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ARTICLE

Asymmetric Mean Annual Temperature Wavelets Surface Air Layer of Berlin for 1701–2021

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ABSTRACT

The regularities of the dynamics of the average annual temperature of Berlin from 1701 to 2021 are revealed. A total of 65 wavelets were received. The temperature has a high quantum certainty, and the change in the average annual temperature of Berlin was identified by a model that contains only two components for prediction. The basis of the forecast at 320 years makes it possible to look into the future until the year 2340. The forecast confirms the conclusions made in the CMIP5 report on global warming. With an increase in the number of components in the model up to five, the forecast is possible only until 2060. Therefore, the model with only two components is workable. The trend is characterized by a modified Mandelbrot equation showing exponential growth with a high growth rate of 1.47421. The wave equation also has an amplitude in the form of the Mandelbrot law (in mathematics, the Laplace law, in biology, the Zipf-Pearl law, in econometrics, the Pareto law), when the exponential growth activity is equal to 1. For 1701, the period of oscillation was $2 \times 60.33333 \approx 120.7$ years. By 2021, the period decreased and became equal to 87.6 years. The trend is such that by 2340 the period of oscillation will decrease to 30.2 years. Such an increase in fluctuations indicates an imbalance in climate disturbances in temperature in Berlin. For Berlin, the last three years are characterized by sharp decreases in the average annual temperature from 11.8 °C to 10.5 °C, i.e. by 12.4% in 2021. Therefore, the forecast is still unstable, as a further decrease in the average annual temperature of Berlin in the near future may change the picture of the forecast.

1. Introduction

In the 21st century, global average temperatures are very likely 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 [1]. However, if the temperature decreased during the ice ages, then why should the forecasts in different regions of the Earth be the same? In any case, the influence of the warm

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upper layers of the atmosphere over the Atlantic should affect the slow increase in the average annual temperature not only in the territory of Central England [2], but also at the continental meteorological station of Berlin.

Monthly and annual temperature differences and their changes were considered, for example, in article Ding J., et al. [3] on the Tibetan plateau and its environs for 1963–2015.

The earth warmed at an unprecedented rate during the 1980s and 1990s, and the rapidity of the warming coincided with a 65-year cycle. 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 variability [4]. Then it is impossible to draw conclusions from the short length of the dynamic temperature series. We need data for at least 175 years.

The intensity of Moscow's heat island has intensified despite the pause in global warming. It was found that the heat 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, humidity is released in the lower part of the heat island [5]. In large cities, in addition, the temperature of the surface air layer increases due to the growth of the heat island over the years.

The unprecedented intensification of extreme weather events in recent years motivates research to understand long-term climate change [6]. But this uses averaged data, for example, for 10 years. Therefore, in many studies, transformed series of measurements are used. Mathematical methods are limited only to linear trends and strong data averaging. As a result, the so-called identification of the climate pattern occurs.

Comparison of the surface air temperature variability in three coupled integrations of the "ocean-atmosphere" model over 1000 years is also performed according to linear trends [7]. But land surface temperature measurements are 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. There comes an awareness of the need to identify directly primary data by wave equations without tricks by their groupings.

As a result, time series of global or regional surface air temperatures are of fundamental importance for climate change studies [8].

We carried out a wavelet analysis of the annual dynamics of the maximum temperature from 1878 to 2017 according to the Hadley Center for Central England Temperature (Hadcet) [9].

The sun heats the Earth unevenly: the equator gets more, the poles get smaller. This temperature gradient is one of the main forces that drives 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, the ocean acts as a battery: taking heat from the Sun and heating up, it then shares it with the air [10].

The climate is strongly influenced by solar activity [11]. The influence of solar activity on the temperature of the troposphere and the surface of the ocean proves the following conclusion [12]. According to Zherebcov G.A. et al., "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."

The purpose of the study is to identify asymmetric wavelets of the dynamics of the mean annual temperature in Berlin from 1701 to 2021 by the identification method [12-17], as well as to analyze the warming trends in Berlin until 2340 with a different number of wavelets.

