On the possible influence of the solar quasi-bicentennial cycle on the temperature of the Earth's Northern Hemisphere

© M.G. Ogurtsov

Ioffe Institute,
194021 St. Petersburg, Russia
e-mail: maxim.ogurtsov@mail.ioffe.ru

Received May 4, 2025
Revised July 8, 2025
Accepted July 17, 2025

The possibility of a relationship between the quasi-bicentennial temperature variation in the Northern Hemisphere and the solar cycle of Suess was investigated. Linear and nonlinear correlation coefficients between quasi-bicentennial cycles in temperature and solar activity were calculated. Nonlinear correlation coefficients were calculated based on mutual information estimates. It turned out that in most cases, the significance of nonlinear correlation is significantly higher than that of linear correlation. This result indicates that the relationship between quasi-bicentennial cycles in Northern Hemisphere temperature and solar activity may be nonlinear.

Keywords: Solar activity, solar paleoastrophysics, climate.

DOI: 10.61011/TP.2025.12.62382.227-25

Introduction

The sun is the main source of energy supplied to the Earth's climate system, so the possible impact of solar activity on the climate has long been actively studied. Steadily developing methods of solar paleoastrophysics and paleoclimatology make it possible to test solar-climatic relationships over time intervals of up to several thousand years. An analysis of the available paleoclimatic information has shown that the climate of both individual regions of the Earth and the Northern and Southern hemispheres as a whole has a quasi-two-century (period of about 200 years) periodicity [1]. The period of this variation is close to the period of the quasi-two-hundred-year Suess solar cycle. However, the study [1], in which the relationship of the quasi-two-hundred-year temperature variation with the Suess cycle was tested using the linear correlation coefficient, did not detect such a relationship. It was concluded that the Earth's climate may have its own natural variations with periods close to the periods of solar cycles, but not related to solar activity, which can significantly distort solar signals and make them difficult to detect. An attempt is made in this paper to find a nonlinear relationship between quasi-two-century variations in the temperature of the Northern Hemisphere and solar activity using nonlinear correlation coefficients calculated based on estimates of mutual information.

1. Materials and methods

The following was used in this study: — six reconstructions of solar activity [2–8] obtained using methods of Solar paleoastrophysics, mainly using data on the concentration of cosmogenic isotopes in terrestrial archives; — seven reconstructions of the temperature of the Northern Hemisphere and its extratropical part [9–16]. The main source of information was tree rings, additional sources of information included concentrations of stable isotopes $\delta^{18}O$ and $\delta^{13}C$ in the terrestrial radiocarbon records, plant pollen, ribbon clays, historical documents.

Bicentennial variations were identified by wavelet filtering in the period band (range) of 172−260 years, performed using the MHAT real basis [17]. The MHAT wavelet has good time resolution and is therefore well suited for detecting various spectral components of a signal. The relationship between the studied series was tested using linear (R_l) and nonlinear (R_{nl}) correlation coefficients. Nonlinear correlation coefficient [18]:

$$R_{nl} = \sqrt{1 - \exp(-2MI)} \qquad (1)$$

where MI is mutual information that describes the amount of information contained in one random variable relative to another. This value can be interpreted as the ability to predict one time series using another as a source of information. The nonlinear correlation coefficient has already been used quite successfully in climatology [19]. The significance of the correlation between the wavelet-filtered series was evaluated using a statistical experiment described in Ref. [20].

2. Results and discussion

The calculation results are listed in the Tables 1 and 2.

The bold numbers in both tables describe the correlation coefficients, the significance of p (probability of null hypothesis) which are less than 0.32 (level 1σ). Large bold numbers — $p < 0.10$.

The calculations have shown that, although the significance of correlations is low in both cases, it is significantly higher for nonlinear correlation than for linear correlation.

Table 1. Coefficients of linear correlation between temperatures in the Northern hemisphere and solar activity, calculated over the last 1–2 millennia. All time series are wavelet filtered in the range of 172–260 years

