QUASI-BICENTENNIAL VARIATION IN TEMPERATURE IN THE EARTH'S NORTHERN HEMISPHERE

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Abstract. Eight Northern Hemisphere temperature reconstructions covering time intervals of 1192–2016 years were analyzed using Fourier and wavelet analysis and principal component analysis. A hemispheric-scale cyclicity with a period of 170–250 years was found, manifested over the past 1000 years. It was shown that this variation may have a certain contribution to the warming in the first half of the 20th century. However, the last 4–5 decades are most likely a period of decline in this cycle. Although the period of the detected variation is close to the period of the Suess solar cycle, no connection between the temperature and solar cyclicities could be found. Possible sources of the detected bicentennial periodicity are discussed.

Keywords: *solar-climatic relationship, solar cycles, paleoclimatology*

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1. INTRODUCTION

Global climate change, because of its great impact on all aspects of human activity, has become one of the most important problems of modern environmental science. One of the main challenges of studying global climate change is to recognize those changes that are caused by external forcings. For example, identifying the anthropogenic contribution to the global warming of the past 120 years is an important scientific challenge. The main difficulty in such an analysis is related to the brevity of the available instrumental series. Direct temperature measurements usually cover no more than the last 100-150 years, so they are too short to establish limits amplitude of long-term (multidecadal and longer) variations of climatic parameters. Paleoclimatology, which has been actively developed in recent years, makes it possible to overcome these difficulties. The use of long-term climate reconstructions provides an opportunity to expand our knowledge of secular climate change. Current long-term climate reconstructions obtained using natural archives cover the last few millennia. These series reconstruct up to 65% of the temperature variance on multidecadal time scales [Barnett et al., 1996; Briffa, 2000]. Thus, they are a potential source of information on climate change with periods of a hundred years or more. Dendrochronology is the most reliable source of information on past temperature because tree rings provide year-to-year temporal resolution and accurate dating of climate signals. One of the key problems in dendroclimatology is that the standardization procedure - removing the biological trend - can suppress long-term changes and thus inhibit the recovery of medium- and low-frequency variability. However, recent advances in standardization methods allow much more low-frequency climate information to be retained. Therefore, modern temperature reconstructions have become suitable for analyzing both secular and longer-term variations in climate parameters.

Over the last 15 years, a number of evidences of the existence of a two-century (a period of about 200 years) variability of the Earth's climate have been obtained. This variation has already been identified in (*a*) temperature in Central Asia [Raspopov et al., 2008], (*b*) temperature in northeastern Alaska [Ogurtsov et al., 2016], (*c*) monsoon precipitation on the Qinghai-Tibetan Plateau [Liu et al., 2009], (*d*) monsoon precipitation in South America [Novello et al., 2016], (*e*) temperature in the Southern Hemisphere [Ogurtsov, 2022a, b]. Breitenmoser et al. [2012] analyzed a set of seventeen dendrochronological reconstructions covering almost the entire globe and found bicentennial variation in ten of them. The researchers' interest in the bicentennial variation in climate data is due to the fact that a similar bicentennial variation, the Suess cycle (or de Vries cycle) with a period of 170-260 years [Ogurtsov et al., 2002], is observed in solar activity. This paper is devoted to the search for hemispheric-scale quasi-biennial temperature variations. It considers the most recent reconstructions of the Northern Hemisphere temperature covering time intervals of 1192-2016 years.

2. METHODS

This paper utilized the longest modern reconstructions of various types based on a variety of temperature indices, including annual ring width (TRW), maximum latewood density (MXD), stable isotope $\delta^{18}O$ concentration in terrestrial records, pollen data (P), temperature measured in boreholes (BT), melted ice layer thickness (IM), ice accumulation rate (AC), banded lake sediments (VS), and documentary information (D). These series span at least several 200-year cycles and include (*a*) reconstructions based on annual ring thickness data [Esper et al., 2002; Schneider et al., 2015; Wilson et al, 2016], (*b*) multireconstructions that include both annual ring width data and other types of data [Moberg et al., 2005; Christiansen and Ljungqvist, 2012; Guillet et al., 2017; Büntgen et al., 2021], (*c*) the multireconstruction of Loehle [2007] in which dendrodata were not used. The selected series reconstruct the temperature of different seasons in the Northern Hemisphere during 1192-2016 years. These time series are shown in Fig. 1 and described in Table 1. They were obtained by generalizing to several thousand individual temperature indicators.

