

Article

A Study on Possible Solar Influence on the Climate of the Southern Hemisphere

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Abstract: Three multi-proxy reconstructions of temperature in the Southern Hemisphere, were analyzed over the last millennium. Fourier and wavelet analysis showed that century-scale (55–120 years) and bicentennial (ca 250 years) variability is present in this series. That means that the climate of the Southern Hemisphere has periodicities similar to the solar cycles of Gleissberg and Suess. However, a comparison of the century-long variations in the Southern Hemisphere temperature records with the corresponding variation in four solar activity proxies showed that only one reconstruction of displays century-long correlation with solar activity. The solar-like periodicities in the other two records do not show significant correlation with solar cycles. Therefore, based on the results obtained, it is difficult to draw a definite conclusion about the influence of solar activity on the climate of the Southern Hemisphere. To clarify this issue, it is necessary to obtain and analyze new independent temperature reconstructions in the Southern Hemisphere.

Keywords: solar activity; climate; paleoclimatology



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1. Introduction

For a long time, scientists have searched for a possible effect of solar activity on atmospheric dynamics and terrestrial climate (see, e.g., [1,2]). Research in this field has advanced considerably during recent decades, but a detailed physical mechanism explaining the connection between solar activity, space weather, and climate is still unclear. Moreover, the geographic distribution of solar-climate evidence is not uniform. Most of the indications were obtained from the Northern Hemisphere [3–12], whereas evidence from the Southern Hemisphere is not so copious [13–16]. This is largely due to the fact that the Southern Hemisphere is less covered by meteorological records, in particular by long-term temperature paleoreconstructions. In addition, the authors of [17], who carefully studied the possible influence of solar activity on the climate of Northern Fennoscandia, established that the available data are insufficient for a final conclusion. Ogurtsov et al. [17] noted that the study of new long-term temperature reconstructions is necessary to clarify this issue. In this context, the study of a possible solar-climatic relationship in the Southern Hemisphere, especially on a long-term scale, looks promising. Despite the paucity of long-term reconstructions of the Southern Hemisphere climate, several such series can be found in the current literature. Present work is devoted to search for a solar-climate link by means of three millennial multi-proxy reconstructions of annual temperature in the Southern Hemisphere obtained by Jones et al. [18], Mann and Jones [19], and Neukom et al. [20]. As these series cover a whole millennium, they are suitable for studying the influence of all known solar periodicities on climate: (a) the Schwabe quasi-11-year cycle, (b) the Hale quasi-22-year cycle, (c) the Gleissberg century-scale cycle (period of 55–130 years), and (d) the bicentennial cycle of Suess (period 170–250 years). In this work, I focused on studying the possible impact of long-term variations in solar activity on the climate. This is because: (a) on the one hand, serious evidence of the influence of the century-long solar cycle on the climate has been obtained in the Northern Hemisphere [4,21]; (b) on the other

hand, a roughly 50–150 yr natural periodicity is present in many Northern Hemisphere temperature proxies [22]. This intrinsic variability can obscure the solar impact on climate. Therefore, testing these effects in the Southern Hemisphere is of considerable scientific interest.

2. Materials and Methods

The temperature reconstructions used in the work are shown in Figure 1. The reconstruction of Jones et al. [18] was obtained using seven multi-proxy (tree-ring, ice core, corals, historic documents) temperature predictors. Mann and Jones [19] used five tree-ring and ice-core proxy records. Neucom et al. (2014) generalized 111 multi-proxy (tree-ring, ice core, corals, historic documents, sediments) temperature indicators.

