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ARTICLE

Quantum Biophysics of the Atmosphere: Asymmetric Wavelets of the Average Annual Air Temperature of Irkutsk for 1820-2019

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ABSTRACT

The regularities of the dynamics of the average annual temperature of Irkutsk from 1820 to 2019 were revealed. It is proposed to use the sum of temperatures. However, this indicator requires the continuity of the dynamic series, so for Irkutsk the sum of temperatures could be accepted only from 1873. The first three terms of the general wavelet model gave a very high correlation coefficient of 0.9996. The second indicator is a moving average, calculated as the ratio of the sum of temperatures to the current time. Here the first three wavelets gave a correlation coefficient of 0.9962. In the dynamics of the average annual temperature from 1820 to 2019, 86 wavelets were obtained, of which 47 affect the future. The temperature has a high quantum certainty, and the change in the average annual temperature of Irkutsk is obtained up to a measurement error of 0.05 °C, and the identification process occurs as a full wavelet analysis. The basis of the forecast in 200 years makes it possible to replace the non-linear two-term trend with an oscillatory perturbation. With an increase in the number of terms in the model, the ordinate of the average annual temperature increases: For three terms, the temperature interval is from –2.95 °C to 2.61 °C; for 12 members from –4.06 °C to 4.02 °C; for the forecast for 47 members for 2020-2220, from –4.62 °C to 4.40 °C.

1. Introduction

In the 21st century, global average temperatures are very likely, according to studies by Friedrich T. and others [1], to exceed the maximum levels recovered over the past 784,000 years. Based on temperature data from eight glacial cycles, the results provide an independent validation of current CMIP5 warming projections.

However, if the temperature decreased during the ice ages, then why should the forecasts in different regions of the Earth be the same?

An analysis of the transient 15-year trends presented in "Causes of variability in long-term warming" [2] shows that the rate of warming slowed down between 1999 and 2014. Another article [3] states that global temperature records from 1901 to 2008 refer to natural fluctuations: sometimes they cause warming, sometimes cooling. As noted in the materials "The Modern Temperature Trend" [4], it

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became clear that the cooling effect (mainly in the Northern Hemisphere) was temporary. When the rise continued into the 21st century, penetrating into the depths of the ocean (oceanologists admitted their mistakes and therefore everything is not so obvious in recent years), it signaled a profound change in the climate system. Nothing like it has happened for centuries. The article [5] considers the factors that could influence the slowdowns and the natural causes for each of them.

For example, in an article by Swain D.L. and others [6] data from the California drought in 2012-2015 show that the frequency of the harshest and hottest years has increased, and they are not associated with wet years.

The earth warmed at an unprecedented rate during the 1980s and 1990s, and the rapidity of the warming coincided with a 65-year cycle. However, Wu Z. and others argue [7] that the observed trends in global average surface temperature up to one-third of the warming at the end of the 20th century could be due to natural temperature variability.

The intensity of the heat island of Moscow, as noted in the article [8], has increased, moreover, despite the pause in global warming. It was found that the island can be traced vertically up to a height of 2 km. In summer, the lower part of the heat island represents dryness, while the upper part of the heat island corresponds to humidity. In winter, moisture is released in the lower part of the heat island.

The unprecedented intensification of extreme weather in recent years is motivating research for understanding, as pointed out by Zappalà et al. [9], long-term climate change. But this article uses averaged data, for example, over periods of 10 years. Many studies use converted measurement series. Mathematical methods are limited to linear trends and strong data averaging. As a result, the so-called identification of the climate pattern occurs.

For example, the article [10] shows the dynamics of air temperature on the land surface in the world since 1880, the so-called "linear objective estimate" is given, which immediately casts serious doubt on the interpretation of the results. From the point of view of climate behavior quanta, in the article [10], "a new analysis of the average annual global air temperature on the Earth's surface since 1880 was carried out". However, again, the deepening in the understanding of processes does not go further than linear models.

The comparison of the surface air temperature variability in three coupled integrations of the "ocean-atmosphere" model over 1000 years [11] was also performed using linear trends. But land surface temperature measurements are the longest and most reliable.

However, land surface temperature measurements are known to be the longest and most reliable. Gradually comes the understanding of the invariability of dynamic series according to the primary measurement data and the ban on all sorts of groupings in favor of the linearization method. Gradually comes the realization of the need for wave equations to identify directly primary data without tricks by their groupings and other simplifications.

As a result, the time series of global or regional surface air temperature, according to the conclusions of Li G.X. and Zhou G. [12] are of fundamental importance for climate change research. For example, in the article [13], monthly and annual temperature differences and their changes on the Tibetan plateau and its environs for 1963-2015 were considered.

2. The Concept of Quantum Biophysics of the Atmosphere

The concept of heat movement on the Earth is described in the article [14]. According to A. Chernokulsky, our Sun heats the Earth unevenly: The equator gets more, the poles get less. This temperature gradient is one of the main forces that drive the ocean and atmosphere. In the tropics, the climate system of our planet receives energy, and in temperate and polar latitudes it gives it away. The main transfer of heat from the equator to the pole is carried out in the atmosphere. The ocean is the slow component of the climate system. It does not respond as sharply to external influences as the atmosphere. In heat transfer, it acts as a battery: Taking heat from the Sun and heating up, the ocean then shares it with the air.

But with the bifurcations of the atmosphere and climate, many natural landscapes do not change for millennia, for example, as shown in our articles [15,16], the grass cover of the steppes. Grass appeared on land about 100 million years ago. Maybe she, as the strongest type of vegetation, has such values of the parameters of oscillatory adaptation that she will survive in any climatic changes in the future. What are the limits of the life of this grass cover? For example, the Eurasian steppe 8000 km long from Hungary to Inner Mongolia China?

To answer such questions, it is necessary not only to develop weather forecasts, but also to identify the behavioral quanta of the surface air layer at different points on the Earth according to weather stations, but the time series must be at least 175 years old. Then, for example, for the Eurasian steppe, there will be differences (distinguishing features) in temperature dynamics and opportunities for the synthesis of quantum biophysics of soil and parameters of the surface air layer at various points in the range of steppe grass.

While climatology is trying to develop independently.

The choice of informative criteria and objective classification methods remains an urgent task of climatology. For example, the article [17] studies temperature changes according to the data of 818 stations in the Northern Hemisphere for 1955-2011. The results of climatic clustering for different time periods corresponding to the main trends in global temperature changes are given.

Summer hot temperatures affect health, the economy (agriculture, energy and transport) and ecosystems in many ways. In Western Europe, the summers of 2003 and 2015 were exceptionally warm. The events of the last decades [18] were associated with the anticyclonic circulation of the atmosphere and the deficit of spring precipitation in Southern Europe. Such results were obtained for the second half of the 20th century.

The role and mechanisms of climatic impact on plant productivity are multifaceted. Research by Babushkina and others [19] found that among the meteorological variables, the humidity index had the maximum effect on plants.

Climate, such as air temperature and rainfall, varies greatly between urban core and peripheral areas [20], resulting in different growing conditions for trees.

The measurement results showed that soil moisture is decreasing and CO_2 emissions from the soil are increasing. It is known from the article [21] that this will reduce the sensitivity to the soil respiration temperature in the ecosystem of alpine meadows in the area of permafrost in the Tibetan Plateau, especially for short and medium periods.

In the article [22] Zharkova V. proved that solar activity has a strong influence on the climate dynamics on Earth.

The authors of the article [23] concluded: "There is reason to believe that global warming is now almost over and we should expect a slow decrease in the period 2014-2040, primarily in the Northern Hemisphere over land".

Therefore, when modeling for heuristic identification of the essence of infinite-dimensional wavelet signals, we used various cycles of solar activity. However, the parameters of the atmosphere are highly dynamic due to synoptic phenomena and processes, so the cycles of solar activity become, as it were, just starting, after a short time, fluctuations in temperature and other meteorological parameters receive variables, as a rule, increasing, amplitudes and periods.

The purpose of the study is to identify asymmetric wavelet signals of the dynamics of the sum of temperatures and the moving average annual temperature from 1873 to 2019, as well as a set of infinite-dimensional and finite-dimensional wavelets for predicting up to 2220 on the dynamic series of the average annual temperature of the surface air layer, using the identification method [24-26] in Irkutsk from 1820 to 2019.