Fig. 1.

Table. 1.

Figure 1 clearly demonstrates that almost all of the selected paleoreconstructions of temperatures contain multidecadal variations. This proves the ability of these series to reconstruct long-term variations and their suitability for studying two-century periodicity.

Spectral properties of the analyzed time series were studied using wavelet and Fourier analysis. Fourier spectra were normalized by the variance (see Torrence and Compo [1998]). Wavelet spectra obtained using the Morlet complex basis were normalized to a confidence level of 0.95, calculated for red noise with the appropriate AR(1) factor according to [Torrence and Compo, 1998]. Because the strong long-term (multi-year and longer) variations contained in most of both solar and climate series can seriously complicate the analysis of shorter-term variations, 2nd order polynomial trends were pre-subtracted from all data series used in this work. Principal component analysis (PCA) was used to assess the variations dominating the set of temperature reconstructions used. The first principal component (PC1), a linear combination of the original observed variables that captures the maximum part of variance of this data set, was also subjected to spectral analysis using wavelet analysis and Fourier methods.

To isolate quasi-twenty-year cycles, all temperature series were subjected to wavelet filtering in a band of scales 171 - 259 years using the valid MHAT (Mexican Hat) basis (see [Torrence and Compo, 1998]). The significance of the correlation between the series filtered in a given band was assessed using a statistical experiment involving a set of Monte Carlo draws. Each draw contained: (*a*) generation of random copies of the analyzed signals by randomizing the phases of their Fourier transforms, (*b*) wavelet filtering of the random copies in the range of 171-259 years, (*c*) calculation of the correlation coefficient between two filtered random copies and comparing them with the correlation coefficients between the filtered real series.

3. RESULTS

The Fourier spectra and global wavelet spectra of the temperature reconstructions are shown in Fig. 2 and Fig. 3.

Fig. 2.

Fig. 3.

As follows from Figs. 2 and 3, the variation with a period of 180-270 years is present in the spectra of all Northern Hemisphere temperature reconstructions, although it is weakly expressed in the series [Moberg et al., 2005] and [Loehle, 2007]. Thus, the spectral analysis of the eight temperature reconstructions spanning 1192-2016 shows the presence of a two-hundred-year variation in Northern Hemisphere temperature. The first principal component of Northern Hemisphere temperature during the period 800 - 1973, recovering 55% of the total variance, is shown in Fig. *4*a.

Fig. 4.

Fig. *4b* shows an obvious peak with a period of 189 years. The Fourier spectrum (Fig. *4c*) allows us to identify significant peaks with periods of 190 and 86 years. Thus, the spectral analysis of the first principal component confirms the presence of a bicentennial periodicity in the Northern Hemisphere temperature. The local wavelet spectrum shows that this variation is more pronounced in the period 800-1000 AD and after 1600 AD.

The correlation coefficients between the data series wavelet-filtered in the bicentennial band are shown in Table 2 along with their significances (in parentheses). Correlations were calculated on time intervals common to both series, e.g., 17-1973 AD for the [Christiansen and Ljungqvist , 2012] and [Loehle, 2007] series, 800-2002 AD for the proxies [Schneider et al, 2015] and [Wilson et al., 2016], etc.

Table. 2.

As can be seen from Table 2, most of the two-century correlation coefficients are significant. Thus, the correlation analysis provides additional evidence for the presence of a quasi-bicentennial cyclicity in the Northern Hemisphere climate during the last 1-2 millennia. The correlation between the two-hundred-year variations in the eight Northern Hemisphere temperature reconstructions is shown in Fig. 5.

Fig. 5.

Figure 5 demonstrates the presence of moderate synchrony between the 200-year periodicities in the eight temperature reconstructions - some of the individual 200-year fluctuations are correlated and some are not. In general, this synchrony becomes more evident after the end of the 13th century, i.e. during the last 3-4 cycles. The average amplitude of the bicentennial temperature periodicity is 0.03-0.10°C (peak-to-minimum amplitude 0.06-0.20°C). However, individual fluctuations have a larger magnitude. For example, the temperature increase from the mid-19th century to the seventies of the 20th century reaches 0.10-0.35°C. The last 4-5 decades are the period of decline of this cycle.