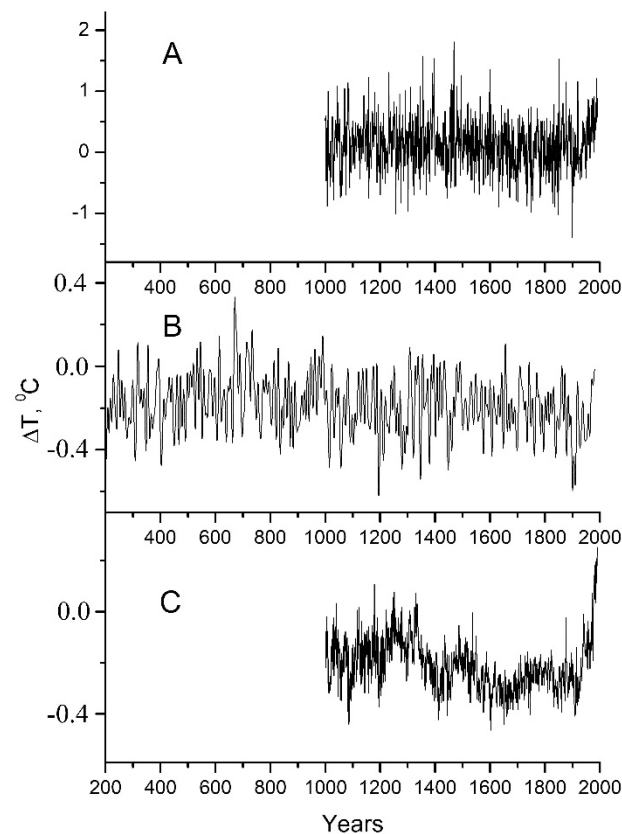


Figure 1. Reconstructions of annual temperature in Southern Hemisphere: (A) the time series of Jones et al. [18]; (B) the time series of Mann and Jones [19]; (C) the time series of Neucomb et al. [20].

The dataset of Mann and Jones [19] is decadal resolved, whereas the other two are annually resolved.

A serious difficulty in solar-climatic studies is related to the shortness of available experimental data. The longest instrumental record of solar activity, the number of sunspot groups, has been available since 1610 AD. The use of indirect (proxy) data makes it possible to overcome these difficulties. Cosmogenic isotopes ^{14}C and ^{10}Be have long been known as reliable indicators of long-term changes in the GCR flux and solar activity [23,24]. They are generated in the stratosphere and troposphere due to high-energy (500 MeV–50 GeV) charged cosmic particles, are included in a number of recirculation processes, and are finally fixed in tree rings (^{14}C), polar ice, and bottom sediments (^{10}Be). In this work, I used both direct data on cosmogenic ^{10}Be concentration and reconstructions of such parameters of solar activity as the total solar irradiance (TSI) and solar modulation potential (a value indicating how much energy (per unit charge) a cosmic ray particle must have to avoid being deflecting by the heliospheric magnetic field) obtained using these beryllium

records. Thus, to study a possible solar-climate relationship, I used the following long-term indicators of solar activity:

- Concentration of the cosmogenic ^{10}Be in the South Pole core obtained by Bard et al. [25];
- Total solar irradiance reconstructed by means of the cosmogenic isotopes ^{14}C and ^{10}Be [25];
- Concentration of the cosmogenic ^{10}Be in the two Antarctic records (South Pole and Dome Fuji stations) obtained by Delaygue and Bard [26];
- Solar modulation parameter Φ reconstructed by means of the two Antarctic records of ^{10}Be [26]. Data [26] were annually interpolated.

All indicators of solar activity used in the work are shown in Figure 2.

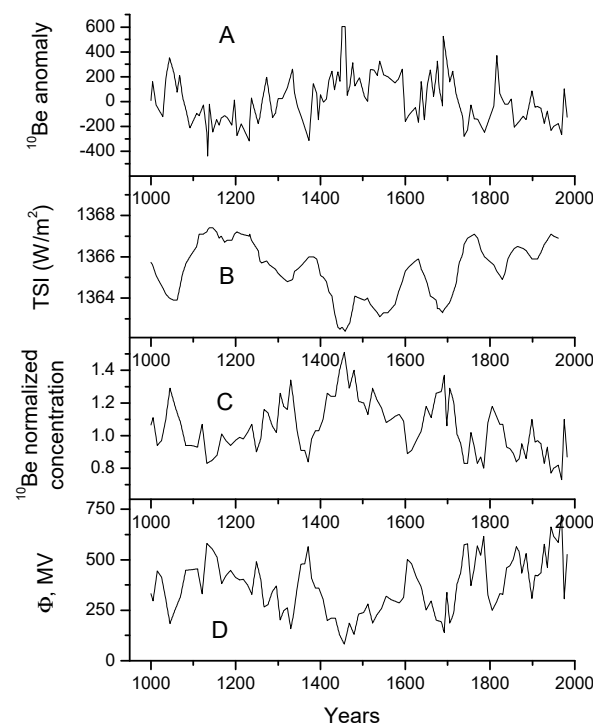


Figure 2. (A) Concentration of the cosmogenic ^{10}Be in Antarctic ice [25]; (B) total solar irradiance (TSI) reconstructed by Bard et al. [25]; (C) concentration of the cosmogenic ^{10}Be in Antarctic ice [26]; (D) solar modulation parameter Φ (in MV) reconstructed by Delaygue and Bard [26].