3. Initial Data of the Irkutsk Weather Station

For the possibility of modeling the dynamics of the average annual temperature by a set of wave equations, the initial time is taken for 1820. For modeling the dynamics, a series of average annual temperatures are taken with discontinuities (lack of data for some years). Gaps in the time series according to the data do not give an accurate division of the dynamics into a set of wavelets (quanta of behavior).

Figure 1 shows the landscape along the meridian from the Arctic Ocean to Irkutsk (URL: https://cs11.pikabu.ru/post_img/big/2020/11/27/4/1606456328111940732.jpg).

The location of Irkutsk is conventionally shown as a white square. From the side of the Arctic Ocean, cold winds pass unhindered to the city. And the mountain range interferes with warm winds from the south. Therefore, Irkutsk is located in a unique place in Asia.

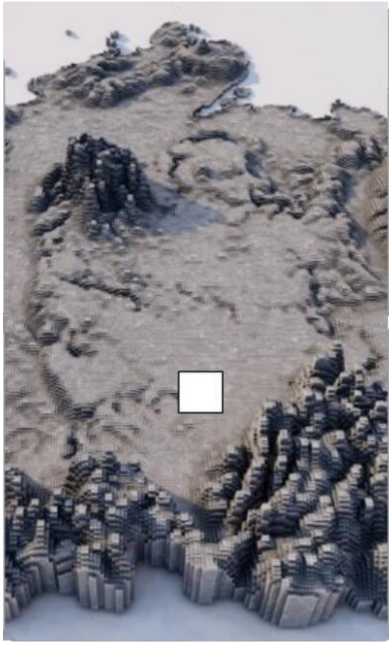


Figure 1. Landscape of Irkutsk.

To calculate the sum of temperatures and the moving average over years of temperature, breaks in the time series are not allowed, therefore, for these parameters, the series starts from 1873. For some years (1820, 1832, 1841, 1844-1857, 1860, 1861, 1863, 1867-1872) there are also no data on average annual measurements. For the missing value of the average annual temperature for 1881, interpolation was adopted, then the calculated average annual temperature is ((–1.3) (1880) + (–1) (1882)) / 2 = –1.1 °C.

Irkutsk is a complex object of climatic geomorphology.

The article [27] analyzes the changes in the extremeness of the winter thermal regime in the Cis-Baikal region. An estimate of the temporal variability in the frequency of daily minimum air temperatures below –30 °C, –35 °C, –40 °C, –45 °C and –50 °C for the period 1943-2012 is given. Winter conditions become thermally milder over the years, although periods with abnormally low temperatures are not ruled out.

On the basis of data on the concentrations of pollutants indexed at the posts of observation of atmospheric pollution, the dynamics of their change in the period from 2000 to 2012 are presented [28]. Now the main weather station is located inside Irkutsk, so the influence of the heat island from the growing city, apparently, increases over the years. Therefore, the temperature forecast for Irkutsk becomes conditional, since it is necessary to take into account the growing influence of the urban environment on the heat island.

The article [29] presents the materials of a continuous study of the chemical composition of atmospheric aerosols and precipitation (rain, snow) at the Irkutsk monitoring station, which is part of the Southeast Asia atmospheric fallout monitoring network (EANET) for the period 2000-2012. In the last five years, there has been an increase in the mineralization of atmospheric precipitation, especially in winter. The number of gaseous impurities in the air of the city increased against the background of a low total content of ions in aerosols.

The series of the surface average annual temperature for Irkutsk were taken from the website http://www.pogodaiklimat.ru/history.php?id=ru (Accessed 07/07/2020).

Table 1 gives a fragment of the data array of the average annual temperature of the surface air layer at a height of 2 m according to measurements at the meteorological station in Irkutsk.

Table 1. Average annual air temperatures (°C) of Irkutsk for 1820-2019.

Year	Temperature		Sum of temperatures		Moving average	
	Time τ	t	Time τ_1	$\sum t$	Time τ_2	$\tilde{t}$
1820	0	-	-	-	-	-
1821	1	0.6	-	-	-	-
1822	2	0.3	-	-	-	-
…	…	…	…	…	…	…
1873	53	–0.7	0	–0.7	1	–0.70
1874	54	0.2	1	–0.5	2	–0.25
1875	55	–1.1	2	–1.6	3	–0.53
…	…	…	…	…	…	…
2017	197	2.6	144	–57.4	145	–0.40
2018	198	1.3	145	–56.1	146	–0.38
2019	199	2.1	146	–54.0	147	–0.37

The year 1820 was taken as the beginning of the countdown of time (years) according to the dynamic series of temperature. Then, 200 years have passed from the beginning of 1820 to the end of 2019, so the indicative forecast can be made for the forecast horizon equal to the forecast base, that is, until 2020 + 200 = 2220. For the sum of temperatures and the moving average temperature, 1873 is taken as the beginning of the series. , therefore, these parameters are needed only to understand the picture of the dynamics of the average annual temperature from 1820 to 2220.

Table 1 contains 2019 – 1819 = 200 years in total, and for the sum of temperatures and the moving average annual temperature 2019 – 1872 = 147 years.

4. Generalized Asymmetric Wavelet and Sum of Quantums of Behavior

Success in physics is largely determined by the use of mathematics. Physicists often create the necessary mathematical apparatus themselves [30].

We have developed a method for identifying successively a set of regularities in the form of asymmetric wavelet signals. This set is essentially an algebraic equation according to René Descartes.

Oscillations (asymmetric wavelet signals) are generally written by the wave formula [24-26] of the form.

$$y = \sum_{i=1}^{m} y_i \,,\; y_i = A_i \cos(\pi x / p_i - a_{8i}) \,,$$

$$A_i = a_{1i} x^{a_{2i}} \exp(-a_{3i} x^{a_{4i}}) \,,\; p_i = a_{5i} + a_{6i} x^{a_{7i}} \,, \quad (1)$$

where y is the indicator (dependent factor), i is the number of the component of the model (1), m is the number of members in the model (1), x is the explanatory variable (influencing factor), $a_1 ... a_8$ are the parameters of the model (1) that take numerical values during structural and parametric identification in program environment CurveExpert-1.40 (URL: http://www.curveexpert.net/) according to statistical data, A_i is the amplitude (half) of the wavelet (axis y), p_i is the half-period of oscillation (axis x).

This article refers to quantum meteorology [26], which makes it possible to isolate the quanta of the behavior of the surface layer of the atmosphere in the form of asymmetric wavelets (1) for three types of temperature in Irkutsk. According to these selected quanta of the behavior of the average annual temperature, the signals are unknown, therefore, each wavelet needs to be analyzed by specialists using heuristic methods to find out the reasons for the occurrence of fluctuations. This will reveal the mechanisms of oscillatory climate adaptation.

5. Research Results

5.1 Dynamics of the Sum of Temperatures in Irkutsk Since 1873

Temperature is a physical quantity that is a measure of the average kinetic energy of the translational motion of molecules, in our case, air molecules in the surface layer of air at a height of 2 m above the land surface in Irkutsk.

Over time, energy accumulates, so we can estimate this accumulation by the sum of temperatures according to Table 1 using the calculation formula:

$$\sum t_{\tau_1} = \sum_{\tau_1=0}^{\tau_1=146} t_{\tau_1} \qquad (2)$$

Then the sum of temperatures will show an aligned series.

Table 2 shows the parameters of the general model (1) and the adequacy in terms of the correlation coefficient, and Figure 2 shows the graphs of the components.

After the five components of the model (1), the identification can be continued. However, over time, the relative error of the formula in the form of a sum of five terms in Table 2 decreases sharply for the interval 2009-2019 and becomes less than 1.17%.