4. CONCLUSIONS

Spectral and correlation analysis of eight temperature paleoreconstructions showed that there was a cyclicity with a period of 170-250 years in the climate of the Northern Hemisphere for more than a thousand recent years. This conclusion can be drawn from the study of temperature paleoreconstructions obtained by different methods and summarizing from 54 [Wilson et al., 2016] to hundreds [Schneider et al., 2015] and thousands [Büntgen et al., 2021] of individual temperature indicators of different types. Quasi-biennial variations are expressed in all eight series, but to different degrees. They may be a manifestation of a global rhythm of hemispheric scale, but it is still difficult to identify the actual form of this rhythm. This may be due to the fact that (*a*) modern paleoreconstructions of temperature cover only a small part of the Northern Hemisphere (see Fig. 1 [Christiansen and Ljungqvist, 2012] and Fig. 1 [Büntgen et al., 2021]), and (*b*) there are still problems in reconstructing long-term temperature variations. The differences occurring in the earlier period, before the 14th century, may be due to the fact that existing reconstructions less accurately reconstruct temperature in this epoch. Indeed, the number of individual temperature indices used in its reconstruction decreases significantly as one goes deeper into the past (see Fig. 2 in [Wilson et al., 2016]). It may be noted that in [Ogurtsov, 2022a], a variation with a period of about 250 years was also found in the Southern Hemisphere temperature. This means that the quasi-bicentennial periodicity may have a global character.

The average amplitude of the bicentennial temperature periodicity is 0.06-0.20°C. But some oscillations have a larger magnitude. Importantly, the quasi-bicentennial cycle can provide a temperature increase from the mid-19th century to the seventies of the 20th century of up to 0.35°C (Fig. *5e*). Thus, this variation may have some contribution to global warming in the first half of the twentieth century (see Fig. 5). However, the last 4-5 decades are likely to be a period of decline in this cycle. This makes the significant temperature increase in the Northern Hemisphere in the last 30-40 years even more anomalous and provides additional evidence that factors that did not operate in the past have made a significant contribution to this warming.

The cause of the quasi-biennial variation in Northern Hemisphere climate is not yet clear. Breitenmoser et al. [2012] suggested that the bicentennial climatic periodicity may be caused by: (*a*) internal intrinsic oscillations in the ocean− atmosphere system, (*b*) the influence of solar activity, and (*c*) volcanic effects. However, Ogurtsov [2024], who examined six solar activity reconstructions and eight paleoreconstructions of Northern Hemisphere temperature over intervals of 919-2015 years, found no significant correlation between the bicentennial cycles in temperature and solar activity. On the other hand, [Ogurtsov, 2024] studied four recent reconstructions of Northern Hemisphere temperature and two reconstructions of volcanic activity covering time intervals of up to 1500 years. Using Fisher's statistical test, evidence was obtained that a quasi-bicentennial temperature change is related to the corresponding cycle in volcanic activity. Thus, further studies are needed to identify the sources of the detected periodicity

To clarify the actual shape, amplitude, and spatial distribution of the 200-year temperature periodicity, it is desirable to obtain new long-term temperature reconstructions covering a significant number of two-century cycles. It can also be noted that the presence in the Earth's climate of its own natural variations with periods close to the periods of solar cycles, but not related to the activity of the Sun, can significantly distort the solar signals and complicate their detection. This may be one of the reasons why, despite the long searches for connection between the Earth's climate and solar activity, no conclusive evidence of the existence of such a connection has yet been obtained.

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Table 1. Northern Hemisphere temperature reconstructions used in this work

