Earth and Planetary Science
https://ojs.nassg.org/index.php/eps

RESEARCH ARTICLE

On the Millennial-scale Variability in Climate of the Northern Hemisphere

Maxim G. Ogurtsov[1,2]

1. Ioffe Physico-Technical Institute, St. Petersburg, 194021, Russia
2. Central Astronomical Observatory at Pulkovo, 196140, Russia

ARTICLE INFO

Article history
Received: 19 March 2023
Revised: 10 April 2023
Accepted: 23 April 2023
Published Online: 26 April 2023

Keywords:
Climatic change
Paleoclimatology
Dendrochronology

ABSTRACT

The question of the existence of millennial-scale climate variability and its possible impacts is important for interpreting long-term climate changes and predicting its future. In the present work a statistical analysis of the seven most recent annual reconstructions of the Northern Hemisphere temperature, covering time intervals with a length from 1260 to 2016 years, was carried out. The analysis included data of different types - both tree-ring paleo reconstructions and multi-proxies. The study was carried out using both methods of Fourier and wavelet analysis. It is shown that the yearly resolved modern temperature reconstructions indicate that in the temperature of the Northern Hemisphere of the Earth in the last 1–2 millennia there is a strong variation with a period close to 900 years. The 1400-year variation appears only in a few temperature reconstructions. Thus, the presence of a weaker 1400-year variation in the temperature of the Northern Hemisphere is not excluded but this is uncertain. The obtained difference in the spectral compositions of different data sets can be associated with: (a) the difference in the geographical location of the individual temperature indicators used, (b) the difference in the methods of standardization and generalization of the used individual proxies, (c) the difference in the seasonality of the temperature reconstructions. Although the evidence obtained for the existence of the millennial-scale variability in the climate of the Northern Hemisphere is sufficiently convincing, a concluding answer to the question of its character requires the analysis of more reconstructions that: (a) are at least several millennia-long, (b) have high time resolution, (c) use a network of individual indicators covering the largest part of the Northern Hemisphere.

1. Introduction

Many studies have claimed the presence of a ca 1470-year climate cycle in various types of Pleistocene geologic and ice deposit records from the North Atlantic region [1-3]. The period of this variation was reported as 1470 ± 500 years [1]. It was determined only approximately because the time resolution of the majority of the analyzed records was low, usually 50–180 years [1,4]. A similar cycle was identified in two annually resolved temperature proxies for the Northern Hemisphere [5], but the length of these

---

*Corresponding Author:
Maxim G. Ogurtsov,
Ioffe Physico-Technical Institute, St. Petersburg, 194021, Russia; Central Astronomical Observatory at Pulkovo, 196140, Russia;
Email: ogurtsov.maxim@mail.ru

DOI: http://dx.doi.org/10.36956/eps.v2i1.828

series—about two millennia—is insufficient to accurately determine the oscillation period. The question of the existence of a 1470-year cycle and its possible impacts is important for interpreting centennial and millennium time scales of climate variability, in particular, North Atlantic ice drift and surface hydrography, as well as for understanding atmospheric-ocean coupling and predicting future climate changes. For example, the question of whether the Little Ice Age was an isolated climatic event or was it the most recent cold phase in the series of millennial-scale fluctuations is closely related to the question of the existence of the 1470-year periodicity [1]. Attempts have been made to explain the nature of this cycle:

(a) By the influence of Dansgaard-Oeschger events [1]. Bond et al. [1] concluded that the 1470 year cycle is the result of a chain of climatic episodes in each of which, cool, ice-bearing waters from north of Iceland were advected south to the latitude of Britain. They considered the surface North Atlantic as a hydrographic system that shifts persistently in Dansgaard/Oeschger-like oscillation.

(b) By the influence of solar cycles [2,3]. For example, Brown et al. developed a non-linear two-state model based on the superposition of the solar 210-year and 87-year cycles affected by white noise. The model demonstrates transitions between climatic states when a certain threshold is exceeded with a spacing of 1470 years.

(c) By an astronomical mechanism that consists of fluctuations in the Earth-Sun-Moon distance [6]. In this approach the 1470-year cycle is the result of an interaction between the lunar-linked 209-year cycle and the 133-year cycle of change in Earth-Sun and Earth-Moon distances.

