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Possible determination of temperature and space-time probable distribution of air temperature in the territory of the Republic of Armenia

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ABSTRACT

Formulation of the problem. Climate studies cover a wide range of issues, from causes to consequences and adaptations to climate change, aimed at collectively addressing environmental protection, conservation, and sustainable use of natural resources within the framework of sustainable development goals (SDGs). Considering that air and soil, like any other terrestrial or astrophysical objects, are characterized by an important scalar physical quantity-temperature, which constantly changes in the Cartesian coordinate system, it is crucial to understand the features of its distribution. It has been established that temperature is considered a physical quantity that characterizes the degree of heat of an object. Given that modern physical studies describe temperature both from a thermodynamic perspective and statistically, according to the molecular-kinetic theory, which characterizes the average kinetic energy of the thermal motion of molecules and is measured on the Kelvin scale. In meteorology in many countries around the world, the temperature of air, soil, and water is typically measured in SI units, specifically in degrees Celsius (°C).

The aim of the work. Analysis and assessment of regularities and features of the spatio-temporal distribution of air temperature for the period 1931-2021.

Methods. The following methods were used in the work: mathematical-statistical, analysis, correlation methods, fundamental laws of modern physics were used in the work.

Results. 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 initial data sources. 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. In the territory of the Republic of Armenia, a trend of increasing air temperature is observed, which is also a result of the entropy change of the system. It can be changed very quickly, depending on the process of disruption of excessive permissible norms of environmental factors in the given area, which currently needs separate serious research. The tendency to increase temperature indicators can be considered as the result of a change in the entropy of the system. This trend can change rapidly depending on the influence of excessive environmental factors in a certain area, which requires a separate and thorough study.

Keywords*: temperature, temperature scale-bar, air temperature, thermodynamics, entropy, warming, space-time distribution, the Sustainable Development Goals (SDGs), Armenia.*

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Problem description. Climate studies today attract the attention of researchers, government officials, and civil society organizations. They cover a wide range of issues from the causes to the consequences of climate change, aimed at joint solutions to environmental protection, conservation, and sustainable use of natural resources within the framework of achieving sustainable development goals (SDGs) [6].

Human activity is identified as the main factor in climate change and its negative consequences. Understanding this is key to the necessity of environmental protection, conservation, and the sustainable use of resources.

Air and soil, as well as any other terrestrial and astrophysical body, is characterized by an important scalar physical quantity - temperature, which is constantly changing in the Cartesian coordinate system of calculation. Thus, the air temperature near the Earth's surface varies from 58.1 °C (tropical deserts) to -88.3 °C (Antarctica), and depending on the height, it usually decreases to 10-17 km, then increases to Heights of 50-55 km and then decreases again and so on [2, 7-9].

As a rule, temperature is the kinetic energy of moving atoms or molecules. 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 1cm3 volume (N_L, which is called Loschmid's number) is determined by the following equation [1, 3-4].

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

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

The role and importance of temperature as an indicator of climate change is extremely important in evaporation, flow formation, melting and elimination of ice phenomena, thermal and moisture circulation, occurrence of frosts and droughts, desertification and many other processes [7-8, 13, 22-24]. 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 and non-periodic fluctuations in the density 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 of agricultural crops, crop and yield formation within the solution.

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 [4]. Because of this, the feeling of temperature was subjective and could be misleading. So, 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.

Taking into account the above, the aim of the work is to give the most modern and reasonable definition of temperature, as well as to evaluate the patterns of possible spatiotemporal distribution of air temperature in the territory of Armenia.

Material and methods. In order to solve the presented problems, the relevant scientific studies served as a theoretical and informative basis [1, 17-18]. 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 initial data sources [5].

Mathematical-statistical, analysis, correlation methods, fundamental laws of modern physics were used in the work.

