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Physical meaning of temperature and evaluation of distribution laws (in the area of the Lake Sevan basin)

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ABSTRACT

Formulation of the problem. In the work, the most general definition of temperature was discussed and presented, the temporal probability distribution of air temperature was analyzed and evaluated. Temperature has no specific definition. Thus it will be difficult to study the nature of any geophysical phenomena, including the characteristics of temperature distribution, without understanding the modern scientific definition and adjustment of temperature.

The aim of the work is to give the most modern reasonable definition of temperature or what the thermometer measures, the answer to which requires a more specific scientific justification, as well as to evaluate the patterns of possible spatiotemporal distribution of air temperature in the territory of Armenia and in the area of the Lake Sevan basin.

Methods. To solve the set tasks, the authors used corresponding research and published works as a theoretical basis in the work. In the work, the average monthly data of actual observations of the temperature of the ground surface air layer and the amount of precipitation of the «Center for Hydrometeorology and Monitoring» SNCO of the Ministry of Environment of the Republic of Armenia were used. It was found that temperature is a quantity characterizing the thermal state and radiation of the terrestrial and celestial bodies and, in general, the environment, which is strongly related to the entropy change of the system; temperature is the main thermodynamic characteristic of thermal equilibrium; the thermodynamic and microscopic concepts of temperature coincide; the temperature-heat (energy) difference becomes known in the sense that a system can have high energy but low temperature.

The authors applied the following research methods in the article: mathematical and statistical, extrapolation, analysis, analogy, correlation, cartographic.

Results. Energy depends on the geometry (dimensions) of the system, but temperature does not. A trend of increasing air temperature is observed in the RA territory, which is also a result of the entropy change of the system. It can change very quickly, depending on the environmental factors in the given area (the growth rate of greenhouse farms, the artificial filling of valleys, which are wave carriers of air flow, the relentless use of green spaces for the purpose of public buildings, and other factors) in the process of disrupting the excessively permissible norms, which are currently separate needs serious research and prevention.

The long-term variability of surface air temperature in the area of the Lake Sevan basin is analyzed. The analysis carried out made it possible to give a quantitative assessment characterizing the climate change in this region over the past 98 years. An analysis of the observational data showed that the trend of climate warming is confirmed by an increase in air temperature both in winter and over a long period of time. The change in surface air temperature occurs at a rate of 0.002 ºC/year to 0.012 ºC/year and is generally 0.008 ºC/year (or 0.08 ºC/10 years) for all analyzed stations. The results obtained confirm the presence of two periods of warming observed in 1927–1970 and 1971–2021. All the results obtained in the course of the work testify to the trend of climate mitigation in the area of the Lake Sevan basin at the end of the 20th - beginning of the 21st century.

Keywords: *temperature, air temperature, thermodynamics, entropy, energy, trend lines, warming, probability distribution.*

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Problem description. It is known that any terrestrial (air, soil) and astrophysical body is characterized by an important scalar physical measure - temperature, which constantly changes periodically / non-periodically in the Cartesian coordinate system / space of calculation, mainly related to periodic fluctuations of the heat flow density reaching the environment. And the role and significance of temperature, as an important indicator of climate change, evaporation, flow formation, formation and elimination of ice phenomena, heat and moisture circulation, occurrence of frosts and droughts, desertification and many other processes is extremely important. On the other hand, the patterns of the possible spatiotemporal distribution of temperature in the context of modern climate changes, which are associated with periodic/non-periodic fluctuations in the frequency of heat flows reaching the environment, should be taken into account in the efficient use and conservation of water resources, including the problems of water consumption by agricultural crops, harvest and yield formation. Therefore, it is difficult to understand the nature of this or that geophysical process and the features of the thermal regime distribution without knowing the modern scientific definition and justification of temperature. In modern science, there are two basic parameters that make it possible to study and accurately assess any natural phenomenon. It is energy and entropy. Let's define the temperature from that point of view.