Table 2. Parameters of the sum of average annual temperatures in Irkutsk for 1873-2019.

i	Asymmetric wavelet $y_i = a_{1i}x^{a_{2i}}\exp(-a_{3i}x^{a_{4i}})\cos(\pi x/(a_{5i}+a_{6i}x^{a_{7i}}) - a_{8i})$								Coef. correl. r
	Amplitude (half) oscillation				**Half cycle oscillation**			**Shift**	
	a_{1i}	a_{2i}	a_{3i}	a_{4i}	a_{5i}	a_{6i}	a_{7i}	a_{8i}	
1	41.28078	0	0.00044829	1	0	0	0	0	
2	–0.011685	2.35352	0.00061386	1.68579	0	0	0	0	0.9996
3	–335.5300	0	0.066596	0.92114	813.6061	–435.5187	0.11863	1.44577	
4	–0.050041	1.67099	0.80452	0.38283	12.28539	–0.0010573	1.63220	–0.77318	0.7439
5	0.0019846	2.00250	0.27280	0.57517	29.74132	–0.035096	1.16942	1.25137	0.4434

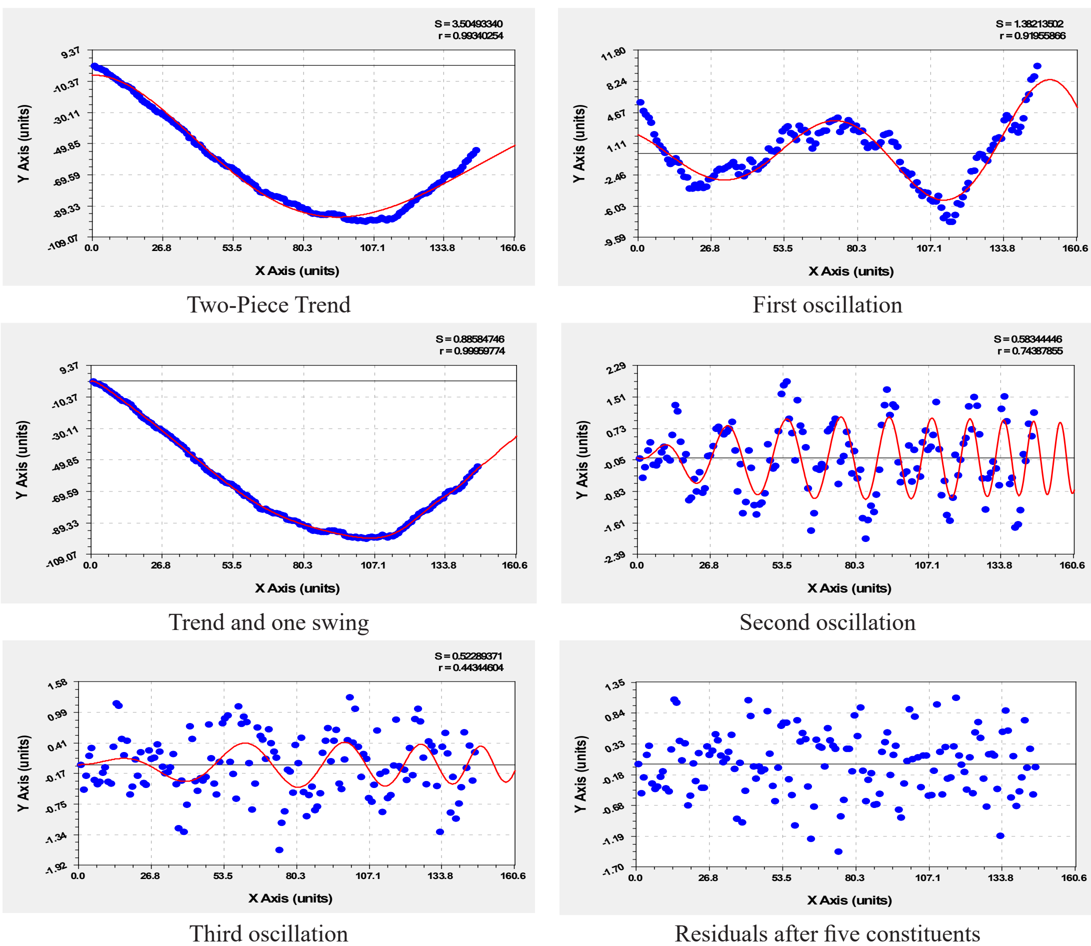


Figure 2. Graphs of changes in the sum of temperatures in Irkutsk for 1873-2019.
(in the upper right corner: *S* - standard deviation; *r* - correlation coefficient)

From the scatter plot in Figure 2, the lowest point of the sum of temperatures is –99.2 °C for 1977. From this moment, the sum of temperatures begins to rise. As a result, as well as throughout the land of the Earth, warming in Irkutsk began in 1977. However, it may turn out that the second term in Table 2 can eventually turn into a fluctuation. In addition, the other three oscillations can also be far from strong disturbances.

The first term of the model in Table 2 is the well-known Laplace law (in mathematics), Mandelbrot (in physics), Zipf-Pearl (in biology) and Pareto (in econometrics). It shows the tendency of the sum of temperatures to decrease. The second component is the biotechnical law [25] and it always shows the convexity of the parameter values. However, the thermodynamics of the atmosphere always has the property of oscillatory adaptation and the biotechnical law cannot indicate a wave in the future, therefore, after the rise, there will be only one transition to a decrease.

The third term from Table 2 (the first oscillation in Figure 1) is an infinite-dimensional wavelet that has no boundaries along the abscissa axis, in which the amplitude changes according to the Mandelbrot law modified by us with the introduction of a degree not equal to 1. The oscillation period for 1873 equals 2 × 813.6061 = 1627 years. Over time, the oscillation period began to decrease sharply, and since 1987 a new wave began with a half-period of about 140 years. The remaining two wavelets are finite-dimensional, having boundaries along the abscissa. Gradually, they will fade in amplitude to zero, but, as can be seen from the graphs, after a very distant time in the future.

By direct calculations in Excel using the formulas from Table 2 (preserving 11 decimal places from the results of parameter identification (1) in the CurveExpert-1.40 software environment), we obtain an approximate forecast up to 2165 (Figure 3).

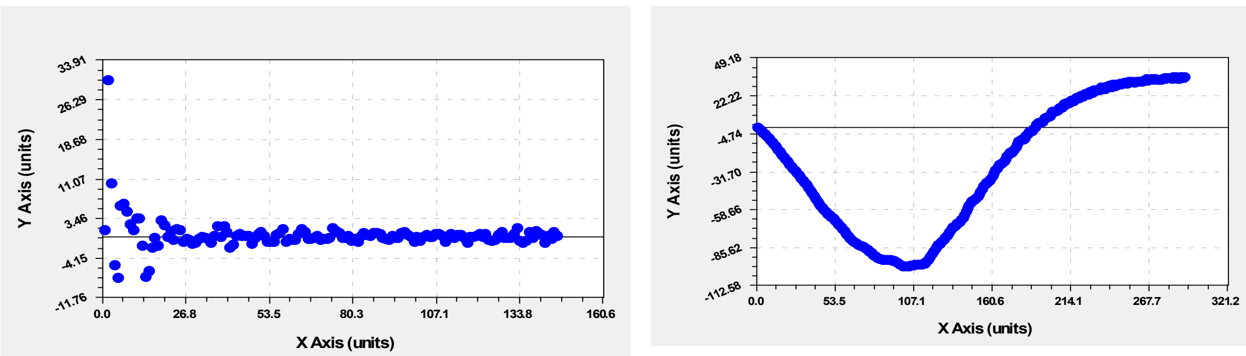
The forecast graph in Figure 2 shows that in 2064 the sum of temperatures will become above zero, and by 2165 it can reach 35.6 °C. But it may turn out that after the year 2165 the sum of temperatures can decrease again.

5.2 Dynamics of Moving Average Annual Temperature Since 1873

This parameter, which smoothes the time series, is calculated by the formula:

$$\widetilde{t}_{\tau_2} = \sum t_{\tau_1} / \tau_2 = \sum_{\tau_2=1}^{\tau_2=147} \sum_{\tau_1=0}^{\tau_1=146} t_{\tau_1} / \tau_2 \qquad (3)$$

Table 3 gives the values of the parameters of the general model (1) and the adequacy in terms of the correlation coefficient, and Figure 4 shows the graphs of individual wavelets.



