Special Issue: "Fundamental and Applied Aspects of Geology, Geophysics and Geoecology"

Investigation of the Cyclicity and Trend of the Surface Air Temperature According to the Weather Station Mayak of Sukhum

I. S. Afanasyev[1,2], **L. V. Khintuba**[3,4], **Y. A. Ekba**[3,4], **R. G. Zakinyan**[1,2]

[1]North Caucasus Federal University, Stavropol, Russia
[2]North Caucasus Center for Mathematical Research, Stavropol, Russia
[3]Institute of Ecology of the Academy of Sciences of Abkhazia, Sukhum, Abkhazia
[4]Abkhaz State University, Sukhum, Abkhazia
* **Correspondence to:** I. S. Afanasyev, afanasevigor278@gmail.com

Abstract: This paper analyzes the surface air temperature data for the city of Sukhum for the period 1961–2022. These values are presented as time series of average annual temperatures. As a result, we get 2 main components: trend, spectrum (including cycles). In general, the average annual temperature has a predominantly positive trend, i. e. over the entire period the temperature has increased by 1.31 degrees, which may occur against the background of global warming. Accordingly, another task of the current work was to identify cyclic components and determine their physical nature. A quasi-two-year, 5–6-year, solar activity cycle and a multi-year cycle (2–3 decades) are observed.

Keywords: surface air temperature, time series, trend, moving average, average annual temperature, cycles, solar activity, spectral analysis.

Citation: Afanasyev I. S., Khintuba L. V., Ekba Y. A., Zakinyan R. G. (2023), Investigation of the Cyclicity and Trend of the Surface Air Temperature According to the Weather Station Mayak of Sukhum, *Russian Journal of Earth Sciences*, Vol. 23, ES0204, https://doi.org/10.2205/2023ES02SI04

Research Article

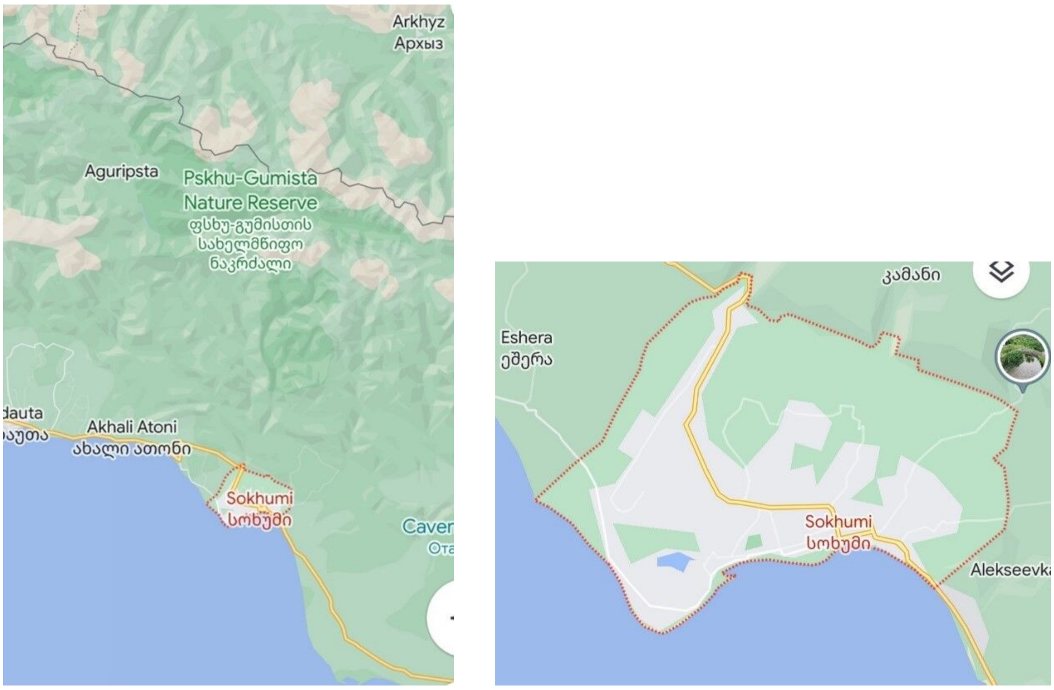
Received: 20 October 2023
Accepted: 27 November 2023
Published: 15 December 2023