Surface air temperature is used as one of the main indicators of climate change. As a result, the long-term variability of surface air temperature in the area of the Lake Sevan basin was analyzed in the work.

Taking into account the above, the aim of the work is to give the most modern reasonable definition of temperature or what the thermometer measures, the answer to which requires a more specific scientific justification, as well as to evaluate the patterns of possible spatiotemporal distribution of air temperature in the territory of Armenia and in the area of the Lake Sevan basin.

Material and methodology. In order to solve the presented problems, relevant scientific studies served as a theoretical and informative basis in the work [5, 8, 12, 16-17, 22-23]: The actual data of temperature observations of meteorological stations of «Hydrometeorology and Monitoring Center» of RA Ministry of Environment, climate bulletins and chronicles were used as starting material. Mathematical-statistical, analysis, correlation methods and fundamental laws of modern physics were used in the work.

Results and discussion. As a rule, temperature is the kinetic energy of moving molecules/atoms. Therefore, the increase in energy of the atoms during heating is easy to detect by touching the other end of the iron rod. Under normal conditions (P=1 atmosphere, t=0 °C) the number of gas molecules in 1cm^3 volume (N_L, which is called Loschmid number) is determined by the following equation [4, 15]

$$N_L = \frac{N_A}{V_m} = 2{,}68 \times 10^{19}, \qquad (1)$$

where N_A – is Avogadro's constant ($N_A = 6{,}02214129 \times 10^{19}$), V_m-is 1 mol material volume.

Temperature is a physical quantity that characterizes the amount of heating of bodies, which entered science with the subjective feeling of a person with the concepts of hot and cold [24]. Because of this, the feeling of temperature was subjective and could be misleading. Thus, for example, a metal object in a room appears colder than a wooden object, even though they are in the same conditions of thermodynamic thermal equilibrium. And it is better not to try to determine the temperature of molten metal and liquid nitrogen by touch. That is why the modern problem of a clear definition of temperature as a physical quantity is very important.

First, let's try to answer the question, what is temperature and how can it be scientifically justified? The main heat, whose main characteristic physical parameter is temperature, comes from the Sun. It propagates continuously, in all directions, in the form of an electromagnetic quantum. Therefore, temperature is also characterized in terms of quantum physics. Modern physics can answer this question in two ways: statistical (from the point of view of molecular kinetic theory) and thermodynamic.

1. Definition of temperature from the point of view of molecular kinetic theory. The basic equation of molecular theory for the pressure of an ideal gas can be expressed in the form of the following equation `$P = \frac{2}{3} n \frac{\overline{mv}^2}{2}$. If $\frac{2}{3}\frac{\overline{mv}^2}{2}$ relation assign θ , then the pressure of an ideal gas can be expressed as $P = n\theta$, where θ-is is the temperature of an ideal gas in Joules. Therefore, in order to express the temperature in degrees, a correction factor must be added to θ, which will replace the unit of energy with the unit of temperature. On the other hand, according to molecular kinetic theory, $\frac{\overline{mv}^2}{2} = \frac{3}{2}KT$, where K –is the Boltzmann constant, $\bar{v}^2$- is root mean square velocity, T–is absolute temperature. Since kinetic energy is only positive, temperature measured on the Kelvin scale is also positive (T>0) and is called absolute temperature. Therefore, it turns out that temperature and pressure are determined by the average kinetic energy of thermal motion of molecules, since they are statistical quantities. For example, expressions such as temperature or pressure of one or more molecules are meaningless. It follows from this that it would be more correct to present the temperature in the form of thermodynamic parameters, because it cannot be measured in any way and it makes no sense to talk about the temperature of a single particle.

From the point of view of molecular kinetic theory, it follows from such a definition of temperature that T=0 corresponds to the cessation of thermal motion of molecules, which is impossible from the point of view of quantum physics: when the temperature tends to absolute zero, the average energy of the molecule does not tend to zero, but tends to a certain minimum energy value. Therefore, absolute zero temperature equates to the minimum internal energy of the system.