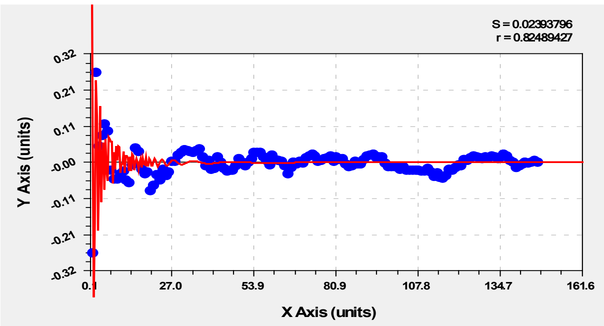
Dynamics of relative error

The sum of temperatures for the period 1873-2165

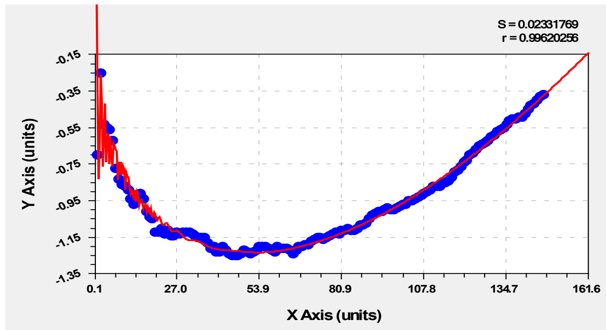
Figure 3. Plots for the five-term model with parameters from Table 2.

Table 3. Parameters (1) of the moving average temperature of Irkutsk for 1873-2019.

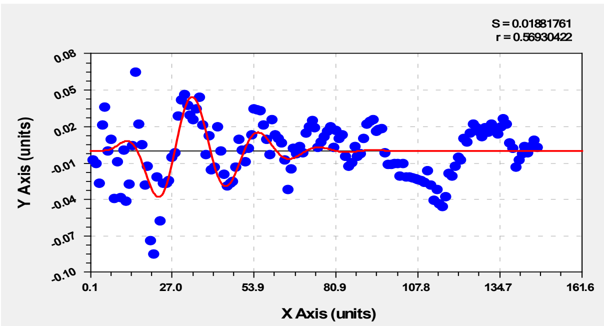
i	Asymmetric wavelet $y_i = a_{1i}x^{a_{2i}} \exp(-a_{3i}x^{a_{4i}}) \cos(\pi x / (a_{5i} + a_{6i}x^{a_{7i}}) - a_{8i})$								Coef. correl. r
	Amplitude (half) oscillation				**Half cycle oscillation**			**Shift**	
	a_{1i}	**a_{2i}**	**a_{3i}**	**a_{4i}**	**a_{5i}**	**a_{6i}**	**a_{7i}**	**a_{8i}**	
1	–0.18414	0	–0.8717503	0.27778	0	0	0	0	
2	0.0045055	1.42940	0	0	0	0	0	0	0.9962
3	6.77951	0.18727	2.71511	0.29156	0.912231	–0.043886	1.27041	1.43681	
4	–6.02349e-7	4.75806	0.18717	0.96540	13.42004	–0.016304	1.11774	–1.02747	0.5693
…	…	…	…	…	…	…	…	…	…
19	–1.40196e-6	2.61204	0.056036	0.99096	3.63892	–0.00098656	0.96206	0.61459	0.1869



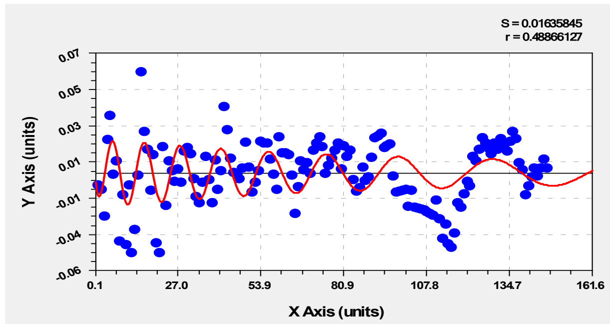
First oscillation



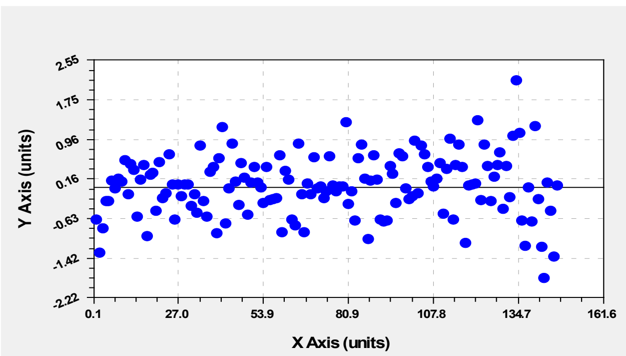
Trend and one swing



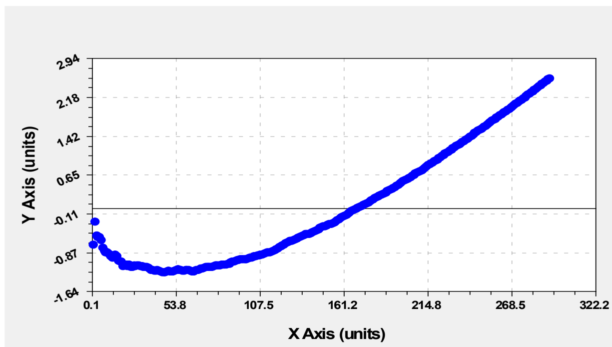
Second oscillation



Third oscillation



Relative error after the 19th component



Forecast of the moving average for 1873-2165

Figure 4. Graphs of moving average temperature in Irkutsk for 1873-2019.

Due to the second term of the power law trend, it is impossible to predict this temperature parameter, since according to this simple equation there is a continuous increase in the sliding temperature over the years. Therefore, it is necessary to switch to the identification of the mean annual temperature from 1820.

5.3 Dynamics of the Average Annual Temperature Since 1820

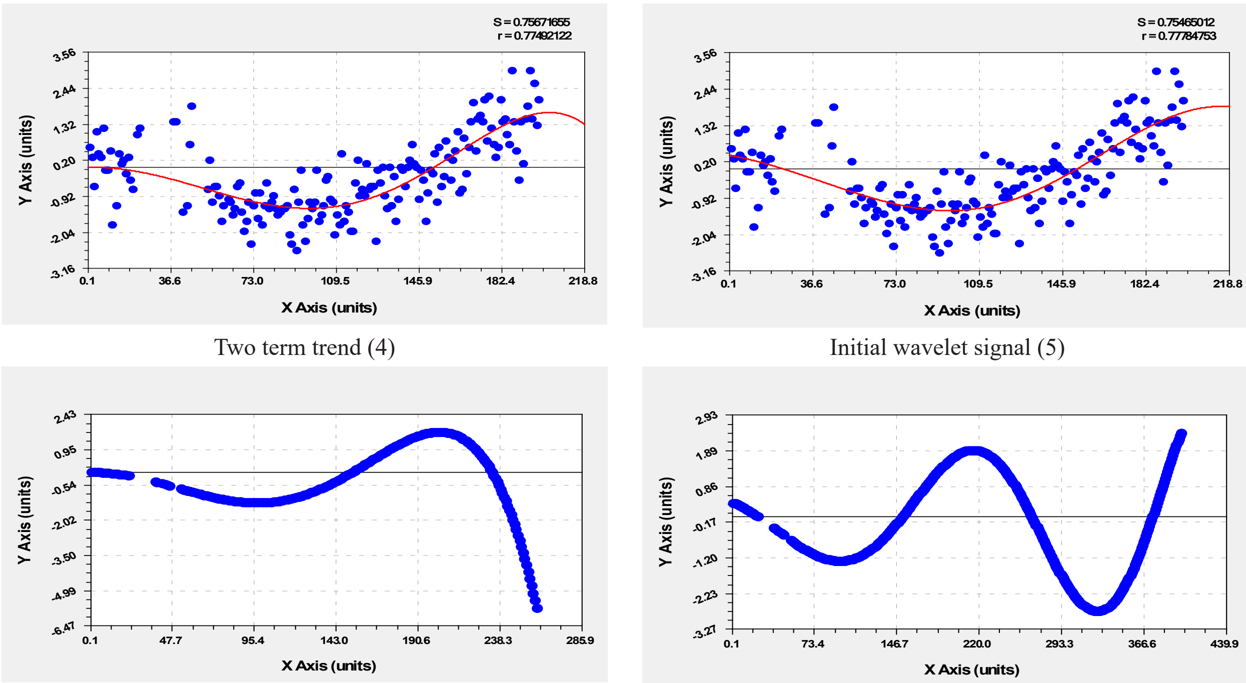
Our research has shown that the duration of 146 years since 1873 is not enough time to identify only non-linear trends. It turned out that to identify the first oscillation (instead of a trend), a series with a length of at least 175 years is needed. In this regard, a series of 200 years for Irkutsk (albeit with gaps at the beginning of the series) made it possible to reveal the first quantum of behavior in the form of an asymmetric wave equation (wavelet). It follows from this that it is impossible to make temperature forecasts with a series length of at least 175 years, that is, the dynamic series of the average annual temperature with any measurement period and for any weather stations should begin no later than 1845.