One of the most important environmental factors determining the state of the biosphere is the climate, which has a significant impact on human activity, agriculture, the economy and the environment as a whole [*Ekba et al.*, 2020]. The climate changes occurring in the last century are subject to the most attention, a significant increase in the average global air temperature at the earth's surface by 0.5 °C / 100 years has been recorded. There is an increase in the negative impact of natural phenomena on the economic and social life of the world community. Total losses in the world directly related to natural disasters have increased 40 times since the 1960s and amount to an average of hundreds of billions of US dollars per year [*Khintuba and Ekba*, 2018].

In our work, we analyze the surface air temperature data for the city of Sukhum for the period 1961–2022. The time series (TS) is investigated in order to assess the dynamics of changes in atmospheric air temperature by decomposing TS into trend and cycles. The trend is found by smoothing, i. e. a moving average is obtained [*Kendall and Stuart*, 1976].

Sukhum is located in the central part of the Republic of Abkhazia and is located 107 km from the border with Russia on the Black Sea coast (Figure 1). There are 3 rivers on the territory of Sukhum: Basla, Sukhumka and Kyalasur, the latter is the border of the city in the south.

The climate in Sukhum is humid subtropical. Average annual temperature: +14.8 °C, sea water warms up to +28–30 °C. Winters in Sukhum are warm and mild: from +8 °C to +14 °C, summers are hot and humid: from +24 °C to +30 °C.



(a) **(b)**

Figure 1. Sukhum on the map (at different scales).

The lighthouse (Mayak station) is located on a sandy promontory washed by the Gumista River (Figure 2). The height of the lighthouse is 37 m, the lighting horizon is 24 km. The lighthouse overlooks the cities of New Athos and Sukhum.

According to Ya. A. Ekba and R. S. Dbar, the long-term variability of the average annual temperature of sea water in the water area of Sukhum is in the range of 15.2–17.6 °C [*Akhsalba et al.*, 2013]. With a general positive trend in the temperature of the upper horizon of the sea, amounting to 0.4–0.5 °C / 100 years, from the beginning of the XX century until the 90s. it decreased. Since 1994, the water temperature has been rising synchronously with the increase in air temperature, and in recent decades the temperature of the upper horizon of the Sukhumi water area has increased by 1.1 °C.

In this paper, we consider the time series of air temperature for the Mayak station in Sukhum, which also has a positive trend, although there are some temporary temperature drops over several decades, as well as for the temperature of seawater.

Using both a simple moving average and an exponential one allows for the most detailed analysis of temperature time series. For example, a simple moving average over 10 years makes it possible to estimate the temperature change on average for each cycle of solar activity, trace the temperature trend and identify cycles with periods of several decades [*Melnikova et al.*, 2020].

As a result, we get a graph that can be represented as sets of polynomials. Let's start by considering the trend line, making a simple smoothing, and only then we will select the degrees of the polynomials. When smoothing, a moving average of 10 and 30 years was given.

The final trend line is not growing monotonously. It grows and falls. The presence of highs and lows suggests the existence of fluctuations, the frequency of which is 30–40 years. In Figure 3, the picture of global warming is not so obvious, but the value of the moving average temperature has increased.

Figure 4 shows a moving average and a linear trend, where the following peak values of the simple moving average temperature (10 years) are visible: +14.52 °C (1970 y.), +13.95 °C (1994 y.), +16.25 °C (2010 y.), +15.73 °C (2020 y.), with the most pronounced the growth was up to 1994–2010 (by 2.3 degrees, from +13.95 °C to +16.25 °C. Over the entire

Figure 2. Mayak station in Sukhum on the map.