(d) By stochastic resonance within the climate system of North Atlantic [7]. These authors hypothesized that weak periodic forcing combined with some noise from ice sheet-related events could cause the observed 1470-year variation.

However, the actual physical mechanism of this climate change is still unknown. Moreover, some authors have disputed the existence of ca 1470-year quasi-periodicity [4,8,9]. For example, Obrochta et al. [4] concluded that the original 1500 cycles may actually be a mixture of the 1000 and 2000 cycles. Since the question of millennial climate variations is important for understanding the mechanisms of the climate system, in this work the study was continued using new data. Seven temperature reconstructions in the northern hemisphere were analyzed, including a series of Loehle [10] and Moberg et al. [11] used by Loehle and Singer [5].

2. Data

One of the advantages of dendroclimatology is that it allows you to reconstruct climatic parameters with a resolution of 1 year. On the other hand, standardization of tree ring sizes, which takes into account the natural decrease in their size and makes it possible to remove purely biological trends from tree ring indices, can suppress any long-term variability in the tree-ring series and make it difficult to study long-term climate changes. However, the recent improvement of dendrochronological methodologies makes it possible to preserve long-term changes in tree rings caused by climate. Thus, modern temperature dendroreconstructions retain fluctuations with a period of up to 1000 years or more. This makes them more or less suitable for studying millennium-scale variability, as has been done, for example, by Loehle and Singer [5]. In the present work paleoclimatic reconstructions of Moberg et al. [11]; Loehle [10]; Christiansen and Ljungqvist [12]; Schneider et al. [13]; Wilson et al. [14]; Guillet et al. [15]; Büntgen et al. [16] were used. For the N-TREND2015 reconstruction of Wilson et al. [14] an average between the data for North America and Eurasia was used. All data sets are described in Table 1 and are shown in Figure 1.

Table 1. Millennial-length reconstructions of the Northern Hemisphere temperature used in analysis.

Source	Time Span	Seasonality	Geographic Area	Data Type
Moberg et al. (2005) [11]	1–1979	annual	Northern Hemisphere	Tree-ring, δ^{18}O, pollen, Mg/Ca, diatoms, stalagmite, borehole
Loehle (2007) [10]	16–1980	annual	Northern Hemisphere	δ^{18}O, pollen, diatoms, Mg/Ca, stalagmite, documentary
Christiansen and Ljungqvist (2012) [12]	0–1973	annual	Extratropical part of the Hemisphere ($\Phi > 30^0$ N)	Tree-ring, δ^{18}O, δ^{13}C, sea and lake sediments, δAr/N, pollen, sta-lagmite, documentary
Schneider et al. (2015) [13]	600–2002	June–August	Extratropical part of the Hemisphere ($\Phi > 30^0$ N)	Tree-ring
Wilson et al. (2016) [14]	750–2010	May–August	Northern Hemisphere	Tree-ring
Guillet et al. (2017) [15]	500–2000	June–August	Northern Hemisphere	Tree-ring, δ^{18}O
Buntgen et al. (2021) [16]	1–2016	June–August	Northern Hemisphere	Tree-ring