2. Materials and Methods

For the possibility of modeling the dynamics of the average annual temperature by a set of wave equations, the initial time is taken $\tau_0 = 0$ for 1701. For modeling the dynamics, a series of average annual temperatures is 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).

The surface average annual temperature series for Berlin were taken from the site http://www.pogodaiklimat.ru/history/10384.htm (Accessed 04/01/2022).

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 Berlin.

For 1701, data are not available for all months, so there is no average annual temperature.

In Table 1 there are 292 values in total with some gaps out of 28 values. As you know, the measurement error decreases over the years due to the increase in the accuracy of thermometers.

Success in physics is largely determined by the use of mathematics. Physicists often create the necessary mathematical apparatus themselves [18].

We have developed a method for identifying successively a set of regularities in the form of asymmetric wavelet signals. This set is essentially a general algebraic (trigonometric) equation according to Rene Descartes. In this case, each component becomes a separate quantum of behavior of the surface air temperature.

Table 1. Berlin temperature

Year	Time τ , year	Temperature t , °C
1701	0	-
1702	1	6.8
1703	2	7.4
1704	5	7.0
1705	6	6.9
1706	7	6.2
…	…	…
2017	316	10.6
2018	317	11.7
2019	318	11.8
2020	319	11.7
2021	320	10.5

Oscillations (asymmetric wavelet signals) are generally written by the wave formula [12-16] of the form:

$$y_i = A_i \cos(\pi x / p_i - a_{8i}) ,$$
$$A_i = a_{1i} x^{a_{2i}} \exp(-a_{3i} x^{a_{4i}}) ,$$
$$p_i = a_{5i} + a_{6i} x^{a_{7i}} , \quad (1)$$

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), $a_1 \ldots a_1$ 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 [15,16], 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 the average annual temperature in Berlin. According to these identified 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 the fluctuation. This will reveal the mechanisms of oscillatory climate adaptation at the point of the Earth.

3. Results and Discussion

Difficulties arose with the identification of the wave equation for the long period 1702–1850. At this time in Berlin there was a strong fluctuation in the average annual temperature. This indignation had a significant impact on the distant future. The results and their discussion are given by increasing the number of components of the general wave model (1). The next difficulty was the increase in the average annual temperature in 2018-2020 by 1.3 °C compared to 2021 (10.5 °C). In 2018, the average annual temperature was 10.6 °C. The beginning of the series, apparently, is irreparable, and the end of the series will have to wait a few years.

3.1 Two Components of the Dynamics of the Average Annual Temperature

3.1.1 Pattern

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

Initially, only two components of the model were identified (1). The arithmetic mean temperature was taken as the first component (Figure 1). This technique is justified by the large length of the dynamic temperature series of 320 years. If we immediately take a two-term trend as a pattern for identification, then it may turn out that a identification will occur. And the second component was taken as an infinite-dimensional wavelet containing the amplitude in the form of an exponential law.

From the trend graph, it can be seen that the correlation coefficient of the arithmetic mean temperature value is zero, but the maximum value of the standard deviation is 0.9455. However, the two components of the model (1) do not yet have a complete structure. Therefore, we further increase the construction of the equation (Table 2) by the parameters further and determine the limits of such construction.

Table 2 shows the design parameters of the general model (1) and the adequacy of the correlation coefficient, and Figure 2 shows a graph for these parameters.

The trend is characterized by a modified Mandelbrot equation showing exponential growth with a high growth rate of 1.47421. The wave equation also has an amplitude in the form of the Mandelbrot law (in mathematics, the Laplace law, in biology, the Zipf-Pearl law, in econometrics, the Pareto law), when the exponential growth rate is 1.

For 1701, the period of oscillation was $2 \times 60.33333 \approx$ 120.7 years. By 2021, the period has decreased and became equal to 87.6 years. The trend is that by 2340 the period of oscillation will decrease to 30.2 years. Such an increase in fluctuations indicates an imbalance in climate disturbances in temperature in Berlin.