Results and discussion. First, let's try to answer the question, what is temperature? Modern physics can answer this question in two ways: statistical (from the point of view of molecular kinetic theory) and thermodynamic.

a) 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 following form `$P = \frac{2}{3} n \frac{\overline{mv}^2}{2}$ [4,5]. If $\frac{2}{3}\frac{\overline{mv}^2}{2}$ relation express by θ , then the pressure of an ideal gas can be expressed as P= $n\theta$, where θ is the ideal gas temperature 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 the molecular kinetic theory is $\frac{\overline{mv}^2}{2} = \frac{3}{2} KT$, where K is Boltzmann's constant,$\bar{v}^2$is the root-mean-square velocity and T is the 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 for 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 the thermal movement 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.

b) Definition of temperature in terms of distribution of energy levels of molecules (atoms). According to the Boltzmann distribution law [1, 3].

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

where $\frac{n}{n_0}$ ratio is the fraction of molecules or atoms whose energy is greater from kT by E, k-is Boltzman constant. The logarithm of (2) expression is:

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

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.

c) Now let's try to give the general modern formulation of temperature. It turns out that the two properties of temperature listed above are simultaneously satisfied by the inverse of the derivative of entropy with respect to internal energy at constant volume (S'): That quantity is called temperature.

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

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

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

For any body at constant volume, as the internal energy increases, 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- $U_1, S_{1,}T_1$ Ա $U_{2,}S_{2,}T_2$ physical parameters. 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.

$$\Delta S=\Delta S_1+\Delta S_2>0 \quad (6):$$

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

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

and

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

As $\Delta S>0$, 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 ($\Delta S=0$). 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

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

therefore from (5) it follows that Q=TΔS, which is the Clausius formula and is true only for non-closed systems.

The temperature is mainly measured with 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]. Since temperature is the kinetic energy of molecules, it would be more natural to measure it in units of energy (Joules). 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. In meteorology, air, soil, and water temperatures are commonly measured in units of SI (i.e., degrees Celsius (°C)) in many countries of the world. As already mentioned, before the invention of the thermometer, people judged heat only by their immediate feelings: whether it is warm or breezy, hot or cold.

To measure the temperature in 1592 Galileo made a thermoscope. It was a glass sphere connected to a tube that was in water. And the first practical thermometer (alcohol in 1709, mercury in 1714) was made by the German physicist and glassmaker Farenheit in Amsterdam. He marked three points on the scale: 32 °F (the freezing point of hydrochloric acid), 96 °F (the temperature of the human body), and 212 °F (the boiling point of water). According to that scale, 0 °C corresponds to 32 °F, 100 °C to 212 °F, that is, 100 °C on the Celsius scale corresponds to 180 °F, 1 °F = 100/180 °C= 5/9 °C, 1 °C=9/5 °F. Until the 70s of the 20th century, this scale was used mainly in English-speaking countries, and in the United States until now.

Celsius scale thermometers are widely used in the world. In 1742 Swedish physicist and astronomer A. Celsius introduced the 100 °C temperature scale, where zero degrees (0 °C) is the temperature of melting ice, and one hundred degrees (100 °C) is the temperature of boiling water. Degree Celsius (°C) is accepted as a unit of temperature on the Celsius scale. The relationship between Fahrenheit (t_F) and Celsius (t) temperatures can be expressed by the following equation (table 1):

$$t_F=32+\frac{9}{5}t, \text{ or } t=\frac{5}{9}(t_F-32): \quad (10)$$

In addition to the Celsius scale, the Kelvin scale (absolute or thermodynamic temperature scale) is also widely used. According to this scale, the calculation starts at absolute zero, which corresponds

Table 1

The relationship between temperatures expressed on different scales [2]

Name of scale-bar	The relationship between other and Celsius temperatures	The relationship between Celsius and other scale temperatures
Fahrenheit (°F)	[°F] = [°C] × 9⁄5 + 32	[°C] = ([°F] − 32) × 5⁄9
Kelvin (Ч)	[Î] = [°C] + 273,15	[°C] = [Î] − 273,15
Renkin (°R)	[°R] = ([°C] + 273,15) × 9⁄5	[°C] = ([°R] − 491,67) × 5⁄9
Delil (°De)	[°De] = (100 − [°C]) × 3⁄2	[°C] = 100 − [°De] × 2⁄3
Newton (°N)	[°N] = [°C] × 33⁄100	[°C] = [°N] × 100⁄33
Reomur (°Ré)	[°Ré] = [°C] × 4⁄5	[°C] = [°Ré] × 5⁄4
Romer (°Rø)	[°Rø] = [°C] × 21⁄40 + 7,5	[°C] = ([°Rø] − 7,5) × 40⁄21