2. Definition of temperature in terms of distribution of energy levels of molecules/atoms.

According to the Boltzmann distribution law [4, 18].

$$\frac{n}{n_0} = \exp(-E/kT) \qquad (2)$$

where $\frac{n}{n_0}$ ratio is the fraction of molecules/atoms/ whose energy is bigger from kT as E, $k$is Boltzmann's constant [24]: Let's slide the expression (2), we get:

$$\ln\frac{n}{n_0} = -\frac{E}{kT} \text{ or } \ln\frac{n_0}{n} = \frac{E}{kT} \Rightarrow, T = \frac{E}{k\ln\frac{n_0}{n}} \qquad (3)$$

It follows from equation (3) that body temperature is determined by the number of excited molecules or atoms per unit volume. Such a definition of temperature, in contrast to the above, is, in our opinion, relatively simple and somewhat complete.

3. Now let's try to give the general modern formulation of temperature. It turns out that entropy simultaneously satisfies the two properties of temperature listed above [26-27] inverse of the derivative of the internal energy at constant volume (S') [3]: That quantity is called temperature.

$$T = \frac{1}{S'}, \qquad (4)$$

where $S' = \left(\frac{\Delta S}{\Delta U}\right)_{V=const}$, therefore

$$T = \left(\frac{\Delta U}{\Delta S}\right)_{V,N=const} \qquad (5)$$

For any body with a constant volume, as the internal energy increases, the entropy also increases, as a result of which the absolute temperature of all bodies is positive (T>0).

Let us show that the absolute temperature satisfies the two properties defined above.

To prove definition I, consider a closed system consisting of two bodies with physical U_1, S_1, T_1 and U_2, S_2, T_2 (fig. 1). As a result of heat exchange, the internal energy and entropy of each of the bodies will change, so $\Delta U_1 = -\Delta U_2$ and the entropy of the complete system increases.

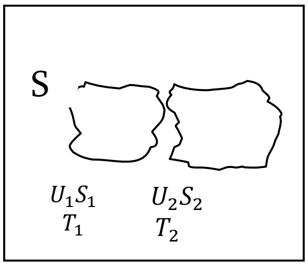

Fig. 1. A closed system with bodies having different physical parameters

$$\Delta S = \Delta S_1 + \Delta S_2 > 0 \qquad (6).$$

From the definition of temperature (see formulas (4) and (5)) it follows that

$$\Delta S_1 = \frac{\Delta U_1}{T_1} \text{ և } \Delta S_2 = \frac{\Delta U_2}{T_2} = -\frac{\Delta U_1}{T_1}, \qquad (7)$$

and

$$\Delta S = \frac{\Delta U_1}{T_1} - \frac{\Delta U_1}{T_2} = \Delta U_1 \left(\frac{T_2 - T_1}{T_1 \cdot T_2}\right): \qquad (8)$$

Since $\Delta S > 0$, then $U_1(T_1 - T_2) > 0$: For example, if the first body has a lower temperature than the second ($T_2 > T_1$), then in the process of heat exchange it will receive, and the second body will give that energy and vice versa, if $T_1 > T_2$, then $\Delta U_1 < 0$, and $\Delta U_2 > 0$, which was required to be proved.

To prove Definition II, consider again a closed system consisting of two bodies. At thermal equilibrium, the entropy of the system remains constant ($\Delta S = 0$) [14]: Putting that value in (8), we get $T_1 = T_2$, which was required to be proved.

Thus, temperature is the **main characteristic of thermal equilibrium**. All other parameters (for example, pressure and volume) may have different (but constant) values in different parts of the system at thermal equilibrium. At constant volume

$$(\Delta U)_{v=const} = Q: \qquad (9)$$

Therefore, it follows from (5) that $Q = T\Delta S$, which is the Clausius formula and is true only for non-closed systems.

