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Decadal and Bi-Decadal Periodicities in Temperature of Southern Scandinavia: Manifestations of Natural Variability or Climatic Response to Solar Cycles?

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Abstract: Nine proxies of temperature over the last 225–300 years in Southern Fennoscandia (55–63° N) were analyzed. Seven reconstructions of the mean growing season temperatures were obtained by dendroclimatological methods. Reconstructions of spring temperatures in Stockholm and winter temperatures in Tallinn were based on historical documentary sources. It was found that significant decadal (10–13 years) and bi-decadal (22–25 years) periodicities were present in many of these series during the entire time interval. Four proxy records correlated significantly with the quasi 22-year solar cycle of Hale. Three time series correlated significantly with the quasi 11-year solar cycle of Schwabe. This can be considered as evidence of a link between decadal and bi-decadal changes in solar activity and climate in Southern Fennoscandia. On the other hand, signs of correlation differed, as well as the time shift between the solar and temperature cycles. It is difficult to explain such an intricate relationship and, thus, the physical mechanism of solar–climatic linkages remains unclear. That is why assumptions about the purely occasional appearance of correlations cannot yet be rejected. Guidelines for further research are suggested.

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1. Introduction

The question of the reality of a relationship between solar activity and the Earth's climate and its possible physical mechanism is becoming increasingly important in solar–terrestrial research. Evidence of the solar influence on the climate of Northern Fennoscandia (NF) was obtained from a number of studies, based on the data of paleoclimatology [1–5]. On the other hand, some evidence against the Sun–climate link in NF was obtained as well [6,7]. Moreover, it was shown that the solar–climatic effects, if they really exist, have an apparent regional distribution [8–10]. That is why the study of possible solar–climatic associations in the area adjacent to NF is of great importance. Southern Fennoscandia (SF) is the region situated the closest to NF. This work is aimed at the analysis of solar–climate relations over the southern part of Scandinavia (55–63° N, 10–35° E) during the 18th–20th centuries.

2. Materials and Methods

Paleoclimate reconstructions based on maximum latewood density (MXD) and historical documentary sources (H) were used in this study (Table 1). Gridded summer temperatures over Europe, reconstructed by Briffa et al. [11], were presented in a gridpoint form on a 5° latitude by 10° longitude grid.

Table 1. A list of proxy records used in this analysis.

Reference	Region	Type of Proxy Data	Season	Period
Briffa et al. [11]	(55° N, 10° E)	MXD	April–September	1750–1975
Briffa et al. [11]	(60° N, 10° E)	MXD	April–September	1750–1975
Briffa et al. [11]	(60° N, 20° E)	MXD	April–September	1750–1975
Briffa et al. [11]	(60° N, 30° E)	MXD	April–September	1750–1975
Zhang et al. [12]	West-Central Scandinavia (62.8–63.2° N, 13.2–14.9° E)	MXD	April–September	1700–2000
Gunnarson et al. [13]	Jämtland (62.2–62.3° N, 13.15–13.6° E)	MXD	April–September	1700–2000
Helama et al. [14]	Finnish Lakeland (61.8–62.85° N, 25.48–31.17° E)	MXD	May–September	1700–2000
Leijonhufvud et al. [15]	Stockholm (59.2° N, 18.03° E)	H	January–April	1756–2000
Tarand and Nordli [16]	Tallinn, Estonia, (59.4° N, 24.75° E)	H	December–March	1700–2000

A new improved version of the instrumental record of the sunspot number (SN) [17] was used as an indicator of the variations of the Sun’s activity. In order to isolate the quasi 22-year Hale cycle from the original sunspot record, we firstly removed long-term changes in the SN and then constructed an alternate record S_N^{22} —odd solar cycles were considered as positive and even ones as negative. Intensity of the galactic cosmic rays (GCR) can be a physical value, which follows the double solar cycle because drift and diffusion of charged particles is sensitive to changes of polarity of the Sun’s magnetic field. During solar cycles with negative polarity (positive values of S_N^{22}) the cosmic ray flux displays a peaked form while during cycles with positive polarity (negative values of S_N^{22}) it has a flat-topped form (see [18]).

3. Results

Fourier spectra of the analyzed time series, calculated over the last 225–300 years, were used for detecting the periodicities in the temperature proxies (Figure 1, Table 2).

Table 2. Peaks of Fourier spectra of temperature reconstructions significant at more than 0.95 CI (1700–2000 AD).