Source	Time interval	Response season	Geographical coverage	Data type
Esper et al. [2002]	831-1992	Warm season	Extratropical part of the hemisphere ($\Phi>30^0$ N)	Dendrodata (TRW)
Moberg et al. [2005]	1- 1979	Annual average	Northern Hemisphere	Multireconstruction (TRW, $\delta^{18}O$, P, BT, IM)
Loehle [2007].	16-1980	Annual average	Northern Hemisphere	Multireconstruction without dendrodata (BT, $\delta^{18}O$, P, Mg/Ca, VS, diatoms)
Christiansen and Ljungqvist [2012]	0-1973	Annual average	Extratropical part of the hemisphere ($\Phi>30^0$ N)	Multireconstruction (TRW, MXD, ^{18}O, VS, D, P, speleotempreatura)
Schneider et al. [2015]	600-2002	June-August	Extratropical part of the hemisphere ($\Phi>30^0$ N)	Dendrodata (MXD)
Wilson et al. [2016]	800-2010	May-August	Northern Hemisphere	Dendrodata (MXD)
Guillet et al. [2017]	500-2000	June-August	Northern Hemisphere	Multireconstruction (TRW, MXD, $\delta^{18}O$)

Buntgen et al. [2021]	1-2016	June-August	Northern Hemisphere	Dendrodata (TRW)

Table 2. Correlations between different temperature reconstructions filtered between 171 and 259 years

Source	Esper et al. [2002]	Moberg et al. [2005]	Loehle [2007].	Christiansen and Ljungqvist [2012]	Schneider et al. [2015]	Wilson et al. [2016]	Guillet et al. [2017]	Büntgen et al. [2021]
Esper et al. [2002]	-	0.40 (0.37)	0.28 (0.45)	**0.81** (0.009)	0.37 (0.61)	**0.68** (0.023)	0.16 (0.72)	**0.75** (0.009)
Moberg et al. [2005]	-	-	**0.49** (0.059)	**0.61** (0.001)	**0.51** (0.097)	**0.67** (0.012)	0.49 (0.57)	**0.67** (0.001)
Loehle [2007].	-	-	-	**0.45** (0.058)	**0.62** (0.024)	0.32 (0.43)	**0.61** (0.008)	0.23 (0.72)
Christiansen and Ljungqvist [2012]	-	-	-	-	**0.67** (0.046)	**0.87** (0.001)	**0.66** (0.017)	**0.76** $<10^{-3}$)
Schneider et al. [2015]	-	-	-	-	-	**0.50** (0.090)	**0.69** (0.012)	**0.71** (0.012)
Wilson et al. [2016]	-	-	-	-	-	-	0.45 (0.14)	**0.91** ($<10^{-3}$)
Guillet et al. [2017]	-	-	-	-	-	-	-	**0.64** (0.009)

Note. Numbers in parentheses show the significance of the correlation coefficient. Small bold figures show correlation coefficients with significance $p<0.10$, large bold figures - $p<0.05$.

Figure captions

Fig. 1. Northern Hemisphere temperature reconstructions used in this work: (*a*) - dendroreconstruction from Esper et al. [2002]; (*b*) - multireconstruction from Moberg et al. (2005]; (*c*) - multireconstruction not using dendrodata from Loehle [2007]; (*d*) - multireconstruction from Christiansen and Ljungqvist [2012]; (*e*) - dendroreconstruction from Schneider et al. [2015]; (*f*) - dendroreconstruction from Wilson et al. [2016]; (*g*) - dendroreconstruction from Guillet et al. [2017]; (*h*) - dendroreconstruction from Büntgen et al. [2021].

Fig. 2. Fourier spectra of temperature series: (*a*) - dendroreconstructions from Esper et al. [2002]; (*b*) - multireconstructions from Moberg et al. [2005]; (*c*) - multireconstructions from Loehle [2007]; (*d*) - multireconstructions from Christiansen and Ljungqvist [2012]; (*e*) - dendroreconstructions from Schneider et al. [2015]; (*f*) - dendroreconstructions from Wilson et al. [2016]; (*g*) - dendroreconstructions from Guillet et al. [2017]; (*h*) - dendroreconstructions from Büntgen et al. [2021]. Dotted lines are confidence level 0.95.

Fig. 3. Global wavelet spectra of temperature series: (*a*) - dendroreconstructions from Esper et al. [2002]; (*b*) - multireconstructions from Moberg et al. [2005]; (*c*) - multireconstructions from Loehle [2007]; (*d*) - multireconstructions from Christiansen and Ljungqvist [2012]; (*e*) - dendroreconstructions from Schneider et al. [2015]; (*f*) - dendroreconstructions from Wilson et al. [2016]; (*g*) - dendroreconstructions from Guillet et al. [2017]; (*h*) - dendroreconstructions from Büntgen et al. [2021]. Dotted lines are confidence level 0.95.