The temperature is mainly measured by mercury and alcohol thermometers, whose operation is based on the phenomenon of thermal expansion of liquids. Other properties of bodies that depend on temperature can also be used to measure temperature [2, 13]: Naturally, different types of thermometers are required for different temperature ranges (fig. 2). In the low temperature range, the temperature is measured by the change in the receptivity of paramagnetic salts, in the everyday temperature range by a hydrogen-gas

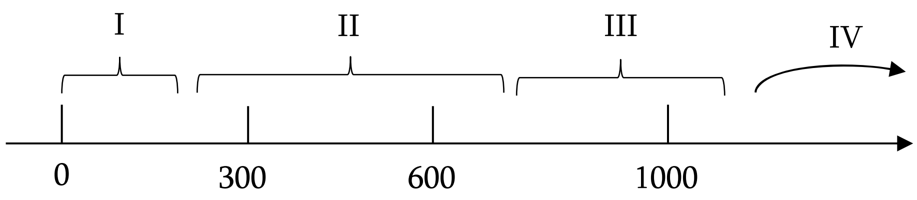

Fig. 2. Different temperature ranges and measurement methods

thermometer, in the temperature range of 600-1000 K by thermocouples (based on the Seebeck phenomenon), in the temperature range above 1000 K by a pyrometer (fire gauge).

So it would be more natural to measure temperature in units of energy (Joules) because it is the kinetic energy of molecules. However, temperature was measured long before the creation of the molecular-kinetic theory. Therefore, in practice, the temperature is expressed in a conventional unit - degree.

Statistics show that not only in our republic [10, 25, 31], but also in different regions of our planet [6, 9, 19, 21, 28-30] and throughout [32] (fig. 3) a trend of increasing air temperature is observed. At the end of the 20th - beginning of the 21st century, the most noticeable climate changes are observed in the Arctic region [7, 24].

Between 1929 and 1996, the average annual temperature in Armenia increased by 0.4 degrees compared to the average of 1961-1990 (standard period), and by 1.23 degrees between 1929 and 2016 (norma: 5.5 °C) [31].

Studies show that Armenia is vulnerable to climate change with its entire mountainous area, despite having little influence on the global climate change process. According to the RCP8.5 scenario of the

