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Long-term variations of the solar activity — lower atmosphere relationship

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Short title: LONG-TERM VARIATIONS OF THE SOLAR ACTIVITY

Abstract. Long-term variations of the air temperature in St. Petersburg ($\varphi = 60°$N), Stockholm ($\varphi = 59°$N), Salzburg ($\varphi = 48°$N) and English Midlands ($\varphi \sim 50°$N) are considered. There is shown that in the regions under consideration the air temperature distinctly depends on the intensity of the lower atmospheric zonal circulation (Blinova index and North Atlantic Oscillation index (NAO)). In turn, the NAO index is shown to depend on the solar activity. However, this dependence is rather complicated and exhibits long-period variations associated with secular variations of the solar activity. A possible mechanism of this phenomena is discussed.

Introduction

The idea on the existence of a close relationship of solar activity with the state of the lower atmosphere, though being at present under discussion, is now commonly accepted. During the last twenty years several authors have shown that there exists an influence of the solar and geomagnetic activity on the parameters of the lower atmosphere [*Bauer,* 1982; *Bucha and Bucha,* 1998; *Brown and John* 1979; *Hurrell,* 1996; *Kondratyev and Nikolsky,* 1983; *Pudovkin and Babushkina,* 1992a, *Pudovkin et al.,* 1995, 1996; *Schuurmans and Oort,* 1969; *Svensmark and Friis-Christensen,* 1997; *Tinsley et al.,* 1989, *Tinsley and Heelis,* 1993].

Physical mechanisms of this influence were proposed by *Tinsley et al.* [1989] and by *Pudovkin and Babushkina* [1992b], and they were based on the modulation of the cosmic ray flux intensity by solar activity variations. According to *Pudovkin and Babushkina* [1992a], *Pudovkin et al.* [1995, 1996], *Pudovkin and Morozova* [1997], *Morozova et al.* [1999], the change of cosmic ray flux intensity is responsible for the change of the atmospheric transparency. As a result, the direct solar radiation input into the lower atmosphere has significant variations [*Veretenenko and Pudovkin,* 1999]. During Forbush-decreases of Galactic Cosmic Rays (GCR) the lower atmosphere is heated, and during Solar Proton Events (SPE) it is cooling [*Morozova and Pudovkin,* 1999; *Pudovkin et al.,* 1995].

In the papers by *Pudovkin et al.*, in which these temperature variations were investigated in detail, the authors had considered some sample events of a rather short time duration.

In this article we study ground-level air temperature variations in different regions of Europe for the period of some tens, up to 125 years in connection with solar activity cycle variations.

Data Analysis

The long-term variations of the air temperature in St. Petersburg ($\varphi = 60°$N, $\lambda = 30°$E), Stockholm ($\varphi = 59°$N, $\lambda = 18°$E), Salzburg ($\varphi = 48°$N, $\lambda = 13°$E), and English Midlands ($\varphi = 50°$N, $\lambda = 2°$W) where considered. It was shown earlier [*Pudovkin and Lubchich,* 1989] that influence of solar activity on air temperature variations at St. Petersburg are more noticeable during winter time. Therefore the four winter months (December, January, February and March) were chosen for the analysis. For all parameters used in this study the four-month mean values were calculated and used.

It is well known that GCR flux intensity variations effects are most pronounced at the epochs of the solar activity minima while SPEs are most often observed at the solar activity maxima. Taking this into account one may expect that the cyclic variations of effects of cosmic rays (galactic and solar) will manifest themselves in the cyclic variations of the atmospheric circulation differently. And indeed, this phenomenon was detected and described by *Brown* [1979], *Pudovkin et al.* [1995] and *Veretenenko and Pudovkin* [1999].

Let us consider the relationship between atmospheric circulation and air temperature in the regions under consideration. To describe the global zonal atmospheric circulation the Blinova Indices (BI; [*Blinova,* 1978]) and for the regional circulation the North Atlantic Oscillation Index (NAO), based on the difference of normalized sea level pressure between Azores and Iceland, were used. They correlate rather well with each other ($r = 0.72$).

As one can see in Figure 1, the connection between air temperature of the English Midlands and Blinova Index does really exist ($r = 0.57$). Unfortunately Blinova Index was available for 25 years only (1950–1975). To study longer time intervals of the ground-level temperature behavior with the change of atmosphere circulation, we used the NOA index, which started in 1865.

In Figure 2 the values of winter-time air temperature in all the regions under investigation for 125 years are presented in dependence on the NAO indices. It can be deduced that there exists a strong connection of NAO with the temperature in England and in Stockholm ($r = 0.75$). For St. Petersburg, the correlation coefficient of NAO and air temperature values is smaller ($r = 0.57$). In spite of the location of St. Petersburg being rather close to Stockholm the nearby Arctic Ocean seems to influence the weather of St. Petersburg more noticeable than the weather of Stockholm.

