.2	-34.2	-15.5	18.7	3.98	0.17	0.33
6.313	-30.0	-40.1	-21.5	18.6	3.97	0.17	0.33
7.140	-36.6	-45.7	-27.5	18.2	4.00	0.17	0.33
8.050	-43.9	-53.3	-35.4	17.9	3.96	0.17	0.33
9.067	-51.3	-58.9	-43.3	15.6	3.43	0.14	0.28
10.235	-56.6	-65.6	-49.1	16.5	2.62	0.11	0.22
11.644	-57.2	-67.2	-48.6	18.6	4.10	0.17	0.34
13.468	-56.4	-69.9	-49.3	20.6	3.66	0.15	0.30
16.024	-59.4	-67.5	-53.8	13.7	2.76	0.12	0.23
20.332	-61.1	-69.5	-53.3	16.2	2.77	0.12	0.23
26.064	-56.4	-69.5	-44.7	24.8	4.24	0.18	0.35

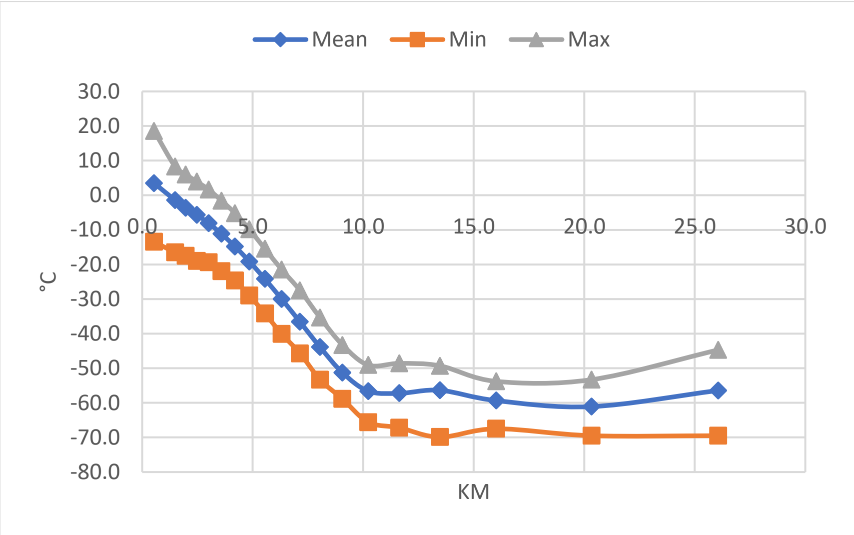

Fig.6. Monthly vertical distribution, maximum and minimum air temperature over territory of Kakheti in February.

During February (Table 2 and Fig. 6) the average monthly air temperature approximately linearly diminishes with 3.5 °C (maximum range of hours values from -13.5 °C to 18.5 °C) on the earth's surface to -56.6 °C (Range: -65.6 ÷ -49.1 °C) at the height of 10.2 km (lower boundary of tropopause), then insignificantly change to an altitude 26 km (T = -56.4 °C, Range: -69.5 ÷ -44.7 °C). Limits of a change of the values T in the layer 11.6 - 26.0 km: from -61.1 °C (height of 20.3 km) to -56.4 °C (height 13.5 and 26.6 km). The greatest variations are observed in the air temperature on the earth's surface, and also at heights 1.5 and 26.0 km (Range >24.0 °C).

Table 3

Statistical characteristics of the five years mean of diurnal air temperature values on the different heights above Kakheti during March

Km	Mean	Min	Max	Range	St Dev	σ_m	95%(+/-)
0.543	7.3	-3.4	22.6	26.0	4.55	0.18	0.36
1.474	0.7	-11.0	12.7	23.7	4.27	0.17	0.34
1.958	-2.1	-14.4	8.5	22.9	4.27	0.17	0.34
2.469	-4.6	-17.9	6.0	23.9	4.40	0.18	0.35
3.009	-7.4	-21.3	3.8	25.1	4.53	0.18	0.36
3.583	-10.7	-24.4	0.8	25.2	4.57	0.18	0.36
4.195	-14.4	-28.8	-3.3	25.5	4.50	0.18	0.35
4.849	-18.6	-33.7	-8.3	25.4	4.36	0.18	0.34
5.553	-23.5	-37.1	-13.0	24.1	4.22	0.17	0.33
6.315	-29.1	-41.1	-18.1	23.0	4.10	0.16	0.32
7.146	-35.7	-46.6	-24.2	22.4	3.98	0.16	0.31
8.060	-42.9	-52.4	-31.7	20.7	3.72	0.15	0.29
9.082	-50.2	-58.0	-41.1	16.9	2.91	0.12	0.23
10.257	-55.6	-61.5	-45.6	15.9	3.05	0.12	0.24
11.672	-56.6	-69.1	-44.7	24.4	5.12	0.21	0.40
13.504	-55.7	-71.4	-47.6	23.8	3.83	0.15	0.30
16.075	-58.4	-67.4	-48.9	18.5	2.56	0.10	0.20
20.411	-60.1	-67.7	-51.7	16.0	2.88	0.12	0.23
26.147	-55.8	-70.4	-39.7	30.7	4.93	0.20	0.39

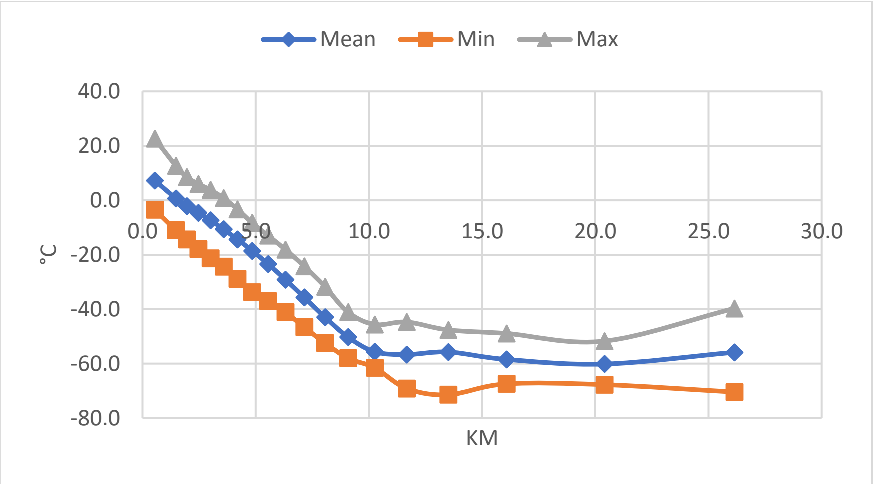

Fig.7. Monthly vertical distribution, maximum and minimum air temperature over territory of Kakheti in March

During March (Table 3 and Fig. 7) the value T linearly diminishes with 7.3 °C (maximum range of hours values from -3.4 °C to 22.6 °C) at the level of meteorological station to -55.6 °C (range: -61.5÷ -45.6 °C) at the height of 10.3 km (lower boundary of tropopause), then as during January and February, little change to the height of 26 km (T = -55.8 °C, the range: -70.4÷ -39.7 °C). Limits of a change of the values T in the layer 11.7 - 26.0 km: from -60.1 °C (height of 20.4 km) to -55.7 °C (height of 13.5 km). The greatest variations are observed in the temperature of air on the earth's surface, in the layer of heights from 3.0 to 4.85 km, and also at the height of 26.0 km (Range > 25.0 °C).

Table 4

Statistical characteristics of the five years mean of diurnal values of the air temperature on the different heights above Kakheti during April

Km	Mean	Min	Max	Range	St Dev	σ_m	95%(+/-)
0.543	12.9	-0.9	27.6	28.5	5.15	0.21	0.41
1.486	6.7	-5.3	17.5	22.8	4.25	0.17	0.34
1.981	3.6	-7.9	12.7	20.6	4.02	0.16	0.32
2.502	0.7	-10.6	9.3	19.9	3.79	0.15	0.30
3.054	-2.4	-14.1	5.7	19.8	3.59	0.15	0.29
3.638	-6.0	-17.8	1.9	19.7	3.39	0.14	0.27
4.260	-10.0	-22.0	-3.0	19.0	3.19	0.13	0.26
4.925	-14.4	-26.1	-7.6	18.5	3.06	0.12	0.24
5.641	-19.4	-30.9	-12.2	18.7	2.98	0.12	0.24
6.415	-25.2	-35.9	-17.6	18.3	2.94	0.12	0.24
7.258	-31.8	-41.8	-24.4	17.4	2.89	0.12	0.23
8.187	-39.2	-46.7	-32.3	14.4	2.77	0.11	0.22
9.224	-47.3	-53.8	-41.0	12.8	2.43	0.10	0.19
10.408	-54.6	-59.8	-44.6	15.2	2.42	0.10	0.19
11.823	-56.9	-65.3	-45.1	20.2	4.06	0.17	0.33
13.652	-55.5	-64.1	-47.8	16.3	2.65	0.11	0.21
16.219	-58.3	-65.0	-52.0	13.0	2.25	0.09	0.18
20.553	-59.4	-64.1	-51.2	12.9	2.14	0.09	0.17
26.347	-53.8	-62.9	-43.9	19.0	2.85	0.12	0.23

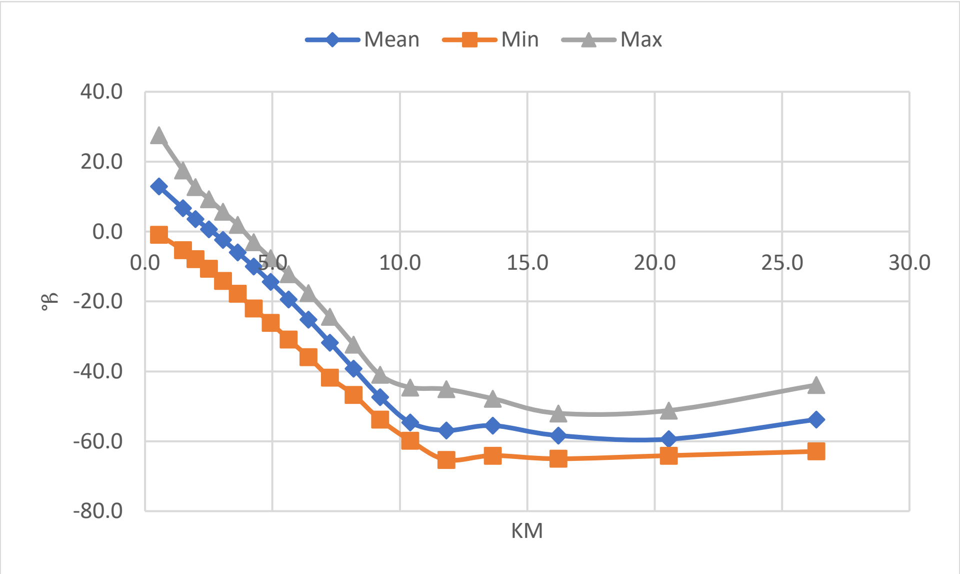

Fig.8. Vertical distribution of mean monthly, maximum and minimum air temperature over territory of Kakheti in April

During April (Table 4 and Fig. 8) the average monthly temperature of air linearly diminishes with 12.9 °C (maximum amplitude of hours values from -0.9 °C to 27.6 °C) at the level of meteorological station to -54.6 °C (range: -59.8 ÷ -44.6 °C) at the height of 10.4 km (lower boundary of tropopause), then as in the foregoing months, insignificantly change to an altitude 26.3 km (T = -53.8 °C, the range: -62.9 ÷ -43.9 °C). Limits of a change of the values T in the layer 11.8 - 26.3 km: from -59.4 °C (height of 20.6 km) to -53.8 °C (height of 26.3 km). The greatest variations are observed in the temperature of air on the earth's surface and at heights 1.5 and 2.0 km (Range > 20.0 °C). It should be noted that in comparison with the foregoing months, during April is somewhat more greatly expressed the tendency of an increase in the temperature at the height of approximately 26.0 km.

Table 5

Statistical characteristics of the five years mean of diurnal values of the air temperature on the different heights above Kakheti during May

Km	Mean	Min	Max	Range	St Dev	σ_m	95%(+/-)
0.543	17.7	4.8	30.4	25.6	4.15	0.17	0.33
1.494	11.4	-8.7	27.0	35.7	4.55	0.18	0.36
1.998	7.9	-11.9	21.9	33.8	4.25	0.17	0.33
2.527	4.7	-15.9	17.1	33.0	4.02	0.16	0.32
3.087	1.4	-20.0	13.7	33.7	3.93	0.16	0.31
3.680	-2.3	-24.2	9.6	33.8	3.81	0.15	0.30
4.311	-6.4	-28.8	4.1	32.9	3.64	0.15	0.29
4.986	-10.8	-32.2	-1.8	30.4	3.48	0.14	0.27
5.711	-15.7	-35.8	-7.4	28.4	3.39	0.14	0.27
6.497	-21.4	-41.1	-13.2	27.9	3.39	0.14	0.27
7.354	-27.9	-46.6	-19.2	27.4	3.44	0.14	0.27
8.298	-35.4	-51.7	-25.0	26.7	3.37	0.14	0.27
9.352	-43.9	-54.2	-31.3	22.9	3.01	0.12	0.24
10.552	-52.0	-59.3	-36.9	22.4	2.82	0.11	0.22
11.981	-55.2	-63.3	-44.6	18.7	4.13	0.17	0.33
13.822	-54.3	-63.5	-47.3	16.2	2.88	0.12	0.23
16.396	-58.5	-66.6	-53.6	13.0	2.09	0.08	0.16
20.721	-59.5	-63.6	-56.4	7.2	1.31	0.05	0.10
26.549	-51.0	-56.7	-45.4	11.3	2.02	0.08	0.16

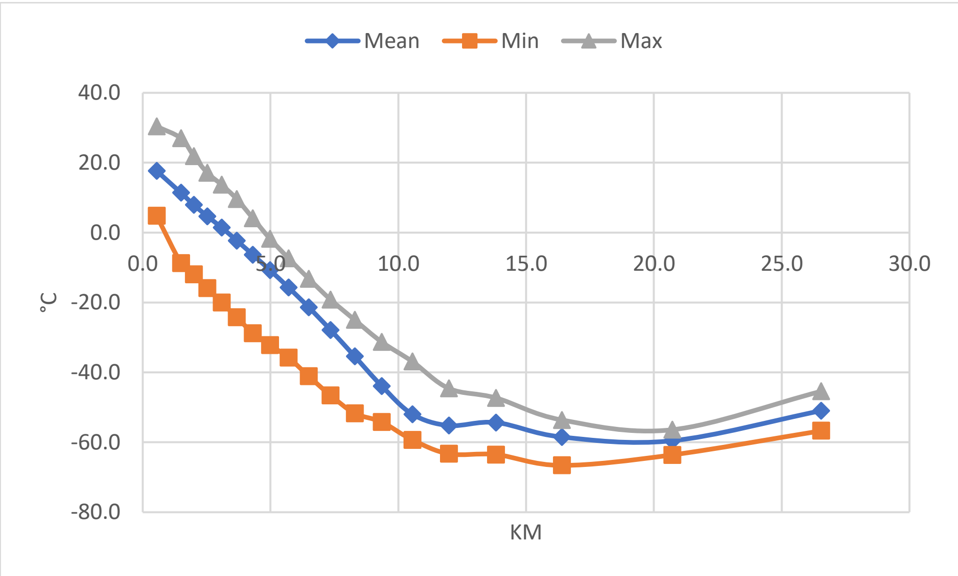

Fig.9. Vertical distribution of mean monthly, maximum and minimum air temperature over territory of Kakheti in May

During May (Table 5 and Fig. 9) the value T linearly diminishes with 17.7 °C (maximum amplitude of hours values from 4.8 °C to 30.4 °C) at the level of meteorological station to -52.0 °C (range: -59.3⟝ -36.9 °C) at the height of 10.6 km, then very considerably it does not change to the height of 26.6 km (T = -51.0 °C, the range: -56.7⟝ -45.4 °C). Limits of a change of the values T in the layer 12.0 - 26.5 km: from -59.5 °C (height of 20.7 km) to -51.0 °C (height of 26.5 km). The greatest variations are observed in the temperature of air in the layer of heights from 1.5 to 4.3 km (Range >30.0 °C). Lower boundary of tropopause - 12.0 km. During May the tendency of an increase in the air temperature at the height of more than 26.0 km is more expressed than during April.

Table 6

Statistical characteristics of the five years mean of diurnal values of the air temperature on the different heights above Kakheti during June

Km	Mean	Min	Max	Range	St Dev	σ_m	95%(+/-)
0.543	21.7	11.3	33.6	22.3	4.56	0.19	0.37
1.498	16.0	6.8	23.9	17.1	3.28	0.13	0.26
2.009	12.3	4.6	19.2	14.6	2.94	0.12	0.24
2.547	8.8	1.3	15.4	14.1	2.67	0.11	0.21
3.115	5.5	-2.0	11.7	13.7	2.52	0.10	0.20
3.717	1.7	-5.3	7.3	12.6	2.43	0.10	0.19
4.358	-2.4	-9.3	3.1	12.4	2.32	0.09	0.19
5.042	-6.9	-13.2	-1.5	11.7	2.22	0.09	0.18
5.779	-11.9	-18.2	-6.2	12.0	2.22	0.09	0.18
6.577	-17.4	-23.1	-10.4	12.7	2.29	0.09	0.18
7.448	-23.7	-29.4	-13.8	15.6	2.56	0.10	0.20
8.409	-30.8	-37.5	-18.2	19.3	3.04	0.12	0.24
9.485	-38.4	-45.5	-25.2	20.3	4.08	0.17	0.33
10.719	-44.9	-53.8	-32.5	21.3	5.33	0.22	0.43
12.197	-48.5	-61.0	-39.8	21.2	4.52	0.18	0.36
14.069	-53.6	-59.9	-48.3	11.6	2.48	0.10	0.20
16.622	-61.7	-70.6	-55.3	15.3	3.35	0.14	0.27
20.908	-59.0	-62.9	-54.2	8.7	1.55	0.06	0.12
26.790	-48.3	-50.8	-45.3	5.5	1.07	0.04	0.09

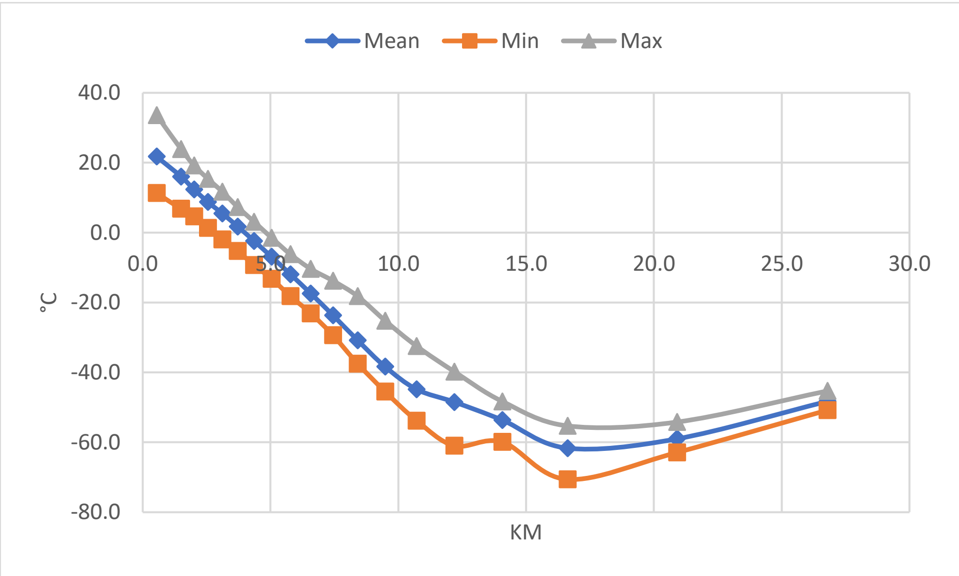

Fig.10. Vertical distribution of mean monthly, maximum and minimum air temperature over territory of Kakheti in June

During June (Table 6 and Fig. 10) the average monthly temperature of air linearly diminishes with 21.7 °C (maximum amplitude of hours values from 11.3 °C to 33.6 °C) on the earth's surface to -44.9 °C (range: -53.8 ⟝ -32.5 °C) at the height of 10.7 km then, with the smaller gradient, the linear decrease of the temperature of air continues in the layer from 12.2 km (T = -48 °C, the range: -61.0 ⟝ -39.8 °C) to 16.6 km (lower boundary of tropopause, T=-61.7 °C, the range: -70.6 ⟝ -55.3 °C). After this, the temperature of air grows to -48.3 °C (range: -50.8 ⟝ -45.3 °C) at the height of 26.7 km. The greatest variations are observed in the air temperature on the earth's surface in the layer of heights from 9.5 to 12.2 km (Range > 20.0 °C). During June the tendency of an increase in the temperature at the height of more than 26.0 km is more expressed than during April and May.