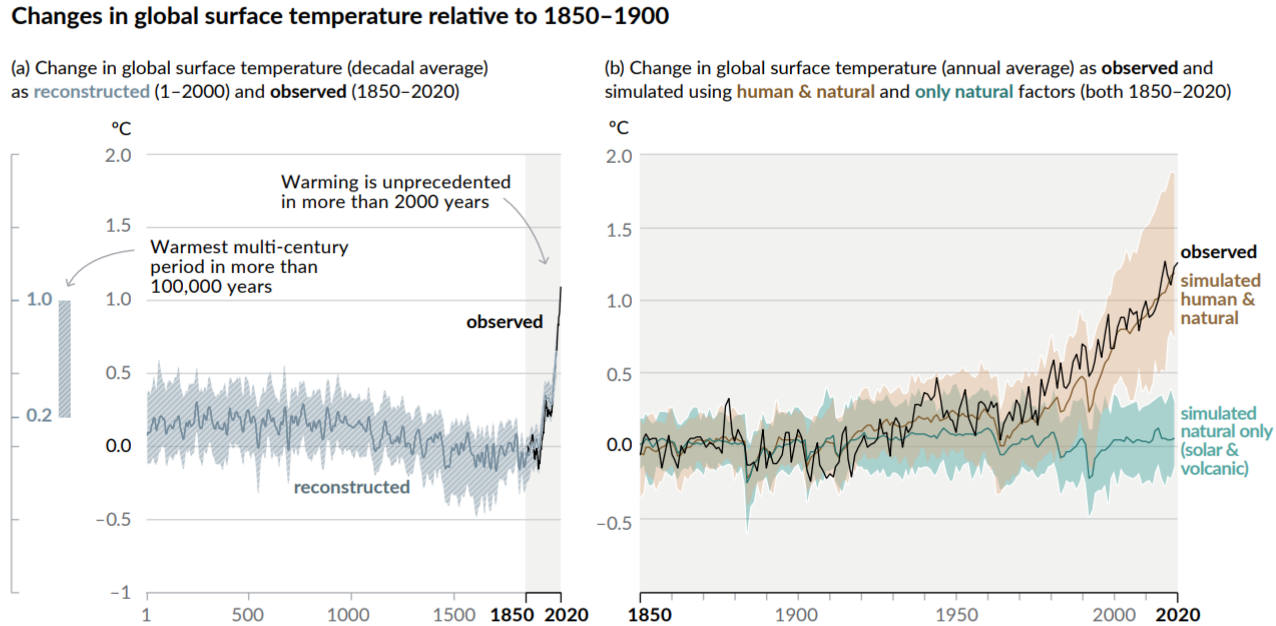

Fig. 3. History of global temperature change and causes of recent warming Panel (a) Changes in global surface temperature reconstructed from paleoclimate archives (solid grey line, years 1–2000) and from direct observations (solid black line, 1850–2020), both relative to 1850–1900 and decadal averaged. The vertical bar on the left shows the estimated temperature (very likely range) during the warmest multi-century period in at least the last 100,000 years, which occurred around 6500 years ago during the current interglacial period (Holocene). The Last Interglacial, around 125,000 years ago, is the next most recent candidate for a period of higher temperature. These past warm periods were caused by slow (multi-millennial) orbital variations. The grey shading with white diagonal lines shows the very likely ranges for the temperature reconstructions. Panel (b) Changes in global surface temperature over the past 170 years (black line) relative to 1850–1900 and annually averaged, compared to Coupled Model Intercomparison Project Phase 6 (CMIP6) climate model simulations (see Box SPM.1) of the temperature response to both human and natural drivers (brown) and to only natural drivers (solar and volcanic activity, green). Solid colored lines show the multi-model average, and colored shades show the very likely range of simulations. (See Figure SPM.2 for the assessed contributions to warming) [32]

METRAS model, the increasing air temperature trends will continue throughout the 21st century in all high-altitude zones of the Republic of Armenia (table 2). Moreover, the greatest increase in the annual average air temperature is predicted in low-lying areas, which decreases according to altitude.

On fig. 4 shows the long-term course of the average winter air temperature, which gives an idea of the nature of fluctuations of this characteristic for the period 1927–2021. for all analyzed stations in the area of the Lake Sevan basin. Thus, the "first" warming falls on the time interval 1927–1970. It should be noted that in this time interval, against the background of a general increase in temperature, short-term periods of temperature decrease ("cooling") are distinguished from 1926/27 to 1934/35, from 1970/71 to 1977/78, from 1987/88 to 1992/93 and from 2003/04 to 2008/09.

Table 1

Forecast values of annual average air temperatures in the highlands of Armenia according to the METRAS model (RCP8.5 scenario) [31]

Altitude zones, m	< 800	800-1000	1000-1500	1500-2000	2000-2500	2500-3000	> 3000	Total area
1961-1990	11,2	10,8	8,4	5,5	3,3	1,6	-0,7	5,5
2011-2040	12,8	12,4	10,0	7,1	4,9	3,2	0,9	7,1
2041-2070	14,5	14,1	11,7	8,8	6,6	4,9	2,6	8,8
2071-2100	15,9	15,5	13,1	10,2	8,0	6,3	4,0	10,2