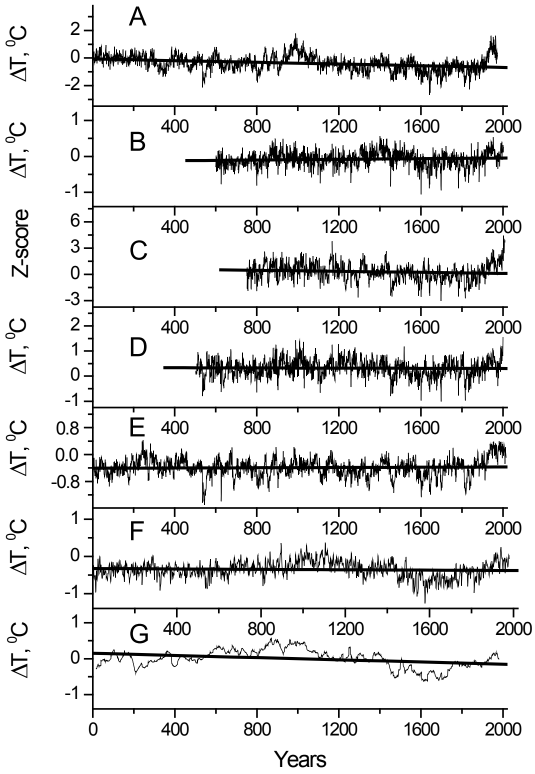

Figure 1. Reconstructions of the Northern Hemisphere temperature over the last 1.5–2.0 millennia: (A)—the multiproxy of Christiansen and Ljungqvist [12]; (B)—the tree-ring proxy of Schneider et al. [13]; (C)—the tree-ring proxy of Wilson et al. [14] (Z-score relative to the 1750–1950 period); (D)—the multiproxy of Guillet et al. [15]; (E)—the tree-ring proxy of Büntgen et al. [16]; (F)—the multiproxy of Moberg et al. [11]; (G)—the non tree-ring proxy of Loehle [10]. The figure also shows linear trends.

3. Methods and Results

Spectral properties of the seven reconstructions were studied by means of wavelet and Fourier analysis. The main disadvantage of Fourier methods, which have been used for a long time in the analysis of time series, is the assumption that the process is stationary. In the case of a non-stationary dataset (the class of datasets to which the main part of the climate series belongs), the Fourier transform allows only the average power at a given frequency to be estimated, and it is impossible to trace the change in the spectral composition over time. This disadvantage is absent when using the wavelet transform. The wavelet transform has a fundamental difference from the Fourier transform – here the analyzed signal is decomposed not into infinite sinusoidal harmonics, but into a series of wavelets – m orthogonal waves of the solyton type. These waves are called wavelets and they are well localized in both frequency and time [17], while Fourier harmonics are only localized in frequency. Due to this property, the wavelet transform is suitable for the analysis of non-stationary time series, including non-periodic inhomogeneities, deterministic chaos, and local periodic structures. Wavelet analysis has long been successfully used in the study of climate series [18]. Linear trends were preliminarily subtracted from all the series. The Fourier spectra of the analyzed data sets have strong peaks in the range of 750-1960 years, but the resolution in their low-frequency part is low. Wavelet analysis (basis of Morlet) can provide better resolution. Global wavelet spectra are shown in Figure 2. All the spectra are normalized to a 0.95 confidence level calculated for red noises with the corresponding AR(1) coefficient.

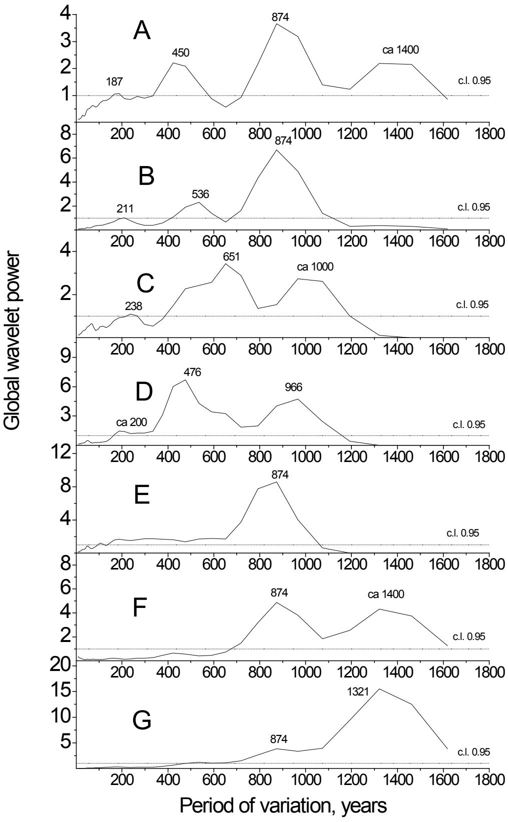

Figure 2. Global wavelet spectra of: (A)—the multiproxy of Christiansen and Ljungqvist [12]; (B)—the tree-ring proxy of Schneider et al. [13]; (C)—the tree-ring proxy of Wilson et al. [14]; (D)—the multiproxy of Guillet et al. [15]; (E)—the tree-ring proxy of Büntgen et al. [16]; (F)—the multiproxy of Moberg et al. [11]; (G)—the non tree-ring proxy of Loehle [10].