Table 7

Statistical characteristics of the five years mean of diurnal values of the air temperature on the different heights above Kakheti during July

Km	Mean	Min	Max	Range	St Dev	σ_m	95%(+/-)
0.543	23.5	13.0	35.8	22.8	4.20	0.17	0.33
1.497	17.7	9.2	26.9	17.7	3.00	0.12	0.24
2.012	13.9	5.9	21.9	16.0	2.63	0.11	0.21
2.553	10.5	3.3	17.0	13.7	2.39	0.10	0.19
3.125	7.6	0.9	13.3	12.4	2.38	0.10	0.19
3.733	4.3	-3.3	9.6	12.9	2.34	0.09	0.18
4.380	0.4	-7.2	5.7	12.9	2.20	0.09	0.17
5.073	-4.0	-11.7	0.9	12.6	2.08	0.08	0.16
5.818	-8.7	-16.7	-4.0	12.7	2.09	0.08	0.16
6.626	-13.9	-22.3	-7.4	14.9	2.30	0.09	0.18
7.510	-19.5	-29.1	-11.7	17.4	2.84	0.11	0.22
8.490	-25.6	-36.6	-17.3	19.3	3.63	0.15	0.29
9.591	-32.2	-44.1	-23.2	20.9	4.20	0.17	0.33
10.860	-38.4	-47.8	-31.4	16.4	3.45	0.14	0.27
12.370	-45.7	-53.5	-41.5	12.0	1.82	0.07	0.14
14.242	-55.8	-60.7	-48.7	12.0	2.33	0.09	0.18
16.760	-64.7	-70.2	-54.1	16.1	3.10	0.12	0.24
21.020	-58.7	-63.9	-54.9	9.0	1.56	0.06	0.12
26.919	-47.5	-49.8	-44.9	4.9	0.79	0.03	0.06

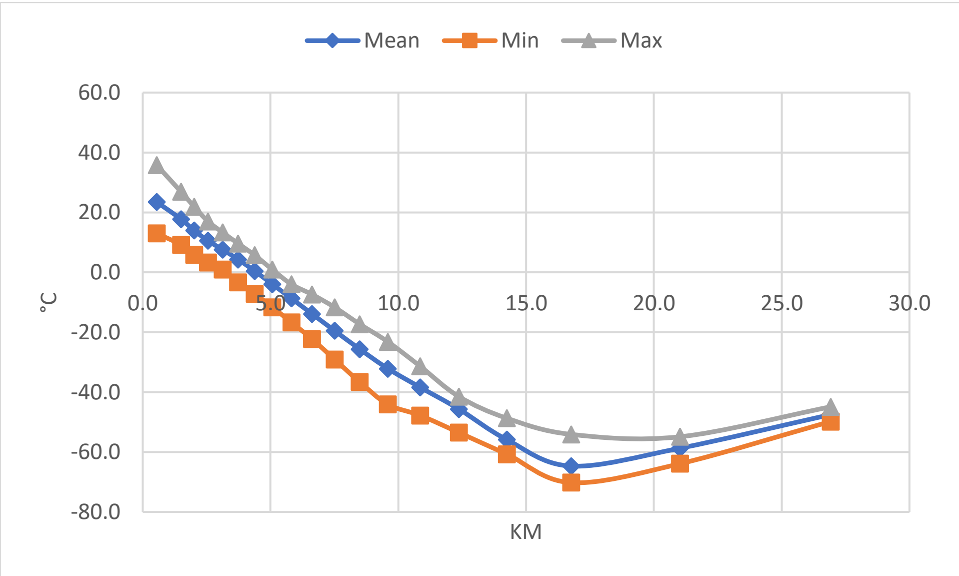

Fig.11. Vertical distribution of mean monthly, maximum and minimum air temperature over territory of Kakheti in July

During July (Table 7 and Fig. 11) the value T approximately linearly diminishes with 23.5 °C (maximum amplitude of hours values from 13.0 °C to 35.8 °C) on the earth's surface to -64.7 °C (range: -70.2 ÷ -54.1 °C) at the height of 16.8 km (lower boundary of tropopause), then grow to -47.5 °C (range: -49.8 ÷ -44.9 °C) at the height of 26.9 km.The greatest variations are observed in the temperature of air on the earth's surface and at an altitude 9.6 km (Range >20.0 °C).

Table 8

Statistical characteristics of the five years mean of diurnal values of the air temperature on the different heights above Kakheti during August

Km	Mean	Min	Max	Range	St Dev	σ_m	95%(+/-)
0.543	25.0	13.5	41.0	27.5	5.00	0.20	0.39
1.512	18.1	3.7	28.0	24.3	4.03	0.16	0.32
2.027	14.4	1.4	22.8	21.4	3.66	0.15	0.29
2.570	11.0	-0.5	17.7	18.2	3.36	0.14	0.26
3.143	8.0	-4.0	14.4	18.4	3.22	0.13	0.25
3.751	4.6	-7.8	10.3	18.1	3.07	0.12	0.24
4.399	0.5	-11.2	5.6	16.8	2.79	0.11	0.22
5.091	-4.2	-15.5	1.2	16.7	2.51	0.10	0.20
5.835	-9.2	-20.3	-4.3	16.0	2.38	0.10	0.19
6.642	-14.5	-26.6	-9.4	17.2	2.42	0.10	0.19
7.524	-20.4	-33.4	-14.5	18.9	2.63	0.11	0.21
8.499	-27.2	-41.2	-20.1	21.1	2.97	0.12	0.23
9.592	-34.1	-47.0	-26.0	21.0	3.45	0.14	0.27
10.851	-40.3	-51.0	-31.6	19.4	3.69	0.15	0.29
12.349	-47.5	-57.2	-42.7	14.5	2.22	0.09	0.18
14.207	-57.3	-60.8	-51.7	9.1	1.70	0.07	0.13
16.715	-64.5	-70.2	-56.0	14.2	2.65	0.11	0.21
20.986	-58.7	-62.5	-52.5	10.0	1.35	0.05	0.11
26.876	-48.3	-54.8	-45.2	9.6	1.51	0.06	0.12

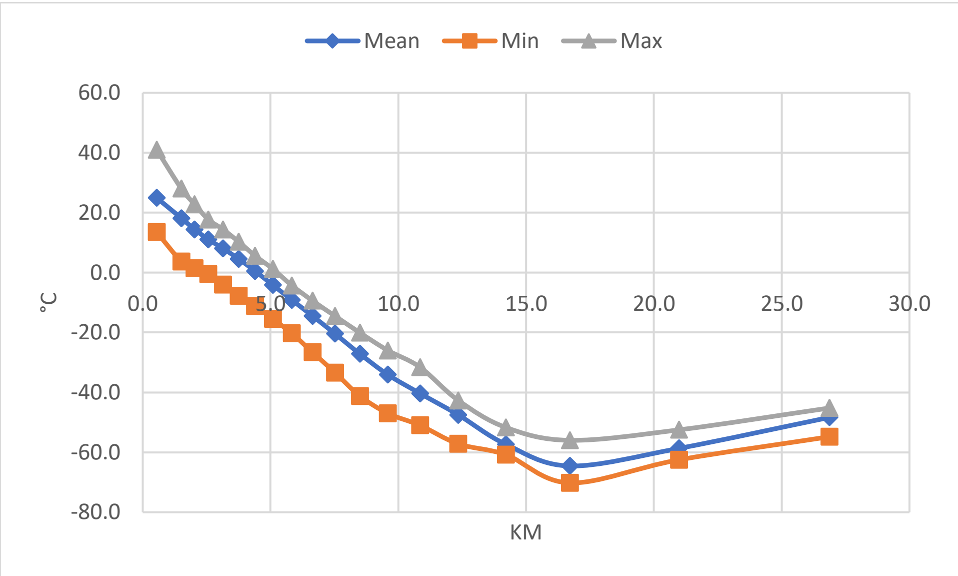

Fig.12. Vertical distribution of mean monthly, maximum and minimum air temperature over territory of Kakheti in August

During August (Table 8 and Fig. 12) the average monthly temperature of air linearly decreases with 25.0 °C (maximum amplitude of hours values from 13.5 °C to 41.0 °C) at the level of meteorological station to -64.5 °C (range: -70.2 – -56.0 °C) at the height of 16.7 km (lower boundary of tropopause), then grow to -48.3 °C (range: -54.8 – -54.8 °C) at the height of 26.9 km. The greatest variations are observed in the temperature of air on the earth's surface and at heights 1.5, 2.0, 7.5 and 9.5 km (Range >20.0 °C).

Table 9

Statistical characteristics of the five years mean of diurnal values of the air temperature on the different heights above Kakheti during September

Km	Mean	Min	Max	Range	St Dev	σ_m	95%(+/-)
0.543	19.8	8.4	32.0	23.6	4.59	0.19	0.37
1.515	12.7	-5.3	22.3	27.6	4.40	0.18	0.35
2.021	9.4	-8.8	17.7	26.5	4.05	0.17	0.32
2.554	6.6	-11.8	13.6	25.4	3.94	0.16	0.32
3.117	3.6	-14.6	10.7	25.3	3.99	0.16	0.32
3.715	0.1	-18.5	6.3	24.8	3.95	0.16	0.32
4.352	-3.8	-22.6	2.5	25.1	3.82	0.16	0.31
5.033	-8.1	-26.8	-1.2	25.6	3.68	0.15	0.29
5.767	-12.9	-31.5	-6.3	25.2	3.59	0.15	0.29
6.561	-18.4	-37.1	-12.5	24.6	3.55	0.15	0.28
7.429	-24.7	-42.1	-19.3	22.8	3.50	0.14	0.28
8.386	-32.0	-47.8	-26.2	21.6	3.33	0.14	0.27
9.456	-40.0	-53.4	-31.6	21.8	3.30	0.13	0.26
10.679	-47.5	-60.4	-37.4	23.0	3.80	0.16	0.30
12.133	-52.8	-61.5	-45.0	16.5	3.73	0.15	0.30
13.969	-57.5	-66.4	-51.4	15.0	2.45	0.10	0.20
16.498	-61.7	-67.4	-53.8	13.6	2.65	0.11	0.21
20.803	-59.0	-66.3	-53.1	13.2	1.92	0.08	0.15
26.653	-50.7	-60.8	-46.4	14.4	2.26	0.09	0.18

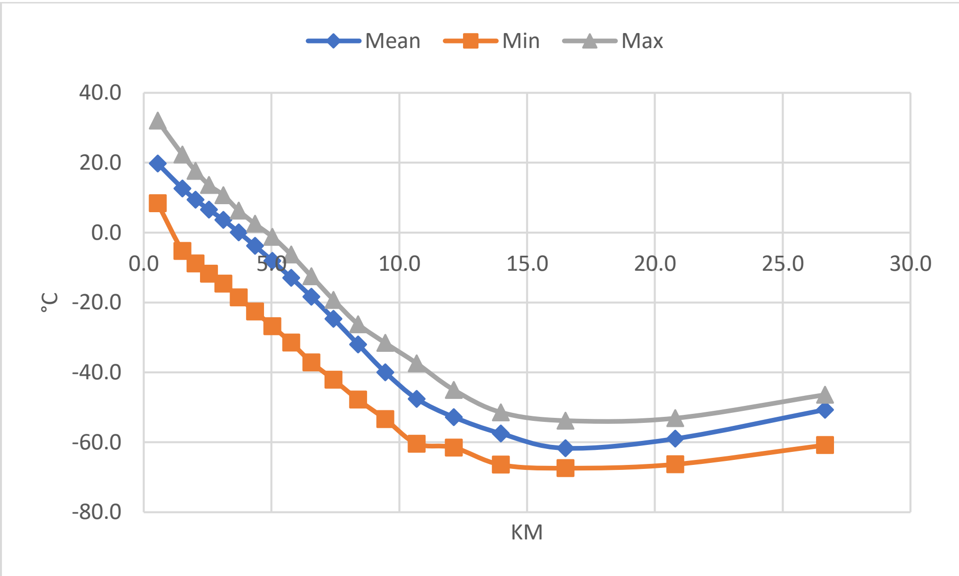

Fig.13. Vertical distribution of mean monthly, maximum and minimum air temperature over territory of Kakheti in September

During September (Table 9 and Fig. 13) the value T approximately linearly decreases with 19.8 °C (maximum amplitude of hours values from 8.4 °C to 32.0 °C) on the earth's surface to -57.5 °C (Range: -66.4⟝-51.4 °C) at the height of 14.0 km (lower boundary of tropopause), then proceeds an increase in the temperature in the range of heights from 16.5 km (T = -61.7 °C, range: -67.4 ⟝-53.8 °C) to 26.7 km (T = -50.7 °C, range: -60.8 ⟝-46.4 °C). The greatest variations are observed in the temperature of air in the layer from 1.5 to 3.1 km, 4.4 and 5.8 km (Range > 25.0 °C).

Table 10

Statistical characteristics of the five years mean of diurnal values of the air temperature on the different heights above Kakheti during October

Km	Mean	Min	Max	Range	St Dev	σ_m	95%(+/-)
0.543	13.1	0.2	28.1	27.9	4.88	0.20	0.38
1.521	6.7	-5.5	17.8	23.3	4.08	0.16	0.32
2.015	4.0	-7.9	13.1	21.0	3.96	0.16	0.31
2.537	1.7	-9.6	10.2	19.8	3.90	0.16	0.31
3.090	-0.9	-11.6	6.8	18.4	3.69	0.15	0.29
3.692	-4.1	-14.4	3.0	17.4	3.45	0.14	0.27
4.318	-7.8	-16.7	-0.6	16.1	3.24	0.13	0.26
4.990	-11.8	-19.3	-5.0	14.3	3.08	0.12	0.24
5.713	-16.6	-24.2	-10.0	14.2	3.01	0.12	0.24
6.496	-22.2	-30.5	-15.5	15.0	2.98	0.12	0.23
7.350	-28.6	-37.1	-22.1	15.0	2.92	0.12	0.23
8.292	-36.0	-44.4	-29.0	15.4	2.81	0.11	0.22
9.343	-44.2	-52.3	-36.4	15.9	2.57	0.10	0.20
10.543	-52.1	-60.7	-43.7	17.0	2.59	0.10	0.20
11.966	-57.4	-67.8	-45.3	22.5	3.91	0.16	0.31
13.776	-59.0	-72.9	-51.8	21.1	3.27	0.13	0.26
16.301	-61.2	-68.4	-54.7	13.7	2.20	0.09	0.17
20.598	-60.8	-66.8	-54.9	11.9	1.96	0.08	0.15
26.378	-53.4	-60.7	-47.7	13.0	2.14	0.09	0.17

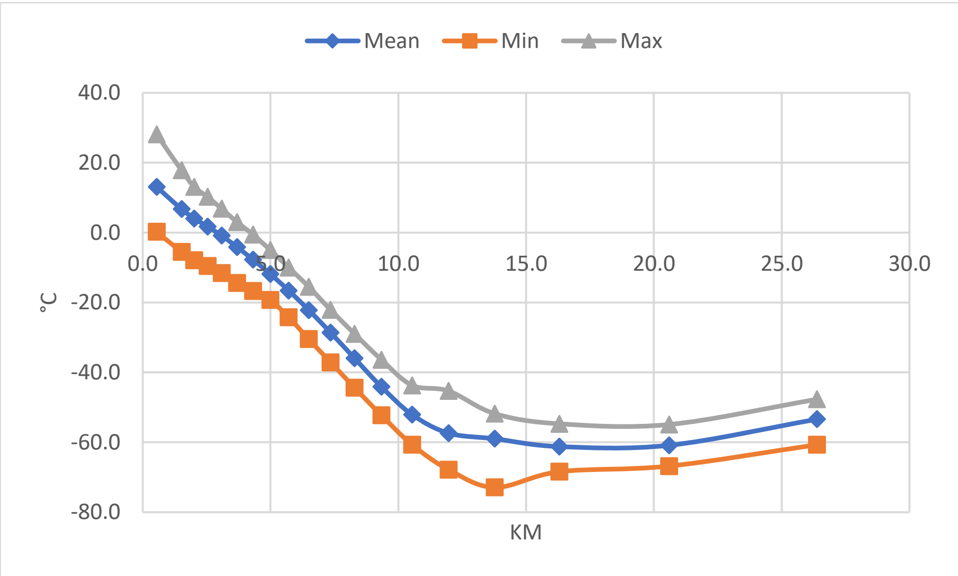

Fig.14. Vertical distribution of mean monthly, maximum and minimum air temperature over territory of Kakheti in October

During October (Table 10 and Fig. 14) the average monthly temperature of air linearly decreases with 13.1 °C (maximum amplitude of hours values from 0.2 °C to 28.1 °C) at the level of meteorological station to -57.4 °C (Range: -67.8 ‒ -45.3 °C) at the height of 12.0 km (lower boundary of tropopause), then after insignificant decrease smoothly it grows to -53.4 °C (Range: -60.7 ‒ -47.7 °C) at the height of 26.4 km. The greatest variations are observed in the temperature of air on the earth's surface and at heights 1.5, 2.0, 12.0 and 13.8 km (Range > 20.0 °C).

Table 11

Statistical characteristics of the five years mean of diurnal values of the air temperature on the different heights above Kakheti during November

Km	Mean	Min	Max	Range	St Dev	σ_m	95%(+/-)
0.543	7.8	-4.3	22.3	26.6	4.43	0.18	0.35
1.525	3.1	-8.1	12.4	20.5	3.97	0.16	0.32
2.014	0.8	-10.6	9.6	20.2	3.86	0.16	0.31
2.530	-1.4	-11.8	6.7	18.5	3.75	0.15	0.30
3.078	-3.9	-14.6	4.1	18.7	3.59	0.15	0.29
3.659	-7.0	-18.5	1.7	20.2	3.55	0.15	0.28
4.279	-10.7	-22.6	-2.5	20.1	3.48	0.14	0.28
4.943	-14.9	-26.8	-7.3	19.5	3.42	0.14	0.27
5.657	-19.8	-31.5	-12.3	19.2	3.38	0.14	0.27
6.430	-25.5	-37.1	-17.9	19.2	3.36	0.14	0.27
7.273	-32.0	-42.1	-24.6	17.5	3.29	0.13	0.26
8.202	-39.3	-47.8	-32.3	15.5	3.12	0.13	0.25
9.238	-47.5	-55.6	-41.4	14.2	2.82	0.12	0.23
10.422	-55.0	-61.7	-45.4	16.3	2.60	0.11	0.21
11.831	-58.9	-67.8	-47.7	20.1	3.70	0.15	0.30
13.633	-59.7	-72.9	-50.8	22.1	3.52	0.14	0.28
16.153	-62.2	-68.8	-55.9	12.9	2.40	0.10	0.19
20.424	-62.7	-68.3	-52.8	15.5	2.05	0.08	0.16
26.124	-56.9	-65.5	-46.1	19.4	3.41	0.14	0.27

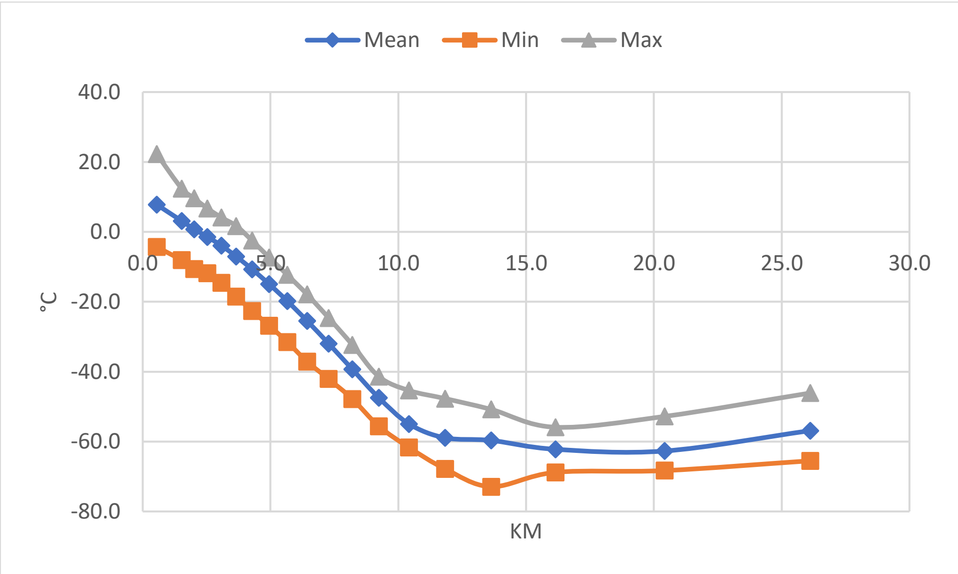

Fig.15. Vertical distribution of mean monthly, maximum and minimum air temperature over territory of Kakheti in November

During November (Table 11 and Fig. 15) the value T approximately linearly decreases with 7.8 °C (maximum amplitude of hours values from -4.3 °C to 22.3 °C) on the earth's surface to -58.9 °C (range: -67.8 ⟝-47.7 °C) at the height of 11.8 km (lower boundary of tropopause), then after certain further decrease occurs an increase in the temperature to -56.9 °C (range: -65.5 ⟝ -46.1 °C) at the height of 26.1 km. The greatest variations) are observed in the temperature of air in the layer from 0.543 to 2.0 km, at the heights 3.7, 4.3, 11.8 and 13.6 km (Range > 20.0 °C.

Table 12

Statistical characteristics of the five years mean of diurnal values of the air temperature on the different heights above Kakheti during December

Km	Mean	Min	Max	Range	St Dev	σ_m	95%(+/-)
0.543	2.6	-7.2	17.8	25.0	4.34	0.17	0.34
1.507	-1.8	-12.1	10.0	22.1	3.99	0.16	0.31
1.988	-3.8	-14.7	7.3	22.0	4.19	0.17	0.33
2.495	-5.8	-16.7	4.3	21.0	4.30	0.17	0.34
3.033	-8.2	-19.5	0.9	20.4	4.39	0.18	0.35
3.605	-11.2	-23.5	-2.4	21.1	4.43	0.18	0.35
4.215	-14.7	-27.7	-5.7	22	-14.1	0.18	0.35
4.869	-18.8	-31.5	-9.3	22.2	4.35	0.17	0.34
5.572	-23.6	-36.5	-13.7	22.8	4.25	0.17	0.33
6.333	-29.2	-41.2	-18.9	22.3	4.05	0.16	0.32
7.164	-35.5	-46.5	-25.3	21.2	3.76	0.15	0.30
8.079	-42.6	-53.7	-33.0	20.7	3.40	0.14	0.27
9.102	-50.1	-56.9	-41.5	15.4	2.78	0.11	0.22
10.274	-56.4	-62.6	-45.8	16.8	2.83	0.11	0.22
11.678	-58.8	-68.0	-45.3	22.7	4.44	0.18	0.35
13.487	-58.0	-71.3	-47.5	23.8	3.39	0.14	0.27
16.029	-60.2	-69.7	-50.4	19.3	2.89	0.12	0.23
20.333	-61.3	-72.9	-50.3	22.6	3.46	0.14	0.27
26.058	-56.8	-68.6	-40.1	28.5	5.07	0.20	0.40

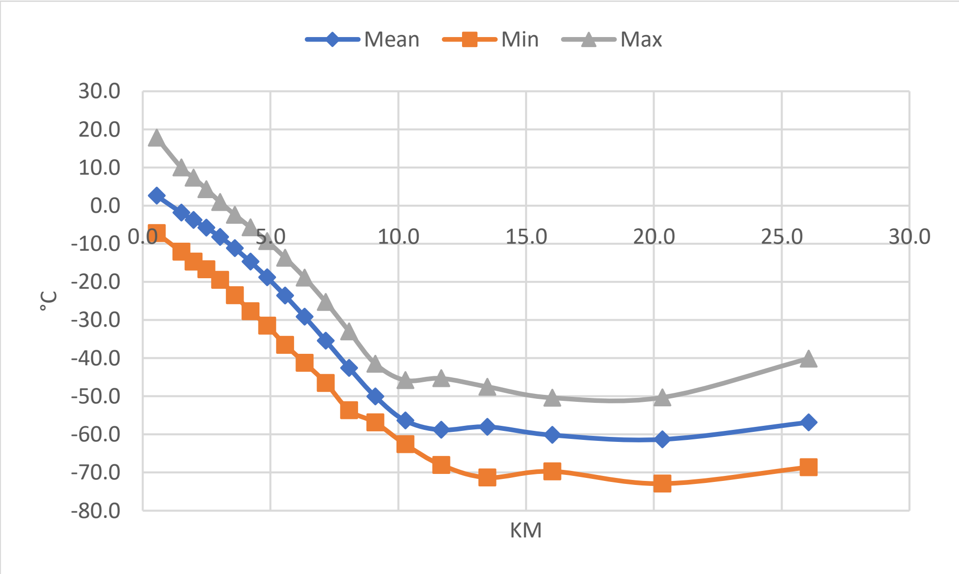

Fig.16. Vertical distribution of mean monthly, maximum and minimum air temperature over territory of Kakheti in December

During December (Table 12 and Fig. 16) the average monthly temperature of air approximately linearly decreases with 2.6 °C (amplitude of hours values from -7.2 °C to 17.8 °C) on the earth's surface to -56.4 °C (range: -62.6 ⟷-45.8 °C) at the height of 10.3 km (lower boundary of tropopause), then little change to an altitude 26 km (T = -56.8 °C, range: -68.6 ⟷ -40.1 °C). Limits of a change of the values T in the layer 11.7 - 26.0 km: from -61.3 °C (height of 20.3 km) to -56.8 °C (height of 26.0 km). The greatest variations are observed in the temperature of air on the earth's surface and at the height of 26.0 km (Range > 25.0 °C).