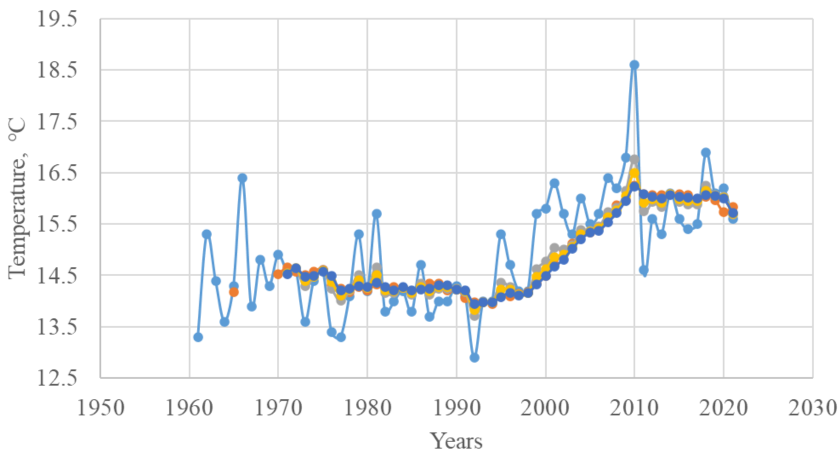


Figure 3. Average annual temperature and moving average for 10 years.

period, the temperature increased by 1.31 degrees, i. e. the areas of growth of the trend temperature were more pronounced than its fall.

After deducting a simple moving average and a linear trend, we do get some long–period fluctuations (with a period of about 30 years), the highs in 1970 and 2010, the minimum in 1994 (Figure 5).

To get rid of long-period fluctuations, we will find a moving average for 30 years. This will also make it possible to determine the change in the climatic norm, compare its characteristics for 1961–1990 and 1991–2020.

From Figure 6 it can be seen that the moving average has predominantly positive dynamics, growing smoothly. The climatic norm also increased by 1.31 degrees, and this was most pronounced in the new century. Accordingly, the talk about global warming is not groundless. This issue has become particularly acute in recent decades. Since 1900, the average temperature of the surface layer of air has increased by about 0.8° (1.4° F), and most of the temperature increase occurred in the period from the mid-70s of the twentieth century up to the present time [*Afanasyev et al.*, 2022]. It is generally believed that the problem of global warming is related to anthropogenic impact (i. e. human emissions into the air), while referring to the fact that the concentration of greenhouse gases has increased in the atmosphere, especially CO_2 [*Semenov and Popov*, 2011]. It is also interesting that the 11-year moving average of the solar constant has been decreasing over the past 2–3 decades, while the global temperature, on the contrary, has been growing rapidly, which

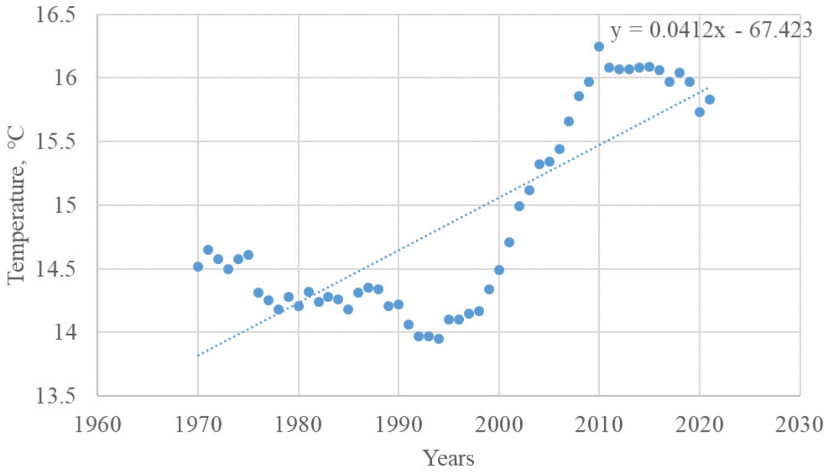


Figure 4. Moving average and trend.