Reconstructed Variable (Reference)	Region	Period	Schwabe (9–14 Years)	Hale (18–25 Years)
Briffa et al. [11]	(55° N, 10° E)	1750–1975		24.7
Briffa et al. [11]	(60° N, 10° E)	1750–1975		22.2
Briffa et al. [11]	(60° N, 20° E)	1750–1975		22.2
Briffa et al. [11]	(60° N, 30° E)	1750–1975		22.2
Zhang et al. [12]	West-Central Scandinavia (62.8–63.2° N, 13.2–14.9° E)	1700–2000		
Gunnarson et al. [13]	Jämtland (62.2–62.3° N, 13.15–13.6° E)	1700–2000		
Helama et al. [14]	Finnish Lakeland (61.8–62.85° N, 25.48–31.17° E)	1700–2000	13.0	
Leijonhufvud et al. [15]	Stockholm (59.2° N, 18.03° E)	1756–2000	13.0, 9.9	
Tarand and Nordli [16]	Tallinn, Estonia, (59.4° N, 24.75° E)	1700–2000	13.0, 11.0, 9.9

Figure 1. Fourier spectra of temperature reconstructions at: (A) (55° N, 10° E) gridpoint [11]; (B) (60° N, 10° E) gridpoint [11]; (C) (60° N, 20° E) gridpoint [11]; (D) (60° N, 30° E) gridpoint [11]; (E) Jämtland [13]; (F) West-Central Fennoscandia [12]; (G) Finnish Lakeland [14]; (H) Stockholm [15]; (I) Tallinn [16]. Dashed lines delineate confidence levels calculated for red and blue noises with AR(1) coefficient individual for each time series. Linear trends were subtracted prior to analyses.

Fourier analysis showed that:

- The significant ($p < 0.05$) quasi 22–24 year (bi-decadal) periodicity was found in four records of growing season temperature. In one of them—temperature at gridpoint (55° N, 10° E), the significance of the bi-decadal variation exceeded 0.999.
- The significant ($p < 0.05$) quasi 10–13 year (decadal) periodicity was present in three proxy records of the temperature in the growing season spring and winter.
- The significant ($p < 0.05$) 60 year and 99 year periodicities were present in the summer temperatures of West-Central Scandinavia. These variations were likely manifes-

tations of the century-scale (60–130 years) cyclicity which has been revealed in the Northern Fennoscandia temperature proxies and was attributed to solar activity changes [2,19].

Here, p is a probability of null-hypothesis—the assumption that the peaks in the Fourier spectra were induced by red noises—random first-order autoregressive processes.

Weaker bi-decadal and decadal variations were present also in some other reconstructions, but they did not reach the $p < 0.05$ level of significance. In order to further study the connection between the temperature data and solar forcing, the coefficients of linear (Pearson) correlation were calculated between solar cycles and the proxy records filtered using Hale (18.1–25.3 years) and Schwabe (8.6–14.1 years) scale bands. Wavelet filtration was performed by means of the real MHAT basis. The statistical significance p of each of the calculated coefficients of correlation was assessed, using a statistical random-phase test, which included a number of 1000 Monte Carlo simulations of similarly smoothed time-series (see [2]) (Table 3).

Table 3. Correlation between the Southern Scandinavian temperature proxy records and solar activity data filtered using the Schwabe (8.6–14.1 years) and Hale (18.1–25.3 years) scale bands. The correlation coefficients with the significance exceeding 0.95, are shown with large font size. Phase shifts (forcing data leading the temperature data) in years are shown in the brackets, with the significance in italics, also in the brackets.

Region	Period	Schwabe (9–14 Years)	Hale (18–25 Years)
(55° N, 10° E)	1750–1975	−0.04 (1, <0.5)	−0.26 (2, 0.75)
(60° N, 10° E)	1750–1975	0.15 (1, 0.83)	− 0.61 (1, 0.963)
(60° N, 20° E)	1750–1975	0.16 (0, 0.84)	− 0.65 (1, 0.982)
(60° N, 30° E)	1750–1975	0.16 (0, 0.82)	− 0.64 (1, 0.985)
West-Central Scandinavia (62.8–63.2° N, 13.2–14.9° E)	1700–2000	0.31 (1, 0.993)	−0.20 (2, 0.78)
Jämtland (62.2–62.3° N, 13.15–13.6° E)	1700–2000	0.34 (1, 0.988)	−0.26 (2, 0.80)
Finnish Lakeland (61.8–62.85° N, 25.48–31.17° E)	1700–2000	0.27 (1, 0.985)	−0.21 (2, 0.55)
Stockholm (59.2° N, 18.03° E)	1756–2000	0.08 (0, <0.5)	−0.47 (6, 0.86)
Tallinn, Estonia, (59.4° N, 24.75° E)	1700–2000	−0.09 (0, <0.5)	− 0.56 (6, 0.983)