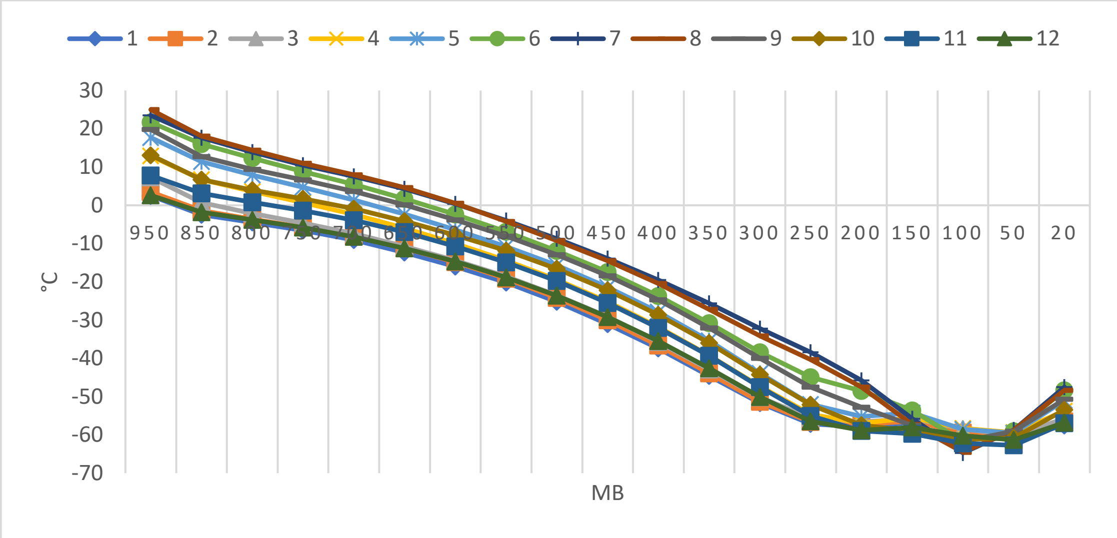

Fig. 17.Vertical distribution of mean monthly air temperature over territory of Kakheti in January – December 2012-2016

Fig. 17 for the clarity depicts the vertical distribution of the average monthly values of the temperature of air above the Kakheti for the separate months of year. Fig. 18 depicts the vertical distribution of the annual amplitude of the average monthly values of the temperature of air above the Kakheti (difference between average monthly maximum and minimum temperature).

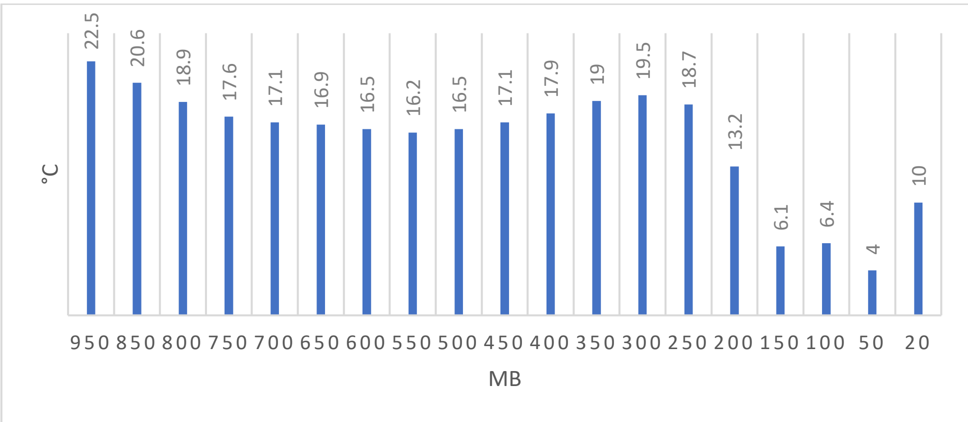

Fig. 18.Vertical distribution of the annual amplitude of mean monthly air temperature values over territory of Kakheti in January-December 2012-2016

As follows from these figures the annual amplitude of average monthly temperature it decreases with the height from the earth's surface (22.5 °C) to the level 550 mb (16.2 °C, height of approximately 5.0 km). Then occurs an increase in this amplitude to the level 300 mb (19.5 °C, height of approximately 9.0 km). In the layer 250-50 mb (approximately 10-20 km) occurs a sharp drop in the annual amplitude of the average monthly temperature of air (18.7 °C at the level 250 mb and 4.0 °C at the level 50 mb). At the level 20 mb (about 26 km) occurs a certain increase in this amplitude (10.0 °C).

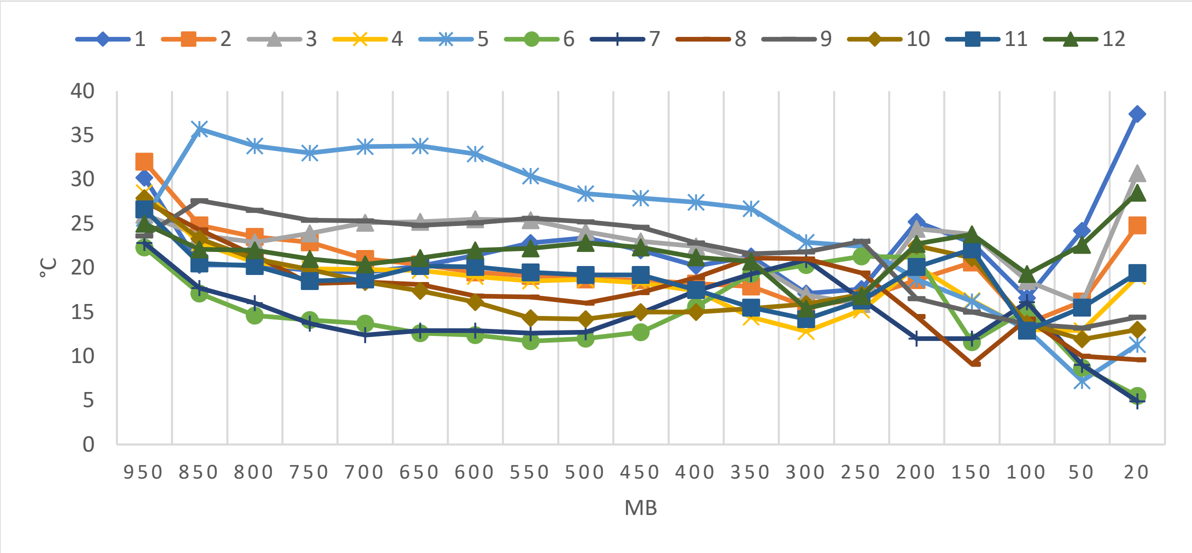

Fig.19. Vertical distribution of monthly values of the range of air temperature over territory of Kakheti in January-December 2012-2016

Finally, Fig. 19 depicts the vertical distribution of the monthly values of the variation scope of the temperature of air above the Kakheti territory for the separate months. As it follows from this figure, the greatest variations in the hourly values of the temperature of air in the layer of the atmosphere from 850 to 450 mb (approximately in the layer 1.5 - 6.0 km) during May and smallest - during June and July are observed. At the level 20 mb (approximately 26 km) the greatest variations are observed in the hourly values of temperature during January and smallest - during June and July.

Conclusion

It is planned In the near future conducting more detailed studies changeability of the vertical distribution of air temperature above Kakheti in the days with the convective processes in atmosphere. This information, in particular, will be useful for the construction of the more detailed maps (than in [28]) of the distribution of potential damage from the hail of agricultural crops, etc. taking into account the dimensions of hailstones in the clouds according to the data of radar measurements, heights of freezing level and locality [1, 29-34].

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კახეთის ტერიტორიაზე (საქართველო) 2012-2016 წწ. ატმოსფეროს 0.54-27 კმ ფენაში ჰაერის ტემპერატურის საშუალოთვიური მნიშვნელობების სტატისტიკური მახასიათებლები

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რეზიუმე

წარმოდგენილია სტატისტიკური ანალიზის მონაცემები 2012 - 2016 წწ. კახეთის ტერიტორიაზე ატმოსფეროში 19 დონეზე 0.54-დან 27 კმ-მდე სიმაღლეების დიაპაზონში ჰაერის ტემპერატურის საშუალოთვიური მნიშვნელობების შესახებ .

Статистические характеристики среднемесячных значений температуры воздуха в слое атмосферы 0.54-27 км над территорией Кахетии(Грузия) в 2012-2016 гг.

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Резюме

Представлены данные статистического анализа среднемесячных значений температуры воздуха в атмосфере над территорией Кахетии на 19 уровнях в диапазоне высот от 0.54 до 27 км для периода с 2012 по 2016.

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Tourism Climate Index in Some Localities of Georgia and North Caucasus (Russia)

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ABSTRACT

Results of investigation of monthly values of the Tourism Climate Index (TCI) in some localities of Georgia (21 localities) and North Caucasus (Russia, 6 localities) are represented. Height of these localities varied from 3 to 2194 m above sea level.
Correlation and regression analysis of the connection of mortality by cardiovascular deceases in Tbilisi with the values of TCI and its separate components is carried out. This analysis confirmed the representativeness of the use of the scale of TCI as bioclimatic indicator for the investigated region (as a whole, with an increase of values of TCI it is noted the decrease of mortality).
The statistical characteristics of values of TCI are represented. In particular it is obtained that with an increase of the height of locality, as a whole occurs the passage of bimodal intra-annual distribution of TCI to the single-modal. The vertical distribution of values of TCI on the average in the year, in the warm and cold periods, and also in the central months of year is studied. The detailed information about the categories of TCI for all investigated localities is represented.

Key words: **tourism climate index, bioclimate**.

INTRODUCTION

Health resort-tourist industry is one of the most important sectors of the world economy. This sector in many respects depends on geographical position, topography, landscape, vegetation, fauna, ecological situation, weather, climate, etc. Weather and climate are two factors, in many respects of the determining bioclimatic resources of localities, which should be visited for the treatment, leisure or tourism [1-5]. Therefore, a special attention is paid to a study of these resources, which can be useful for organization or development of the health resort-tourist of branch in many countries. In early studies was used the set of the simple and combined meteorological and climatic indices for the health resorts and the tourism, and also studying the reaction of the human organism to their changeability.

In last almost one hundred years in the world are carried out sufficiently many studies in the field of bioclimatology, biometeorology and medical meteorology [6-8]. Thus, the analysis of the experiments of the influence of separate meteorological elements and their complexes on the health of people is carried out in the work [6], also the detailed information about different bioclimatic indices used in the different countries in 1925-1970 is presented. It is noted in the same work, that the interest in the problem "person - environment" in Europe in the scientific literature was fixed several centuries ago [9-10].

On the post Soviet space, including Georgia, it was very popular the use of the bioclimatic index air equivalent-effective temperature (EET- combination of the air temperature, relative humidity and wind speed) and air radiation equivalent effective temperature (REET- combination of the air temperature, relative humidity, wind speed and solar radiation intensity) [7,8,11].

Together with the physical quantities of the value of bioclimatic indices is described by the terms ("Coldly", "Comfortably", "Warmly", etc.). A similar terminology is more intelligible for the wide circle of population, than physical quantities. Let us here note, that about three centuries ago for describing the climate of Georgia similar terms were used by the well-known Georgian historian and geographer Vakhushti Bagrationi [12].

The several new indices for evaluating the fitness of climate for the tourist activity were developed in the recent decades [2,13,14]. The most widely known and used index is the Tourism Climate Index, proposed by Mieczkowski [13]. The "Tourism Climate Index" of Mieczkowski (TCI) was developed for using climatic data, which practically are located in all countries. This index is the sum of the marks of five factors, which with the aid of the special tables and the nomograms are determined by the combination of seven meteorological parameters (average monthly and maximum temperature of air, the average monthly and minimum relative humidity of air, monthly total precipitation, monthly insolation duration, average monthly wind speed).

One of the important advantages of this index is the possibility of using archive data, which makes it possible to trace the dynamics of change TCI in time in connection with climate change. Another merit of this index is the possibility of the comparison of the bioclimatic resources of different countries with each other, which can contribute to international collaboration during the determination of the optimum periods of health resort-tourist season for so-called average individual (average tourist). It should be noted, that unfavorable season of year, for the average individual the bioclimatic conditions are not always occasion for the curtailment into this season of tourist activity as a whole. Depending on local conditions for the specific category of people in the indicated months of year it is possible to develop winter, sport, extreme and many other forms of tourism, including medical and sanitary.

TCI is used in many countries of the world [1-3,14-19], including Black Sea-Caspian region countries, such as Turkey [20,21], Iran [22-28], Russia (Sochi, Krasnaya Polyana, Anapa, Tuapse, Primorsko-Akhtarsk, Taganrog, Kislovodsk, Makhachkala) [29]. In this case the authors of work [29] proposed the original method of TCI calculation according to the data of standard three-hour observations of the meteorological parameters.

In the South Caucasus countries the average monthly values of TCI were calculated for Georgia (Tbilisi, Batumi, Anaklia, Telavi, etc.), Armenia (Yerevan), Azerbaijan (Baku) [30-35]. In particular, in the work [34] it was shown that in period 1986-2010 in comparison with period 1961-1985 in average for 4 seaside and alpine points of Adjara (Batumi - capital of Adjarian Autonomous Republic, Kobuleti, Khulo and Goderdzi) substantial changes of the values of TCI was not observed.

For tourism climatology this bioclimatic parameter has also been used lately as Physiologically Equivalent Temperature (PET, one of the most popular physiological thermal indices derived from the human energy balance which is used in the analysis to describe the effect of the climate), Standard Effective Temperature – (SET), Universal Thermal Climate Index (UTCI) – a combination of daily air temperature, relative humidity, wind velocity, mean cloud cover, solar radiation, etc. [36-44].

In recent years, in connection with the problem of global and local climate change, with an increase of anthropogenic pollution of atmosphere, which increased the vulnerability of people to the environmental factors, the analyses of ambient effect on the health of people acquired an even larger urgency [45-64]. In particular, the influence of different separate and complex astro-meteorological and geophysical factors on the general mortality and the mortality apropos of the cardiovascular diseases of the population of Tbilisi city with different scales of averaging - hour, daily, monthly, annual [45,47,48,52-54,56-59,62], was studied. The evaluations of the influence of an increase in the temperature of air, associated with the global warming-up, on the mortality of population in different countries are carried out [50,60,61].

It is possible to soften an increase in the negative ambient effect on human health by the development of the health resort-tourist industry, which makes it possible for people to pass the course of treatment, sanitation- rehabilitative measures, actively to rest. Therefore, in recent years for the development of this sector of economy, and with respect to the refinement of known and to the development of new bioclimatic resources in the acting and promising health resort-tourist zones, is inverted special attention [3,4,63].

Georgia and North Caucasus are noted for their health resort-tourist potential. A lot of studies of different bioclimatic resources and their changeability for the known and promising health resort and tourist zones are conducted [65-73], the plans of the development of health resort-tourist industry, traveling papers of health resort-tourist zones, the refinement of the methodologies of the evaluation of the bioclimatic potential of these zones, medical weather forecast, etc. are refined regularly [74-83]. In particular, significant attention is paid to questions of the organization of ionotherapy [84-92]. Nevertheless, is observed explicit scarcity in the study of the Tourism Climate Index both in Georgia [30-35] and in North Caucasus [29]. This work is the continuation of the foregoing studies about TCI. Below they are represented the data about the average monthly values of TCI for 21 locations of Georgia and 6 locations of North Caucasus.

STUDY AREA, METHOD AND DATA DESCRIPTION

Study area (Table 1) is Georgia (21 locations) and Nord Caucasus (6 locations). Information about coordinates and heights of the meteorological stations is presented in the Table 1.

Table 1

Coordinates and heights of the 27 meteorological stations of Georgia and North Caucasus

Location	Latitude, N°	Longitude, E°	Height, m, a.s.l.
	Georgia		
Batumi	41.64	41.64	9
Kobuleti	41.82	41.78	3
Khulo	41.64	42.3	921
Goderdzi	41.63	42.52	2025
Anaklia	42.4	41.57	3
Mukhuri	42.63	42.18	260
Abastumani	41.75	42.83	1265
Bakhmaro	41.85	42.32	1926
Bakuriani	41.73	43.52	1665
Gudauri	42.47	44.48	2194
Sairme	41.9	42.75	910
Tskaltubo	42.33	42.62	121
Tbilisi	41.72	44.8	403
Telavi	41.93	45.48	568
Mestia	43.05	42.75	1441
Zugdidi	42.52	41.88	117
Dedoplistskaro	41.47	46.08	800
Kvareli	41.97	45.83	449
Sagarejo	41.73	45.33	802
Signagi	41.62	45.92	795
Martvili	42.42	42.38	170
	North Caucasus		
Kislovodsk	43.9	42.72	890
Pyatigorsk	44.10	43.00	576
Yessentuki	44.04	42.86	614
Zheleznovodsk	44.14	43.02	629
Teberda	43.45	41.73	1328
Nalchik	43.53	43.63	441

Tourism Climate Index (TCI) developed by Mieczkowski [13] is used in the work. TCI is a combination of seven parameters, three of which are independent and two in a bioclimatic combination:

$$TCI = 8 \cdot Cld + 2 \cdot Cla + 4 \cdot R + 4 \cdot S + 2 \cdot W$$

Where Cld is a daytime comfort index, consisting of the mean maximum air temperature Ta, max (°C) and the mean minimum relative humidity RH (%), Cla is the daily comfort index, consisting of the mean air temperature (°C) and the mean relative humidity (%), R is the precipitation index, S is the daily sunshine duration index, and W is the mean wind speed index.

In contrast to other climate indices, every contributing parameter is assessed. Because of a weighting factor (a value for TCI of 100), every factor can reach 5 points. TCI values >= 80 are excellent, while values between 60 and 79 are regarded as good to very good. Lower values (40 – 59) are acceptable, but values < 40 indicate bad or difficult conditions for understandable to all tourism.

The data of M. Nodia Institute of Geophysics about the daily mortality of the population of Tbilisi city from the cardiovascular diseases (Mortality) into the period from 1980 through 1992, and also data of hydrometeorological service of Georgia about mean monthly values of meteorological parameters in Tbilisi during the indicated period of time (156 months) are used in the work., also archive data of hydrometeorological services of Russia and Georgia about monthly average value of meteorological parameter on the lasting period of time, necessary for TCI calculation is used in the work.

The analysis of data with the aid of the standard methods of mathematical statistics [93] was conducted. The following designations will be used below: Min – minimal values, Max - maximal values, St Dev - standard deviation, Rc – coefficient of linear correlation, R^2 – coefficient of determination, Relative Range = 100*(Max-Min)/Average, (%).

RESULTS AND DISCUSSION

Results in Fig. 1-18 and Table 2-5 are presented.

The bioclimatic indices of locality, as a rule, with the health of the population of this locality are connected. However, the nature of these connections, although bears as a whole the universal nature, in many respects depends on the specific character of the stay of people in the data of locality (economic position, demographic situation, the level of medical service, etc.). Therefore, during the use of various bioclimatic indices for the specific locality is desirable to conduct the estimation on of their representativeness via the comparison of bioclimatic data with the data about the health of the population of this locality. As it was noted above, similar studies in the investigated region into [47,47,50,51,53,54,57,59,62] were carried out.