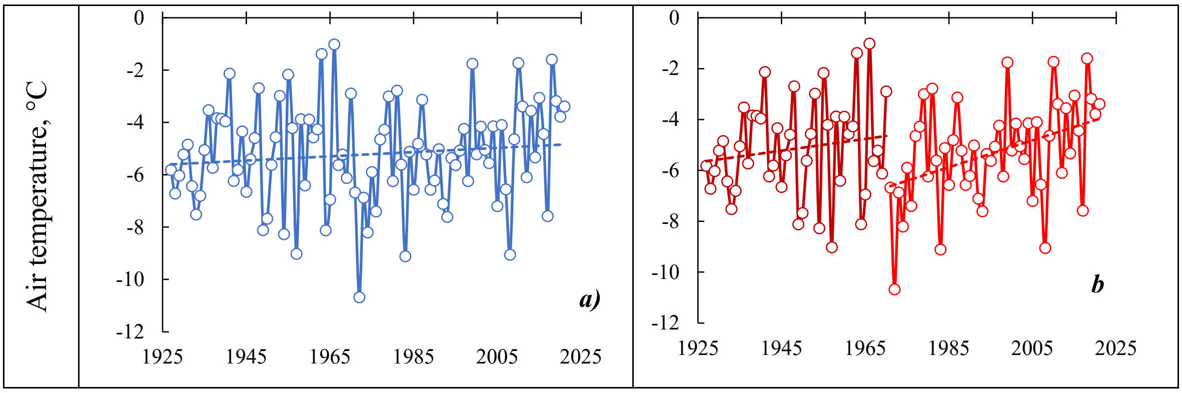

Fig. 4. Long-term course of average winter air temperature (°C) in the area of the Lake Sevan basin for the period from 1926/27 to 2020/21

As a rule, an increase in air temperature during the winter season can play an important role in the formation of winter runoff. As is known, the modern period is characterized by an increase in surface air temperature, which is most pronounced just in the winter period [11].

In the study area, the average air temperature of the winter season is distinguished by an uneven spatial and temporal distribution. Thus, the average air temperature of the winter season ranges from -3.55 (Shorzha) to -7.11 (°C) (Masrik) (table 2). We found a close relationship between the average winter air temperature for the period 1927-2021 and for the period 1927-2070 (fig. 5, a), for the period 1927-2021 and for the period 1971-2021 (fig. 5, b). It can be used to calculate and estimate the average winter air temperature for the period 1927-2021 of unexplored or little-explored areas.

Table 2

Average air temperature (°C) in the winter season in the area of the Lake Sevan basin for the period from 1926/27 to 2020/21

Meteorological station	For the period 1927–1970	For the period 1971–2021	For the period 1927–2021
Semyonovka	-6.23	-6.27	-6.25
Sevan	-4.18	-4.38	-4.29
Shorzha	-3.32	-3.75	-3.55
Gavar	-5.93	-5.88	-5.90
Masrik	-6.93	-7.26	-7.11
Martuni	-4.25	-4.21	-4.23