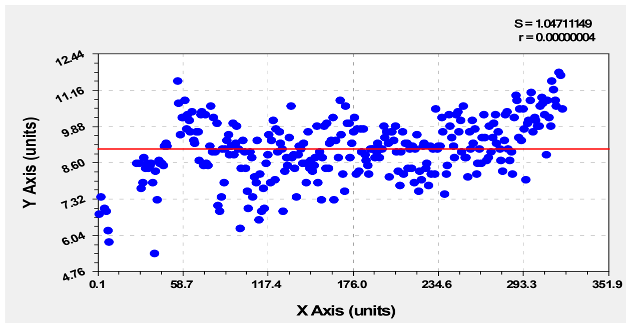
3.1.2 Distribution of Modeling Error

The number of points n_ε (pieces) in the intervals through 1 °C of the relative error $[\varepsilon]$ (%) is given in Table 3.

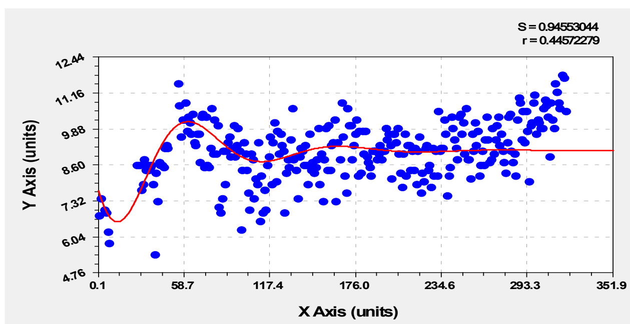
Three dots are excluded here (–36 two dots and –59 one dot).

Then the error changes according to the Gauss law (Figure 3) in the form of the equation:

$$n_\varepsilon = 13.3322\exp(-0.0062225([\varepsilon]-1.69821)^2)\,. \qquad (2)$$



Trend as arithmetic mean



Trend and Infinite Wavelet

Figure 1. Preliminary graphs of temperature dynamics in Berlin for 1701–2021.
(in the upper right corner: S – standard deviation; r – correlation coefficient)

Table 2. Parameters of the dynamics of average annual temperatures in Berlin for 1701–2021

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	8.42480	0	–3.45328e-5	1.47421	0	0	0	0	0.5933
2	–2.02059	0	0.011180	1	60.33333	–0.0038429	1.45095	0.42159	

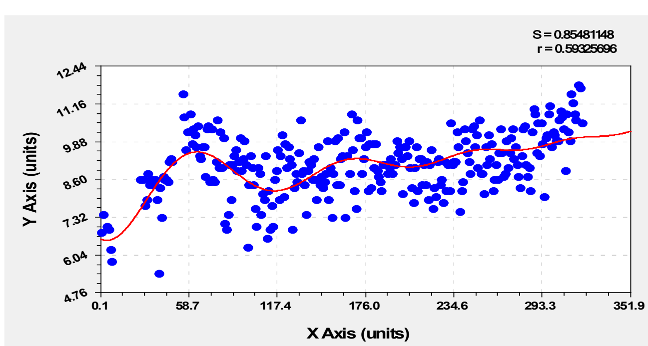
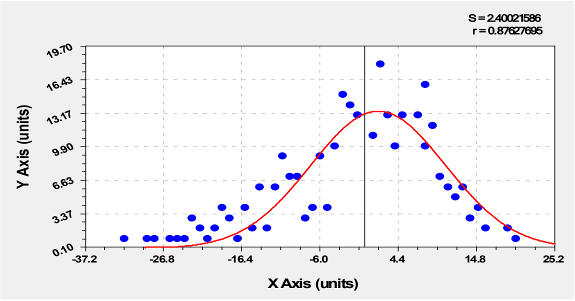