Figure 2 shows that ca 900-year (period 874–966 years) cycle is clearly expressed in all seven series, while ca 1400-year variation is manifested in three records. Here, however, a problem arises—is it possible to distinguish a 900-year variation from a 1400-year variation on such a short time interval? To answer this question, two series of 2000 years were generated, each consisting of the sum of a sine wave with a period of 900 or 1400 years and red noise (AR(1) = 0.6). The power of the red noise was such that the signal-to-noise ratio $(\sigma^2(signal)/\sigma^2\ (noise))$ was 0.1. Then the global wavelet spectra of these noisy time series were calculated. They are shown in Figure 3.

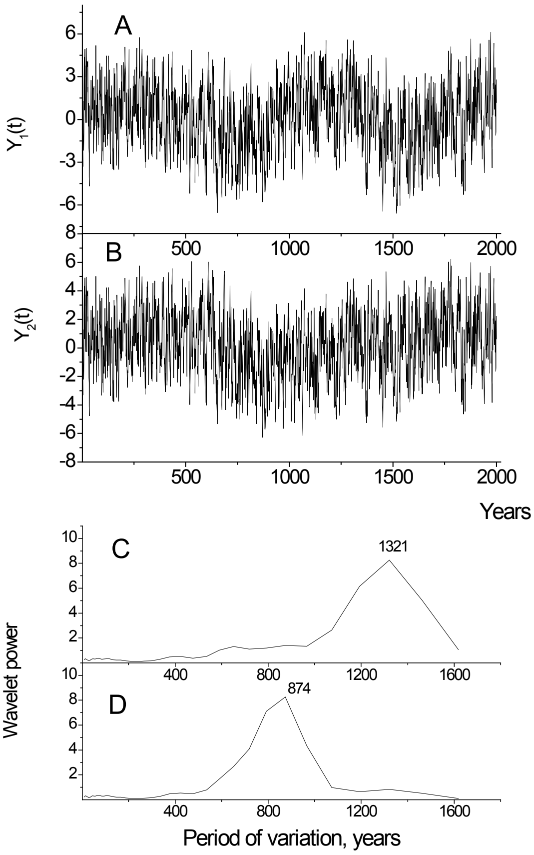

Figure 3. (A)—$Y_1(t)$ – a sine wave with a period of 900 years plus red noise; (B)—$Y_2(t)$—a sine wave with a period of 1400 years plus red noise; (C)—global wavelet spectrum of $Y_1(t)$; (D)—global wavelet spectrum of $Y_2(t)$.

Figure 3 shows that despite the shortness of the time series, it is possible to distinguish the 900-year oscillation from the 1400-year oscillation.

4. Discussion and Conclusions

It is shown the yearly resolved modern temperature reconstructions indicate that there is a strong cyclicity in the temperature of the Northern Hemisphere of the Earth with a period close to 900 years. This testifies that the 1000-year periodicity reported in the climate of the North Atlantic [4] has a global character. The 1400-year variation is less pronounced and appears only in a few temperature reconstructions. The difference in the spectral compositions of different data sets can be associated with:

(a) The difference in geographical location of the individual temperature indicators used. In fact, it is known that interdecadal and century-scale temperature variability has a strong spatial distribution with a marked change in amplitude and phase depending on geographic location [19]. In this regard, it can be noted that the subpolar sector of North Atlantic, in which the 1470-year variation has been established most reliably [1,2], is poorly covered by individual proxies in the reconstructions [13,14].

(b) The difference in the methods of standardization and generalization of the used individual proxies. In this regard, it can be noted that the 1470-year cycle is most pronounced in the series of Loehle (2007) [10], which did not use any tree-ring data and, as a result, the long-term variations of which were completely free from any influence of standardization procedures.

(c) The difference in seasonality of the temperature reconstruction. This difference may also play a role, since different seasons may show different temperature fluctuations. For example, in Southern Scandinavia bi-decadal variation is present in a warm season, while decadal variation is observed in winter [20].

For a concluding answer to the question of the millennial-scale variability in the climate of the Northern Hemisphere, it is necessary to obtain new paleoreconstructions that: (a) are at least several millennia long, (b) have high time resolution, (c) use a network of individual indicators covering as much of the Northern Hemisphere as possible. The use of non tree-ring reconstructions, whose low-frequency variations are not distorted by standardization procedures, appears to be preferable.