3. Results

Wavelet and Fourier spectra of the analyzed time series, calculated over the last 1000 years, were used for detecting the periodicities in the temperature proxies. Local and global wavelet spectra are shown in Figure 3. Fourier spectra are shown in Figure 4. Because the time series of Mann and Jones [19] was decadal smoothed, estimation of 0.95 significance level of the Fourier spectrum was based on evaluation of the background noise as a mean (median) spectral power, which then was multiplied by the corresponding value (2.99). Morlet wavelet spectrum of the temperature proxy [19] was normalized by variance—no estimation of significance of its details was made. Second-order polynomial trends were preliminarily subtracted from all series.

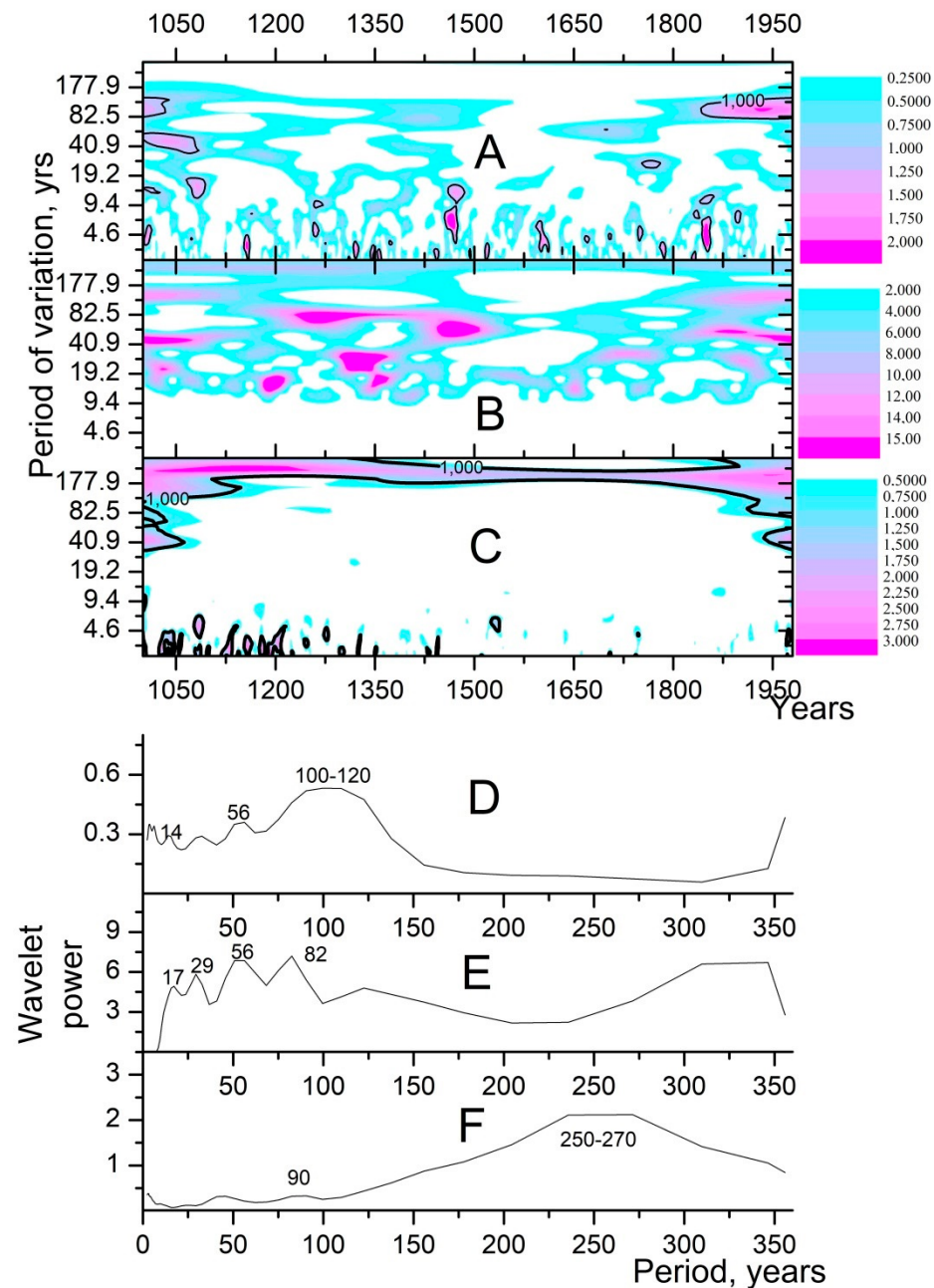


Figure 3. (A) Local Morlet wavelet spectrum of temperature proxy after Jones et al. [18]. The spectrum is normalized to 0.95 confidence level calculated for a red noise with $AR(1) = 0.35$. (B) Local Morlet wavelet spectrum of temperature proxy of Mann and Jones [19]. The spectrum is normalized to variance. (C) Local Morlet wavelet spectrum of temperature proxy of Neucomb et al. [20]. The spectrum is normalized to 0.95 confidence level calculated for a red noise with $AR(1) = 0.65$. (D) Global wavelet