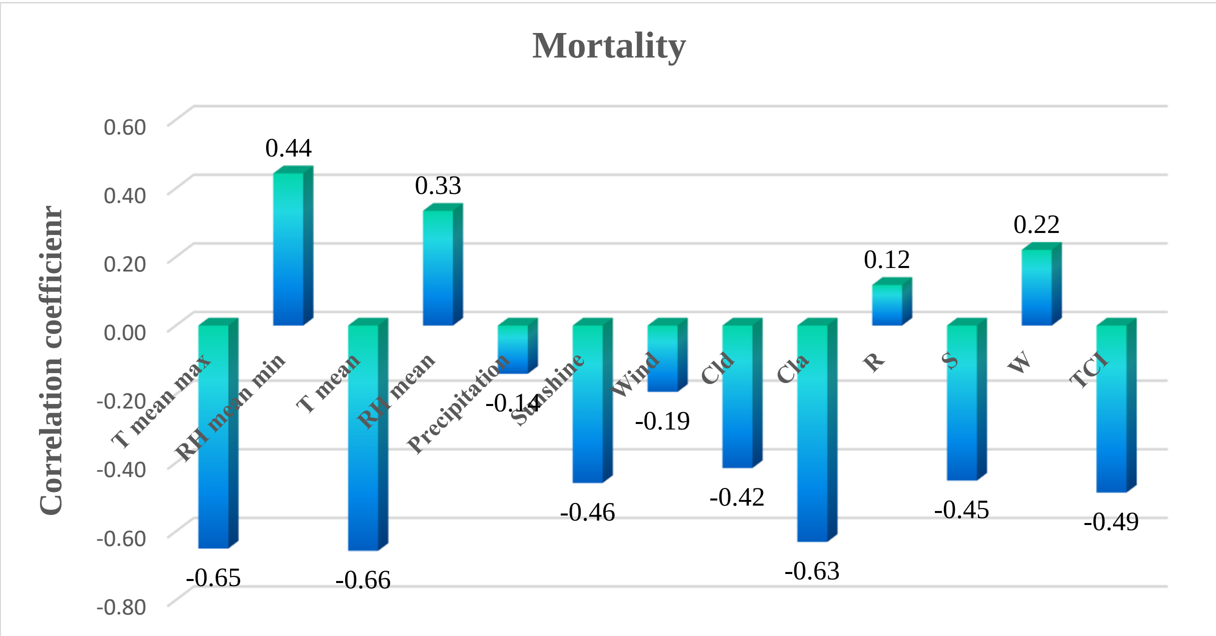

Fig. 1. Linear correlation between mean monthly decade mortality by cardiovascular deceases and simple and complex constituent of TCI and TCI in Tbilisi.

Results of studying of connection of TCI and its simple and combined components with the mortality of population for reasons the cardiovascular diseases based on the example of Tbilisi city are represented below (Fig. 1-4). As follow from Fig. 1 value of the coefficient of linear correlation between the average monthly decade mortality of the population of Tbilisi for reasons the cardiovascular diseases and simple and complex components of TCI and TCI are found in the range from - 0.66 to +0.44 (all values of the correlation coefficients are significant).

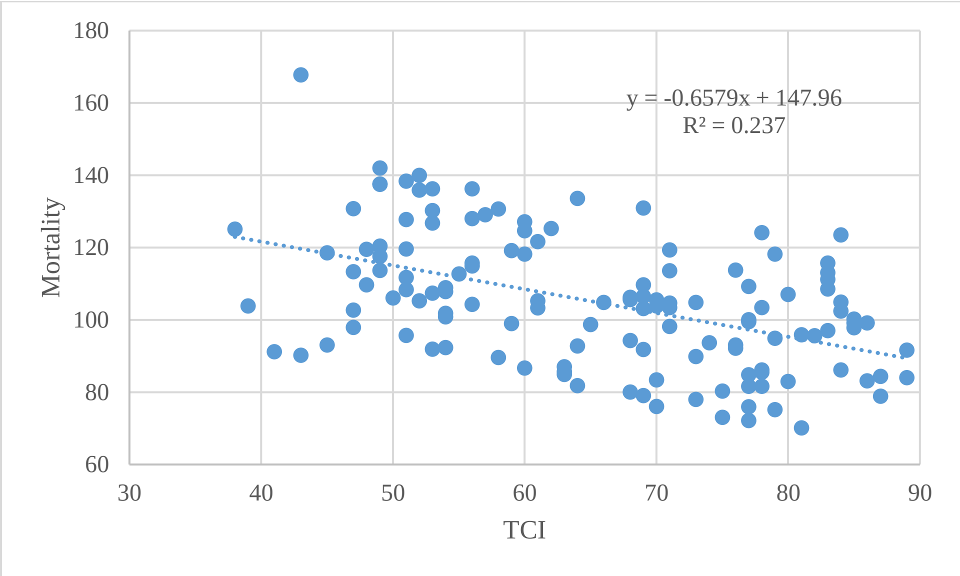

Fig. 2. Linear correlation and regression between mean monthly decade mortality by cardiovascular deceases and mean monthly values of TCI in Tbilisi.

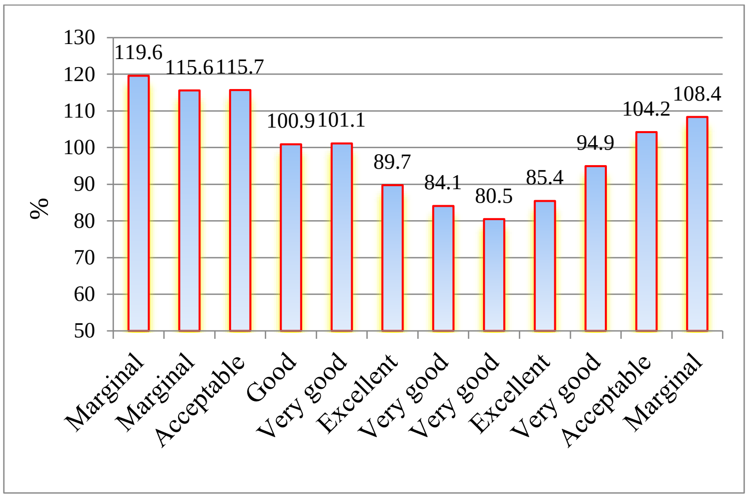

Fig. 3. Values of mean monthly decade mortality by cardiovascular deceases in Tbilisi normalize by the mean annual decade mortality under different TCI categories.

Very weak inverse correlation between the mortality and precipitation, and also wind speed is observed. Mortality noticeably correlates with average monthly maximum temperature and average monthly temperature of air, and also with values of Cla (correlation is negative). The moderate inverse correlation is noted between mortality and insolation duration, and also by the values of Cld, S and TCI. The moderate positive correlation is observed between the mortality and the average minimum and average humidity of air. Very weak positive correlation is noted between the mortality and the values of R, and weak positive correlation - between the mortality and the values of W.

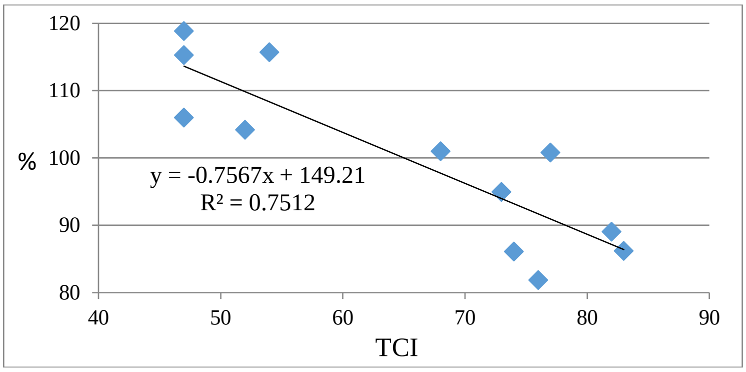

Fig. 4. Linear correlation between mean monthly decade mortality by cardiovascular deceases in Tbilisi normalize by the mean annual decade mortality and TCI according to fig. 3.

Fig. 2 for the clarity depicts the regression graph between the mortality and TCI. As it follows from this figure (as from Fig. 3,4), with an increase in the category TCI it is observed the decrease of mortality. Thus, gradations of TCI and its constituting completely adequately describe bioclimatic situation in the conditions of Tbilisi, at least for the period from 1980 through 1992. Concerning present time, similar studies it is planned to conduct in the near future.

Table 2

The statistical characteristics of TCI for 27 locations of Georgia and North Caucasus

Location	Average	Min	Max	St Dev	Distribution type
Batumi	57	36	75	14	Bimodal, May-Jun; Sept-Oct
Kobuleti	55	34	74	15	Bimodal, May-Jun; Sept-Oct
Khulo	57	31	78	19	Unimodal, plateau: May-Sept
Goderdzi	40	19	63	15	Unimodal, Aug
Anaklia	59	40	77	14	Bimodal, May-Jun; Sept-Oct
Mukhuri	55	29	70	14	Bimodal, May-Jun; Sept
Abastumani	58	34	81	18	Unimodal, plateau: Aug-Sept
Bakhmaro	41	16	67	17	Unimodal, Aug
Bakuriani	53	30	82	17	Unimodal, Aug
Gudauri	39	27	62	11	Unimodal, Aug
Sairme	53	26	81	21	Unimodal, Aug
Tskaltubo	56	36	74	15	Bimodal, May; Aug-Sept
Tbilisi	65	47	83	14	Bimodal, Jun; Sept
Telavi	62	47	79	12	Bimodal, May-Jun; Sept
Mestia	55	31	76	18	Unimodal, plateau: Jun-Sept
Zugdidi	57	33	76	15	Bimodal, May; Oct
Dedoplistskaro	63	44	81	15	Bimodal, Jun; Sept
Kvareli	61	45	75	11	Bimodal, May; Sept
Sagarejo	63	45	80	15	Unimodal, plateau: Jun-Sept
Signagi	62	46	77	11	Bimodal, May; Sept
Martvili	55	29	77	16	Bimodal, May; Sept-Oct
Kislovodsk	60	42	80	15	Unimodal, plateau: Jul-Sept
Pyatigorsk	59	38	82	18	Unimodal, plateau: Jul-Aug
Yessentuki	58	37	84	19	Unimodal, Aug
Zheleznovodsk	57	34	84	19	Unimodal, Aug
Teberda	57	35	80	18	Unimodal, plateau: Jul-Aug
Nalchik	58	35	78	17	Unimodal, plateau: Aug-Sept

Table 2 and in Fig. 5-18 clearly presents the results of the statistical analysis of annual, half year and average monthly long-standing values of TCI for 27 localities of Georgia and North Caucasus. As it follows from table 2 average annual values of TCI change from 39 (Gudauri) to 65 (Tbilisi), minimum average monthly - from 16 (Bakhmaro) to 47 (Tbilisi, Telavi), maximum average monthly - from 62 (Gudauri) to 84 (Yessentuki, Zheleznovodsk).

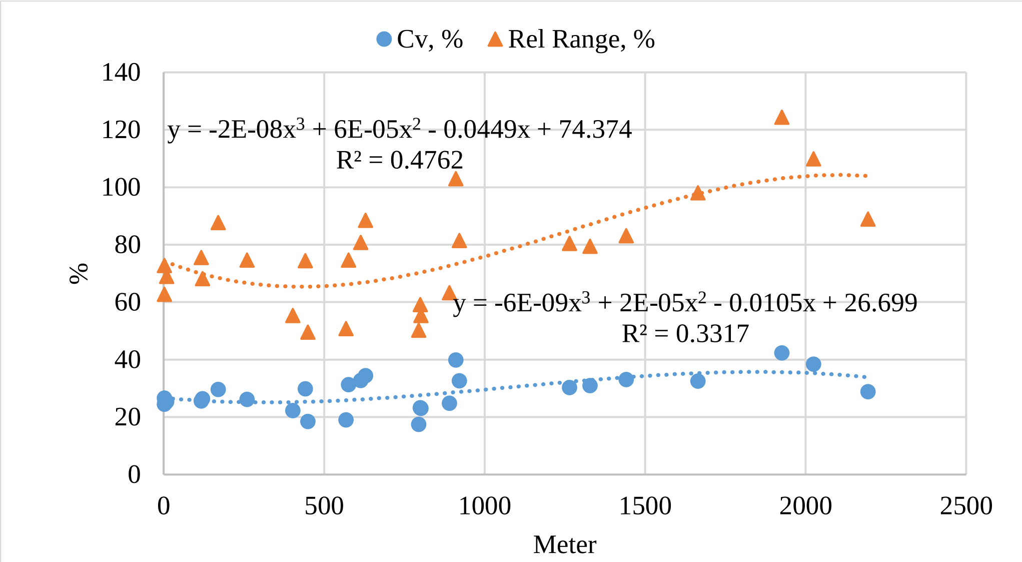

Fig. 5. Values of coefficient of variation and relative range of annual variability of TCI at the different heights.

With the height of locality, as a whole, occurs an increase in the values of the coefficient of variation and relative variation scope of intra-annual changeability of TCI (Fig. 5).

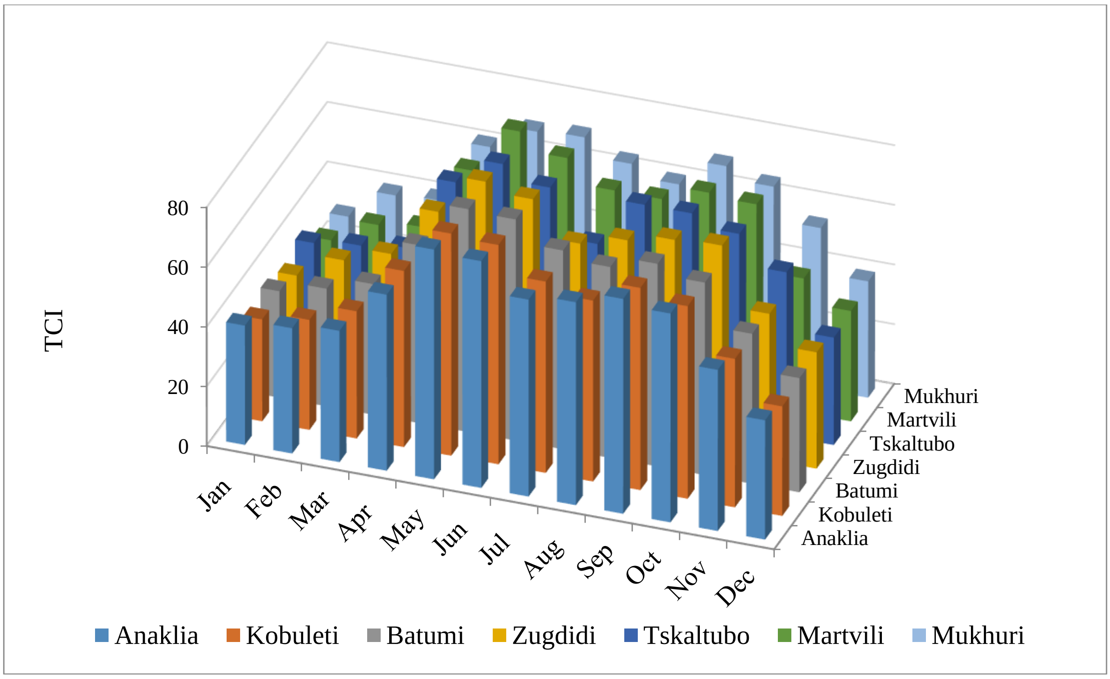

Fig. 6. Intra annual variations of TCI at the levels of terrain height from 3 m (Anaklia) to 260 m (Mukhuri).

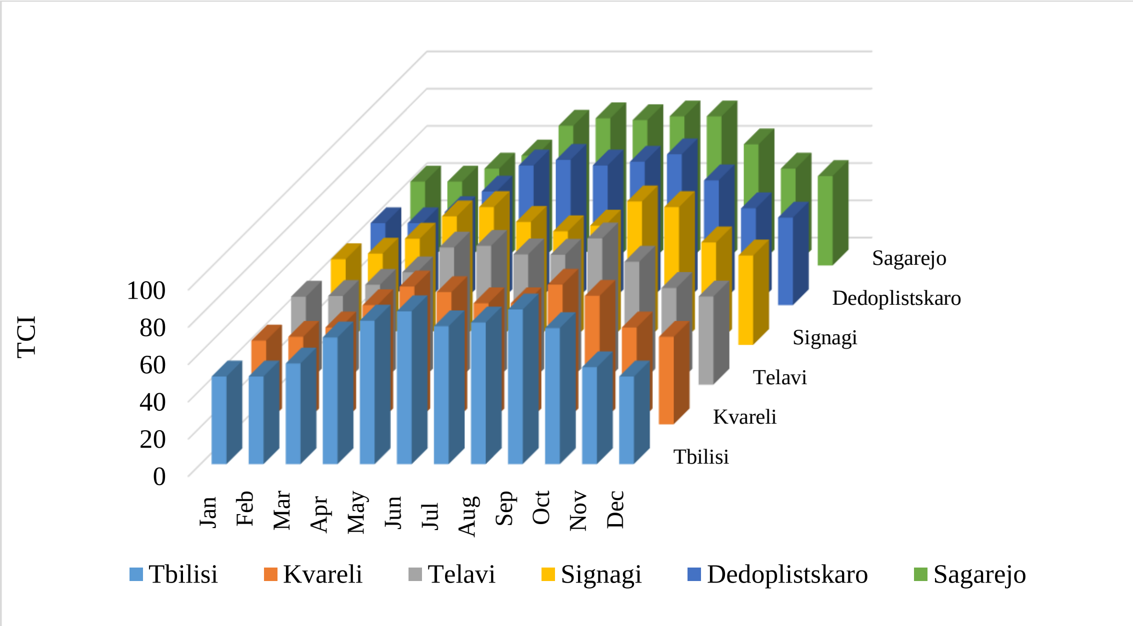

Fig. 7. Intra annual variations of TCI at the levels of terrain height from 403 m (Tbilisi) to 802 m (Sagarejo).

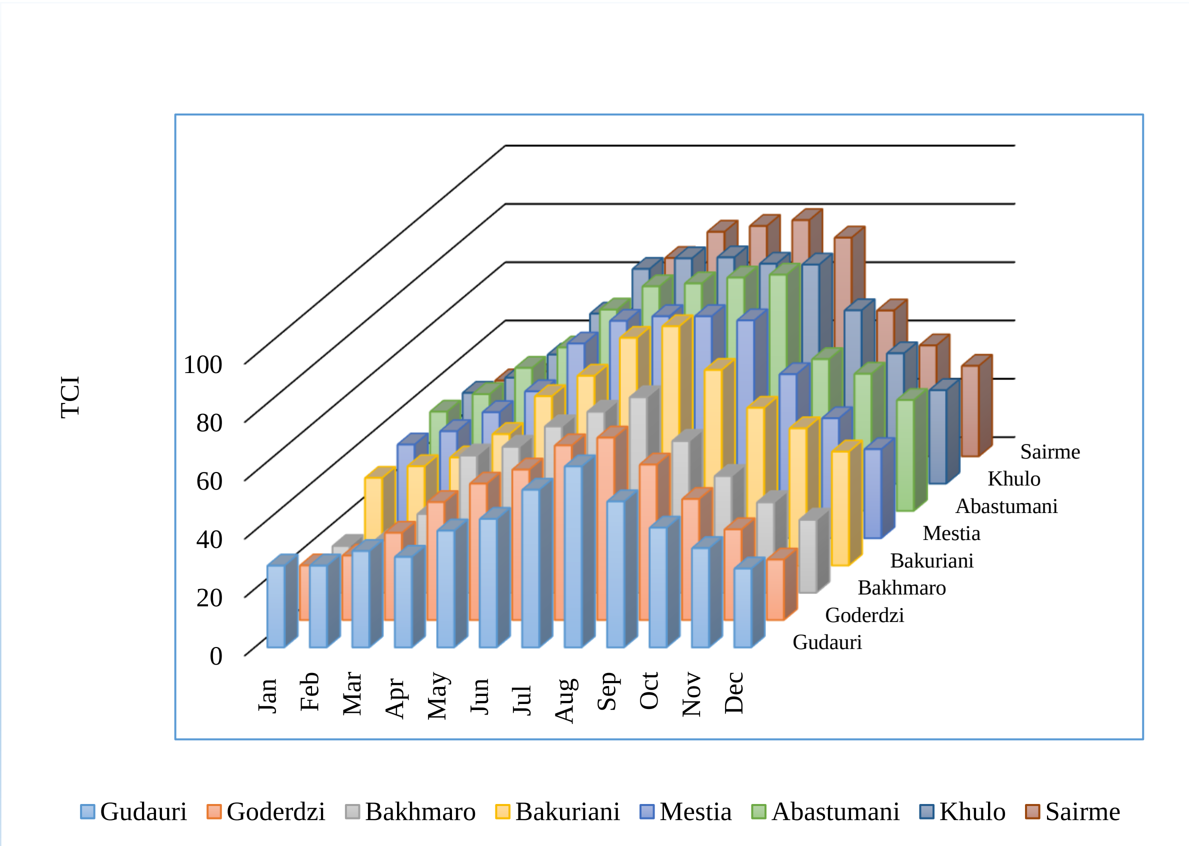

Fig. 8. Intra annual variations of TCI at the levels of terrain height from 910 m (Sairme) to 2192 m (Gudauri).

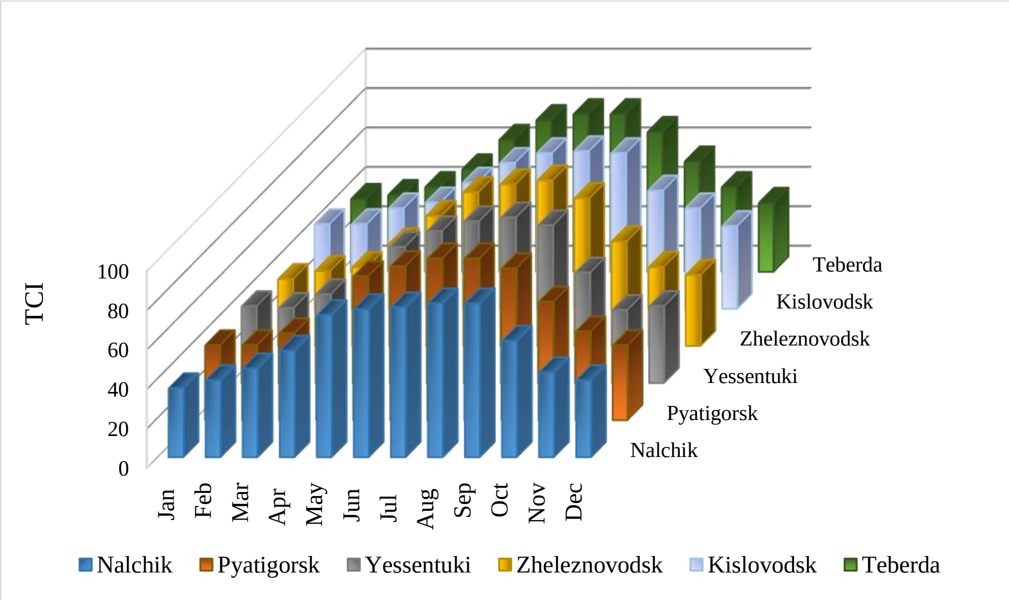

Fig. 9. Intra annual variations of TCI in six locations of the North Caucasus. Terrain height from 441 m (Nalchik) to 1328 m (Teberda).