Fig. 4. (*a*) - First principal component of the eight PC1 temperature series; (*b*) - global Morlet wavelet spectrum of PC1 normalized to 0.95 confidence level; (*c*) - Fourier spectrum of PC1, dashed line is 0.95 confidence level.

Fig. 5. Temperature reconstructions wavelet-filtered between 171 and 259 years.

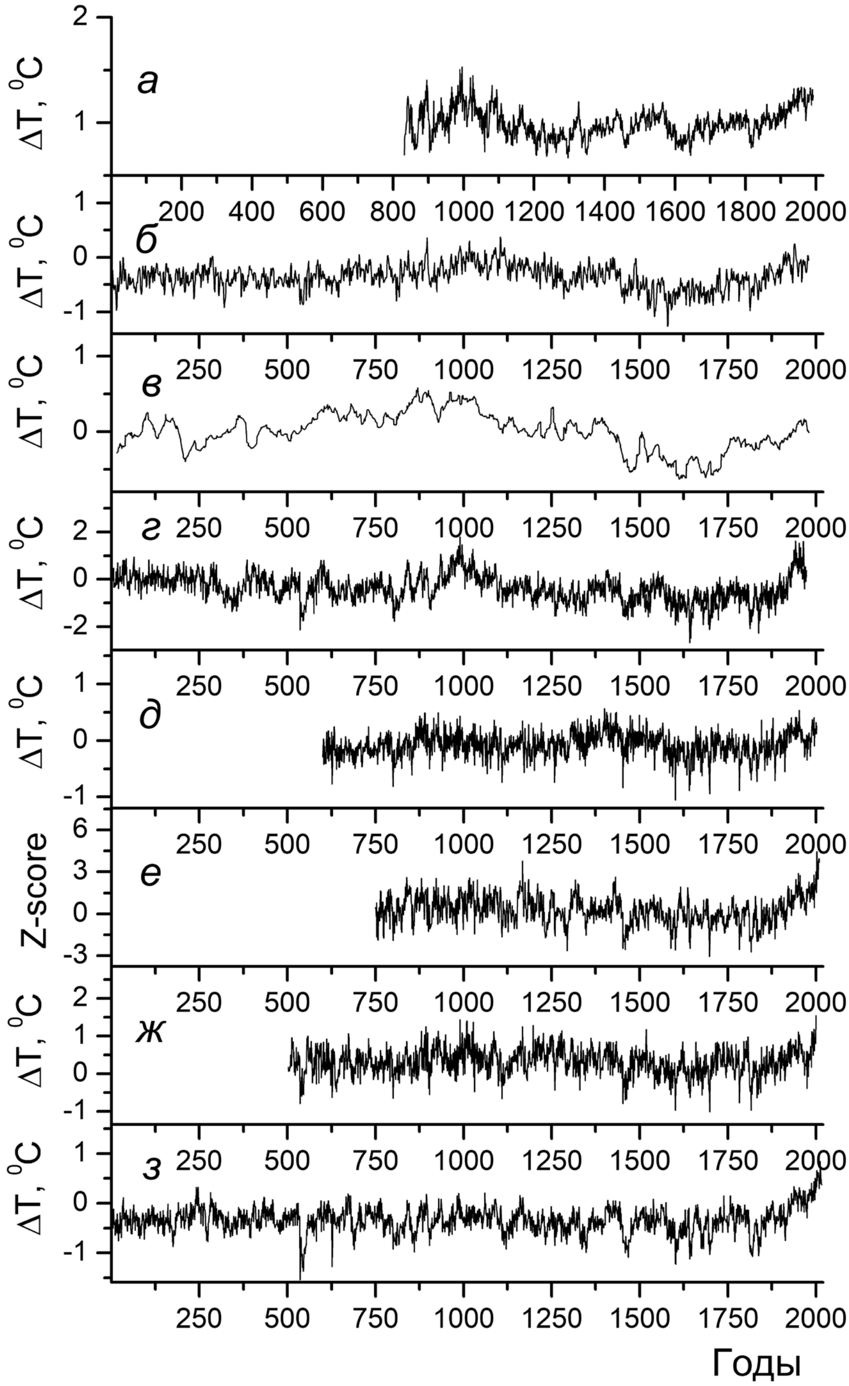
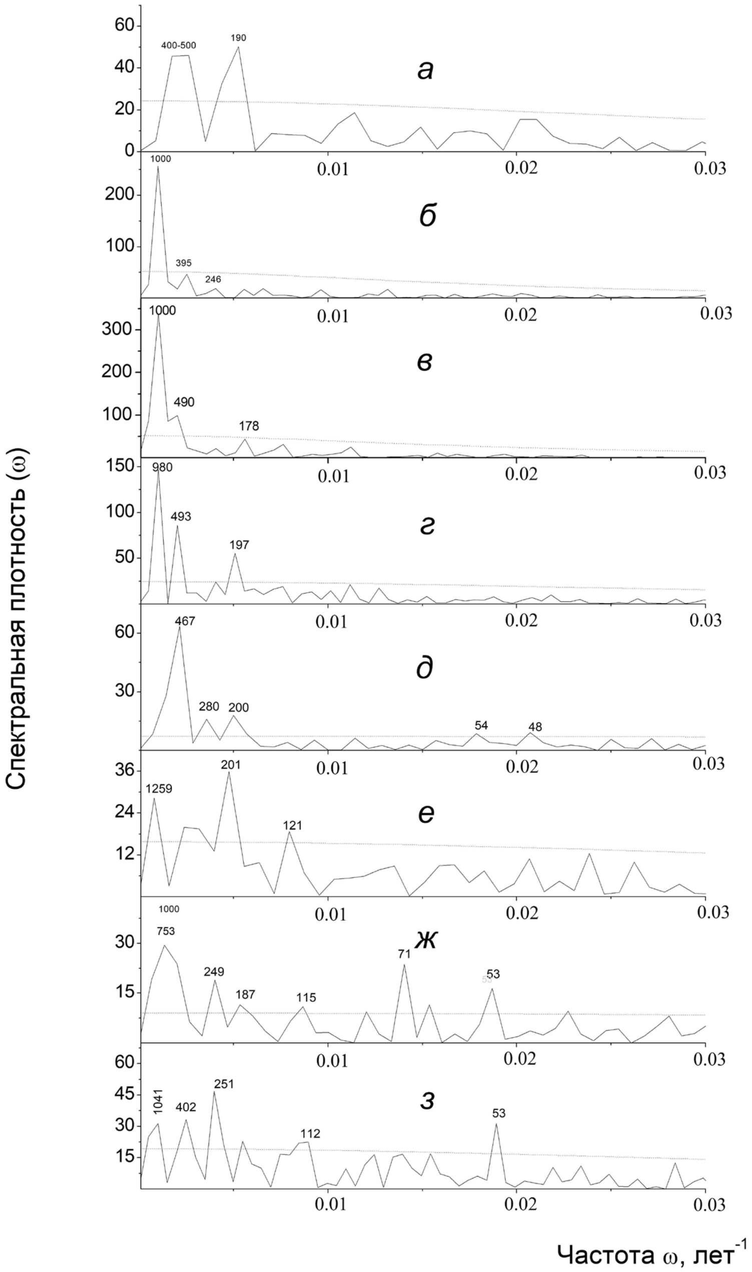