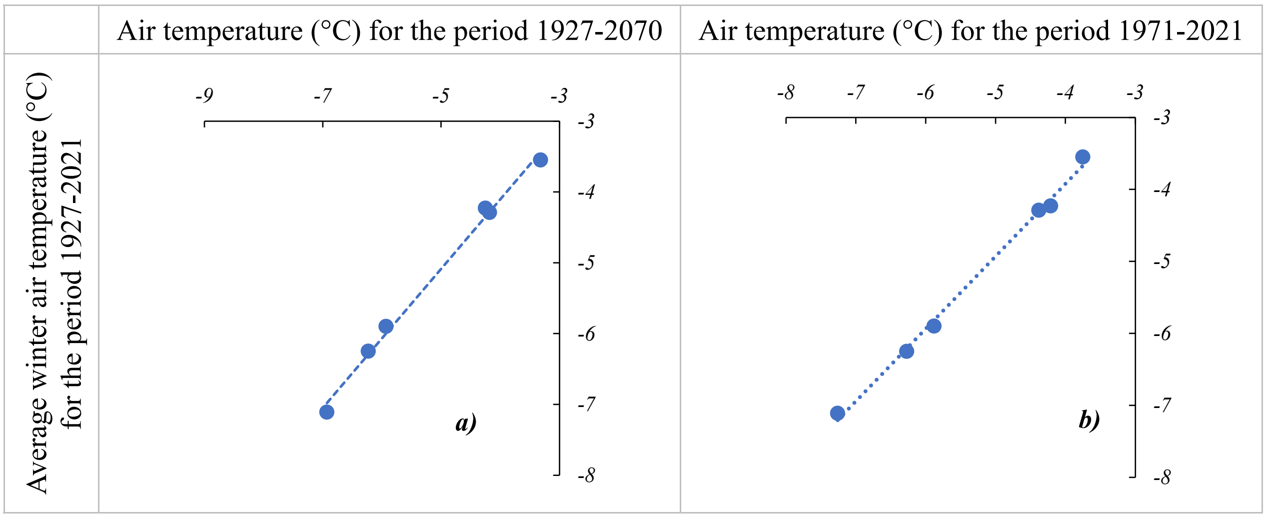

Fig. 5. Regression relationship between the average winter air temperature for the period 1927-2021 and 1927-2070 (*a*), for the period 1927-2021 and 1971-2021(*b*)

The most intensive increase in the average air temperature of the winter season has been observed from 1970 to the present period of time - the «modern» period of warming. In the «modern» period of warming, short-term periods of temperature decrease («cooling») are also observed, but at much lower amplitudes and time scales compared to the period of the "first" warming.

Calculation of the linear trend of the average air temperature of the winter season shows that warming occurs on average for all analyzed stations at a rate of 0.002 ºC/year to 0.012 ºC/year and in general is 0.008 ºC/year (or 0.08 ºC/10 years) (table 3).

Considering the manifestation of warmings for the time intervals 1927–1970 and 1971–2021, it can be argued that during each of the warmings, a more intense increase in air temperature is observed than for the entire analyzed period of 1927–2021.

So, for the «first» warming, the coefficient of the linear trend of the average air temperature of the winter season is on average 0.023 ºC/year, for the «modern» warming - 0.053 ºC/year. Based on the data obtained, it can be concluded that the «modern» warming occurs at a rate significantly higher than the rate of the «first» warming for all analyzed stations (table 3).

Table 3

The magnitude of warming in the area of the Lake Sevan basin for the period from 1966/67 to 2020/21

Meteorological station	**Linear trend coefficient, ºC/year**		
	for the period 1927–70	for the period 1971–2021	for the period 1927–2021
Semyonovka	+0,049	+0,045	+0,011
Sevan	+0,007	+0,062	+0,007
Shorzha	+0,026	+0,050	+0,003
Gavar	+0,040	+0,047	+0,012
Masrik	-0,001	+0,049	+0,002
Martuni	+0.018	+0,065	+0,013

All the results obtained in the course of the work testify to the trend of climate mitigation in the area of the Dvina Bay of the White Sea at the end of the 20th - beginning of the 21st century [9].

In recent decades, there has been a significant change in the global climate, as measured by increases in surface air temperature, extremes, variability and changes in precipitation, etc. Such current and predicted changes in meteorological conditions cannot but affect the river runoff generation [1].

Global mean temperature in 2022 is currently estimated to be 1.15 ± 0.13 °C above the 1850-1900 average. The eight years 2015 to 2022 are likely to be the eight warmest years on record, with 2022 most likely to be 5th or 6th warmest [33].

Such a change in air temperature will have both positive and negative many natural and socio-economic consequences, which require complex and detailed studies. The result of the latter will be the quantum development of effective measures of adaptation to the consequences of temperature changes, the key to the solution of which should be complete and governed by the mathematical predictions of the laws of quantum physics.