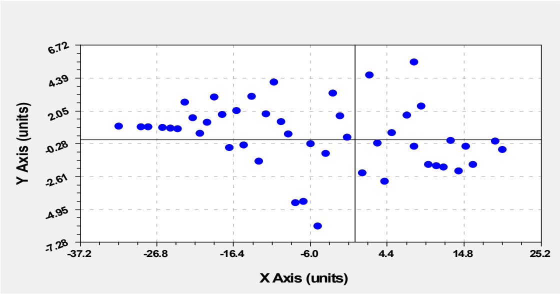
Figure 2. Graph of the dynamics of the average annual temperature in Berlin for 1701–2021

Table 3. Distribution of the relative error of the model according to Table 2 by intervals

Interval [ε], °C	Quantity n_ε, шт.	Interval [ε], °C	Quantity n_ε, шт.	Interval [ε], °C	Quantity n_ε, шт.	Interval [ε], °C	Quantity n_ε, шт.
20	1	8	10	–7	4	–19	4
19	2	5	13	–8	3	–20	2
16	2	4	10	–9	7	–21	1
15	4	3	13	–10	7	–22	2
14	3	2	18	–11	9	–23	3
13	6	1	11	–12	6	–24	1
12	5	–1	13	–13	2	–25	1
11	6	–2	14	–14	6	–26	1
10	7	–3	15	–15	2	–28	1
9	12	–4	10	–16	4	–29	1
8	16	–5	4	–17	1	–32	1
7	13	–6	9	–18	3	-	-



Relative error



Remainders of Equation (2)

Figure 3. Graphs of the distribution of relative error and residuals from the model (2)

The normal distribution law is observed with the adequacy of 0.8763.

3.1.3 A Look into the Future until 2340

The forecasting theory assumes that the forecast horizon is maximally equal to the length of the forecast base. By direct calculations in the Excel software environment using the formula from Table 2, the graph shown in Figure 4 was obtained. The graph shows that for the period 2021–2340 the average annual temperature is increasing. This confirms the CMIP5 prediction [1].

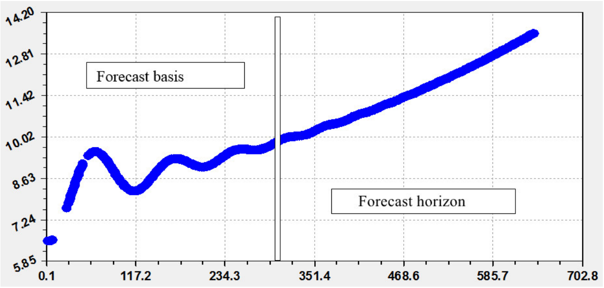


Figure 4. Forecast graph up to 2340 for the model with two components

Next, we increase the number of wavelets in the general model (1) to five.

3.2. General Formula (1) with Five Components

3.2.1 Features of CurveExpert-1.40

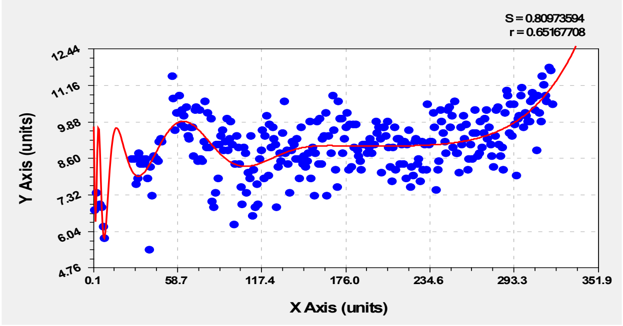
Subsequently, the identification method was used to increase the asymmetric components until five components were reached (Table 4 and Figure 5). The first four components were placed together in the CurveExpert-1.40 software environment, and the fifth component was identified separately.