spectrum of temperature proxy of Jones et al. [18]. (E) Global wavelet spectrum of temperature proxy of Mann and Jones [19]. (F) Global wavelet spectrum of temperature proxy of Neucomb et al. [20].

Both Fourier and wavelet analysis showed that:

- Strong fluctuations on the 100–120 year scale are presented in a proxy record [18]. They give a significant ($p < 0.05$) peak in Fourier spectrum at a period of 110 years. Some fluctuations on the decadal and didecadal scales are also present. See Figure 3A,D and Figure 4A.
- Spectrum of the proxy record [19] shows concentration of variance in the range of 50–82 years. See Figure 3B,E and Figure 4B.

- (c) Strong fluctuations on the scale of ca 100 years are presented in a reconstruction of Neucomb et al. [20]. They give a significant ($p < 0.05$) peak in Fourier spectrum at a period of 91 years. A strong and highly significant ca 250 year cyclicality exists in proxy series [18] during all the millennium. See Figure 3C,F and Figure 4C.

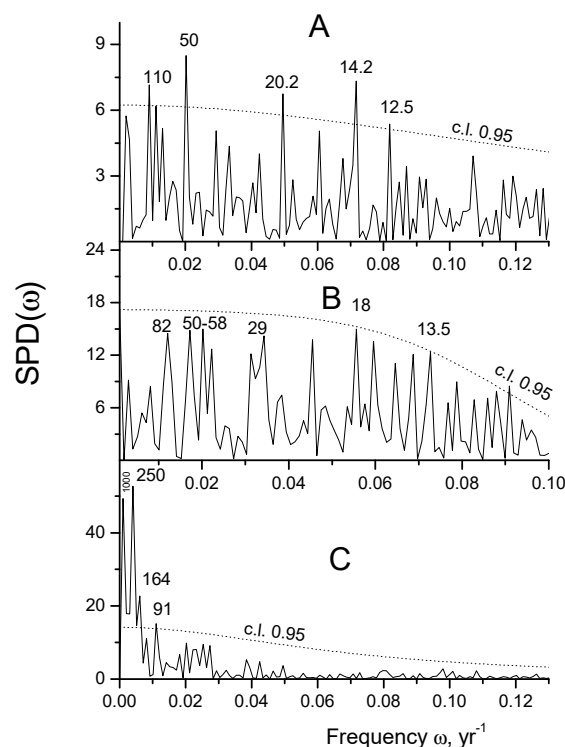


Figure 4. (A) Fourier spectrum of temperature proxy of Jones et al. [18]. (B) Fourier spectrum of temperature proxy of Mann and Jones [19]. (C) Fourier spectrum of temperature proxy of Neucomb et al. [20]. Confidence levels are based on spectra of appropriate noises.