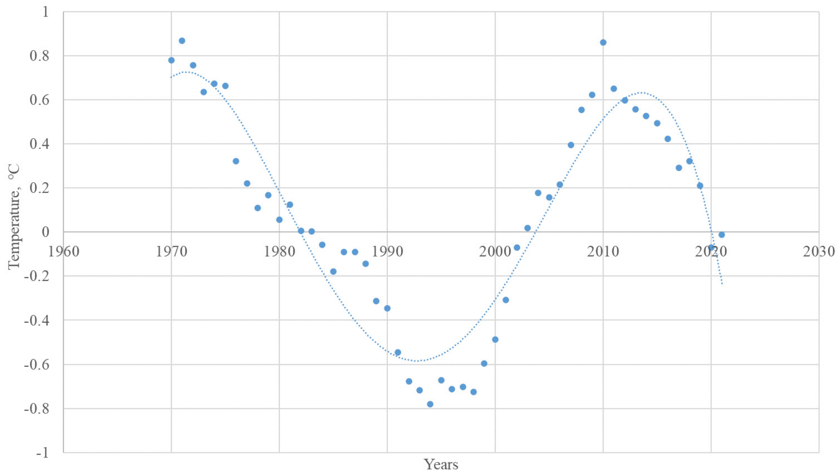


Figure 5. The difference between the actual values and the moving average over 10 years.

was an additional argument in favor of strengthening the greenhouse effect [*Melnikova et al.*, 2020].

However, the mechanism of the greenhouse effect itself is much more complicated. In addition to the anthropogenic factor, the change in the concentration of greenhouse gases may also be due to natural causes, for example, volcanic activity. A significant part of carbon dioxide is in the ocean. Accordingly, the growth of greenhouse gases can be both the cause of an increase in temperature (anthropogenic activity, volcanic activity) and a consequence (during evaporation, water vapor and carbon dioxide contained in the oceans enter the atmosphere).

It is worth noting that there is a significant difference between water vapor and carbon dioxide in the mechanism of the greenhouse effect. Thus, the concentration of saturated water vapor directly depends on temperature, i. e., with an increase in global temperature, the moisture capacity of the air increases. However, carbon dioxide spreads evenly on the planet, and we observe this against the background of the fact that the temperature increase differs in different latitudes. Accordingly, global warming is more pronounced in the circumpolar zones than in moderate, and even more subequatorial ones [*Melnikova et al.*, 2020]. An increase in temperature at the poles leads to the melting of glaciers, which also contain greenhouse gases. Thus, the problem of increasing the concentration of greenhouse gases is quite acute.

Exponential smoothing can also be performed for a time series of average annual temperatures. After all, in addition to cyclical factors associated with solar activity (and

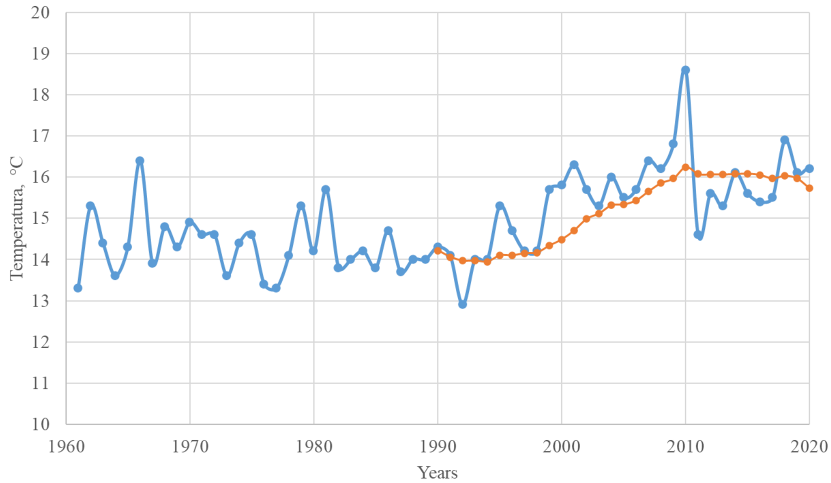


Figure 6. Average annual temperature and moving average for 30 years.

other harmonics), [*Semenov and Popov*, 2011] there are also random events, for example, the eruption of powerful volcanoes whose tephra height reaches the stratosphere [*Eliseev and Mokhov*, 2008]. Their role can be revealed when considering exponential moving averages (Figure 7).