The bimodal type of the intra-annual distribution of average monthly values of TCI in the following points are observed: Kobuleti, Anaklia, Mukhuri, Tskaltubo, Tbilisi, Telavi, Zugdidi, Dedoplistskaro, Kvareli, Signagi, Martvili; single-modal with the plateau - on the points: Khulo, Abastumani, Mestia, Sagarejo, Kislovodsk, Pyatigorsk, Teberda, Nalchik; single-modal - on the points: Goderdzi, Bakhmaro, Bakuriani, Gudauri, Sairme, Yessentuki, Zheleznovodsk (Fig. 6-9). With an increase in the height of locality, as a whole occurs the passage of bimodal intra-annual distribution of TCI to the single-modal.

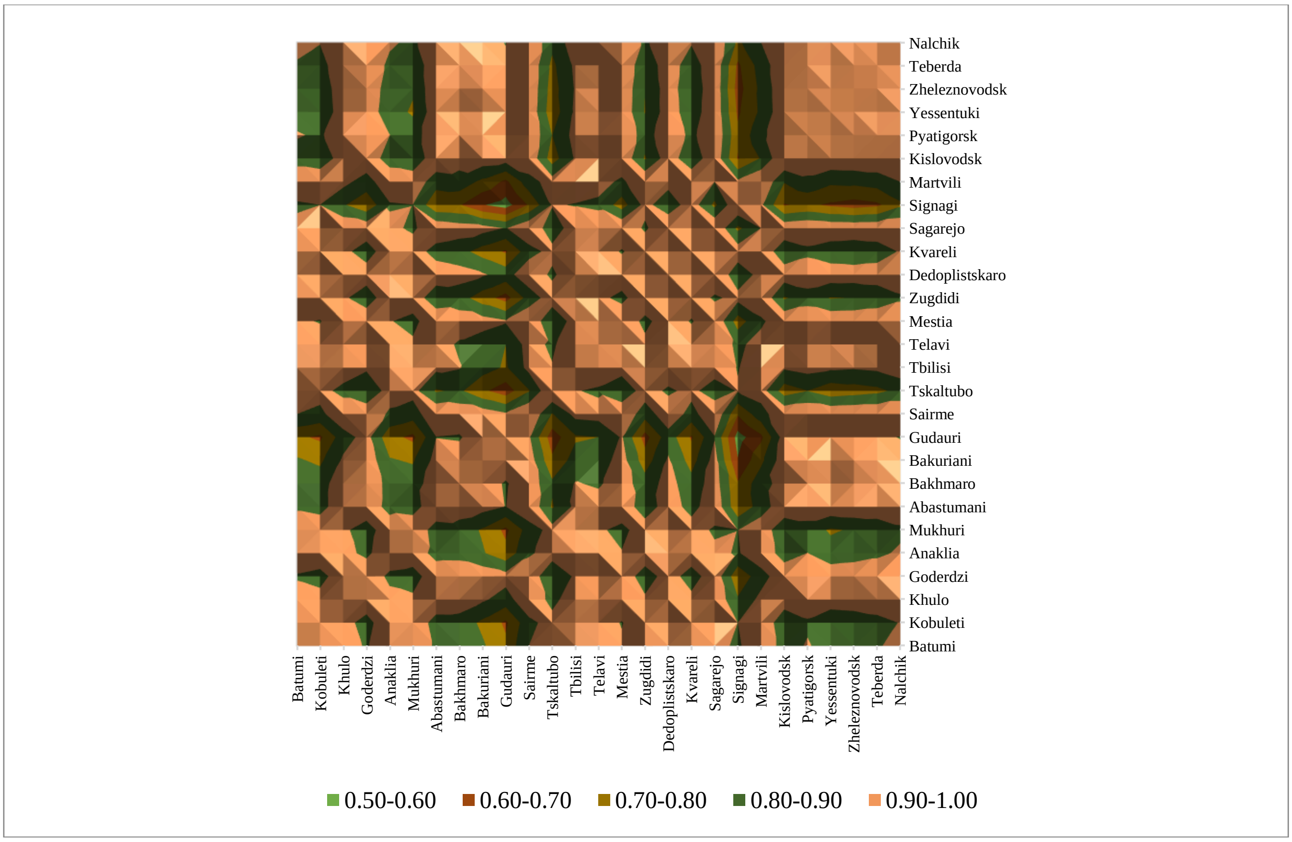

Fig. 10. Correlation field between investigation locations on values of TCI.

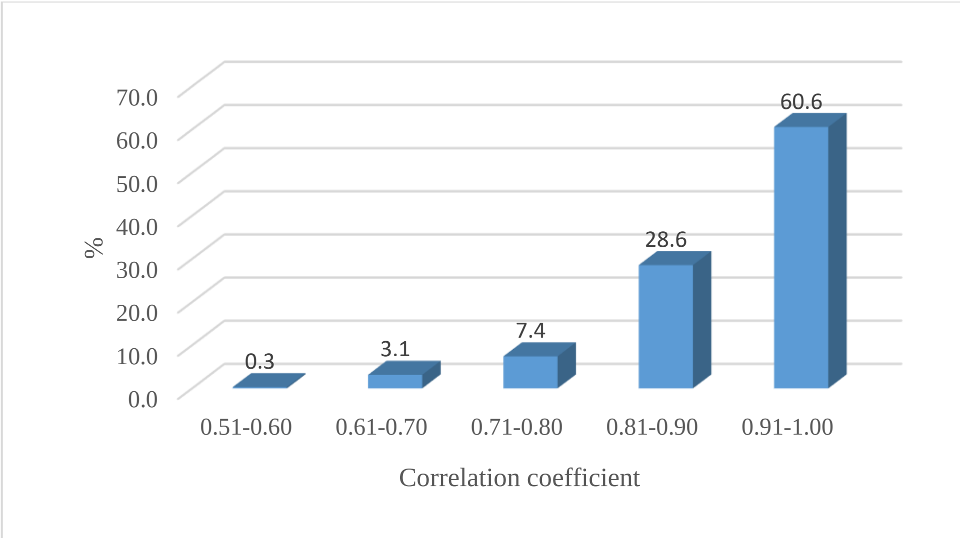

Fig. 11. Repetition of values of correlation coefficient between investigation locations on values of TCI.

Between the investigated localities in terms of the values of TCI is noted high linear correlation (Fig. 10,11). Values of Rc change from 0.56 to 1.0. Values of Rc in the range 0.91-1.0 into 60.6 % of the cases are observed. Values of Rc in the range 0.51-0.7 only in into 3.4 % of the cases are observed (Fig. 11).

Fig. 12-16 presents the data about the vertical distribution of values of TCI in the investigated region (corresponding categories of TCI are indicated together with their values on the Y-axis). As follows from Fig. 12 vertical distribution of average annual and half year values of TCI takes the form of the second power polynomial. Average annual values of TCI and values of TCI for the warm half-year with the height of locality grow (to the heights of 500-100 m), then - they diminish. In the cold half-year of value of TCI little change to the height of 1000 m, then - they diminish.

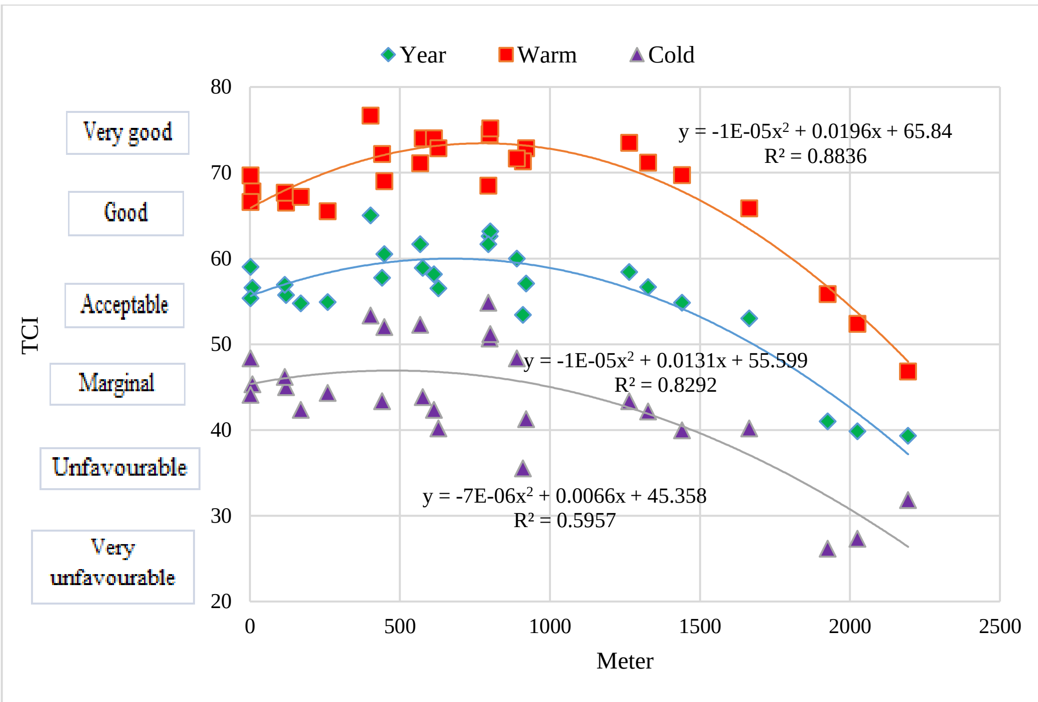

Fig. 12. Vertical distribution of TCI in three periods of Year in Georgia and North Caucasus.

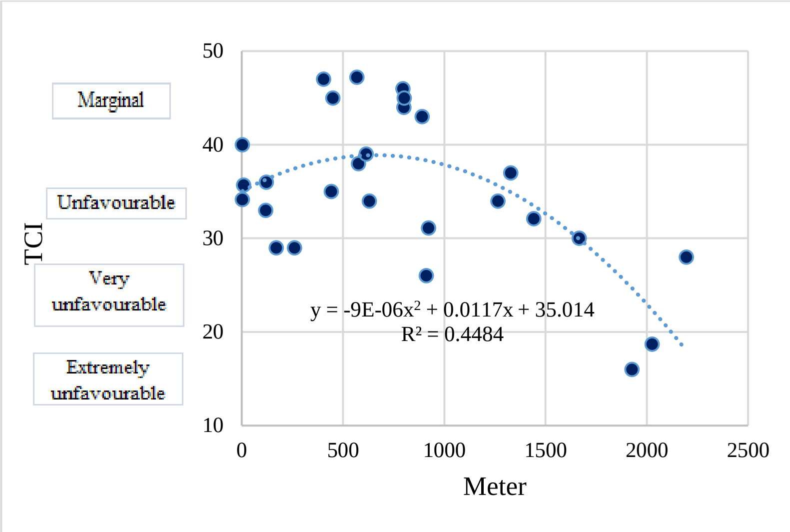

Fig. 13. Vertical distribution of TCI in January.

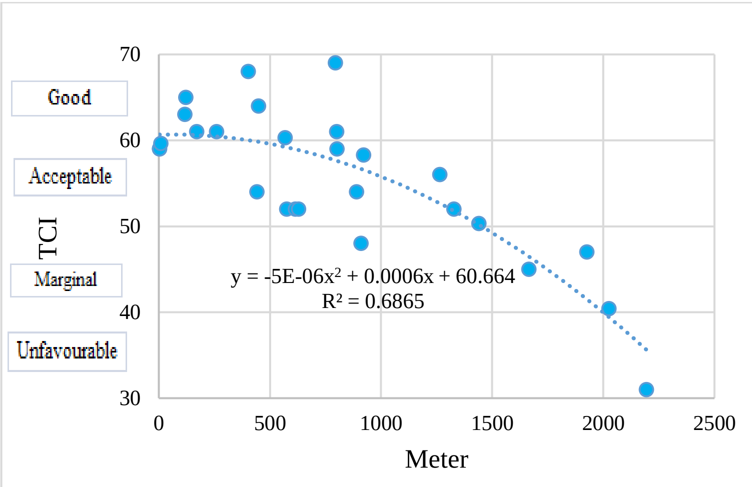

Fig. 14. Vertical distribution of TCI in April.

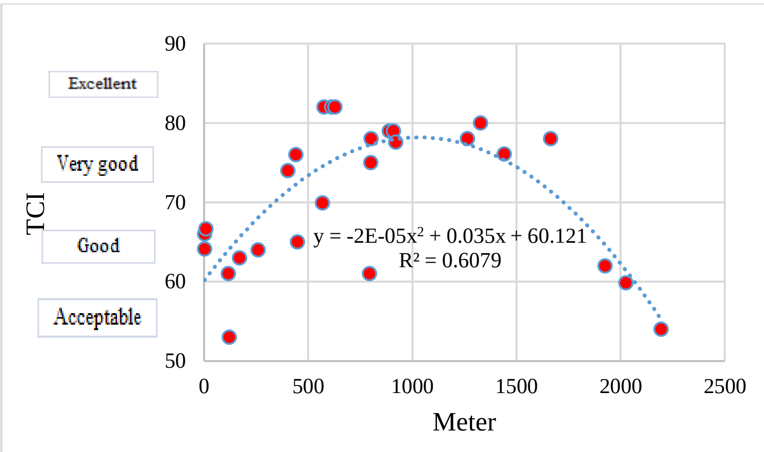

Fig. 15. Vertical distribution of TCI in July.

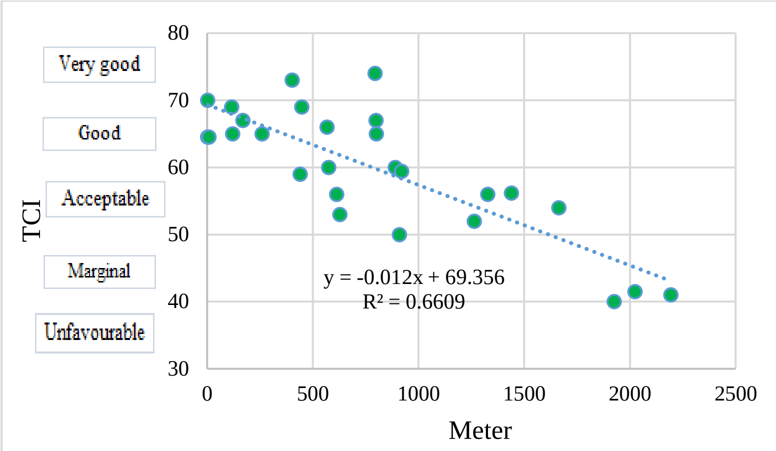

Fig. 16. Vertical distribution of TCI in October

During January, April and July vertical distribution of values of TCI takes the form of the second power polynomial (Fig. 13-15), while during October with an increase in the height the values of TCI linearly diminish (Fig. 16). Let us note, that during July an increase in the values of TCI to the height of 1000 m is clearly noticeable, then - decrease.

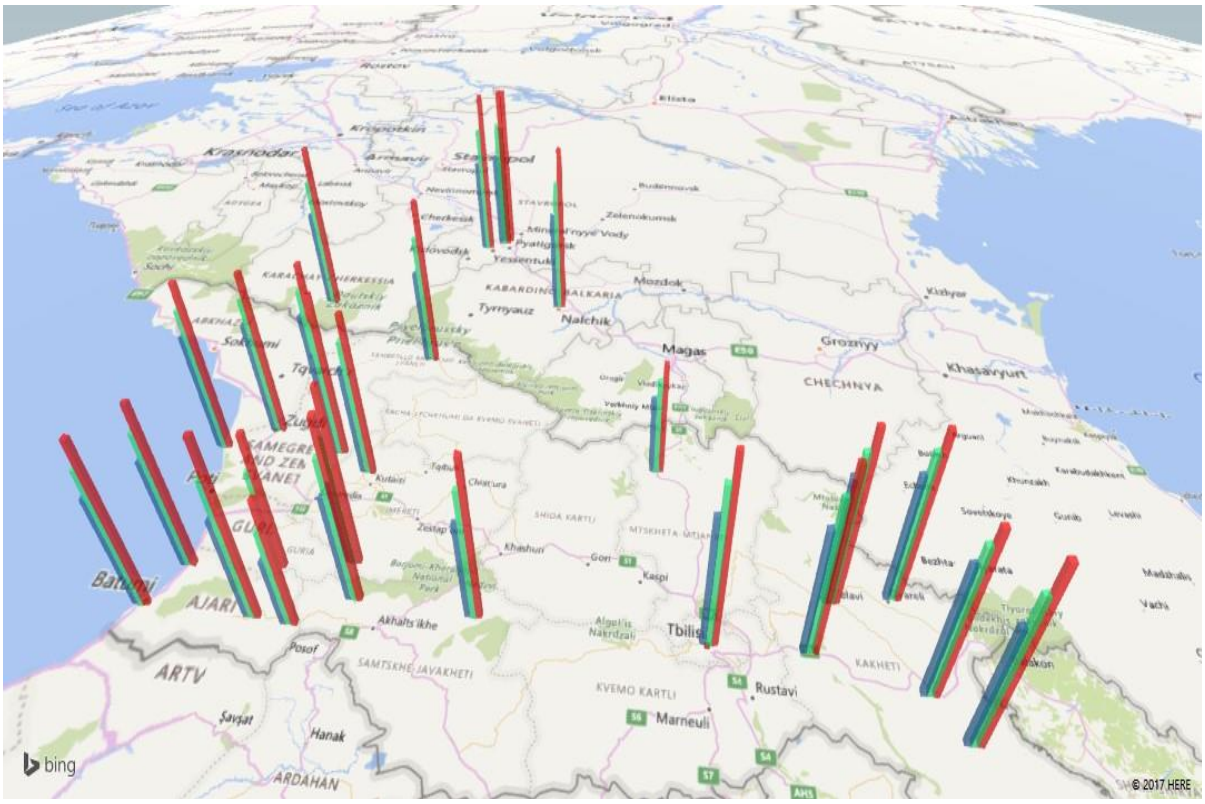

Fig. 17. Distribution of annual and half year values of TCI on the territory of Georgia and North Caucasus. April-September (red), October-March (blue), January-December (green)

Fig. 17, as the illustration, depicts the map of the distribution of average annual and half year values of TCI in Georgia and North Caucasus.

Table 3

Annual and half year average of c TCI categories for 27 locations of Georgia and North Caucasus

Location	TCI Categori		
	Year	Warm	Cold
Anaklia	Acceptable	Very Good	Marginal
Batumi	Acceptable	Good	Marginal
Kobuleti	Acceptable	Good	Marginal
Zugdidi	Acceptable	Good	Marginal
Mukhuri	Acceptable	Good	Marginal
Khulo	Acceptable	Very Good	Marginal
Bakhmaro	Marginal	Acceptable	Very Unfavorable
Martvili	Acceptable	Good	Marginal
Goderdzi	Marginal	Acceptable	Very Unfavorable
Tskaltubo	Acceptable	Good	Marginal
Sairme	Acceptable	Very Good	Unfavorable
Mestia	Acceptable	Very Good	Marginal
Abastumani	Acceptable	Very Good	Marginal
Bakuriani	Acceptable	Good	Marginal
Gudauri	Unfavorable	Marginal	Unfavorable
Tbilisi	Good	Very Good	Acceptable
Sagarejo	Good	Very Good	Acceptable
Telavi	Good	Very Good	Acceptable
Kvareli	Good	Good	Acceptable
Signagi	Good	Good	Acceptable
Dedoplistskaro	Good	Very Good	Acceptable
Kislovodsk	Good	Very Good	Marginal
Pyatigorsk	Acceptable	Very Good	Marginal
Yessentuki	Acceptable	Very Good	Marginal
Zheleznovodsk	Acceptable	Very Good	Marginal
Teberda	Acceptable	Very Good	Marginal
Nalchik	Acceptable	Very Good	Marginal

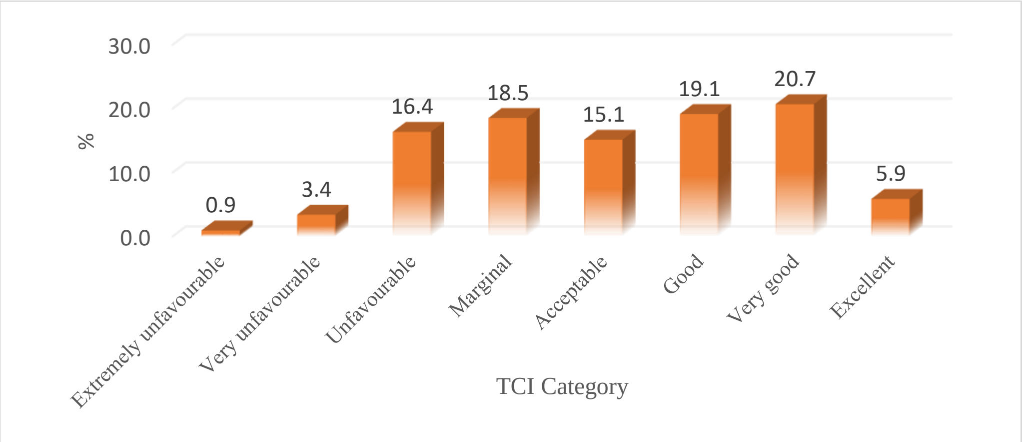

Fig. 18. Repetition of TCI categories for 27 locations of Georgia and North Caucasus from January to December

Finally, tables 3-5 present detailed information about the categories of TCI on the average during the year, the warm and cold periods (table 3), and also monthly (table 4,5). These tables, in particular, can be useful for different tourist agencies.

Fig. 18 presents the data about the repetition of monthly categories of TCI for the investigated region. As it follows from this figure, as a whole more than into 79% cases the value of TCI they are located in the range of categories from "Marginal" to "Excellent". I.e., in the overwhelming majority of the months of year the investigated localities are suitable for the so-called " average tourist ".