The two-term trend (Figure 5) is determined by an equation of the form:

$$t = -4.77083 \cdot 10^{-7} \exp(7.36060\tau^{0.18257}) + 1.09883\tau^{3.49994} \quad (4)$$

And the oscillatory perturbation of the average annual temperature in Irkutsk is determined by the first equation of the infinite-dimensional wavelet.

$$t = -0.95369 \exp(0.0032716\tau)\cos(\pi\tau / (879.70973 - 672.03732\tau^{0.020834}) - 2.01653) \quad (5)$$



Two term trend (4) — Initial wavelet signal (5)

Forecast on a two-component trend until 2080 — Oscillation forecast (5) until 2220

Figure 5. Graphs of temperature dynamics in Irkutsk for 1820-2019 and forecast until 2220.

The trend correlation coefficient in the form of a wavelet (5) is 0.7778, and in the form of a two-term non-linear trend (4) is 0.7749. Then, in terms of adequacy, the wavelet is more significant than the trend. And it can be taken as the beginning of the oscillatory separation of the climate.

According to Equation (5), we have that the fluctuation period in 1820 for the climate of Irkutsk was equal to 2 × 879.70973 = 1759.4 years. The amplitude, according to the Mandelbrot law, shows the tendency of the average annual temperature to the absolute temperature of –273.15 °C, that is, the separation of the Earth's climate system will lead, as on Mars, to global cooling. Therefore, warmings are only episodes in climate evolution.

According to the trend wave from 1820 to 1916, the average annual temperature at the meteorological station of Irkutsk dropped from +0.40 to –1.29 °C, so this period is characterized as a cooling. Then, from 1916 to 2035, with a time interval of 119 years, there is a warming up to 1.91 °C. The difference in average annual temperatures will be equal to 3.20 °C. After that, from 2035 to 2145, the average annual temperature will again decrease to –2.75 °C. Over a time interval of 110 years, a cooling of 4.66 °C will occur. From 2145 to 2251 in the interval of 106 years, according to the preliminary forecast, there will again be warming from –2.75 °C to +3.88 °C with a difference of 6.63 °C. Thus, the climate near Irkutsk will go into overdrive with increasing amplitude.

According to the initial wave, it turns out that the ecological system at the Irkutsk point tends to increase the amplitude and reduce the half-period of oscillation, thereby gradually approaching an emergency situation, as in a car engine. Moreover, this situation is approaching more and more quickly along the half-period from about 1760 years to the values of 119, 110 and 106 years. Of course, such a strong increase in climate fluctuations depends on the strengthening of anthropogenic influence.

5.4 Full Wavelet Analysis of Mean Annual Temperature

Climate change occurs along a powerful bundle of a large number of wavelets, when up to 200 wavelets can be consistently identified in one bundle in the form of a general model (1) of temperature dynamics [25].

A complete wavelet analysis is possible when all behavior quanta at the end of the identification process will give a modeling error on the residuals from the last asymmetric wavelet less than the measurement error. According to the values of the average annual temperature in Table 1, the division price is 0.1 °C. Then the measurement error of the mean annual temperature will be ± 0.05 °C.

According to the computing capabilities of the CurveExpert-1.40 software environment, joint identification is possible up to 3-4 members. In this case, the parameters of the model change by value and this is similar to the effect of compaction when the box is shaken. Then it turns out that it is necessary to create a special software environment that allows obtaining up to 200 terms of Equation (1) for the time-temperature pair. They will have up to 1600 simultaneously shaken model parameters. The length of the row by the number of lines should be at least 100 thousand. We have scenarios for the identification process.

Table 4 shows examples of wavelets that continue beyond 2019 and this allows direct prediction in Excel. Of the 86 terms, 47 components have an impact after 2019 (all infinite-dimensional wavelets fall here), and 39 finite-dimensional wavelets have already remained in the past until 2019. Therefore, they can be ignored in forecasting.

In Table 4, together the first three terms gave a correlation coefficient of 0.8126, with the first four oscillations being infinite dimensional wavelets. Of these, terms No. 1 and No. 4, according to the half-amplitude formula, are the Mandelbrot law for $a_{4i}=1$, and terms No. 2 and No. 3 are the Mandelbrot law modified by us under the condition $a_{4i}\neq 1$. With the highest adequacy at a correlation coefficient of 0.6548, oscillation No. 36 belongs to a finite-dimensional wavelet.

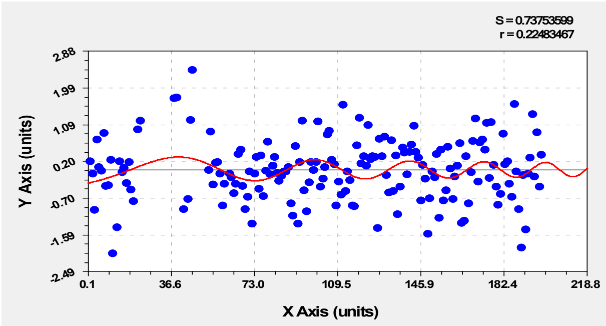
Some of the 86 wavelets are shown in Figure 6, and the initial wavelet was shown in Figure 6. The presence of finite-dimensional wavelets with the beginning and end of the oscillation makes forecasting difficult, since after the end of the forecast base, new local (short segments on the x-axis) oscillations may appear.

Together, the three fluctuations give a small temperature tremor since 1996. At the same time, terms #27 and #36 continue into the future, but begin around 1840.

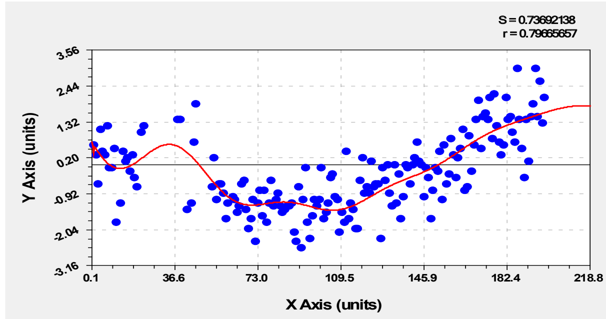
Figure 7 shows graphs of the 86th quantum of the behavior of the average annual temperature of Irkutsk and points from the residuals, which are much less than ± 0.05 °C. Therefore, we can assume that the full wavelet analysis of the dynamic series of the average annual temperature of Irkutsk from 1820 to 2019 was carried out. Then for those components that continue their influence (infinite-dimensional and finite-dimensional wavelets) after 2019, the sum can be calculated with 11 significant digits for the model parameters (1). To verify the forecasts, the formulas should be calculated for 2020 and 2021 and compare the calculated and actual values of the average annual temperature.

Table 4. Parameters (1) of the dynamics of the average annual temperature of Irkutsk for 1820-2019.