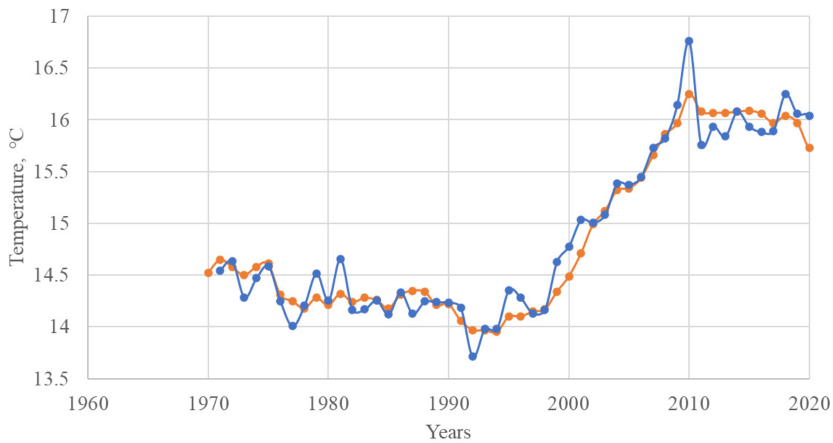


Figure 7. Simple and exponential smoothing with alpha equal to 0.3 (10-year moving average).

At the same time, “jumps” are clearly visible on the charts that are not related to seasonal factors. First of all, we can pay attention to the nature of temperature changes and its moving averages in 1990–1995 and 2010–2012. This is due to the eruptions of the volcanoes Pinatubo (1991) and Eyjafjallajekul (2010). In addition, on the graphs of the exponential moving average temperature, we see other peaks that may also be associated with volcanic eruptions:

- 1980 – St. Helens;
- 1982 – El Chichon;

1. Spectral analysis. Fourier Analysis

To consider cycles, it is advisable to pay attention to the time series of average annual temperatures [*Vityazev*, 2001].

The periodogram is a function of frequency, which shows an estimate of the spectral density of the signal.

To carry out spectral analysis, it is necessary to take away the trend line from the actual values of average annual temperatures. It can be seen from the figure that the trend line can be represented as a polynomial of the 4th degree, or as 2 polynomials of the 2nd degree, where the transition point will be 2010 (the eruption of the Icelandic volcano and the achievement of the maximum of the 30-year cycle, the trend change to the opposite). The use of a polynomial of the 4th degree is impractical, therefore, we will consider the TS spectrum, limiting ourselves to the data before the eruption of the Eyjafjallajekull volcano.

For a 48-year period of time (1961 – 2008), we will construct a periodogram of the average annual temperature.

It is possible to note several harmonics of the time series period (Figure 8), which are presented in the form of pointed ends. The most pronounced are 16-year, 5–6-year and quasi-two-year cycles. The graph shows that the arrival function is monotonically decreasing, i. e. we cannot consider fluctuations of a large period. Considering the 48-year range, we cannot talk about the presence of cycles in it, the period of which is greater than or equal to 24 years (a consequence of Kotelnikov's theorem). Another disadvantage of the FFT is that the considered harmonic periods depend on the sample, i. e. the presence of a 16-year cycle is questionable. Also, the FFT excludes the possibility of the existence of cycles with a variable period, which is characteristic of solar activity [*Tarasov*, 2004]. However, the latter problem is solved by wavelet analysis.