Source	Usoskin et al. [5]	Muscheler et al. [2]	Horiuchi et al. [3]	Steinhilber et al. [4]	Usoskin et al. [7]	Egorova et al. [6]
Moberg et al. [10]	−0.03 (> 0.32)	−0.06 (> 0.32)	−0.05 (> 0.32)	0.18 (> 0.32)	**0.42** (0.22)	0.10 (> 0.32)
Loehle [11]	0.22 (> 0.32)	0.017 (> 0.32)	−0.11 (> 0.32)	0.12 (> 0.32)	0.31 (> 0.32)	0.25 (> 0.32)
Christiansen, Ljungqvist [12]	−0.04 (> 0.32)	−0.29 (> 0.32)	0.04 (> 0.32)	0.20 (> 0.32)	−0.18 (> 0.32)	0.07 (> 0.32)
Schneider et al. [13]	−0.09 (> 0.32)	**−0.47** (0.12)	0.20 (> 0.32)	0.15 (> 0.32)	−0.21 (> 0.32)	0.15 (> 0.32)
Wilson et al. [14]	0.06 (> 0.32)	−0.11 (> 0.32)	−0.21 (> 0.32)	**0.39** (0.29)	0.06 (> 0.32)	0.19 (> 0.32)
Guillet et al. [15]	0.06 (> 0.32)	−0.28 (> 0.32)	0.04 (> 0.32)	0.19 (> 0.32)	0.07(> 0.32)	0.14 (> 0.32)
Buntgen et al. [16]	−0.24 (> 0.32)	−0.28 (> 0.32)	0.16 (> 0.32)	0.08 (> 0.32)	−0.03 (> 0.32)	0.06 (> 0.32)

Table 2. Coefficients of nonlinear correlation between temperatures in the Northern hemisphere and solar activity, calculated over the last 1–2 millennia. All time series are wavelet filtered in the range of 172–260 years

Source	Usoskin et al. [12]	Muscheler et al. [9]	Horiuchi et al. [10]	Steinhilber et al. [12]	Usoskin et al. [14]	Egorova et al. [13]
Moberg et al. [10]	0.64 (> 0.32)	0.59 (> 0.32)	0.64 (> 0.32)	0.67 (> 0.32)	**0.81** (0.07)	0.55 (> 0.32)
Loehle [11]	0.64 (> 0.32)	0.72 (> 0.32)	0.64 (> 0.32)	0.62 (> 0.32)	0.71 (> 0.32)	0.61 (> 0.32)
Christiansen, Ljungqvist [12]	0.53 (> 0.32)	0.64 (> 0.32)	0.65 (> 0.32)	0.63 (> 0.32)	0.59 (> 0.32)	0.55 (> 0.32)
Schneider et al. [13]	0.63 (> 0.32)	0.67 (> 0.32)	0.65 (> 0.32)	0.68 (> 0.32)	0.63 (> 0.32)	0.57 (> 0.32)
Wilson et al. [14]	**0.70** (0.23)	0.66 (> 0.32)	**0.76** (0.15)	**0.74** (0.18)	0.68 (> 0.32)	0.67 (> 0.32)
Guillet et al. [15]	0.61 (> 0.32)	0.68 (> 0.32)	0.63 (> 0.32)	0.69 (> 0.32)	0.56 (> 0.32)	0.61 (> 0.32)
Buntgen et al. [16]	0.64 (> 0.32)	0.65 (> 0.32)	0.62 (> 0.32)	0.66 (> 0.32)	0.70 (> 0.32)	0.67 (> 0.32)

In only two cases out of 42, the probability of a null hypothesis for the linear correlation coefficient turns out to be less than 0.32 $(1\,\sigma)$ and in no case it is less than 0.1. For the nonlinear correlation coefficient, the significance is less than 0.32 in four cases, and a fairly high level of significance is achieved $p = 0.07$ for the series [7] and [10]. This indicates that there is a real relationship between quasi-two-hundred-year variations in temperature and solar activity, but it is nonlinear. In addition, the solar signal can be distorted, firstly, by natural climatic noises, and secondly, by the quasi-two-hundred-year variation in volcanic activity [2]0.

Conclusions

Statistical analysis of six reconstructions of solar activity and seven paleoreconstructions of temperature in the Northern Hemisphere, covering time intervals up to 2000 years, has shown that the relationship between quasi-two-hundred-year cycles in temperature and solar activity may exist, but it may be nonlinear and distorted by natural variations. In this case, identifying and studying the solar effect on the climate turns out to be a difficult task, the solution of which requires, among other things, a serious improvement in mathematical statistics methods.

Conflict of interest

The authors declare that they have no conflict of interest.

References

[1] M.G. Ogurtsov. Geomagn. aeronomiya, (2025) (in Russian). V pechati.