Table 4. Parameters of the Berlin mean annual temperature dynamics model for 1701–2021

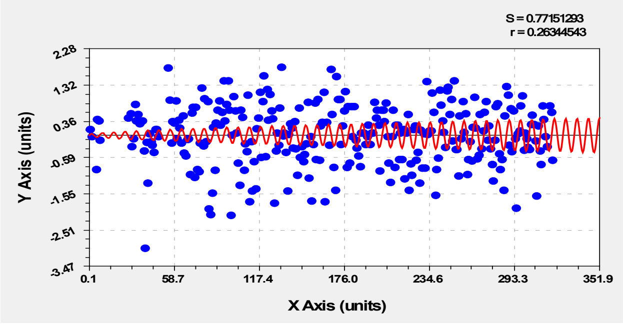
i	Asymmetric wavelet $y_i = a_{1i}x^{a_{2i}} \exp(-a_{3i}x^{a_{4i}})\cos(\pi x / (a_{5i} + a_{6i}x^{a_{7i}}) - a_{8i})$								Coef. correl. *r*
	Amplitude (half) oscillation				Half cycle oscillation			Shift	
	a_{1i}	a_{2i}	a_{3i}	a_{4i}	a_{5i}	a_{6i}	a_{7i}	a_{8i}	
1	10.70443	0	–0.00098192	1	0	0	0	0	0.6819
2	–3.70801	0	0.00044630	1.80931	84.54606	–17.31516	9.13583	0.82444	
3	–1.63401	0	–0.0055698	1.17114	1.38827	0.17453	1.01460	–3.93651	
4	0.0045885	0	–1.99283	0.14237	3.89621	0	0	1.04925	
5	1.0182e-28	14.28439	0.045726	105821	105.6803	–0.20700	1.00480	–3.91402	0.1647

The level of adequacy with a correlation coefficient of 0.6819 almost approached 0.7, that is, a strong relationship between time and average annual temperature in Berlin. An equation with three components gets a correlation coefficient of 0.6517. Having fixed the degrees in the form of numbers, the fourth component is additionally introduced. The correlation coefficient increased to 0.6819.

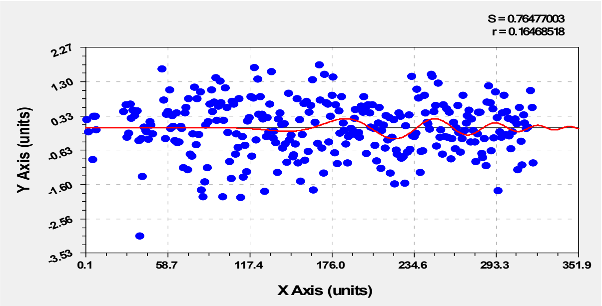
An additional fifth component gives a correlation coefficient of only 0.1647 (Figure 5). Therefore, starting from the sixth component, the remaining wavelets do not give fundamental changes in the model. However, due to the quantum certainty of the dynamic series of mean annual temperature, it becomes possible to identify up to the 65th component of the general model (1). We did not bring the wavelet analysis up to the measurement error of ±0.05 °C, because already with the second component, the rest of the wavelets do not have a significant impact on the future.



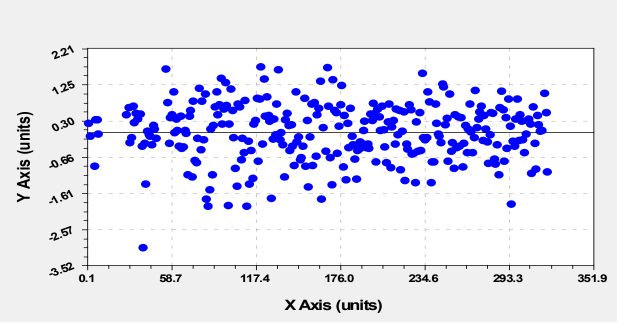
Equation (1) with three components



Fourth component



Fifth component



Residuals after the fifth component

Figure 5. Graphs of the dynamics of the average annual temperature in Berlin for 1701–2021

Figure 6 shows a general graph for the four components.