Correlation analysis showed that:

- Statistically significant ($p < 0.05$) negative correlation between climatic records and solar forcing data at a time scale relevant to the Hale (ca. 22 years) cycle was found for three reconstructions of the growing season temperature at latitude 60° N as well as for a proxy of winter temperature in Tallinn. Correlation reached maximum when the phase shift between the solar cycle and climatic reaction was 1 year for the summer temperature at 60° N and 6 years for the winter temperature in Tallinn.
- There was no significant correlation between strong 24.7 year periodicity in the growing season temperature at gridpoint (55° N, 10° E) and the solar cycle of Hale.
- Statistically significant ($p < 0.02$) positive correlation between climatic records and solar forcing data at a time scale relevant to the Schwabe (ca. 11 years) cycle was found for three reconstructions of the growing season temperature in West-Central Scandinavia and Finnish Lakeland. Correlation was maximal when the phase shift was 1 year.
- There was no significant correlation between the 10–13 year variation of winter temperatures in Tallinn and the solar cycle of Schwabe.

4. Discussion and Conclusions

Thus, the performed study showed that evidence of a solar–climatic connection exists, not only at Northern Fennoscandia but at Southern Fennoscandia as well. Moreover, while in NF the indications of solar–climatic communication have been obtained only for the warm season temperatures, in SF the correlation between the solar forcing and winter temperatures was observed as well (Tallinn). During a cold season, the effect is likely a bit more pronounced that is in line with the result of [20], obtained by means of the direct instrumental data. On the other hand, a ca. 25 year variation in the warm season temperatures at (55° N, 10° E) and ca. 11 year variation in winter temperatures in Tallinn do not correlate with the corresponding solar cyclicities. It testifies that decadal and bi-decadal natural climatic oscillations not connected with solar activity were also present in Southern Scandinavia. The existence of inherent decadal and bi-decadal climatic instability can obscure solar-induced temperature variations and complicate the revealing of the solar–climatic linkage.

Correlations between the band-passed sunspot number and the temperature series have different signs at different frequency bands. The facts that (a) the climatic response to solar activity changes differed at different time scales and (b) the solar–climatic connection had an apparent spatial pattern are difficult to explain. The known possible mechanisms of solar–climatic linkage, including the direct effect of the total solar irradiance [21], the influence of the energetic particles of the galactic and solar cosmic rays on cloud cover [22,23] and atmospheric circulation [8,24], are unlikely to elucidate such complicated relationships. That means that solar–climatic connections, if they really exist, are likely to be rather complex and our knowledge about them still is limited. Moreover, the alternative explanation—that the revealed solar-type periodicities result from the natural instability of the climate system and the revealed correlations appear purely by chance—cannot be fully rejected. However, I have to emphasize that if the obtained correlations are not linked to the Sun's influence it means that climatic system can produce variations which are similar to solar periodicities over a long time. Figure 2 shows that 9–10 individual 22-year cycles in the temperature proxy [11] developed synchronously with the corresponding solar cycles through the entire time interval AD 1750–1975.

Figure 2. Time series wavelet filtered using Hale (18.1–25.3 years) scale band. Black line—temperature at gridpoint (60° N, 30° E) [11], thick grey line—the record S_N^{22} . Temperature is shifted by 1 year.

Such features in the climate of a rather wide region appear somewhat surprising.

Based on the obtained results, some directions for further research aimed at clarifying the question about the possible solar–climatic link can be proposed:

- (1) Obtaining and analyzing new independent reconstructions of temperature of different seasons in SF. It would allow the study of very local temperature variations over this region in more detail.
- (2) Obtaining and analyzing the reconstructions of temperature over northeastern Europe area outside SF. It would allow the tracing of the regional distribution of the solar-type periodicities and the manifestations of the possible solar–climatic link in more detail.
- (3) Expanding the time interval of the analysis by means of different proxies of the Sun’s activity.

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