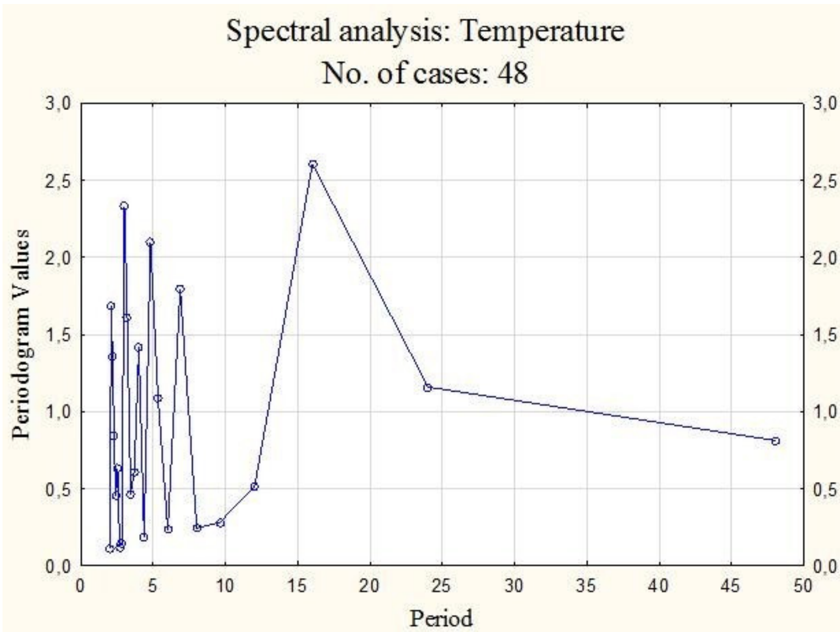


Figure 8. FFT periodogram of average annual air temperatures for Sukhum (1961 -2008), minus the polynomial trend line.

2. Wavelet analysis. Scalogram

When performing a wavelet analysis, a scalogram is constructed that estimates the distribution of energy (which is represented as the square of the amplitude) on the scales. The time is set on the axis, and the period scale is set on the axis. The result is a color graph that shows the amplitude spectrum of the continuous wavelet transform. It allows us to estimate harmonics that can manifest in different time ranges [*Vityazev*, 2001].

In Python, it was possible to build a scalogram for this series, which made it possible to identify cycles, including variables.

Figure 9 shows that there are variable periods of 4–6 years and 8–13 years (the second of them may be associated with an 11-year cycle, which actually varies from about 9 to 13 years), and a weak cycle with a period of 2–3 years is also visible (possibly quasi-two-year).

3. Conclusions

The time series of average annual temperatures for the city of Sukhum were considered on the basis of data for the period 1961–2022. The cyclical components and the trend were

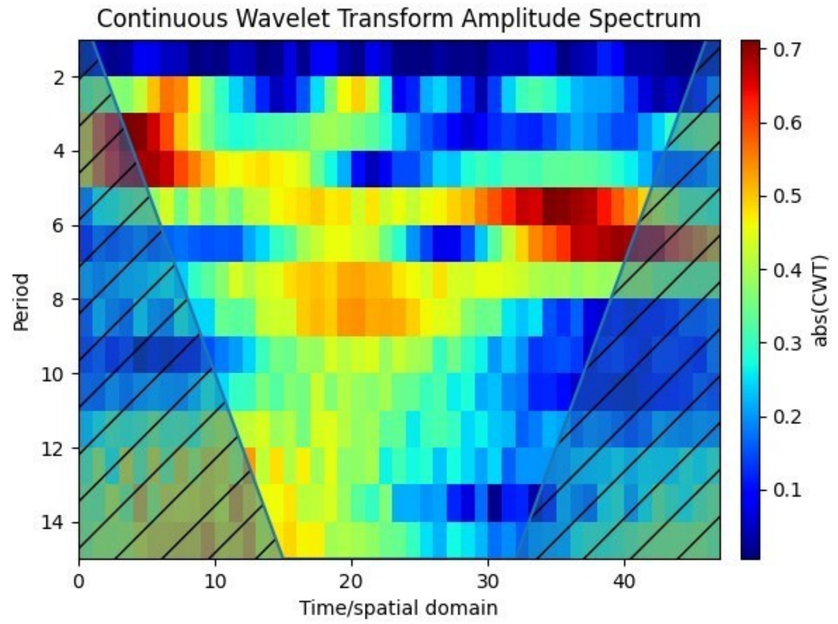


Figure 9. Wavelet analysis of BP average annual temperature values for Sukhum (1961–2008).