Conflict of Interest

There is no conflict of interest.

References

[1] Bond, G.C., Showers, W., Cheseby, M., et al., 1997. A pervasive millennial-scale cycle in North Atlantic Holocene and glacial climates. Science. 278(5341), 1257-1266.

[2] Bond, G.C., Kromer, B., Beer, J., et al., 2001. Persistent solar influence on North Atlantic climate during the Holocene. Science. 294(5549), 2130-2136.

[3] Braun, H., Cyristl, M., Ramhstorf, S., et al., 2005. Possible solar origin of the 1,470-year glacial climate cycle demonstrated in a coupled model. Nature. 438(7065), 208-211.

[4] Obrochta, S.P., Miyahara, H., Yokoyama, Y., et al., 2012. A re-examination of evidence for the North

Atlantic “1500-year cycle” at Site 609. Quaternary Science Reviews. 55, 23-33.

[5] Loehle, C., Singer, F., 2010. Holocene temperature records show millennial-scale periodicity. Canadian Journal of Earth Sciences. 47(10), 1327-1336.

[6] Kelsey, A., 2022. Abrupt climate change and millennial-scale cycles: An astronomical mechanism. Climate of the Past Discussions. (preprint), 1-19.
DOI: https://doi.org/10.5194/cp-2022-49

[7] Alley, R.B., Anandakrishnan, S., Jung, P., 2001. Stochastic resonance in the North Atlantic. Paleoceanography. 16, 190-198.

[8] Ditlevsen, P.D., Andersen, K.K., Svensson, A., 2007. The DO-climate events are probably noise induced: Statistical investigation of the claimed 1470 years cycle. Climate of the Past. 3(1), 129-134.

[9] Clemens, S.C., 2005. Millennial-band climate spectrum resolved and linked to centennial-scale solar cycles. Quaternary Science Reviews. 24(5-6), 521-531.

[10] Loehle, C., 2007. A 2000-year global temperature reconstruction on non-tree ring proxies. Energy and Environment. 18(7), 1049-1058.

[11] Moberg, A., Sonechkin, D.M., Holmgren, K., et al., 2005. Highly variable Northern Hemisphere temperatures reconstructed from low- and high-resolution proxy data. Nature. 433(7026), 613-617.

[12] Christiansen, B., Ljungqvist, F.C., 2012. The extra-tropical Northern Hemisphere temperature in the last two millennia: Reconstructions of low-frequency variability. Climate of the Past. 8(2), 765-786.

[13] Schneider, L., Smerdon, J.E., Büntgen, U., et al., 2015. Revising midlatitude summer temperatures back to A.D. 600 based on a wood density network. Geophysical Research Letters. 42(11), 4556-4562.

[14] Wilson, R., Anchukaitis, K., Briffa, K., et al., 2016. Last millennium northern hemisphere summer temperatures from tree rings: Part I: The long term context. Quaternary Science Reviews. 134, 1-18.

[15] Guillet, S., Corona, C., Stoffel, M., et al., 2017. Climate response to the Samalas volcanic eruption in 1257 revealed by proxy records. Nature Geoscience. 10(2), 123-128.

[16] Büntgen, U., Allen, K., Anchukaitis, K.J., et al., 2021. The influence of decision-making in tree ring-based climate reconstructions. Nature Communications. 12(1), 3411.

[17] Torrence, C., Compo, G.P., 1998. A practical guide to wavelet analysis. Bulletin of the American Meteorological Society. 79(1), 61-78.

[18] Lau, K.M., Weng, H., 1995. Climate signal detection using wavelet transform: How to make a time series sing. Bulletin of the American Meteorological Society. 76(12), 2391-2402.

[19] Mann, M., Park, J., Bradley, R., 1995. Global interdecadal and century-scale climate oscillations during the past five centuries. Nature. 378(6554), 266-270.

[20] Ogurtsov, M., 2021. Decadal and di-decadal periodicities in temperature of Southern Scandinavia: Manifestations of natural variability or climatic response to solar cycles? Atmosphere. 12(6), 676.