Table 4

TCI categories for 27 locations of Georgia and North Caucasus from October to March

Location	**TCI Categori**					
	Oct	Nov	Dec	Jan	Feb	Mar
Anaklia	Very Good	Acceptable	Marginal	Marginal	Marginal	Marginal
Batumi	Good	Acceptable	Unfavourable	Unfavourable	Unfavourable	Marginal
Kobuleti	Good	Acceptable	Unfavourable	Unfavourable	Unfavourable	Marginal
Zugdidi	Good	Marginal	Unfavourable	Unfavourable	Marginal	Marginal
Mukhuri	Good	Acceptable	Unfavourable	Very Unfavourable	Unfavourable	Marginal
Khulo	Acceptable	Marginal	Unfavourable	Unfavourable	Unfavourable	Marginal
Bakhmaro	Marginal	Unfavourable	Very Unfavourable	Extremely Unfavourable	Extremely Unfavourable	Very Unfavourable
Martvili	Good	Marginal	Unfavourable	Very Unfavourable	Unfavourable	Unfavourable
Goderdzi	Marginal	Unfavourable	Very Unfavourable	Extremely Unfavourable	Very Unfavourable	Unfavourable
Tskaltubo	Good	Acceptable	Unfavourable	Unfavourable	Unfavourable	Marginal
Sairme	Acceptable	Unfavourable	Unfavourable	Very Unfavourable	Very Unfavourable	Unfavourable
Mestia	Acceptable	Marginal	Unfavourable	Unfavourable	Unfavourable	Marginal
Abastumani	Acceptable	Marginal	Unfavourable	Unfavourable	Marginal	Marginal
Bakuriani	Acceptable	Marginal	Unfavourable	Unfavourable	Unfavourable	Unfavourable
Gudauri	Marginal	Unfavourable	Very Unfavourable	Very Unfavourable	Very Unfavourable	Unfavourable
Tbilisi	Very Good	Acceptable	Marginal	Marginal	Marginal	Acceptable
Sagarejo	Good	Acceptable	Marginal	Marginal	Marginal	Acceptable
Telavi	Good	Acceptable	Marginal	Marginal	Marginal	Acceptable
Kvareli	Good	Acceptable	Marginal	Marginal	Marginal	Acceptable
Signagi	Very Good	Acceptable	Marginal	Marginal	Marginal	Acceptable
Dedoplistskaro	Good	Acceptable	Marginal	Marginal	Marginal	Acceptable
Kislovodsk	Good	Acceptable	Marginal	Marginal	Marginal	Acceptable
Pyatigorsk	Good	Marginal	Unfavourable	Unfavourable	Unfavourable	Marginal
Yessentuki	Acceptable	Unfavourable	Unfavourable	Unfavourable	Unfavourable	Marginal
Zheleznovodsk	Acceptable	Marginal	Unfavourable	Unfavourable	Unfavourable	Marginal
Teberda	Acceptable	Marginal	Unfavourable	Unfavourable	Unfavourable	Marginal
Nalchik	Acceptable	Marginal	Unfavourable	Unfavourable	Unfavourable	Marginal

Table 5

TCI categories for 27 locations of Georgia and North Caucasus from April to September

Location	TCI Categori					
	Apr	May	Jun	Jul	Aug	Sep
Anaklia	Acceptable	Very Good	Very Good	Good	Good	Very Good
Batumi	Good	Very Good	Very Good	Good	Good	Good
Kobuleti	Acceptable	Very Good	Very Good	Good	Good	Good
Zugdidi	Good	Very Good	Very Good	Good	Good	Good
Mukhuri	Good	Good	Verygood	Good	Good	Good
Khulo	Acceptable	Very Good	Very Good	Very Good	Very Good	Very Good
Bakhmaro	Marginal	Acceptable	Acceptable	Good	Good	Acceptable
Martvili	Good	Very Good	Very Good	Good	Good	Good
Goderdzi	Marginal	Marginal	Acceptable	Good	Good	Acceptable
Tskaltubo	Good	Very Good	Good	Acceptable	Good	Good
Sairme	Marginal	Good	Very Good	Very Good	Excellent	Very Good
Mestia	Acceptable	Good	Very Good	Very Good	Very Good	Very Good
Abastumani	Acceptable	Good	Very Good	Very Good	Excellent	Excellent
Bakuriani	Marginal	Acceptable	Good	Very Good	Excellent	Good
Gudauri	Unfavourable	Marginal	Marginal	Acceptable	Good	Acceptable
Tbilisi	Good	Very Good	Excellent	Very Good	Very Good	Excellent
Sagarejo	Acceptable	Very Good	Very Good	Very Good	Excellent	Excellent
Telavi	Good	Very Good	Very Good	Very Good	Very Good	Very Good
Kvareli	Good	Very Good	Very Good	Good	Good	Very Good
Signagi	Good	Very Good	Good	Good	Good	Very Good
Dedoplistskaro	Good	Very Good	Very Good	Very Good	Very Good	Excellent
Kislovodsk	Acceptable	Good	Very Good	Very Good	Excellent	Very Good
Pyatigorsk	Acceptable	Very Good	Very Good	Excellent	Excellent	Very Good
Yessentuki	Acceptable	Good	Very Good	Excellent	Excellent	Excellent
Zheleznovodsk	Acceptable	Good	Very Good	Excellent	Excellent	Very Good
Teberda	Acceptable	Good	Very Good	Excellent	Excellent	Very Good
Nalchik	Acceptable	Very Good	Very Good	Very Good	Very Good	Very Good

CONCLUSIONS

In the near future is planned a study of the bioclimatic resources of Georgia and North Caucasus with the use of such bioclimatic indices as Physiologically Equivalent Temperature (PET), Standard Effective Temperature – (SET), Universal Thermal Climate Index (UTCI), etc. Wherein, both archival and modern data about the health of the population of the studied region and meteorological observations will be used.

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ტურიზმის კლიმატური ინდექსი საქართველოს და ჩრდილოეთ კავკასიის (რუსეთი) ზოგიერთ რეგიონში

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რეზიუმე

წარმოდგენილია ტურიზმის კლიმატური ინდექსის თვიური მნიშვნელობების კვლევის შედეგები საქართველოს ზოგიერთ რაიონსა (21 პუნქტი) და ჩრდილოეთ კავკასიაში (რუსეთი, 6 პუნქტი). პუნქტების მდებარეობა იცვლება 3 -დან 2194 მ-მდე ზღვის დონიდან.
ჩატარებულია გულსისხლძარღვთა დაავადების მიზეზით თბილისში სიკვდილიანობის ტურიზმის კლიმატურ ინდექსის მნიშვნელობებთან და მის ცალკეულ კომპონენტებთან კავშირის კორელაციური და რეგრესიული ანალიზი. ამ ანალიზმა დაადასტურა ტურიზმის კლიმატური ინდექსის შკალის, როგორც მოცემული რეგიონისათვის ბიოკლიმატური მაჩვენებლის გამოყენების რეპრეზენტატულობა (ზოგადად, ტურიზმის კლიმატური ინდექსის ზრდასთან ერთად აღინიშნება სიკვდილიანობის შემცირება).
წარმოდგენილია ტურიზმის კლიმატური ინდექსის მნიშვნელობების სტატისტიკური მახასიათებლები. კერძოდ, მიღებულია, რომ ადგილის სიმაღლის ზრდასთან ერთად მთლიანობაში ტურიზმის კლიმატური ინდექსის შიდაწლიური ბიმოდალური სვლა გადადის ერთმოდალურზე.
შესწავლილია ტურიზმის კლიმატური ინდექსის ვერტიკალური განაწილება საშუალოდ წლის, ცივი და თბილი პერიოდებისა და წლის ცენტრალური თვეებისათვის.
წარმოდგენილია დაწვრილებითი ინფორმაცია ტურიზმის კლიმატური ინდექსის კატეგორიების შესახებ ყველა გამოსაკვლევი პუნქტისათვის.

Климатический индекс туризма в некоторых районах Грузии и Северного Кавказа (Россия)

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Резюме

Представлены результаты исследования месячных значений климатического индекса туризма (КИТ) в некоторых районах Грузии (21 пунк) и Северного Кавказа (Россия, 6 пунктов). Высота расположения пунктов – от 3 до 2194 м над уровнем моря.

Проведен корреляционный и регрессионный анализ связи смертности по поводу сердечно-сосудистых заболеваний в Тбилиси со значениями КИТ и его отдельными компонентами. Этот анализ подтвердил репрезентативность использования шкалы КИТ как биоклиматического показателя для исследуемого региона (в целом, с ростом значений КИТ отмечается убывание смертности).

Представлены статистические характеристики значений КИТ. В частности получено, что с ростом высоты местности, в целом происходит переход бимодального внутригодового хода КИТ к одномодальному.

Изучено вертикальное распределение значений КИТ в среднем за год, теплый и холодный периоды, а также в центральные месяцы года.

Представлена подробная информация о категориях КИТ для всех исследуемых пунктов.

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Comparative Analysis of Mean-Daily Value of Air Equivalent-Effective Temperature in Tbilisi and Kojori

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ABSTRACT

For the confirmation of the applicability of the scale of air equivalent-effective temperature (EET) as the bioclimatic index in daily time scale, the results of studying the connection of average-daily values of EET in Tbilisi with the mortality of the population of this city from the cardiovascular diseases are represented.
It is obtained that the dependence of mortality on EET takes the classical form - the decrease of mortality from the gradation "Sharply Coldly" to "Comfortably" with further increase to the gradation "Warmly". Thus, the existing scale EET is completely acceptable for the evaluation of the severity of exposure to the health of people on a daily scale also.
The comparative analysis of mean-daily values of EET into Tbilisi (3 meteorological stations - Vashlijvari, Tbilisi state university, Tbilisi airport) and in Kojori (mountain health resort settlement in 10 km from the center of Tbilisi) is carried out. In particular it is shown that values of EET in the urbanized part of the city (Vashlijvari, State University) differ significantly from their values after the feature of city (Airport, Kojori); in Kojori are not observed negative for the health of people high values EET, which fall into the range by "Warmly".

Key Words: air equivalent-effective temperature, bioclimatology, biometeorology

Introduction

As is known, the health of people in many respects depends on different natural and anthropogenic components of the medium of its inhabiting. Bioclimate, which causes the degree of the comfort of the vital activity of man, is essential component of this medium, and therefore its studies have long ago been immediate for the scientific different specialties [1-5]. The urgency of these studies even more grew in the connection by intensive industrialization in a whole series of the countries [6], and also by the accelerated changes in the global and local climate [7-10], since both indicated factors are closely related to stability problem of different bioclimatic characteristics of environment [11-16].

The indicated problem is extremely urgent for Georgia, which, among entire other things, possesses great possibilities for realization and development of activity in the health resort-tourist sphere of the economy. Therefore, studies of the bioclimatic characteristics of different regions of Georgia, their special features and changeability, at present acquire special importance not only from a scientific point of view, but also for solving the whole series of practical questions, such, for example, as traveling papers of the health resort and tourist potential of the country [17,18].

Work on the traveling papers of the health resort-tourist potential of Georgia long ago is conducted sufficiently. Thus, work [19] presents the sufficiently detailed description of practically health resort objects all acted in Georgia in the Soviet period. In the post-Soviet period, unfortunately, the set of these objects ended its existence. However, recently in the country the health resort-tourist industry again of beginning vigorously to be developed. In connection with this, taking into account new knowledge in by world association, appeared the need for at the higher scientific level investigating the bioclimatic resources of different regions of Georgia.

In the recent two decades in Georgia are carried out sufficiently many studies in the field of bioclimatology, biometeorology and medical meteorology. In particular, was studied the influence of different separate and complex astro-meteorological and geophysical factors on the general mortality and the mortality apropos of the cardiovascular diseases of the population of Tbilisi city with different scales of averaging -

hour, daily, monthly, annual [6,13,20-27], were studied the special features of intra-annual variations in the tourism climate index of for 21 points of Georgia [28-34], were studied the separate bioclimatic characteristics of different known and promising health resort -tourism zones [14,15,35-41]. This work is the continuation of the foregoing studies.

Below, for the confirmation of the applicability of the scale of air equivalent-effective temperature (EET) as bioclimatic index in daily time scale, are represented the results of studying the connection of average-daily values EET in Tbilisi with the mortality of the population of this city from the cardiovascular diseases. Is carried out Also the comparative analysis of values of EET in Tbilisi (3 meteorological stations - Vashlijvari, Tbilisi State University, Tbilisi airport) and in Kojori (mountain health resort settlement in 10 km from the center of Tbilisi).

Material and methods

In the work the data of M. Nodia Institute of Geophysics about the daily mortality of the population of Tbilisi city from the cardiovascular diseases (Mortality) into the period from 1980 through 1992, and also data of agency on the environment (Vashlijvari, Tbilisi Airport) and I. Javakhishvili Tbilisi State University about the mean diurnal values of air temperature - T (°C), air relative humidity – U (%) and wind speed - V (m/sec) during the indicated period of time were used. Information about coordinates and heights of the meteorological stations in Tbilisi and Kojori in the Table 1 are presented.

The analysis of data with the aid of the standard methods of mathematical statistics [42] was conducted. All analyzed 4749 cases.

Table 1

Coordinates of the meteorological stations in Tbilisi (Vashlijvari, Tbilisi State University - TSU, Airport) and Kojori.

Location	Lat., N°	Lon., E°	Height, m, a.s.l.
Vashlijvari	41.75	44.77	518
TSU	41.71	44.78	455
Airport	41.67	44.95	472
Kojori	41.67	44.70	1338

The Air Equivalent- Effective Temperature Scale for Tbilisi [23] is: <1° - Sharply coldly, 1-8° - Coldly, 9-16° - Moderately coldly, 17-22° - Comfortably, 23-27° - Warmly, >27° - Hotly

Results and discussion

Results in Tables 2,3 and in Fig. 1,2 are represented.

Table 2

The statistical characteristics of daily mean values of T, U, V and EET in 3 locations of Tbilisi and Kojori in 1980-1992 (4749 cases of observations)

Location	Vashlijvari				TSU			
Parameter	T	U	V	EET	T	U	V	EET
Min	-6.1	31.0	0.0	-23.9	-6.0	28.9	0.0	-20.9
Max	31.0	97	10.3	25.7	30.9	98.0	5.6	25.5
Average	13.0	67.5	0.9	9.5	13.2	65.6	0.7	9.2
Location	Airport				Kojori			
Min	-8.3	30.9	0.0	-61.9	-12.5	21.4	0.0	-52.6
Max	31.0	100	23.1	24.4	25.1	100	9.9	20.1
Average	12.8	70.9	4.8	3.4	7.3	74.0	1.3	1.1

Table 2 presents the statistical data about the values of EET and its separate component for all four meteorological stations. As it follows from this table in the limits of Tbilisi of the essential difference in the average, maximum and minimum values of temperature and relative humidity of air it is not noted. What about wind speed - its smallest values are observed at the meteorological station of Tbilisi university, greatest - in the airport. Accordingly, average values of EET in Vashlijvari and TSU fall into the range of "Moderately coldly", and in the airport - into the range Coldly". Maximum values of EET at all three meteorological stations in the limits of city fall into the range of "Warmly", minimum - "Sharply coldly".

In Kojori, because of the height of locality, the average annual temperature of air is approximately on 6°C lower than in Tbilisi, relative humidity somewhat higher than at all three stations into Tbilisi, wind speed approximately such, as in Vashlijvari. Accordingly, in Kojori, in contrast to TSU and Vashlijvari, average annual value of EET falls into the range "Coldly". Maximum value of EET in Kojori, in contrast to all stations of Tbilisi, falls into the range "Comfortably".

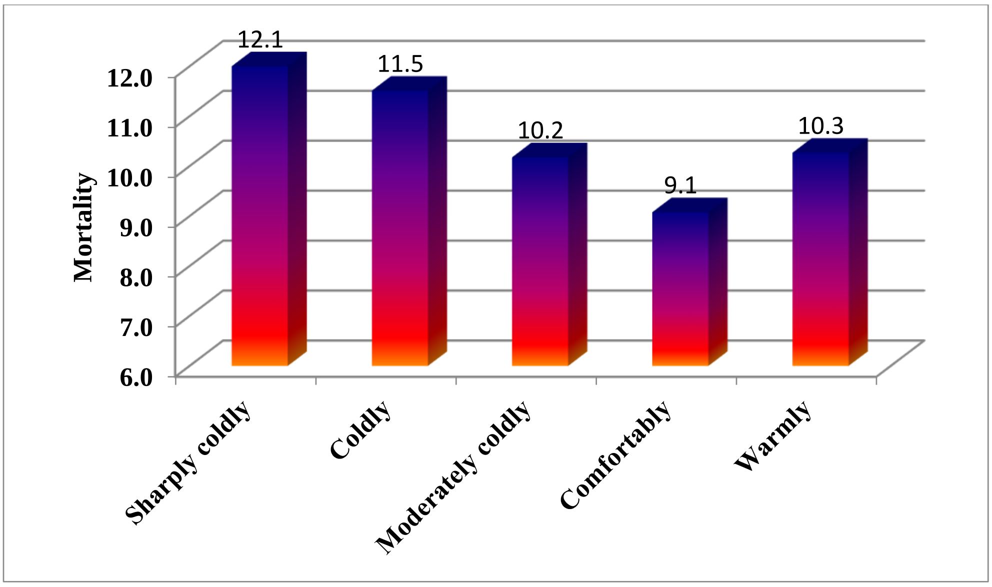

Fig. 1. Mean daily mortality from the cardiovascular diseases in Tbilisi to 1 million inhabitants with different mean daily values of air Equivalent-Effective Temperature in Vashlijvari.

Fig. 1 presents the data about the mean diurnal mortality to one million inhabitants of Tbilisi city with the different values of EET. As it follows from this figure, the smallest mortality is observed with the values of EET in the range "Comfortably" (9.1), greatest - with the values of EET in the range - Sharply coldly" (12.1). With the values of EET in the ranges "Moderately coldly" and "Warmly" the mean diurnal mortality of the population of Tbilisi is approximately identical (10.2 and 10.3 respectively).

Let us note that the dependence of mortality on EET takes the classical form - the decrease of mortality from the gradation "Sharply coldly" to "Comfortably" with further increase to the gradation " Warmly". Thus, the existing scale EET is completely acceptable for the evaluation of the degree of its action on the health of people and on a daily scale.

Table 3

Repetition of daily mean EET Category in 3 locations of Tbilisi and Kojori (%)

EET Category	Sharply Coldly	Coldly	Moderately Coldly	Comfortably	Warmly
Location/EET	<1°C	1-8 °C	9-16 °C	17-22 °C	23-27 °C
Vashlijvari	21.5	22.3	27.2	26.2	2.8
TSU	25.3	19.5	26.0	26.1	3.1
Airport	40.4	15.9	25.1	17.4	1.2
Kojori	45.0	23.0	28.4	3.6	-

Table 3 presents the data about the repetition of categories EET for all investigated points. As follows from this table, the repetition of categories EET in Vashlijvari and TSU approximately is identical. The maximum of repetition falls to the ranges “Moderately Coldly” and “Comfortably”. In the airport and Kojori the maximum of the repetition of categories EET falls to the range “Sharply Coldly”. It should be noted that in Kojori there are no values EET, which fall into the range of the category “Warmly”, with which are observed consequences negative for the health of people.

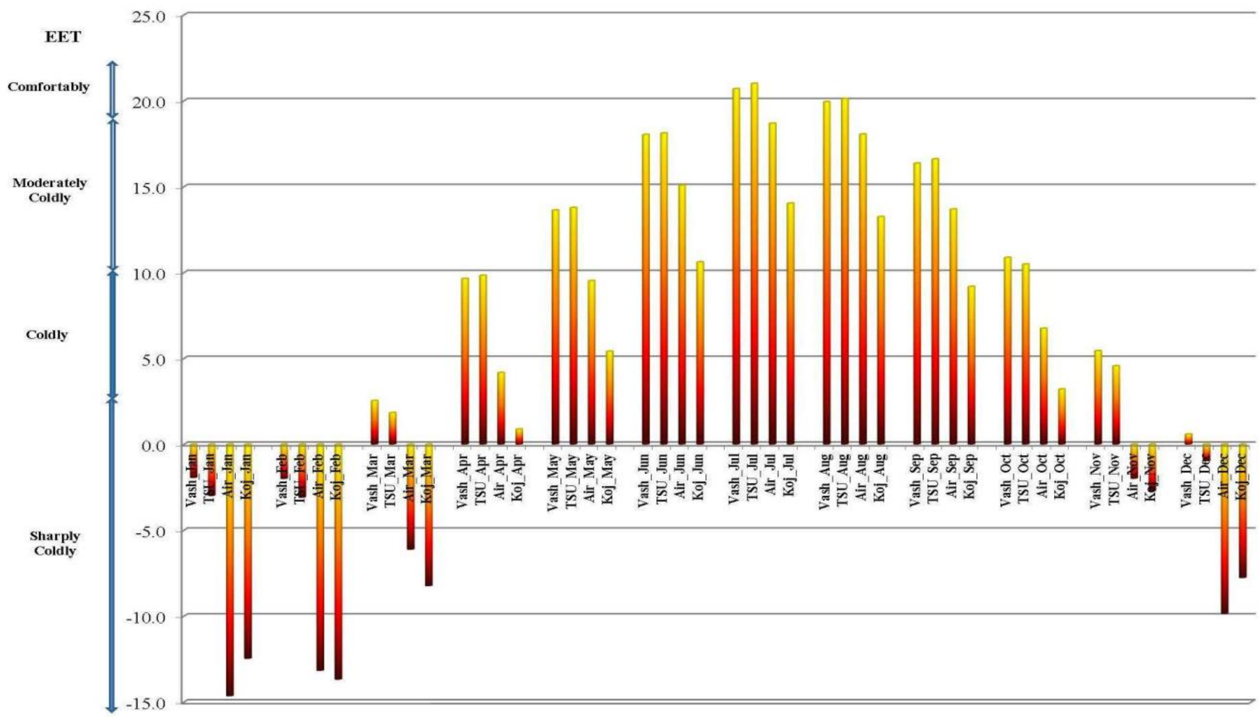

Fig. 2. Mean monthly values of air Equivalent-Effective Temperature in 3 locations of Tbilisi and Kojori.

Finally, Fig. 2 for the clarity depicts the histograms of the intra-annual distribution of average monthly values of EET for all four localities being investigated. As it follows from this figure, from February through December values of EET in Kojori is lower than at all stations in the limits of Tbilisi. Only during January values of EET in Kojori are higher than in the airport.

Conclusion

The detailed study of the bioclimatic resources of Georgia over the visible long term will make it possible to increase substantially attractiveness level of the acting and promising health resort and tourist zones and the objects both for populating of this country and its guests.