Figure 1.



Спектральная плотность (ω)
Частота ω, лет$^{-1}$
а
400-500
190
б
1000
395
246
в
1000
490
178
г
980
493
197
д
467
280
200
54
48
е
1259
201
121
ж
1000
753
249
187
115
71
53
з
1041
402
251
112
53
0.01
0.02
0.03

Figure 2.

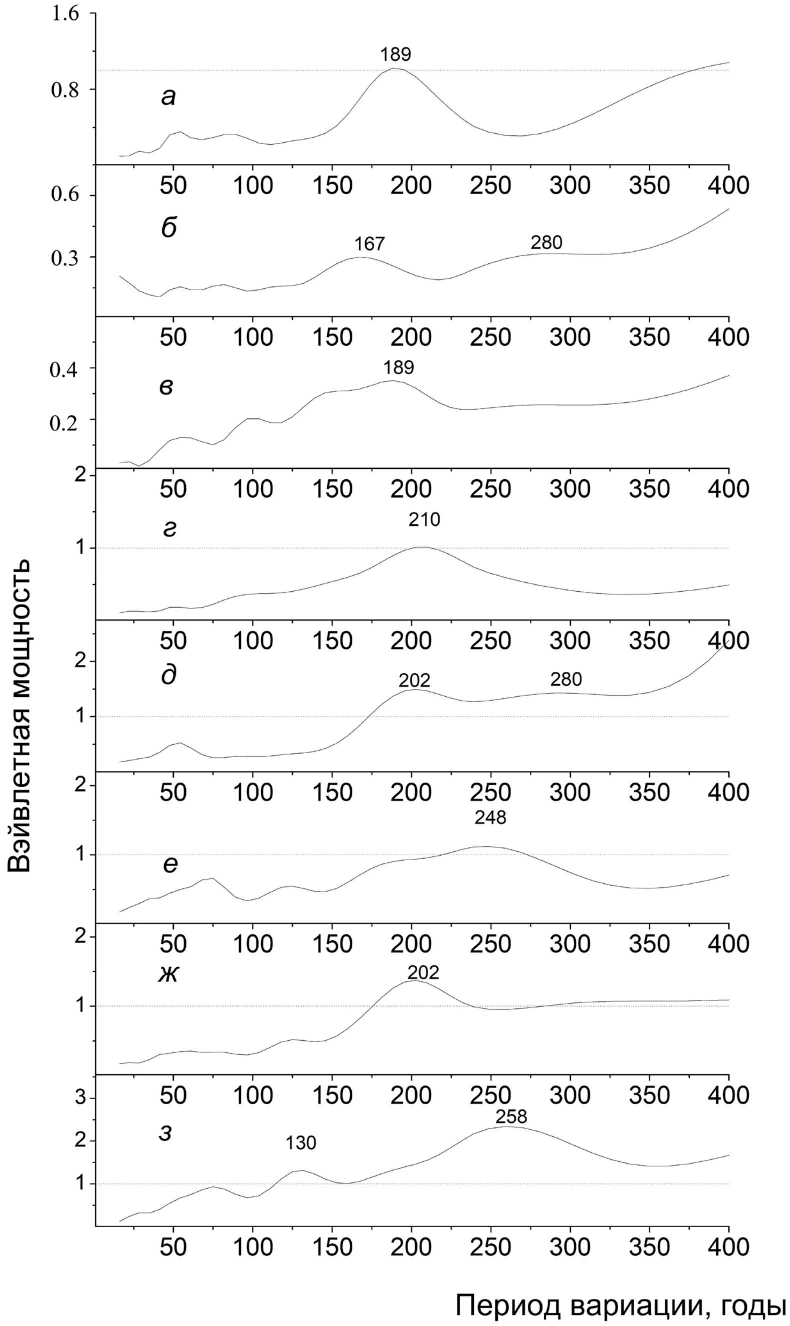

а
189
б
167
280
в
189
г
210
д
202
280
е
248
ж
202
з
130
258
Вэйвлетная мощность
Период вариации, годы

Figure 3.