Conclusions. Thus, as a result of studies, we have come to the conclusion that:

1) temperature is a quantity characterizing the thermal state and radiation of the terrestrial and celestial bodies and, in general, the environment, which is strongly related to the change in entropy of the system;

2) temperature is the main thermodynamic characteristic of thermal equilibrium; the thermodynamic and microscopic concepts of temperature coincide;

3) the temperature-heat (energy) difference becomes known in the sense that a system can have high energy but low temperature. Energy depends on the geometry (dimensions) of the system, but temperature does not;

4) a trend of increasing air temperature is observed in the RA territory, which is also a result of the entropy change of the system. It can change very quickly, depending on the environmental factors in the given area (the growth rate of greenhouse farms, the artificial filling of valleys, which are wave carriers of air flow, the relentless use of green spaces for the purpose of public buildings, and other factors) in the process of disrupting the excessively permissible norms, which are currently separate needs serious research and prevention;

5) long-term variation of the surface mean air temperature in the winter season in the area of the Lake Sevan basin has a unidirectional character. Thus, the change in surface air temperature occurs at a rate of 0.002 ºC/year to 0.012 ºC/year and in general is 0.008 ºC/year (or 0.08 ºC/10 years) for all analyzed stations;

6) the obtained results confirm the presence of two periods of warming observed in 1927–1970 and 1971–2021. Based on the quantitative estimates of the average annual surface air temperature obtained in the course of the work, it can be argued that the "modern" warming (1971–2021) is more powerful than the "first" warming (1927–1970).

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Фізична сутність температури та оцінка закономірностей розподілу (в басейні озера Севан)

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У роботі подається загальновживане визначення терміну температура, проаналізовано та оцінено часовий розподіл ймовірних показників температури повітря. Визначено, що температура – це величина, що характеризує як тепловий стан системи, так і є мірою енергії, як-то випромінювання земних, небесних тіл. Цей термін пов'язаний з зміною ентропії будь-якої системи, кінетичної енергії, але виступає як головна термодинамічна характеристика стану теплової рівноваги. Розглядаючи поняття температура-випромінювання (енергія), треба враховувати, що система може мати значну енергію, але низьку температуру. Енергія залежить від геометрії (розмірів) системи, а температура – немає такої залежності. Отже, для вивчення особливостей природи будь-яких геофізичних процесів, треба враховувати сучасні наукові розуміння процесу, явища та їх фізичну сутність. На прикладі фактичних даних результатів спостереження, а саме: кліматичних рядів середньої місячної температури повітря «Центру гідрометеорології і моніторингу» ГНКО Міністерства навколишнього середовища Республіки Вірменія, аналізувалися закономірності розподілу температури повітря на території Республіки Вірменія. Встановлена тенденція до зростання температури повітря, що можна розглядати як стан зміни ентропії системи. Вона може швидко змінюватися залежно від екологічних факторів на досліджуваній території (темп росту теплічних господарств, штучне заповнення улоговин, що є хвильовими носіями повітряного потоку, використання зелених насаджень на громадських будівлях та багато інших факторів) під час порушення гранично допустимих норм, що окремо потребує вивчення та заходів профілактики. Проаналізована довгоперіодна мінливість приземної температури повітря в районі басейна озера Севан. Визначена кількісна оцінка зміни клімату в цьому районі за останні 98 років. Аналіз даних вказує на тенденцію до потепління, що характеризується зростанням температури повітря як взимку, так і впродовж багаторічного періоду дослідження. Зміна приземної температури повітря відбувається із швидкістю від 0,002 ºC /рік до 0,012ºC/ рік та в цілому становить 0,008ºC/ рік (або 0,08 ºC/10 років) для всіх досліджуваних станцій. Отримані результати підтверджують наявність двох періодів потепління та вказують на тенденцію пом'якшення клімату в районі басейну озера Севан наприкінці XX – початку XXI століть.

***Ключові слова**: температура, температура повітря, термодинаміка, ентропія, енергія, лінія тренду, потепління, розподіл ймовірності.*

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