to the complete cessation of thermal motion of molecules, that is, it is the lowest possible temperature. On the Celsius scale, it corresponds to -273.15 °C (in practice, it is accepted as -273 °C). In honor of the English physicist Kelvin, Kelvin (K) is accepted as a temperature unit on that scale: 1K = 1°C. On the Kelvin scale (absolute) temperature can only be positive (above absolute 0). The relationship between temperatures expressed in Kelvin (T) and Celsius (t) scales can be expressed by the following equation (ref. 1):

$$T = 273{,}15 + t \text{ or } T = 273{,}15(1 + \alpha t), \quad (11)$$

where $\alpha$is the volume expansion coefficient of air: $\alpha = 1/273{,}15 \approx 0{,}00366\ K^{-1}$:

In the 18th century, a scale of 150 degrees was used in Russia, which was prepared by O.N. By Delilah. Later, until 1920 it was replaced by the French Reaumur and then the Celsus scales. In 1730, the French scientist Rene Antoine Reomure suggested using a scale of 0 to 80 degrees, which is not currently used. On that scale, the unit of temperature is the degree Rheomure (°Ré): 1°Ré = 1,25 °C.

A highly accurate, efficient and sensitive inductive method of temperature measurement is also proposed to measure temperature.

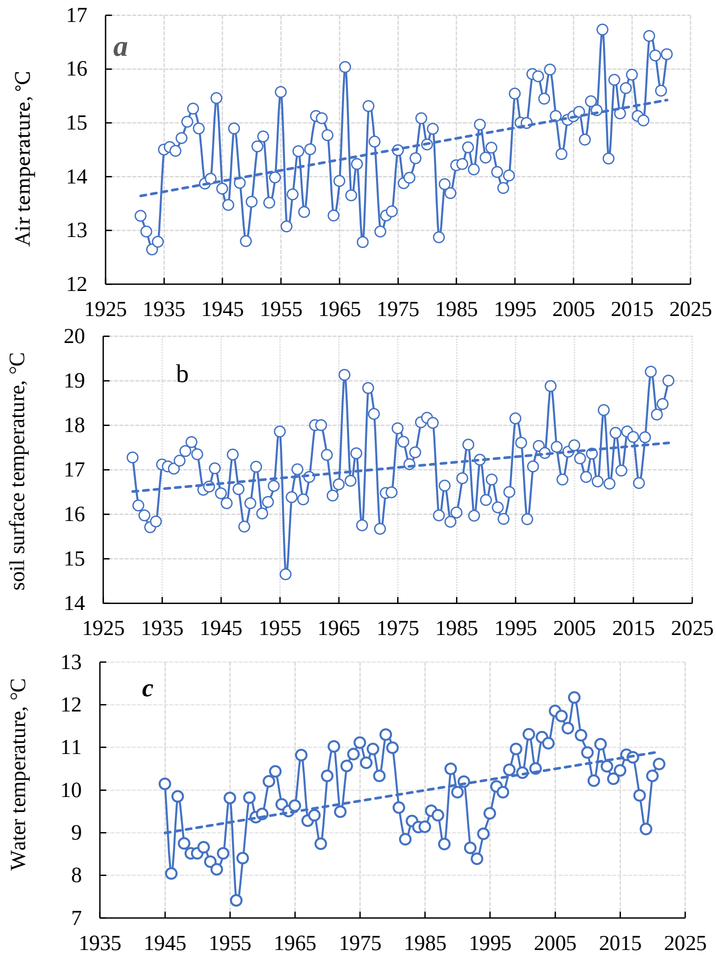

Fig. 1. Dynamics of annual average values of air (a), soil surface (b) and water temperature. Meghri meteorological station, r. Meghriget – p. Meghri

The Celsius and Fahrenheit scales used in everyday life are not absolute. Therefore, they are not suitable for use in certain conditions where the temperature drops below the freezing point of water and it is necessary to express it as a negative number. In that case, absolute temperature scales, Kelvin and Rankine, are used. The start of the count for both is zero. However, if 1 K = 1°C, then 1°R = 1°F.