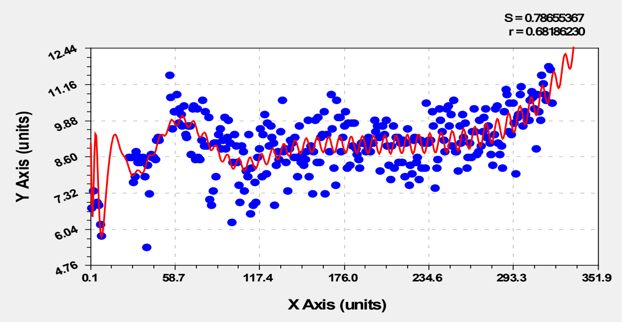


Figure 6. Graph of the average annual temperature in Berlin in four components

Why can a dynamic series be decomposed into a large number of wavelets? However, a small number of the first components are taken for forecasting? So far, we do not have answers to these questions.

From the graph in Figure 6, it can be seen that since 1701 the tremor period has increased. Therefore, it would be very interesting to have a number from 1650. In 1759–1760, the temperature in Berlin rose to almost 11.5 °C. From the data in Table 1 it can be seen that the temperature became slightly higher only in 2018–2020. Then, in 2021, the temperature dropped to 10.5 °C. Therefore, we need to wait a few more years for the dynamic series to be determined.

3.2.2 Distribution of Modeling Error

With five components, the number of points n_ε (pieces) in intervals through 1 °C of the relative error [ε] (%) of modeling is given in Table 5.

Then the error changes according to the Gauss law (Figure 7) with the addition in the form of an asymmetric wavelet according to the equation,

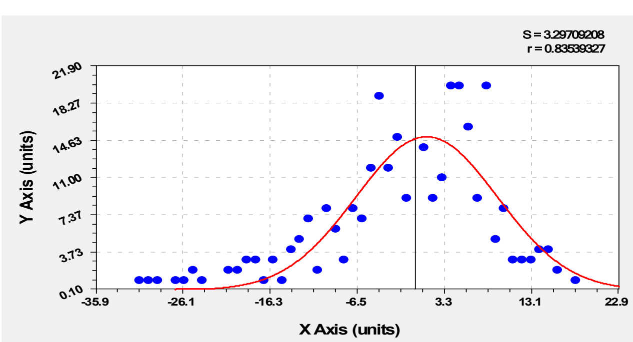
$$\begin{aligned} n_\varepsilon = {} & 13.89770\exp(-0.0065317([\varepsilon]-1.35123)^2) \\ & -1.06484\cdot 10^{-31}([\varepsilon]+40)^{25.83643}\exp(-0.41488([\varepsilon]+40)^{1.08061}) \\ & \times\cos(\pi([\varepsilon]+40)/(1.82689+0.0012950([\varepsilon]+40)^{1.69907}) \\ & -0.016560) \end{aligned} \quad (3)$$

The correlation coefficient of the trend in the form of the Gaussian law of the normal distribution is 0.8354, and with the addition of a wavelet according to formula (3) it is 0.9018. Then it turns out that not only the average annual temperature changes according to the equations of oscillatory adaptation, but also the relative modeling errors have a wave character. It is applied in addition to the Gaussian law of the normal distribution.

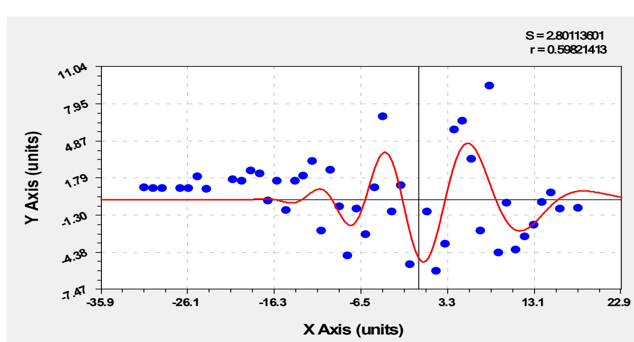
Table 5. Model error distribution from Table 4 with five components