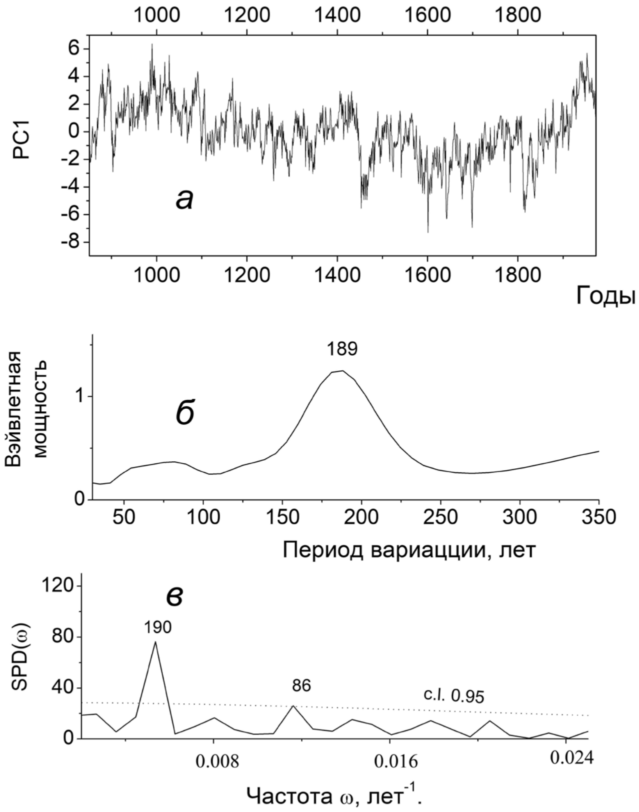
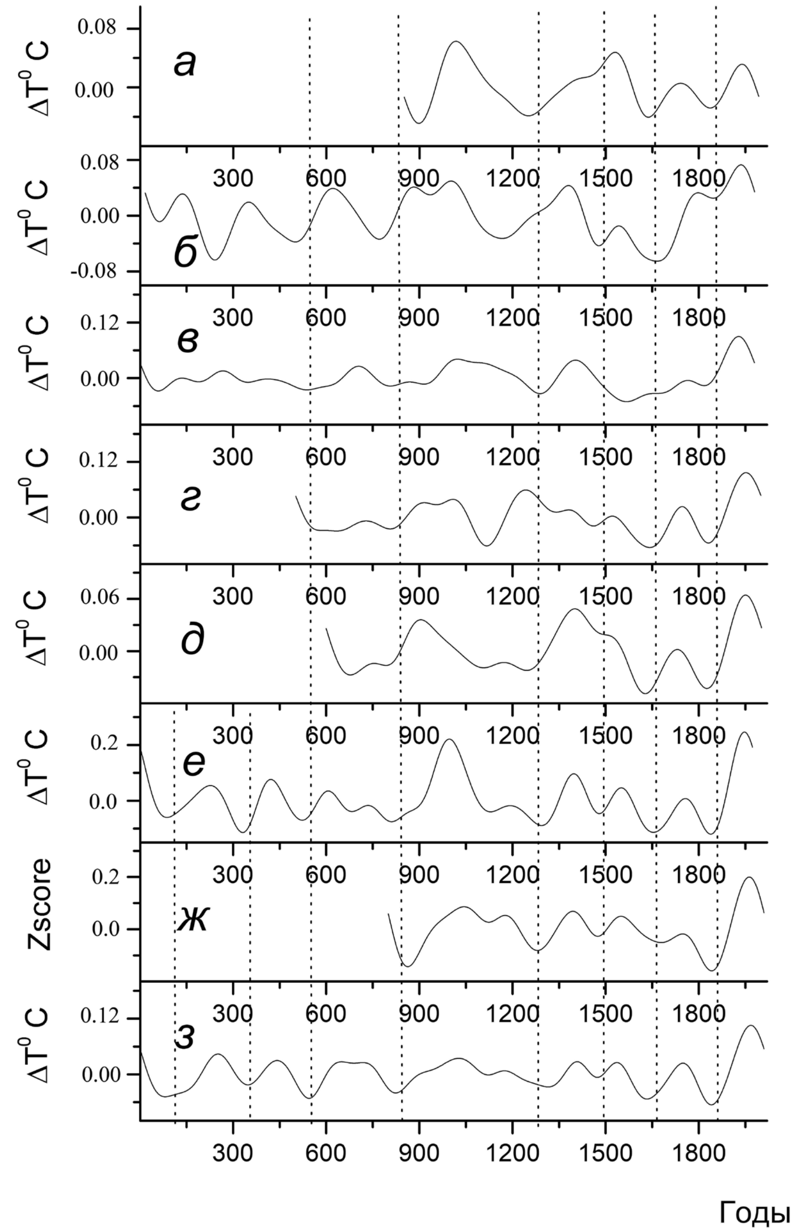

1000
1200
1400
1600
1800
6
4
2
0
-2
-4
-6
-8
PC1
а
Годы
Взвлетная мощность
1
0
б
189
50
100
150
200
250
300
350
Период вариаццки, лет
120
80
40
0
SPD(ω)
в
190
86
c.l. 0.95
0.008
0.016
0.024
Частота ω, лет-1.

Figure 4.



ΔT⁰ C
0.08
0.00
а
-0.08
б
0.12
в
г
0.06
д
0.2
0.0
е
Zscore
ж
з
300
600
900
1200
1500
1800
Годы

Figure 5.