Statistics show that, not only in our republic [10-12], but also in different regions of the planet Earth [7, 13, 16, 20-22] there is a tendency of the air temperature to increase significantly. Fig. 1 shows as an example the multi-year change of annual average values of air (a) and soil surface (b) temperature with the example of Meghri meteorological station. The absolute maximum temperature of our republic was recorded in Meghri, which was 43,7 °C and was observed in 2011. on July 31. During the entire period of its operation (1931-2021), annual air temperature increase of about 1,78 °C was observed in Meghri. An increasing trend is also observed in the water level of the Meghri River (c).

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

Conclusions. Based on the results of the work performed, the following conclusions can be drawn.

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. Energy depends on the geometry (dimensions) of the system, but temperature does not.

In the territory of the Republic of Armenia, a trend of increasing air temperature is observed, which is also a result of the entropy change of the system. It can be changed very quickly, depending on the process of disruption of excessive permissible norms of environmental factors in the given area, which currently needs separate serious research.

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Можливе визначення температури та ймовірного просторово-часового розподілу температури повітря на території Республіки Вірменія

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Враховуючи, що температурні показники відіграють важливу роль як індикатор кліматичних змін, впливають на процеси випаровування, танення льодовиків, формування різних атмосферних явищ, як-то: посух, опустелювання, наводнень тощо. Кліматичні дослідження висвітлюють широкий спектр питань від причин до наслідків та адаптацій до змін клімату, що спрямовані на спільні вирішення проблем захисту довкілля, охорони, раціонального використання природних ресурсів в рамках реалізації цілей сталого розвитку (SDGs). Для ефективного використання та збереження водних ресурсів, при вирішенні питань водоспоживання сільськогосподарськими культурами, формування та підвищення врожаю доцільно враховувати закономірності можливого просторово-часового розподілу температурних показників, пов'язаних як з періодичними, так і неперіодичними коливаннями щільності теплових потоків, що впливають на природне середовище. У роботі розглядається температура як фізична величина, що характеризує ступінь нагрівання тіла. Сучасні фізичні дослідження описують температуру як з термодинамічної точки зору, так і статистичної, відповідно до молекулярно-кінетичної теорії, що характеризує середню кінетичну енергію теплового руху молекул та вимірюється за шкалою Кельвіна. У метеорології багатьох країн світу температура повітря, ґрунту та води зазвичай вимірюється в одиницях СІ, а саме в градусах Цельсія (°C). Використовуючи дані рядів спостережень за температурою повітря та ґрунту на метеостанції Мегрі «Центру гідрометеорології і моніторингу» ГНКО Міністерства навколишнього середовища Республіки Вірменія, аналізувалися закономірності та особливості просторово-часового розподілу температури повітря за період 1931-2021 рр. Встановлена тенденція до зростання температури повітря на досліджуваній території. Так, на прикладі метеостанції Мегрі визначено абсолютний максимум температури повітря 31 липня 2011 року, що становив 43,7 °C. За весь період спостереження фіксувалося річне підвищення температури повітря приблизно на 1,78 °C. Крім того, відзначається тенденція до зростання рівня води в річці Мегрі. Тенденцію до підвищення температурних показників можна розглядати як результат зміни ентропії системи. Ця тенденція може швидко змінюватися в залежності від впливу надмірних екологічних факторів на певній території, що вимагає окремого та ґрунтовного дослідження. Отже, зміна температурних показників призводить до виникнення численних як позитивних, так і негативних природних, соціально-економічних наслідків, які вимагають всебічного та глибокого дослідження.

***Ключові слова**: температура, температурна шкала, температура повітря, термодинаміка, ентропія, потепління, просторово-часовий розподіл, цілі сталого розвитку (ЦСР), Республіка Вірменія.*

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