analyzed, which allowed us to draw the following conclusions. Over the entire period, the temperature increased by 1.31 degrees, i. e. the areas of growth of the trend temperature (a simple moving average for 10 years) were more pronounced than its fall. And the difference between the moving average and the straight trend line showed the presence of highs and lows of the trend temperature, which suggests the existence of fluctuations, with a periodicity of about 30 years. In the Fourier analysis and wavelet analysis, a periodogram of the FFT and a scalogram of average annual temperatures were obtained, which showed 5–6-year, quasi-two-year and solar cycles.

Attention was also paid to non-periodic deviations. The average annual temperature and the moving average for 10 years showed changes in temperature and its moving averages in 1990–1995 and 2010–2012. This is due to the eruptions of volcanoes Pinatubo (1992) and Eyjafjallajökull (2010). If we talk about the exponential moving average temperature, it showed other peaks that are associated with volcanic eruptions in 1980 – St. Helens and in 1982 – El Chichon.

References

Afanasyev, I. S., A. R. Komarova, R. G. Zakinyan, and A. I. Shevchenko (2022), Greenhouse effect, in *Problems of Atmospheric Physics, Climatology and Environmental Monitoring: Reports of the IV International Scientific Conference (Stavropol, May 23-25, 2022)*, p. 256, North-Caucasus Federal University (in Russian).

Akhsalba, A. K., Y. A. Ekba, and S. I. Marandidi (2013), The influence of gas composition of atmospheric air of the seashore of Abkhazia, *Izvestiya SFEDU. Engineering sciences*, *9*(146), 30–34 (in Russian).

Ekba, Y. A., A. K. Akhsalba, L. V. Khintuba, and K. A. Nachkebia (2020), Variability of major climate-forming factors in the territory of Abkhazia for the global warming period, *Bulletin of the Academy of Sciences of Abkhazia. A series of natural sciences*, pp. 172–182 (in Russian).

Eliseev, A. V., and I. I. Mokhov (2008), Influence of volcanic activity on climate change in the past several centuries: Assessments with a climate model of intermediate complexity, *Izvestiya, Atmospheric and Oceanic Physics*, *44*(6), 723–736 (in Russian).

Kendall, M., and A. Stuart (1976), *Multivariate statistical analysis and time series*, 736 pp., Nauka, Moscow (in Russian).

Khintuba, L. V., and Y. V. Ekba (2018), The impact of volcanoes on the climate, in *International Scientific and Practical Conference "Open Physical Readings" Abstracts of Reports Youth Section*, pp. 29–30, LNU named after V. Dahl, Lugansk (in Russian).

Melnikova, M., A. Perdero, and E. Zalyubovsky (2020), *Global climate threat and Russia's economy in search of a special path*, 69 pp., Energy Center of the Moscow School of Management SKOLKOVO, Moscow (in Russian).

Semenov, S. M., and I. O. Popov (2011), Comparative estimates of influence of changes in carbon dioxide, methane, nitrous oxide, and water vapor concentrations on radiation-equilibrium temperature of Earth's surface, *Russian Meteorology and Hydrology*, (8), 33–34 (in Russian).

Tarasov, B. G. (2004), On the nature of cycles of geodynamic activity and the method of their forecast, Bulletin of the Kuzbass State Technical University, *Bulletin of the Kuzbass State Technical University*, (6-2(44)), 3–13 (in Russian).

Vityazev, V. V. (2001), *Wavelet analysis of time series*, 58 pp., St. Petersburg State University, St. Petersburg (in Russian).