[2] R. Muscheler, F. Joos, J. Beer, S.A. Müller, M. Vonmoos, Ia. Snowball. Quat. Sci. Rev. **26**, 82 (2007). DOI: 10.1016/j.quascirev.2006.07.012

[3] K. Horiuchi, T. Uchida, Yu. Sakamoto, A. Ohta, H. Matsuzaki, Ya. Shibata, H. Motoyama. Quaternary Geochronology, **3** (3), 253 (2008). DOI: 10.1016/j.quageo.2008.01.003

[4] F. Steinhilber, J. Abreu, J. Beer, F. Wilhelms. Proc. Nat. Acad. Sci. USA, **109** (16), 5967 (2012). DOI: 10.1073/pnas.1118965109
[5] G. Usoskin, G. Hulot, Y. Gallet, R. Roth, A. Licht, F. Joos, G.A. Kovaltsov, E. Thébault, A. Khokhlov. Astron. Astrophys., **562**, L10 (2014). DOI: 10.1051/0004-6361/201423391
[6] T. Egorova, W. Schmutz, E. Rozanov, A.I. Shapiro, I. Usoskin, J. Beer, R.V. Tagirov, T. Peter. Astron. Astrophys., **615**, A85 (2018). DOI: 10.1051/0004-6361/201731199
[7] G. Usoskin, S.K. Solanki, N.A. Krivova, B. Hofer, G.A. Kovaltsov, L. Wacker, N. Brehm, B. Kromer. Astron. Astrophys., **649**, A141 (2021). DOI: 10.1051/0004-6361/202140711
[8] T. Egorova, W. Schmutz, E. Rozanov, A.I. Shapiro, I. Usoskin, J. Beer, R.V. Tagirov, T. Peter. Astron. Astrophys., **615**, A85 (2018). DOI: 10.1051/0004-6361/201731199
[9] J. Esper, E.R. Cook, F.H. Schweingruber. Science, **295**, 2250 (2002). DOI: 10.1126/science.1066208
[10] A. Moberg, D.M. Sonechkin, K. Holmgren, N.M. Datsenko, W. Karlén. Nature, **433**, 613 (2005). DOI: 10.1038/nature03265
[11] C. Loehle. Energy Environ., **18**, 1049 (2007). DOI: 10.1260/095830507782616797
[12] B. Christiansen, F.C. Ljungqvist. Clim. Past., **8**, 765 (2012). DOI: 10.5194/cp-8-765-2012
[13] L. Schneider, J.E. Smerdon, U. Büntgen, R.J.S. Wilson, V.S. Myglan, A.V. Kirdyanov, J. Esper. Geophys. Res. Lett., **42**, 4556 (2015). DOI: 10.1002/2015GL063956
[14] R. Wilson, K. Anchukaitis, K.R. Briffa, U. Büntgen , E. Cook, R. D'Arrigo, N. Davi, J. Esper, D. Frank, B. Gunnarson, G. Hegerl, S. Helama, S. Klesse, P.J. Krusic, H.W. Linderholm, V. Myglan, T.J. Osborn, M. Rydval, L. Schneider, A. Schurer, E. Zorita. Quat. Sci. Rev. **134**, 1 (2016). DOI: 10.1016/j.quascirev.2015.12.005
[15] S. Guillet, Ch. Corona, M. Stoffel1, M. Khodri, F. Lavigne, P. Ortega, N. Eckert, P.D. Sielenou, V. Daux, O.V. Churakova (Sidorova), N. Davi, J.-L. Edouard, Yo. Zhang, B.H. Luckman, V.S. Myglan, J. Guiot, M. Beniston, V. Masson-Delmotte, C. Oppenheimer. Nat. Geosci., **10**, 123 (2017). DOI: 10.1038/ngeo2875
[16] U. B?ntgen, K. Allen, K.J. Anchukaitis, D. Arseneault, É. Boucher, A. Bräuning, S. Chatterjee, P. Cherubini, O.V. Churakova (Sidorova), Ch. Corona, F. Gennaretti, J. Grießinger, S. Guillet, J. Guiot, B. Gunnarson, S. Helama, Ph. Hochreuther, M.K. Hughes, P. Huybers, A.V. Kirdyanov, P.J. Krusic, J. Ludescher, W.J.-H. Meier, V.S. Myglan, K. Nicolussi, C. Oppenheimer, F. Reinig, M.W. Salzer, K. Seftigen, A.R. Stine, M. Stoffel, S.St. George, E. Tejedor, A. Trevino, V. Trouet, J. Wang, R. Wilson, B. Yang, G. Xu, J. Esper. Nat. Commun., **12**, 3411 (2021). DOI: 10.1038/s41467-021-23627-6
[17] C. Torrence, G.P. Compo. Bull. Amer. Meteorol. Soc., **79**, 61 (1998). DOI: 10.1175/1520-0477(1998)079¡0061:APGTWA ¿2.0.CO;2
[18] H. Joe. J. Am. Stat. Assoc., **84**, 157 (1989). DOI: 10.1080/01621459.1989.104
[19] T.M. Vu, A.K. Mishra, G. Konapala. Entropy, **20**, 38 (2018). DOI: 10.3390/e20010038
[20] M.G. Ogurtsov. Atmosphere, **15** (11), 1373 (2024). DOI: 10.3390/atmos15111373

Translated by A.Akhtyamov