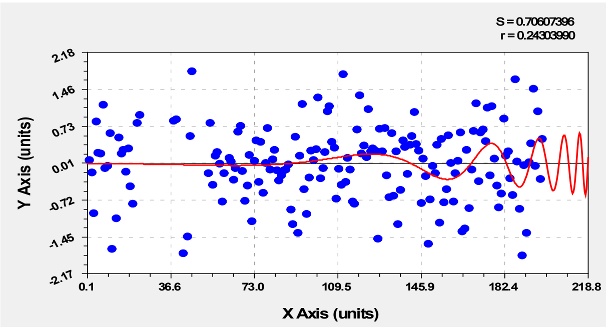
i	**Asymmetric wavelet** $y_i = a_{1i}x^{a_{2i}}\exp(-a_{3i}x^{a_{4i}})\cos(\pi x/(a_{5i}+a_{6i}x^{a_{7i}})-a_{8i})$								**Coef. correl. r**
	Amplitude (half) oscillation				**Half cycle oscillation**			**Shift**	
	a_{1i}	a_{2i}	a_{3i}	a_{4i}	a_{5i}	a_{6i}	a_{7i}	a_{8i}	
1	–1.45648	0	–0.00054511	1	–793.72078	796.84232	0.021229	3.52895	0.8126
2	3.62339	0	0.16097	0.67805	39.07346	–6.80511	0.13692	–1.66398	
3	1.88937	0	–7.40020	0.099365	220.28835	–0.66686	1.06022	–3.23605	
4	–0.20304	0	0.0039260	1	12.59928	–0.028013	1.14617	–1.90902	0.1469
…	…	…	…	…	…	…	…	…	…
36	–1.52521e-12	9.08512	2.21324	0.43428	1.80273	0	0	3.10990	0.6548
…	…	…	…	…	…	…	…	…	…
67	0.00069493	1.10961	0.064035	0.74812	1.02341	0	0	–1.65995	0.2400
73	7.62225e-7	2.22007	0.010537	0.99415	175.25799	–0.75130	1.00002	–5.60264	0.1761
75	1.73871e-8	2.76191	0.00099972	0.95693	1.33323	0	0	–5.13988	0.3414
76	–2.38153e-6	1.92272	0.010470	0.99364	1.28797	0	0	–6.01353	0.1609
81	–0.020567	0	0.20097	0.33435	1.76447	0.0076570	0.99933	–0.89750	0.2845
83	–1.97290e-28	14.83049	0.098036	0.99395	4.50669	–0.0017426	1.11121	–3.32612	0.4362
85	3.33419e-6	1.94059	0.010077	0.98363	2.47227	0	0	–0.13150	0.3877
86	–0.0069195	0	–0.00035802	1	4.03746	0.00048849	0.99942	1.46876	0.2806



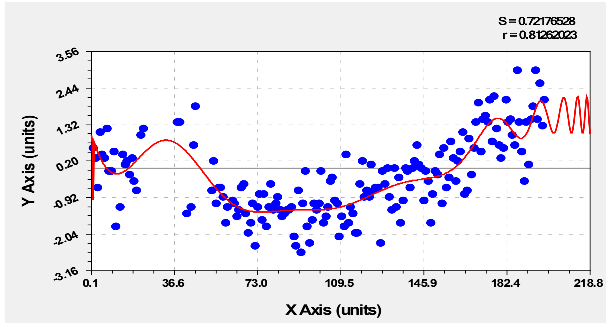
Second oscillation



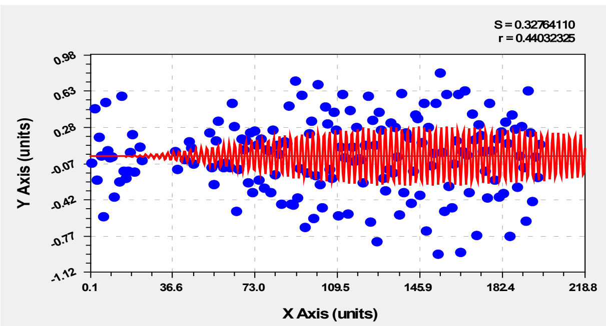
Together, two vibrations



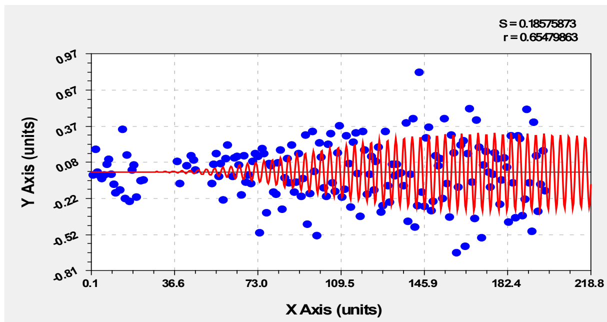
Third oscillation



Jointly three vibrations

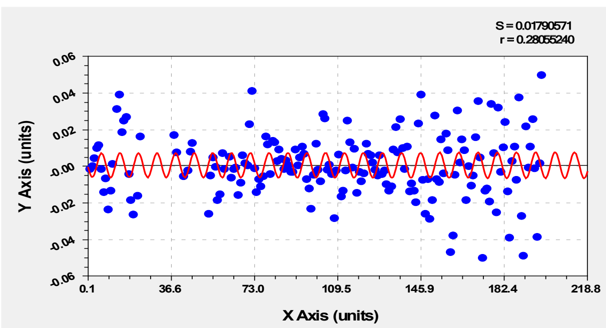


27th model member (1)

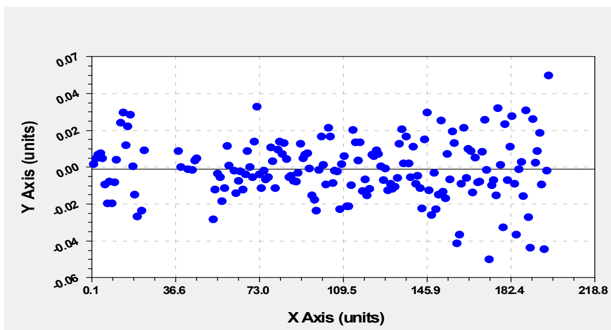


36th model member (1)

Figure 6. Graphs of the dynamics of the average annual temperature in Irkutsk for 1820-2019



86th model member (1)



Residuals after the 86th term of the general model

Figure 7. Latest graphs of the average annual temperature in Irkutsk for 1820-2019.

Then it turns out that the dynamic temperature series has a high quantum certainty, since it allows quantizing the change in the average annual temperature of Irkutsk by 86 oscillations up to a measurement error in 47 components.

6. Discussion of Results

6.1 Stages of Climate Behavior in Irkutsk

In a series from 1820 to 1865, a sharp cooling was observed. Moreover, the beginning of this cycle is unknown. Then, around 1966, warming began, which continues to this day. But the forecast will show how long this warming will continue.

The high pollution of urban air makes the forecast of Irkutsk temperature until 2020 conditional and only indicative. But, apparently, only infinite-dimensional wavelets will be preserved for the future, therefore, in forecasts until 2220, we will not take into account those finite-dimensional wavelets that terminate along the right boundary until 2019.

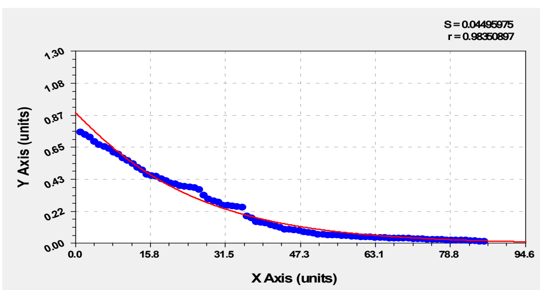
6.2 Fractal Analysis of Wavelets

Standard deviations (shown in the upper right corner) are given in Table 5.

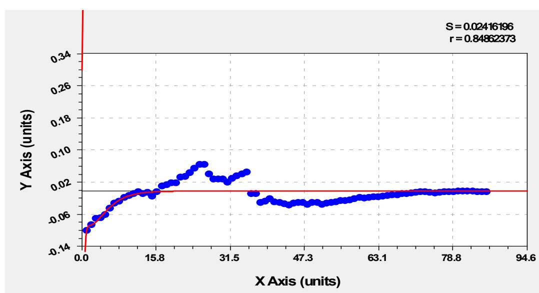
The zero number was given to the arithmetic mean value with a standard deviation of 1.1832 °C. Then the parameter i is the rank of each wavelet (Figure 8).

Table 5. Change in the standard deviation of mean annual temperature wavelets.