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ჰაერის ექვივალენტურ-ეფექტური ტემპერატურის საშუალოდღიური მნიშვნელობების შედარებითი ანალიზი თბილისში და კოჯორში

ქ. ხაზარაძე

რეზიუმე

ჰაერის ექვივალენტურ-ეფექტური ტემპერატურის სკალის. როგორც დროის დღეღამური მასშტაბის ბიოკლიმატური მაჩვენებლის გამოყენების შესაძლებლობის დასადასტურებლად წარმოდგენილია თბილისში ჰაერის ექვივალენტურ-ეფექტური ტემპერატურის საშუალო დღეღამური მნიშვნელობების კავშირი ამ ქალაქში მოსახლეობის გულსისხლძარღვთა დაავადების მიზეზით გამოწვეულ სიკვდილიანობასთან. მიღებულია, რომ ჰაერის ექვივალენტურ-ეფექტური ტემპერატურასთან სიკვდილიანობის კავშირს აქვს კლასიკური ხასიათი - სიკვდილიანობის შემცირება გრადაციიდან „მკვეთრად ცივი“ „კომფორტული“- მდე და შემდგომი ზრდით გრადაციამდე „თბილი“. ამრიგად, ჰაერის ექვივალენტურ-ეფექტური ტემპერატურის არსებული სკალა სავსებით შესაძლებელია გამოყენებულ იქნას მისი ზემოქმედების შესაფასებლად ადამიანების ჯანმრთელობაზე დღეღამურ მასშტაბში.

ჩატარებულია ექვივალენტურ-ეფექტური ტემპერატურის საშუალოდღეღამური მნიშიშვნელობების ფარდობითი ანალიზი თბილისში (3 მეტეოროლოგიური სადგური-ვაშლიჯვარი, თბილისის სახელმწიფო უნივერსიტეტი, თბილისის აეროპორტი) და კოჯორში (სამთო კურორტი თბილისიდან 10 კილომეტრზე). კერძოდ ნაჩვენებია, რომ ექვივალენტურ-ეფექტური ტემპერატურა თბილისის ურბანიზებულ რაიონებში (ვაშლიჯვარი, უნივერსიტეტი) მნიშვნელოვნად განსხვავდება მათი მნიშვნელობისაგან ქალაქის ფარგლებს გარეთ (აეროპორტი,კოჯორი). კოჯორში არ შეინიშნება ადამიანის ჯანმრთელობისათვის ნეგატიური ექვივალენტურ-ეფექტური ტემპერატურის მაღალი მნიშვნელობები, რომლებიც მოქცეულნი არიან დიაპაზონში „თბილი“.

Сравнительные анализ среднесуточных значений эквивалентно-эффективной температуры воздуха в Тбилиси и Коджори

К.Р. Хазарадзе

Резюме

Для подтверждения применимости шкалы эквивалентно-эффективной температуры воздуха (ЕЕТ) как биоклиматического показателя в суточном масштабе времени, представлены результаты изучения связи среднесуточных значений ЕЕТ в Тбилиси со смертностью населения этого города от сердечно-сосудистых заболеваний. Получено, что зависимость смертности от ЕЕТ имеет классический вид - убывание смертности от градации “резко холодно” до “комфортно” с дальнейшим ростом до градации “тепло”. Таким образом, существующая шкала ЕЕТ вполне приемлема для оценки степени ее воздействия на здоровье людей и в суточном масштабе.

Проведен сравнительный анализ среднесуточных значений ЕЕТ в Тбилиси (3 метеорологические станции – Вашлиджвари, Тбилисский государственный университет, Тбилисский аэропорт) и в Коджори (горный курортный поселок в 10 км от центра Тбилиси). В частности показано, что значения ЕЕТ в урбанизированной части города Тбилиси (Вашлиджвари, университет) существенно отличаются от их значений за пределами города (Аэропорт, Коджори); в Коджори не наблюдаются негативные для здоровья людей высокие значения ЕЕТ, попадающие в диапазон “Тепло”.

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Boleslovas Styra. 105 Years from the Birthday. His Role in the Formation, Development and Modern Evolution of Nuclear Meteorology in Georgia

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ABSTRACT

The work is dedicated to the memory of Boleslovas Styra, an outstanding Lithuanian scientist, founder of new direction of atmosphere physics - nuclear meteorology. His role in the formation, development and the modern evolution is noted of this direction of science in Georgia.

Key words: Nuclear meteorology, atmospheric radioactivity.

Boleslovas (Balys) Styra

Date of Birth: *September 9, 1912 - February 12, 1993*
Place of birth: *Leningrad (St. Petersburg)*
Activities: *Habilitated Doctor of Geophysics, Physics and Mathematics, Professor, Corresponding Member of the Lithuanian Academy of Sciences,*
Twice Laureate of the State Premium of Lithuania
Honor: *Memorial Board (Vilnius City, Paneriai Subdistrict / Paneriai)*

Boleslovas (Balys) Styra was born in St. Petersburg (Russia), a family of Lithuanian emigrants. In 1937 graduated from the Faculty of Physics at Leningrad State University (now St. Petersburg State University), worked as a teacher of physics and assistant of the Atmospheric Physics Department at the University.

During the Second World War, he was mobilized and took part in the defense of Leningrad. Worked in the Leningrad Front Hydrometeorological Service Board. In 1944 B. Styra returned to Lithuania. He was appointed director of the Kaunas Geophysical Observatory. In 1946-1963 he worked as a senior researcher at the Institute of Geology and Geography at the Lithuanian Academy of Sciences. He was the head of the Department of Atmospheric Physics of the Institute of Geophysics since 1952. And - Deputy Director for Scientific Work since 1957.

In 1947 he defended doctoral dissertation on physics and mathematics at Kaunas State University. He taught high mathematics at the Lithuanian Academy of Agriculture (now Aleksandras Stulginskis University) in Kaunas in 1947-1957.

In 1947-1964 worked at Vilnius University. In 1953-1960 he was the Meteorology of the Vilnius University, Head of Department of Hydrology and Climatology since 1961. During the reorganization of educational institutions, B. Styra's work and duties were changed several times.

In 1963-1965 he worked at the Botanical Institute (now the Botanical Institute of the Natural Research Center) as Head of Sector, from 1965 to 1967 – in Lithuanian Academy of Sciences (Head of the Department of Applied Nuclear Physics and Radioisotopes Application Bureau), in 1967-1977 - Deputy Director of the Institute of Physics and Mathematics and Head of the Department of Atmospheric Radioactivity, in 1977-1993 - Deputy Director and Head of the Division of the Institute of Physics [1-7].

B. Styra was the editor of the continuing scientific publication "Atmosphere Physics", scientific consultant of the "Lithuanian Soviet Encyclopedia" Since 1973. In 1953 B. Styra was awarded the Docent, in 1964 – was awarded the Professor's name.

In 1965 the researcher has been awarded the title of the honored worker of a science.

In 1976 he was elected as correspondent member of the Lithuanian Academy of Sciences, in 1980 the name of the Lithuanian Nature Conservation Label is given.

In 1983 the literature index "Boleslovas Styra = Болеслав Стыро" prepared by Senior Research Worker Ingos Blažienė, Institute of Labor and Social Research, Vilnius was published [1]. The index was published by the physicist, habilitated doctor of sciences Viktor Luciano in the Lithuanian and Russian languages, presents the main dates of life and activity of B. Styro**,** recorded in 1939-1981. Professor's scientific and scientific publications [http://www.vilnijosvartai.lt/personalijos/boleslovas-styra/].

Scientist died in 1993 February 12. He is buried in the Antakalnis Cemetery in Vilnius. 2007 September 28 in Vilnius, on the building of the Institute of Physics, Savanoriu pr. 231 (Paneriai eldership), commemorating the 95th anniversary of the birth of B. Styras, a memorial plaque unveiled to the scientist [5].

B. Styra's creative heritage consists of about 300 scientific articles. The main areas of scientific work are climatology, atmospheric radioactivity issues, research into radioactive contamination in the atmosphere [8]. He has written monographs "Voprosy yadernoy meteorologii" [9], "Yadernaya meteorologiya" [10], "Samoochishcheniye atmosfery ot radioaktivnykh zagryazneniy" [11]. There were publications of "Radioaktivnost' atmosfery i meteorologiya" [12], "Geophysical problems of krypton-85 in atmosphere" [13], "Izotopy ioda i radiatsionnaya bezopasnost'" [14] (all Russian books). For scientific works B. Styra in 1959 and 1975 the Lithuanian State Premium were awarded [1-7].

B. Styra was the creator of the new direction of atmosphere physics – "nuclear meteorology" [9,10,15-17], that designates number of the problems of the study of the radioactivity of the atmosphere in connection with the meteorological processes, proceeding in it. It notes that artificial radionuclides can be used as the tracers for studying the motion of air masses.

The creation of this direction preceded the significant number of works of B. Styra, his Lithuanian associates and scientists from other countries on a study of the atmosphere radioactivity [8]. It was in particular noted that the atmosphere is the medium, where the process of appearance and of decomposing the radioactive isotopes continuously continues; it was assumed that the air composition is not constant and that its continuous fluctuations – law of the life of the atmosphere; it was indicated that further studies in this direction will lead to the discovery of a new number of reactions and transformations of the air substance in atmosphere. The great attention was paid to the possibility of substantial changes in the composition of atmospheric air under the effect of the space and radioactive radiation. It was indicated the prospect of the using a natural and induced activity of air, as the tracers for studying the dynamics of air masses, atmospheric turbulence, different microphysical and dynamic processes, which take place in clouds and etc. The need for the intensification of studies to discover the role of atmospheric radioactivity of its total ionic balance, in the formation and development of precipitations, etc., was noted.

At the end of June the beginning of July 1960 in Vilnius was conducted the conference on actinometry questions, atmospheric optics and nuclear meteorology, which was called by the institute of geography and geology of Lithuanian academy science together with the radiation subcommittee and the commission atmospheric physics of the Science Soviet Academy, by the administration for the hydrometeorological service of USSR and by the establishments of the ministry of higher education of

USSR. In the work of the section of nuclear meteorology was accepted the participation more than 70 representatives from different scientific organizations. Review on the theme the "Basic Problems of Nuclear Meteorology" was read by B. Styra. It was separately noted in the report, that strongly enlarged studies of radioactive phenomena in the atmosphere give possibility all questions, connected with these phenomena, to isolate into separate independent discipline "Nuclear Meteorology". The basic tasks of this discipline and the possible methods of their solution were designated in the report [15]. Practically, at this conference the term "Nuclear Meteorology" was legally designed.

Studies of the natural radioactivity environment in Georgia have been conducted for a long time. The determination of the content of radioactive elements in the waters of Georgia is conducted since 1912 (mainly the radioactive elements of the uranium series: uranium, radium and radon). At the end of the Thirties of past century these works of the institute geophysics were continued, and was including a study of rock radioactivity, [18-23].

At the end of the Thirties of past century the work was begun in the institute of geophysics on the investigation the rock radioactivity and mineral sources in the territory of Georgia. In this direction was studied the content in them of radium, elements of the group of uranium, its salts and emanations [18-23]. Later, in the Sixties of past century began works, with the active participation of Lithuanian scientists (Styra B., Vebra E., Sopauskas K., etc.), to the direction of nuclear meteorology [24-28]. For the first time in Georgia with the use of a aircraft laboratory were studied the vertical profiles of the short-lived decay products of radon in the lower five-kilometer layer of the atmosphere, the estimations of turbulence factor according to these profiles were carried out. On the basis of the data about the content of the decay products of radon in the drops of clouds were carried out the estimations of the coagulation values coefficient of cloud drops with the solid particles [24-28].

In the seventieth-eightieth years of past century these works were significantly enlarged [29-38]. In this case special attention was given to a study of the natural radioactivity of cumulus clouds, to the determination of different microphysical and dynamic characteristics of clouds according to the data about their natural radioactivity [30-38]. Together with this was studied also the content of nonradioactive aerosols with a diameter of more than 0.7 µm in free-atmosphere conditions and clouds [37,38].

So, in the work [33], aircraft sounding of cumuli clouds in the eastern regions of Georgia during 1973-1977 about 70 vertical distribution profiles of radon decay products α-radioactivity for cloud drops and 50 profiles for the cloud medium were obtained. It was determined that in cumuli in a developed phase there exist 4 types of natural radionuclide vertical distribution. It was established that the accumulation of natural radioactivity takes place mainly in the lower part of the cloud, incidentally the radionuclide accumulation level appears to grow with the cloud power. The radioactivity of cloud drops on the average decreases greatly with height in the lower part of the cloud, and in the middle and upper parts it changes vertically insignificantly. The value of the specific radioactivity of the cloud water in different parts of the cloud varies on the average from $(4.4\pm0.9)\cdot10^{-10}$ up to $(1.2\pm0.2)\cdot10^{-10}$ Ci/g. The parameter of the nonradioactive removal of radioactive aerosols by drops and the effective rate of the vertical air current in cumuli clouds were calculated. Estimation of the radon current through the cloud bottom was performed.

There are presented the results of the investigation natural radioactivity in cumuli at different phases of their development [34]. It has been established that in the process of the development of clouds general accumulation of radioactivity takes place, which in the developed period mounts to the values sometimes exceeding $1\cdot10^{-7}$ Ci/m^2, and subsequently the decrease of the radioactivity is observed. In all the experiments concentration of the radioactive substances decreased with height. After the artificial destruction of the cloud "radioactivity track" still exists for about 20 min with the subsequent dispersion. The estimations of the coefficient of nonradioactive removal of radioactive aerosols and the rates of vertical currents during different phases of clouds have been performed. It was shown that the coefficient of nonradioactive removal of radioactive aerosols is higher in the process of growth and approximately by 30% lower in the period of cloud disintegration.

A nonstationary equation of vertical distribution of natural radioisotope aerosols in cumuli, assuming the constant velocities of up-currents with the absence of the side drawing, is solved [32]. It is presented The equation, describing vertical radioactivity distribution on cloud drops. These equations make it possible to determine the distribution of nonradioactive aerosols in cloud air. The data received show the cloud radioactivity to very sufficiently up to one third of its height and subsequently remaining the same, while nonradioactive aerosol concentration decreases significantly more. Vertical distribution profiles of radioactive and nonradioactive aerosols coincide in general, but nonradioactive aerosols with the run of time accumulate in larger amounts. Aerosol accumulation, at nonradioactive removal coefficient being constant, depends sufficiently upon the velocity of up-currents. Aerosol accumulation grows together with the nonradioactive removal coefficient. The obtained distribution profiles of radioactive and nonradioactive aerosols have analogous character and coincide with the experimental ones within the limits of measuring error.

Under the leadership of B. Styra in institute of geophysics of Georgian academy of sciences two Ph.D. dissertations were defended:

Khundzhua T.G. – Nekotoryye rezul'taty samoletnykh issledovaniy raspredeleniya yestestvennoy radioaktivnosti v nizhney polovine troposfery, (1968)

Amiranashvili A.G. – Issledovaniya yestestvennoy radioaktivnosti kuchevykh oblakov, (1978)

The combined analysis of the aircraft experiments of aerosols in the atmosphere and clouds was carried out in the monograph [38]. In particular, there were given the data about the influence of convective cloudiness on the content of radioactive and nonradioactive aerosols in the atmosphere (table 1). As it follows from this table content of the aerosols of all types in the cloudless atmosphere lower than with the presence of cloudiness. The height of the layer of the atmosphere is 5 km for the radon decay products, and 3 km - for the nonradioactive aerosols.

Table 1

Content of natural radioactive and nonradioactive aerosols in the column of atmospheric air with a single cross-section in cloud days with comparison to the cloudless days (%)

Radon decay products	Calcium	Lead	Aerosols in different ranges of sizes, a radius - μm			Optical measurements of aerosols, a radius - μm	
			0.35÷1.0	1.0÷2.0	>2.0	0.1÷1.0	>1.0
133	104	147	121	113	200	124	193

It was also obtained that the value of the coefficient of nonradioactive removal of radioactive aerosols by cloud drops Λ, the effective upwash velocity of air in the cumulus clouds W, the speed of the flow of radon through the unit of the area of lower cloud base E_r depend on the vertical extent of the clouds H (H from 600 to 1800 m):

$$\Lambda = (9.6 \cdot H - 1) \cdot 10^{-4}\ \text{sec}^{-1}$$
$$W = (0.38 \cdot H - 0.12)\ \text{m/sec}$$
$$E_r = 0.5 \cdot (0.38 \cdot H - 0.12) \cdot 10^{-10}\ \text{Ci/m}^2$$

Besides aircraft studies of the radon decay products in the atmosphere, similar works were conducted both in surface boundary layer [18,39,40] and also in air of karstic caves [18,41-44].

Preliminary studies of radon in the human habitat in different regions in Georgia (habitable and public rooms, Tbilisi subway, etc.) were carried out in 2001-2002 [45-47].

Later there was realized in Georgia the large-scale monitoring of radon in the soil, drinking water and air of apartment houses; were built the maps of the distributions of radon in the indicated media; the connections of the content of radon with the metastasis of lung cancer were revealed; also recommendations were given regarding the protection of population from the dangerous levels of the content of radon. The chemical composition of drinking water simultaneously was studied, were conducted the measurements of the gamma-radiation of soil and walls of the rooms of the houses, content of light ions, meteorological parameters, etc. [48-52]. Traditionally were examined the general problems of radiology [53,54].

Studies of radon not only as the tracer of different atmospheric processes, but of processes, which take place in the earth's crust (prognostication of earthquakes, etc.) and the hydrosphere are carried out [55-64].

Enumerated above works were carried out in the correspondence with the traditional concept of nuclear meteorology (common analyses of the natural radioactivity of environment; the use of radioactive isotopes as the passive tracers of different processes, which take place in the earth's crust, hydrosphere and atmosphere; study of ionizing emissions from the point view of action to the health of people, etc.).

Additionally, to the indicated works, in the recent two decades in the institute of geophysics are conducted studies of the natural ionizing emissions as the active components of the atmosphere, the capable of changing or of modifying its different properties (in our case - microphysical and electrical characteristics of clouds, formation of secondary aerosols, etc.). Push at the beginning of these studies, in particular, were works [65-67]. Thus, there was shown in the work [65] that the freezing point of the radioactive drops of water is higher than nonradioactive; There was revealed in the work [66] the role of radon as the accelerator of the formation of condensation nuclei. Effects of radioactive fallout on increasing of lightning frequency after Chernobil catastrophe studied in [67].

It should be noted that the general prospects for the studies of natural radioactivity as the active component of different processes taking place in the atmosphere, to the author of this work had luck to discuss with B. Styra, who even at the end of the fifties of past century indicated the importance of the similar studies [8].

Thus, here were represented some results of studies of the connection of beta radioactive fallout with the thunderstorm and hail activity of clouds in Georgia [68,69]. In work was study [68] the role of artificial ice forming reagents and radioactive intermixtures in the variation of convective clouds thunderstorm and hail activity. According to Dusheti data mean monthly daytime intensity of thunderstorm discharges is in direct correlation with a thunderstorm day duration and a value of beta-radioactive fall-out, and in inverse correlation with atmosphere aerosol pollution (correlation coefficients are equal to 0,62, 0.5 and -0,54 respectively) [69].

In work [70] it is shown, that under the condition of eastern Georgia radon and tropospheric ozone play important role in the formation of secondary aerosols. In particular, as follows from table 2, value of atmospheric aerosol optical depth (optical active aerosols) is directly connected with the summary content of radon in the five-kilometer layer of atmosphere. The correlation of radon with the large aerosol particles is insignificant (**R** – coefficient of linear correlation, **α** - level of signification).

Table 2

The statistical characteristics of the summary content of radon (**Q_α,**) and aerosols with the diameter more than 0.7 mcm (**Q_a, 10^9 m^{-2}**) in the five-kilometer layer of atmosphere and atmospheric aerosol optical depth (**AOD**). Georgia, Kakheti region, aircraft and ground-based studies 1972-1977, 11 cases [70].

Parameter	Q_a, 10^9 m^{-2}	Q_α, 10^3 Bq m^{-2}	AOD
Mean	4.45	3.68	0.176
St Dev	1.08	1.62	0.046
Min	6.24	6.6	0.222
Max	3.1	1.11	0.042
Correlation Matrix			
Q_a. 10^9 м$^{-2}$	1	No sign	No sign
Q_α. 10^3 Бк м$^{-2}$	0.14	1	α = 0.1
AOD	0.21	R = 0.56	1

A scheme of the interaction of atmospheric aerosols and convective clouds and also generation in the atmosphere and clouds of condensation, crystallization nuclei and ice crystals with allowance to ionization and electrization processes occurring in the atmosphere has been proposed [71-73].