Thus, some century-long and bicentennial variability was found in the analyzed reconstructions of the Southern Hemisphere temperature. These periodicities may be the result of the influence of the solar cycles of Gleissberg (century-type variation) and Suess (bicentennial variation). To examine a possible relationship between the solar-type temperature variations in the Southern Hemisphere and solar activity, correlation coefficients were calculated between time series wavelet filtered in the Gleissberg band (58–133 years).

Bold figures in the table represent correlation coefficients with significance $p < 0.05$. Phase shifts in years as well as statistical significance (in italics) are given in brackets.

Table 1 shows that the century-scale variation of reconstruction of Jones et al. [18] correlates significantly with the solar proxies (see Figure 5). The two other proxies show no century-scale correlation with solar activity.

Table 1. Correlation coefficient between Southern Hemisphere temperatures and solar activity calculated over the last millennium. All the time series wavelet filtered in 58–133-year scale band.

Reference	[25]	[25]	[26]	[26]
[18]	−0.17 (0, 0.40)	0.19 (0, 0.22)	0.21 (0, 0.33)	−0.22 (0, 0.27)
[19]	−0.39 (0, 0.036)	0.41 (0, 0.014)	0.46 (0, 0.029)	−0.41 (0, 0.046)
[20]	−0.08 (0, >0.5)	0.18 (0, 0.31)	0.15 (0, >0.5)	−0.07 (0, >0.5)

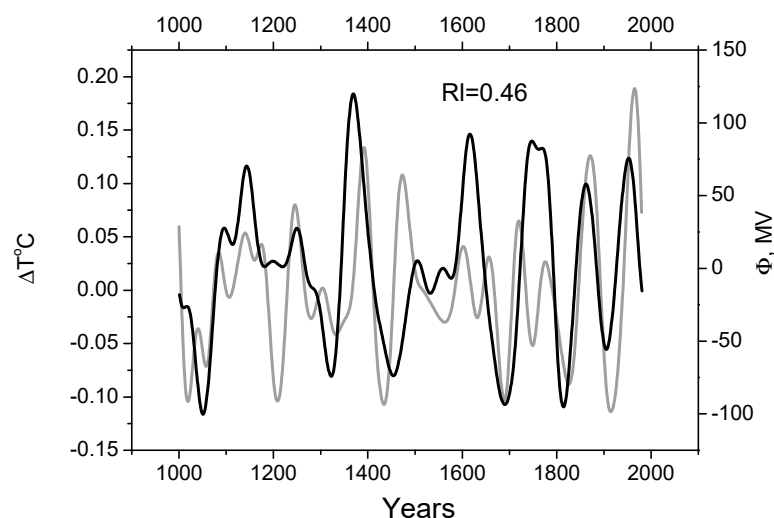


Figure 5. Time series wavelet filtered (MHAT basis) in 58–133-year band. Gray curve—temperature reconstruction of Jones et al. [18], black curve—solar modulation parameter Φ [22]. Second-order polynomial trends were preliminarily subtracted from both series.

No significant correlation was found between the bicentennial temperature variations in the Southern Hemisphere and the corresponding solar cycle of Suess.

4. Discussion and Conclusions

An analysis of three millennial reconstructions of the Southern Hemisphere temperature showed that all of them contain century-scale variations and one contains a bicentennial variation. Century-long periodicity in temperature proxy of Jones et al. [18] correlates significantly with the corresponding variation (the cycle of Gleissberg) in four solar reconstructions. In contrast, the century-scale and bicentennial periodicities in the other two records do not show a correlation with the corresponding solar cycles of Gleissberg and Suess. Thus, at this stage it is difficult to draw an unambiguous conclusion about whether solar activity affects the climate of the Southern Hemisphere. The results obtained provide new evidence in favor of the existence of internal (natural) climate variability with periods close to solar cycles. The presence of such periodicities can complicate the identification of solar-climatic relationships. Obtaining and analysis of new independent and representative reconstructions of temperature in the Southern Hemisphere is necessary to clarify the question about possible solar–climatic association. Improving the quality of solar and climatic paleoreconstructions is also important.

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