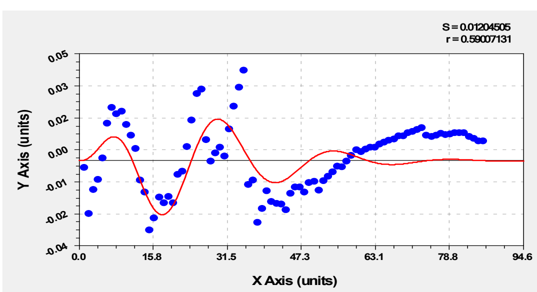
i	S, °C	i	S, °C	i	S, °C	i	S, °C	i	S, °C	i	S, °C
0	1.1832	15	0.4681	30	0.2798	45	0.0987	60	0.0483	75	0.0286
1	0.7547	16	0.4597	31	0.2618	46	0.0947	61	0.0467	76	0.0282
2	0.7369	17	0.4546	32	0.2601	47	0.0883	62	0.0450	77	0.0281
3	0.7218	18	0.4380	33	0.2567	48	0.0798	63	0.0428	78	0.0265
4	0.6922	19	0.4260	34	0.2520	49	0.0784	64	0.0420	79	0.0258
5	0.6704	20	0.4084	35	0.2473	50	0.0734	65	0.0407	80	0.0256
6	0.6585	21	0.4054	36	0.1858	51	0.0646	66	0.0398	81	0.0248
7	0.6424	22	0.3914	37	0.1766	52	0.0639	67	0.0384	82	0.0242
8	0.6201	23	0.3865	38	0.1473	53	0.0614	68	0.0383	83	0.0219
9	0.6038	24	0.3824	39	0.1433	54	0.0594	69	0.0367	84	0.0204
10	0.5824	25	0.3783	40	0.1412	55	0.0579	70	0.0365	85	0.0187
11	0.5632	26	0.3649	41	0.1274	56	0.0541	71	0.0356	86	0.0179
12	0.5438	27	0.3276	42	0.1178	57	0.0532	72	0.0352		
13	0.5166	28	0.3032	43	0.1094	58	0.0524	73	0.0348		
14	0.4980	29	0.2920	44	0.0990	59	0.0519	74	0.0304		



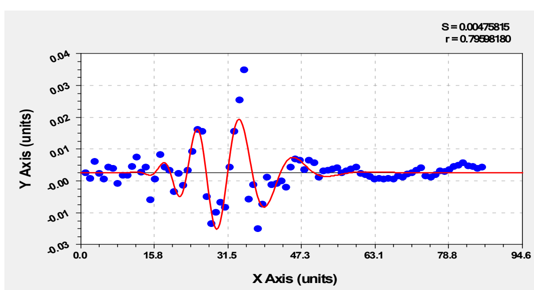
Modified Mandelbrot's Law



First oscillation



Second oscillation



Third oscillation

Figure 8. Graphs of the standard deviation of temperature in Irkutsk for 1820-2019.

After identification, a four-term formula of the form:

$$S = S_1 + S_2 + S_3 + S_4 , \qquad (6)$$

$S_1 = 0.97975\exp(-0.039423i^{1.04953})$,

$S_2 = A_1\cos(\pi i / p_1 + 0.72450)$,

$A_1 = 0.26945\exp(-0.052207i)$,

$p_1 = -63.22677 + 642.19439i^{0.061051}$,

$S_3 = A_2\cos(\pi i / p_2 + 1.90902)$,

$A_2 = -0.0057598i^{2.51939}\exp(-0.28579i)$,

$p_2 = 17.58283$, $S_4 = A_3\cos(\pi i / p_3 - 1.50203)$,

$A_3 = -4.66337\cdot 10^{-17} i^{13.79035}\exp(-0.40072i^{1.02706})$,

$p_3 = 1.68217 + 0.036085i^{1.01190}$.

The first term is modified by us subject $c \neq 1$ to the Mandelbrot law in the form $y = a\exp(-bx^c)$. Then it turns out that the quanta of behavior themselves are distributed fractally, but, unlike Mandelbrot, not multiple and with fluctuations.

6.3 Distribution of Residuals after the 86th Component of the Model

The number of points n_ε (pieces) in one interval after 0.01 °C of the absolute error $[\varepsilon]$ (°C) changes according to the Gauss law (Figure 9) in the form of an equation:

$$n_\varepsilon = 1 + 40.33057\exp(-1774.700([\varepsilon] + 0.0044307)^2) \qquad (7)$$

The normal distribution law is observed with an adequacy of 0.9703.

6.4 Relative Error Distribution of Residuals

A formula was obtained (Figure 9) of the form:

$$n_\Delta = 1 + 42.08733\exp(-0.18650([\Delta] - 0.0091613)^2) \qquad (8)$$

Due to zero temperature, the relative error is equal to infinity, and there were five such points in total. Then, out of 200 points, there are no measurements at 27 points, so the representativeness of the statistical sample for the residuals will be 86.5%, and for the relative error (173 – 5) / 200 = 84.0%.

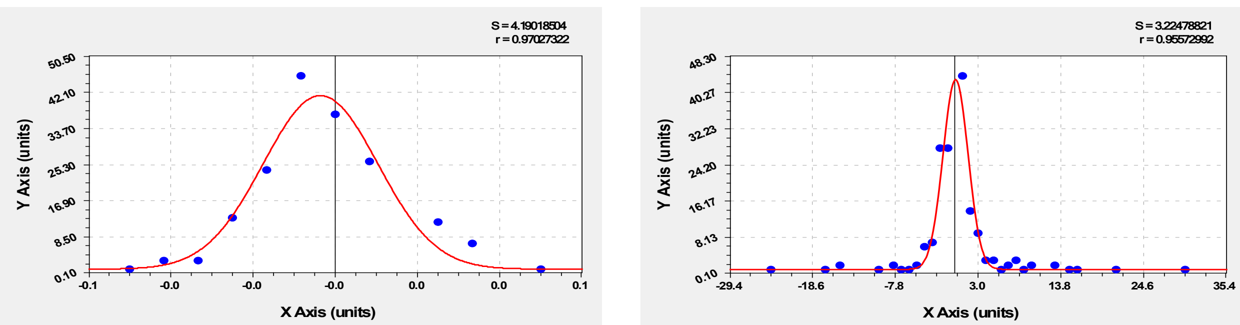
6.5 Influence of Solar Activity Cycles on Temperature Dynamics

Let us briefly consider the relationship of the model parameter (1) a_{5i} with solar cycles (the cycle of revolution of the Sun's core around itself is on average 22.6 years and the cycle of solar activity according to Wolf numbers is on average 11.3 years).

The first three fluctuations, according to Table 4, apparently have cosmic influences outside the solar system. And the fourth term has an initial cycle in 1820 equal to 2 × 12.59928 ≈ 25.2 years, which corresponds to the revolution cycle of the Sun's core. Then it turns out that over time, the Earth's atmosphere, due to the high plasticity of sliding, and the influence of eddies, reduces this initial cycle.

The fifth component has a cycle of 2 × 6.54983 ≈ 13.1 years, but with a negative sign. This initial value corresponds to the cycle of solar activity according to Wolf numbers. The next wavelet has half the cycle of solar activity.

The seventh wavelet at the beginning in 1820 had a one and a half year cycle. But the eighth term received a constant period of oscillation of four years. The next term has a three-year constant period. There are several wavelets No. 10, 12, 26, 43, 63 and 67 around the two-year constant biological cycle of the productivity of fruit trees and shrubs. The rest of the cycles, apparently, depend on the behavior of the Earth's atmosphere.



Absolute error (residuals) | Relative error, %

Figure 9. Graphs of the distribution of statistical indicators of temperature for 1820-2019.

7. Forecast of the Average Annual Temperature of Irkutsk

7.1 Calculation Example in Excel Taking into Account Significant Figures

The parameters of the model with five significant figures given in Table 4 turned out to be insufficient in direct calculations.

In this regard, all 11 significant figures were accepted, for example, the fourth term:

User-Defined Model: y=–a*exp(–b*x)*cos(pi*x/(c–d*x^e)+f)

Coefficient Data:

a = 2.03039345976E – 001

b = 3.92600098388E – 003

c = 1.25992844772E + 001

d = 2.80126347775E – 003

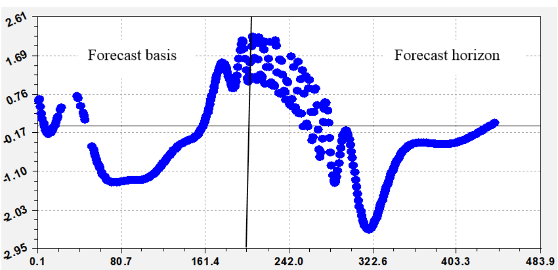
e = 1.14616905207E + 000

f = 1.90902374656E + 000

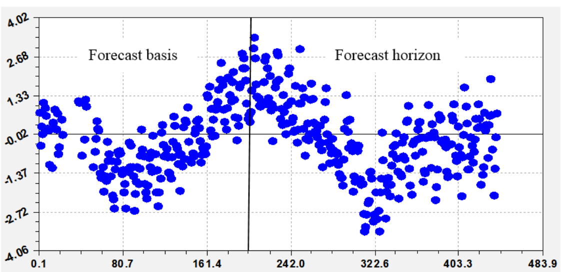
The calculation in Excel was performed on 3, 12 and 47 components of the general model (1).