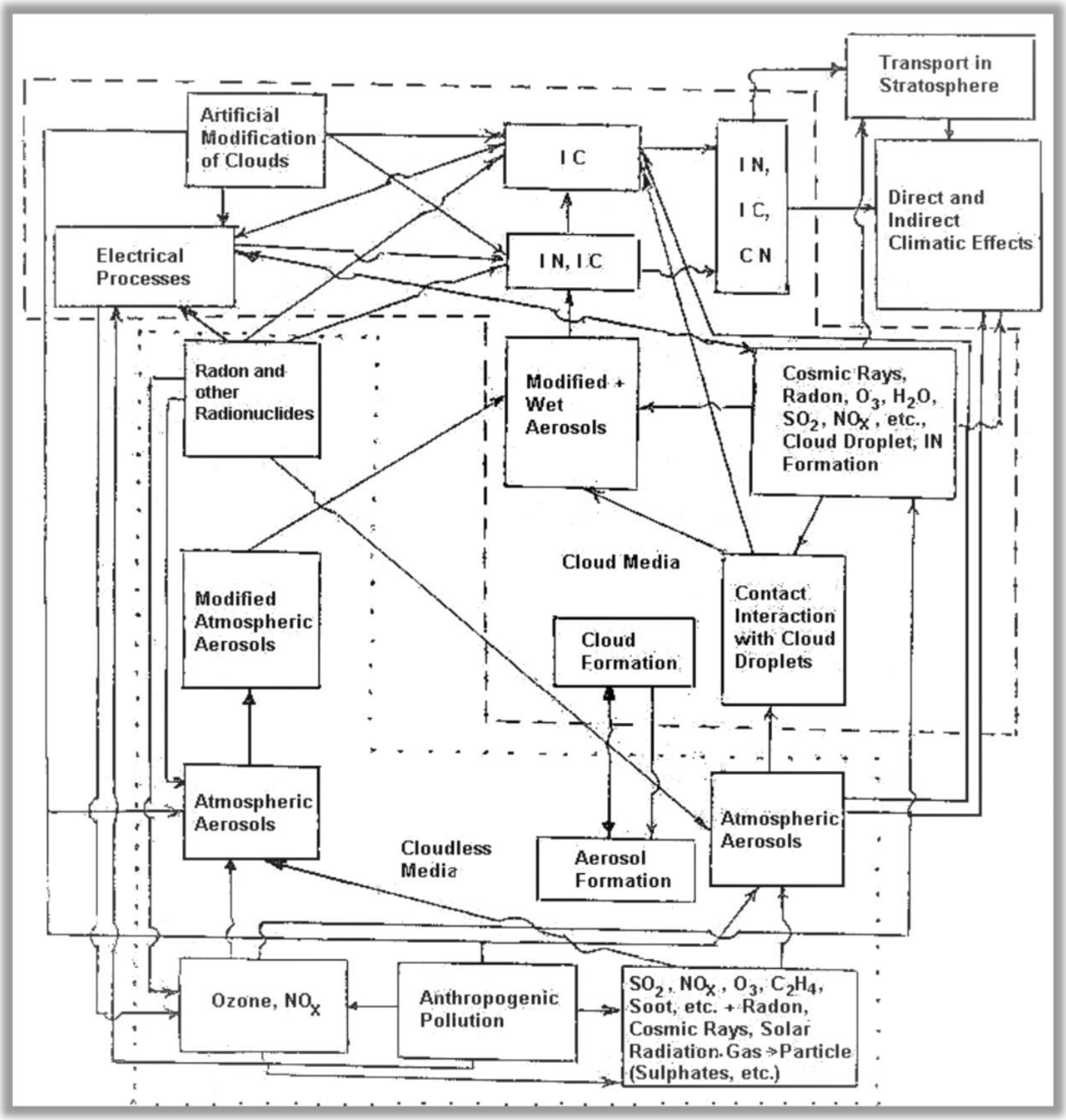

Fig. 1. Scheme of the convective clouds - aerosol interaction and formation of condensation and crystallization nuclei and ice crystals in the atmosphere and clouds. IN - ice nuclei; IC - ice crystals; CN - condensation nuclei

This scheme (fig. 1) shows how versatile the relations between processes in clouds and the clear atmosphere are. On one hand aerosols being modified in the atmosphere and getting into cloud media as a result of being humidified or interacting with cloud droplets conduce the generation of ice crystals. A change in the phase state of the cloud media leads to a change in its electric activity (cloud-to-cloud, intracloud, cloud-to-ground discharges). Discharging activity changes the chemical composition of the cloud media (formation of nitrogen oxides, ozone, etc.). The mentioned gases together with radon, sulphur oxides and other components under conditions of a high humidity and cosmic ionization lead to an intensive generation of condensation nuclei. Condensation of water vapour on these nuclei leads to local oversaturations, activation of inactive aerosols in the interdroplet media and generation of crystallization nuclei and ice crystals, i.e. again to a change in the phase state of the cloud media. At the same time the effect of high ozone concentrations on inactive soil aerosols in the interdroplet media activates them in the sense of the ice formation [38]. Phase transformations and ionization processes lead to changing of the electric activity of a cloud and the cycle repeats anew. Breaking through the troposphere strong vertical air flows can carry into the stratosphere considerable amounts of water vapour, aerosols, ozone, SO_2, NO_x and other admixtures. Thus cumulus, big convective and thunderstorm clouds in addition to direct climatic effects (solar radiation attenuation, precipitation, near-ground temperature changes, etc.) can considerably contribute to variations of the chemical composition of the atmosphere and the content of aerosols in it. The latter also affect radiative forcing and climate change.

In the last ten years was continued the study of the influence of the ionizing radiations (radon, gamma-radiation, cosmic rays) on the formation secondary aerosols in the atmosphere according to scheme gas→ particle. It is obtained that all types of the indicated ionizing radiations are the catalyst of the formation of sub-micron aerosols from the gases [74-84].

The special features of the effect of the radio nuclide emission in the formation of secondary aerosols in the conditions of Tbilisi city (Tbilisi type of smog) are revealed (table 3,4; fig.2,3).

Table 3

Linear correlation between radon content in air and some parameters of atmosphere in Tbilisi in 2009-2011 (daily average from 9 to 18 hour, R_{min} = 0.05, α = 0.07) [80]

T – air temperature; **U** – relative humidity; **P** – atmospheric pressure; **V** – wind speed; **O_3** - surface ozone concentration; **Rn** – radon content in air; **N** – concentration of submicron aerosols with diameter ≥0.1 mcm; **N(+/-)** – sum small ions content in air; **Q** – sum solar radiation intensity; **q** – intensity of galactic cosmic rays.

Parameter	**T**	**U**	**P**	**V**	**O_3**	**N**	**N(+/-)**	**Q**	**q**
Rn	-0.39	0.32	0.29	-0.36	-0.47	**0.43**	**-0.55**	-0.41	0.34

Table 4

Statistical characteristics of gamma-radiation of soil and content in air of radon, sub-micron aerosols and small ions in 20 locations of Tbilisi in 2009-2011 [80]

Parameter	**Gamma-radiation of soil, nSv/hour**	**Radon, Bq/m^3**	**Aerosol, cm^{-3}**	**Sum ions, sm^{-3}**
Average	81.9	6.3	3638	492
Min	53	1.4	750	200
Max	109	16.0	9000	1200
St Dev	10.9	3.0	1928	251
C_v	13.3	47.4	53.0	51.0
	Correlation matrix			
Gamma-radiation	1	0.37	0.24	**-0.15**
Radon	α = 0.05	1	0.70	**-0.51**
Aerosol	α =0.1	α = 0.0005	1	**-0.48**
Sum ions	α = 0.35	α = 0.001	α = 0.001	1

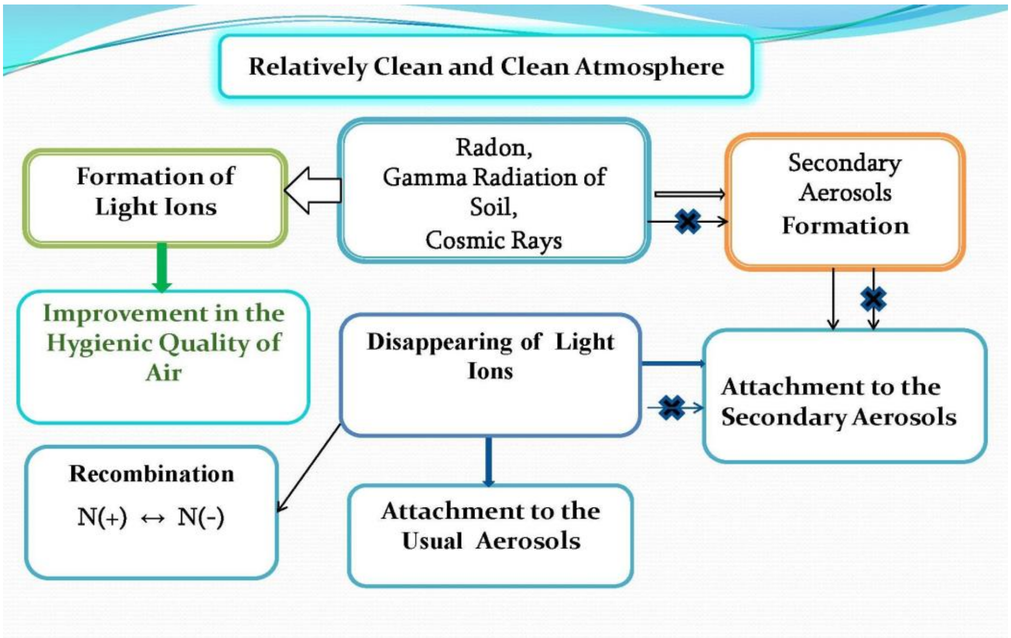

Fig. 2. Formation of secondary aerosols and of small ions in air under the effect of the ionizing radiation in the conditions of relative clean and clean atmosphere

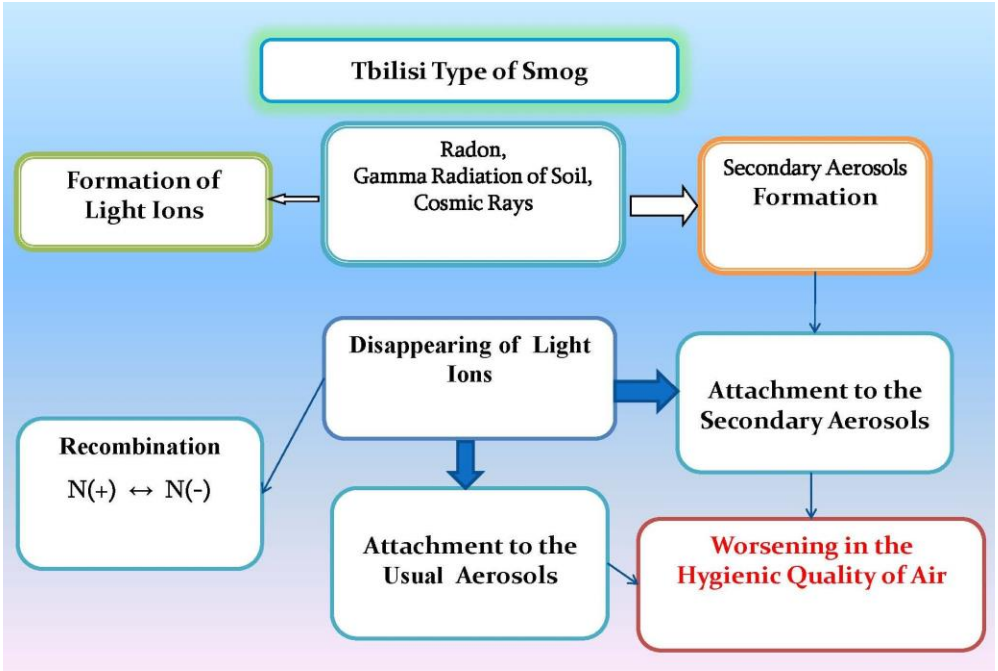

Fig. 3. Formation of secondary aerosols and of small ions in air under the effect of the ionizing radiation in the conditions of the strongly contaminated atmosphere (Tbilisi type of smog)

Intensification by the ionization of the aerosol pollution of the atmosphere under the conditions of Tbilisi is so strong which this leads also to worsening in the quality of air in the aspect of its ionic composition also. As a whole the Tbilisi type of smog is characterized by the impossible under the natural conditions feedback of the content of radon, gamma-radiation and cosmic radiation with the concentration of light ions in air, caused by the formation of secondary aerosols in the quantity, which in conjunction with the usual particles is capable of joining more ions to itself how them it is formed with the ionization [76-84].

The well-known balance equation relating the formation and disappearing of light ions **n,** taking into account the influence of the ionizing radiation on the formation of secondary aerosols, can take the form:

$$\mathbf{dn/dt = g - \alpha' \cdot n^2 - \beta \cdot S \cdot n - \beta' \cdot N(g) \cdot n}$$

where: **g** is the intensity of ion formation, **α′**- recombination coefficient, **S** - usual aerosol concentration, **N(g)** – secondary aerosol concentration as **g** function, **β** and **β′** - coefficient of the capture of light ions by usual and secondary aerosols respectively. Depending on the nature of the connection between **g** and **N(g)** under the conditions of the strongly contaminated atmosphere (similar to Tbilisi) negative correlation between **g** and **n** is completely possible (fig. 2,3). So, Tbilisi type of smog can occur also in other strongly contaminated cities and environments.

In the locked spaces (living quarters, cave, mine, etc.) the high concentrations of radon create direct radiation exposure on the health of people [41-52]. In atmospheric air the direct radiation effects of radon for the health of people are completely insignificant because of their small concentrations.

However, in contaminated air an increase in radon leads to an increase in the content of secondary aerosols and the decrease of the concentration of light ions (i.e., to worsening in the quality of air, table 3,5; fig. 3). In the final - this is negative influences on the health of people (table 5).

Table 5

Linear correlation and multiple linear regression between daily (average from 9 to 18 hour) values of some atmospheric parameters and 24 hours' quantity of calls of fast medical aid (**A**) and the cases of hospitalization (**H**) in Tbilisi into 2009-2010 [80]

$$Y = \mathbf{a \cdot T + b \cdot U + c \cdot P + d \cdot V + e \cdot O_3 + f \cdot Rn + g \cdot N + h \cdot N(+/-) + i \cdot Q + j \cdot q + k}$$

Parameter	T	U	P	V	O_3	Rn	N	N(+/-)	Q	q
I variant	**Correlation matrix** (**R** min = 0.14, **α** = 0.05), 211 cases									
A	-0.48	0.28	0.10	-0.19	-0.12	0.16	0.21	-0.09	-0.40	-0.57
H	-0.03	0.01	-0.17	-0.12	0.16	-0.06	-0.04	-0.17	0.02	-0.19
	For A, (Coefficient of determination R^2=0.579**; α** = 0.01); **For H, (R^2**=0.205**; α** = 0.01**)** Share within the limits of variation scope, %									
A	28.0	0.4	16.4	9.0	7.8	4.3	1.0	11.7	1.3	31.6
H	13.1	1.4	18.0	10.7	18.2	0.7	10.6	19.7	1.7	11.3
II variant	**Correlation matrix** (**R** min = 0.15, **α** = 0.05), 169 cases, $\mathbf{O_3} \geq 20$ mcg/m^3									
A	-0.43	0.20	0.00	-0.07	0.22	-0.05	0.16	0.07	-0.34	-0.63
H	-0.11	0.12	-0.18	-0.13	0.21	-0.09	-0.06	-0.19	-0.06	-0.18
	For A, (R^2=0.617**; α** = 0.01**); For H, (R^2**=0.28**; α** = 0.01**)** Share within the limits of variation scope, %									
A	28.4	13.1	21.9	8.9	12.0	3.5	5.2	7.4	1.3	27.7
H	17.6	12.7	23.0	10.5	15.8	3.0	5.0	22.6	2.5	6.0

In table 5 there are presented data about linear correlation and multiple linear regression between daily values of some atmospheric parameters and 24 hours' quantity of calls of fast medical aid and the cases of hospitalization in Tbilisi [80]. In the upper part of the table (**I variant**) the calculations for all cases of observations are given, in the lower (**II variant**) - with the mean daily concentrations of ozone ≥ 20 mcg/m^3.

In particular, in the first variant the significant correlation between the pairs **Rn - A**, **N - A** and **N(+/-) - H** are observed; in the second variant - between the pairs **N - A** and **N(+/) - H**.

As follows from this table the contribution of variations in the concentration of light ions to the changeability of a quantity of cases of hospitalization is sufficiently essential (20 and 23 % for first and second variants) and commensurate with the contribution of such atmospheric parameters as the air temperature (13 and 18 %), atmospheric pressure (18 and 23 %), surface ozone concentration (18 and 16 %).

The influence of changeability of ion concentration on the quantity of calls fast medical aid is somewhat less (contribution 12 and 7%). The directly contribution of variations in the content in air of radon and secondary aerosols into the changeability of **A** and **H** is considerably lower than ions. Thus, in contaminate air variation of radon content influence on the physiological state of people indirectly, through the variability of the ion concentration.

Recently, work is continuing to study the effect of natural ionizing radiation on climate change and its individual components. For instance, the paper [85] considers the results of the study of the connection between annual variations of intensity of galactic cosmic rays and the changeability of cloudiness and air temperature in 1963-1990 in Tbilisi. The statistical characteristics of the indicated parameters (trends, random component, linear correlations between real and random components, etc.) are studied. In particular, we established that the correlation of the real values of cosmic ray intensity with the real values of total cloudiness is positive, with lower cloudiness – is not significance, with air temperature – is negative. The correlation of the random components of the intensity of cosmic ray intensity with the random components of lower and total cloudiness – are positive, with the air temperature - is negative. Within the variation range the contribution of the studied parameters to air temperature variability is as follows: real values of total cloudiness- 5.0%, random components of lower cloudiness – 1.0%, real values and random components of cosmic ray intensity - 3.0% and 4.1%, respectively.

Boleslovas Styra was in love with his work, was honest, fundamental, always highly valued its colleagues, was responsive and simple in the intercourse with them. His dear expression at the scientific discussions was "A that they will say my wise men? = А что скажут мои мудрецы?", "Let us listen to, that will say my wise men = Послушаем, что скажут мои мудрецы". He brought up a whole cohort of the scientists, with many of whom the author of this work, still being the graduate student of B. Styra, was favored the honor to have direct practical and friendly contacts. His followers possessed the same special attractive charm as B. Styra's itself. Unfortunately, many of them left this peace, bright by them memory. B. Styra was an exemplary family man, he loved guests and was hospitable proprietor, adored his wife Tatiana and son Dmitrijus. His salient qualities always served as an example for the author of this work, which he tries to adhere to this day.

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ბოლესლავ იოსების ძე სტირო. დაბადების 105 წლისთავისათვის. მისი როლი საქართველოს ბირთვული მეტეოროლოგიის ჩამოყალიბებაში, მის განვითარებასა და თანამედროვე ევოლუციაში

ა.ამირანაშვილი

რეზიუმე

ნაშრომი ეძღვნება გამოჩენილ ლიტველ მეცნიერს ბოლესლავ სტიროს, ატმოსფეროს ფიზიკის ახალი მიმართულების - ბირთვული მეტეოროლოგიის დამაარსებელს. აღნიშნულია მისი როლი საქართველოში ამ მიმართულების ჩამოყალიბებაში, მის განვითარებასა და თანამედროვე ევოლუციაში.

Болеслав Иосифович Стыро. К 105-летию со дня рождения. Его роль в становлении, развитии и современной эволюции ядерной метеорологии в Грузии

А.Г. Амиранашвили

Резюме

Работа посвящена памяти выдающегося литовского ученого Болеслава Стыро, основателя нового направления физики атмосферы - ядерной метеорологии. Отмечается его роль в становлении, развитии и современной эволюции этого направления науки в Грузии.

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To the Memories of T. Khurodze (1949-2017)

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ABSTRACT

The biographical information about the scientific worker of N. Muskhelishvili Institute of Computational Mathematics of Georgian Technical University T. Khurodze and the brief survey of scientific works, executed as a result of her long-standing collaboration with the department of atmospheric physics M. Nodia Institute of Geophysics of I. Javakhishvili Tbilisi State University is presented.

Key words: atmospheric processes, hail, ecology, air pollution

T.Khurodze was born 1949 November 2. After completion of secondary school she enters to the division of physics and mathematics of Tbilisi State Pedagogical institute and in 1973 obtains qualification mathematics. In the same year she begins to work in the Computer Center of the Academy of Sciences of Georgia (subsequently the N.Muskhelishvili Institute of Computational Mathematics, and now the N. Muskhelishvili Institute of Computational Mathematics of Georgian Technical University). Already its first works concerned such important and interesting themes, as abounds machine building and technical cybernetics [1,2]. Then it is interested in the application of some concepts and characteristics of cybernetics for the solution of the different problematic problems of the economy [6,8,9].

At the end of the eightieth years of past century T. Khurodze connects its fate with Albert Nodia, colleague of Institute of Geophysics. Not without the influence of the scientific interests of husband, she begins to be occupied by such questions of atmospheric physics as a study of the changeability of number of days with the hail also of their statistical characteristics in Kakheti, also, on entire Georgia in the different time of the year [4,5,7,10-15,17,21,34,35]. This thematic became the basis of its dissertation work "Analysis of the statistic structure of the number of days with the hail into the warm season of year in Georgia", which she presented in the competition of the scientific degree of the candidate of physics and mathematical sciences and successfully protected it in 2005 year.

Besides this direction as a result of long-standing collaboration with the department of physics of atmosphere of M. Nodia Institute of Geophysics of I. Javakhishvili Tbilisi State, T. Khurodze participates also in the studies of electrical conductivity of air and of electric field strength in the atmosphere [16,19,33], studies the possibilities of applying the statistical methods for predicting the lasting changes of air temperature [28-31] and the influence of some astro-meteo-geophysical factors on the health of population [20,22,23], touches on other interesting questions of physics of clouds, aerosols, precipitations, anthropogenic air pollution, etc. [3,24-27,32]. T. Khurodze was a participant in many scientific conferences.

Besides the science, Tamila Khurodze was occupied by pedagogical activity, working as the teacher in Mathematics Public School No 63. For increasing the qualification in this field with the center of pedagogical studies and professional development and in Grigol Robakidze University she studies courses "Reading and letter for the critical thinking" and "Composition and the development of school curriculum".

In spite of the very loaded personal daily graph of life she was very direct and sociable with all. Having outstanding health, for all she was unexpected contingency the break of aneurysm, which happened of it in autumn this year. Intensive medical interference did not unfortunately have a success. It was impossible to save she. T. Khurodze buried in Tbilisi on the Kukia cemetery next to the husband. We all, its associates, that knew and worked next to it, we will always remember this cheerful, always affable woman.

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თ. ხურაძის ხსოვნისათვის (1949-2017)

თ. ბლიაძე

რეზიუმე

მოყვანილია ბიოგრაფიული მონაცემები საქართველოს ტექნიკური უნივერსიტეტის ნ. მუსხელიშვილის სახ. გამოთვლითი მათემატიკის ინსტიტუტის მეცნიერ თანამშრომლის თ. ხუროძის შესახებ და თსუ მ. ნოდიას სახ. გეოფიზიკის ინსტიტუტის ატმოსფეროს ფიზიკის სექტორთან მრავალწლიური თანამშრომლობის შედეგად მისი შრომების მოკლე მიმოხილვა.

ПАМЯТИ Т.В. ХУРОДЗЕ (1949-2017)

Т.Г. Блиадзе

Резюме

Приводятся биографические сведения о научном сотрудникеИнститута вычислительной математики им. Н. Мусхелишвили Грузинского Технического Университета Т. Хуродзе и краткий обзор ее научных работ, выполненных в результате многолетнего сотрудничества с сектором физики атмосферы Института геофизики им. М. Нодиа Тбилисского Государственного Университета им. И. Джавахишвили.

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