Interval [ε], °C	Quantity n_ε, шт.	Interval [ε], °C	Quantity n_ε, шт.	Interval [ε], °C	Quantity n_ε, шт.	Interval [ε], °C	Quantity n_ε, шт.
18	1	5	20	–8	3	–20	2
16	2	4	20	–9	6	–21	2
15	4	3	11	–10	8	–24	1
14	4	2	9	–11	2	–25	2
13	3	1	14	–12	7	–26	1
12	3	–1	9	–13	5	–27	1
11	3	–2	15	–14	4	–29	1
10	8	–3	12	–15	1	–30	1
9	5	–4	19	–16	3	–31	1
8	20	–5	12	–17	1	–57	1
7	9	–6	7	–18	3	-	-
6	16	–7	8	–19	3	-	-

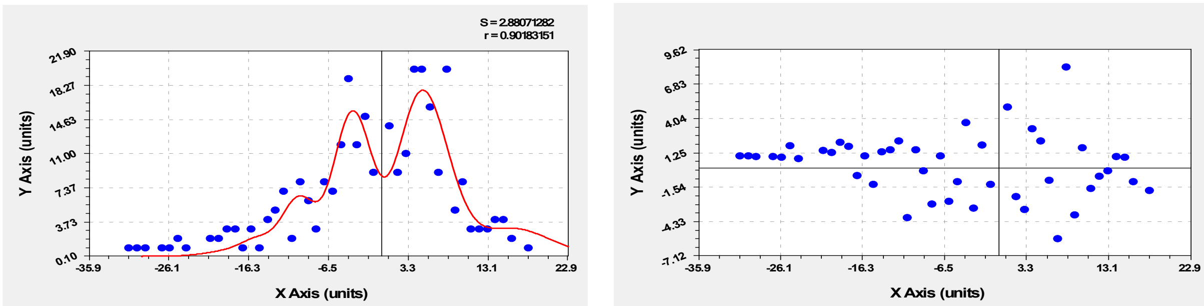
Note: Due to the sharp selection from the series, the last point is excluded.



Error according to the well-known Gauss law



Asymmetric Error Wavelet



The sum of the Gauss law and the wavelet — Leftovers after model (3)

Figure 7. Graphs of the distribution of the relative error from the model from Table 4

3.2.3 Prediction according to Equation (3)

According to the equations from Table 4 in Figure 8, a graph is built. After 2022, it rises sharply. This happens because of the different signs of the components of the general model (1).

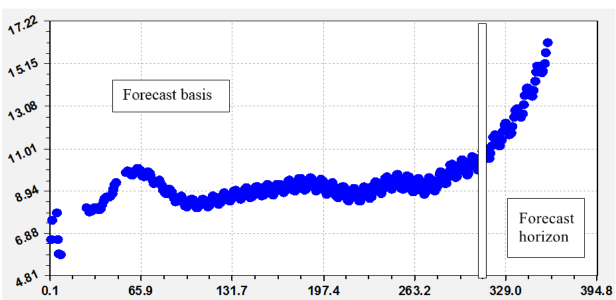


Figure 8. Prediction graph for the five equations of mean annual temperature until 2060

Then it turns out that, as quantums of behavior, the average annual temperature of Berlin is decomposed into 65 components, and the forecast can only be made using the first two formulas from Table 2. The climate of Berlin is significantly influenced by warm air currents over the Atlantic Ocean, which has an oscillatory character.

4. Conclusions

The revealed regularities of the average annual temperature of Berlin from 1701 to 2021 made it possible to positively answer the statement that the model with two components gives continuous growth, which is consistent with the conclusions of the IPCC report on global warming. However, we believe that in the depths of the Eurasian continent, due to the opposition of various mountain ranges to air flows from the Atlantic, there may be other trends aimed at global cooling.

In this regard, it is necessary to study the patterns and other regional assessments of climate change. For Berlin, the last three years are characterized by sharp decreases in the average annual temperature from 11.8 °C to 10.5 °C, that is, by 12.4% in 2021. Therefore, the forecast is still unstable, since a further decrease in the average annual temperature of Berlin in the near future may change the whole picture according to many models.

Conflict of Interest

There is no conflict of interest.

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