7.2 Base and Forecast Horizon Charts 1820-2260

First, for the first three fluctuations from Table 4 with a correlation coefficient of 0.8126 (the level of adequacy is "a strong factorial relationship" with a correlation coefficient of at least 0.7), a graph was plotted in the range from 1820 to 2260, which is shown in Figure 10. Then the graph is built on the first 12 components of the general model (1).



a) by the first three wave components



b) by 12 first wave components

Figure 10. Graphs of the dynamics of the average annual temperature of Irkutsk for 1820-2260.

And Figure 11 shows a graph of the forecast for all 47 members for 2020-2220. At the same time, due to the exclusion of past finite-dimensional wavelets, it is impossible to build a graph for all members to base the forecast 1820-2019. For a complete graph, it is necessary to build according to the calculation of all 86 members of the general model (1).

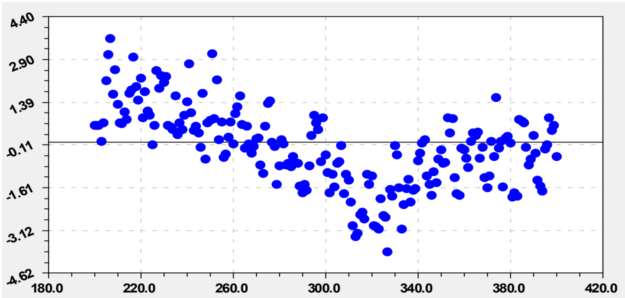


Figure 11. Graph of the forecast horizon for the average annual temperature of Irkutsk for 2020-2220.

It can be seen from the three graphs that with an increase in the number of terms (1), the spread of the average annual temperature ordinate increases: for three terms, the temperature interval along the ordinate axis is from –2.95 °C to 2.61 °C; for 12 members from –4.06 °C to 4.02 °C; for the forecast for the period 2020-2220 from –4.62 °C to 4.40 °C.

As can be seen from the three-term graph, from 2020 to 2080, there will be a strong decrease in temperature with a very strong tremor. The average temperature in Irkutsk has been above zero since 1980. At the same time, 12 components already give an interval forecast. According to 47 wavelets from Figure 11, it can be seen that until 2040 there will be a wave of oscillatory climate disturbance with a strong amplitude according to the data of the Irkutsk meteorological station.

7.3 Verification of the Average Annual Temperature Forecast

Due to strong climate fluctuations and the possibility of more and more fluctuations from factors influencing the average annual temperature (accordingly, new finite-dimensional fluctuations appear), the forecasting process can only be iterative, for example, after the data for each year become available. To do this, it is possible to annually re-identify all 86 members of the general model (1). In this case, additional fluctuations may appear.

To what extent can we trust the forecast data up to 2220? Of course, with the distance from 2019, the probability of a good forecast will significantly decrease.

Such differences in the average annual temperature in Irkutsk are formed with periodicity: –0.10 °C (2045);

–2.53 °C (2047); –0.26 °C (2056). Then there will be differences: 3.11 °C (2071); –0.54 °C (2076); 1.63 °C (2083). From 2120, global cooling will begin in Irkutsk, as it was in the period 1870-1980 (the cycle is 110 years).

Thus, the current global warming will be replaced by global cooling. The climate system on the example of Irkutsk is undergoing oscillatory adaptation to changing external influences. For such short cycles of 2040 – 1980 = 60 years of warming, the vegetation cover will not have time to undergo fundamental changes even in the species composition of plants. This requires millennium cycles, but trees have adapted to such cycles for 400 million years of evolution, and grass for more than 100 million years of development. Then it turns out that the vegetation on the territory is quickly changed by man with his predatory activity and the indefatigable doctrine of the conquest of nature.

7.4 Relative Forecast Error for 2020-2021

Table 6 shows the actual and calculated according to the forecasts by three, 12 and 47 components of the average annual temperature in Irkutsk.

Table 6. Verification of the average annual temperature of Irkutsk for 1820-2021.

Year	Time τ, year	Fact t, °C	Design temperature			Fact - calculation			Error Δ, %		
			3	12	47	3	12	47	3	12	47
2019	199	2.1	1.73	1.86	2.02	0.37	0.24	0.08	17.62	11.43	3.81
2020	200	2.8	1.75	1.06	0.58	1.05	1.74	2.22	37.50	62.14	79.3
2021	201	1.6	1.77	0.52	0.60	-0.17	1.08	1.00	-10.63	67.50	62.5

Three quantum powers (3, 12 and 47 components) of modeling the dynamics of the average annual temperature of Irkutsk by the model identification method (1) show different relative errors. For a model with 47 members in the last year of the time series, 2019, a relative error was obtained. But the next two years, due to the high sensitivity of the model, give a high error of 79.3%. Then a large number of wavelets are redundant. For a model with 12 terms, the maximum error is 67.50% for 2021. For outlooks, a simple three-term model is possible. The modeling error, as in ecological studies, here is mainly within 30%.

8. Conclusions

In the biophysics of the atmosphere, according to long-term data since 1820, it has been proven that the dynamic series of the average annual temperature, using the example of Irkutsk, is decomposed into 86 asymmetric wavelets up to the measurement error. As a result, the fractality of the decomposition of the temperature of the surface air layer over 200 years into individual behavior quanta is clearly visible. At the same time, the frequency of fluctuations will not be able to cause serious changes in the species composition of the vegetation cover. In addition, for an approximate forecast, a model containing only the first three terms of the quantum expansion turned out to be sufficient.

The revealed patterns of the average annual temperature of Irkutsk from 1820 to 2019 made it possible to positively answer the statement that the IPCC reports cannot provide a complete and detailed picture of regional assessments of climate change. Of all the weather stations in Russia, it is necessary to select those that have a temperature series length of at least 175 years, that is, the first temperature measurements were made no later than 1845. Then such series should be identified for other regions of the world with different classes of soil cover according to the UN classification.

A criterion is proposed in dynamics—the sum of temperatures, which is a measure of the average kinetic energy of the translational motion of molecules in a 2 m layer above the land surface. However, this indicator requires the continuity of the dynamic series, therefore, for Irkutsk, the sum of temperatures could be accepted only from 1873. Then the basis of the forecast is 2019 – 1873 = 146 years. The first three components gave a very high correlation coefficient of 0.9996 and the forecast for the five components until 2165 showed a trend towards a certain limit of the sum of the mean annual temperature.

The second proposed indicator is a moving average, calculated as the ratio of the sum of temperatures to the current time. The first three wavelets gave a correlation coefficient of 0.9962. However, a small forecast base does not make it possible to predict.

In the dynamics from 1820 to 2019, 86 wavelets were received, of which 47 oscillations affect the future. Then it turns out that the dynamic temperature series has a high quantum certainty, and this makes it possible to quantize the change in the average annual temperature of Irkutsk by 86 oscillations up to a measurement error of $\pm$0.05 °C. The identification process occurs as a complete wavelet analysis. The basis of the forecast in 200 years made it possible to replace the non-linear two-term trend with an oscillatory temperature perturbation. As a result, the first three fluctuations gave the level of adequacy "strong relationship" with a correlation coefficient of 0.8126, which is much higher than the required level of 0.7 strong adequacy.

With an increase in the number of model members (1), the ordinate of the average annual temperature increases: for three members, the temperature interval along the ordinate axis is from –2.95 °C to 2.61 °C; for 12 members, from –4.06 °C to 4.02 °C; for the forecast for the period 2020-2220, from –4.62 °C to 4.40 °C. As can be seen from the three-term graph, from 2020 to 2080, there will be a strong decrease in temperature with a very strong tremor of temperature values. The average annual temperature in Irkutsk has been above zero since 1980. At the same time, 12 components already give an interval forecast. According to 47 wavelets from Figure 10, it can be seen that until 2040 there will be a wave of oscillatory climate disturbance with a strong amplitude.

Thus, the current global warming will be replaced by global cooling. The climate system, using the example of Irkutsk, undergoes oscillatory adaptation to changing external influences. For such short cycles of 2040 – 1980 = 60 years of warming, the vegetation cover will not have time to undergo fundamental changes in the species composition of plants.

Conflict of Interest

There is no conflict of interest.

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