The connection between NAO indices and the ground-level air temperature in Salzburg is less clear ($r = 0.44$). In general Figure 2 shows that in different regions of Europe the winter-time air temperature is distinctly affected by the North Atlantic Oscillation indices.

As was noted earlier, the change of the lower atmospheric circulation can be produced by the variations of the cosmic ray flux intensity. In this connection, Figure 3 shows the change of GCR flux intensity and Blinova indices for 1954–1975. It can be seen that for the last ten years the GCR fluxes were associated with the Blinova indices rather well; however, for the whole period, this connection is almost negligible ($r = 0.24$). This result permits us to suppose that the observed for some time intervals correlation between cosmic ray flux intensity and atmospheric circulation indices is occasional or varies in time. The data presented in Figure 4 confirm this supposition: the 7-year running correlation coefficient of NAO-indices and GCR flux intensities has cycle-like variations for the last 40 years; herewith r changes from 0.9 in $\approx$ 1972 up to -0.9 in $\approx$1982. To extend this analysis for longer time-intervals we used Wolf numbers instead of GCR data, as the latters are available from 1953 only. It is well known that GCR fluxes and Wolf numbers W anticorrelate with a high value of correlation coefficient, so this change of parameters describing the solar activity is quite reasonable.

Figure 5 shows the variations of Wolf numbers, NAO indices and 5-year running averaged NAO-indices (thick line) for 1865–1996. From the first view at the figure it is clear that for the entire period under consideration the correlation between NAO and W indices is negligibly small. At the same time, one can see that W and smoothed NAO indices at some time correlate well (1880–1910, 1980–1996), and at some time they anticorrelate. Here we can see the same situation as in Figure 3, where Blinova indices and GCR flux intensity were compared.

To get a more clear picture of this fact we studied in detail the behavior of the correlation coefficient between NAO-indices and W for different time intervals. Therefore 7-, 11- and 22-year running averaged correlation coefficients were calculated. In Figure 6 the Wolf numbers and 11-year running averaged correlation coefficient are presented. As is seen from the figure the positive correlation which existed for the first 40 years of the investigated time period (rising up to 0.95) changed on about of 1910 by negative values. For 1910–1980 the correlation coefficient was mainly negative, and in 1980 it again changed to positive values. Within the interval characterized by $r < 0$, there was a very short period (1960–1970) with $r > 0$.

The complicated behavior of the correlation coefficient between Wolf numbers and the lower atmospheric circulation for 1865–1996 permits us to suppose that at different phases of the secular solar activity variations different kinds of cosmic rays (galactic of solar) influence predominantly the state of the lower atmosphere. It has to be noticed that for the period 1900–1910, this change of the sign of the correlation coefficient (Figure 6) was also pointed out in a paper by *Morozova et al.* [1999]. In this paper the authors studied the relationship between the variations of the 22-year smoothed values of Wolf numbers and spring temperature in Switzerland. They found that the sign of the correlation coefficient changes regularly from being positive to being negative, and the years of the sign change coincide with the minima in solar activity secular variations; in particular, one of such moments takes place on about 1900 (see Figure 7 after *Morozova et al.* [1999]). This allows one to suppose that some peculiarities of the solar corpuscular radiation and (or) of the magnetic field of the solar wind noticeably vary with the long-period solar cycles.

Conclusions

1. There exists a statistically significant connection between the winter-time air temperature variations in the investigated regions of Europe (English Midland, Stockholm, St. Petersburg and Salzburg) and the indices of atmospheric circulation (global Blinova indices as well as regional North Atlantic Oscillation indices).

2. The relationship between NAO indices and Wolf numbers for 1865–1996 essentially varies with the solar activity secular variations, in the course of which the sign of the correlation coefficient changes rather regularly.

3. The last result suggests essential long-period variations of the characteristics of the solar wind and of magnetic field frozen in it.

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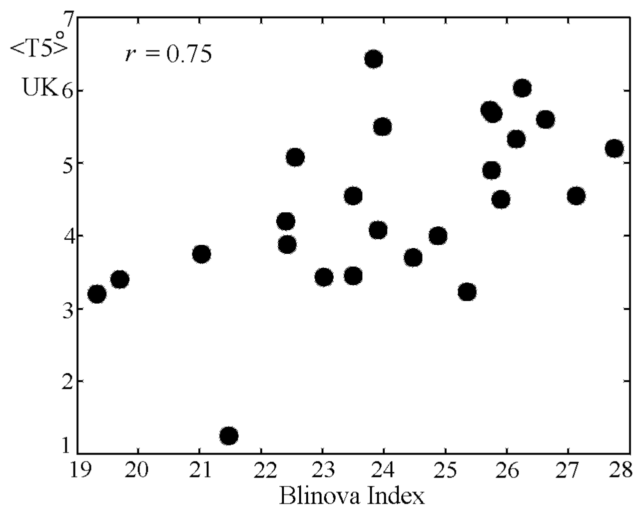

Figure 1. The wintertime temperature variations in the English Midlands (UK) in dependence on the index of zonal atmospheric circulation (Blinova Index).

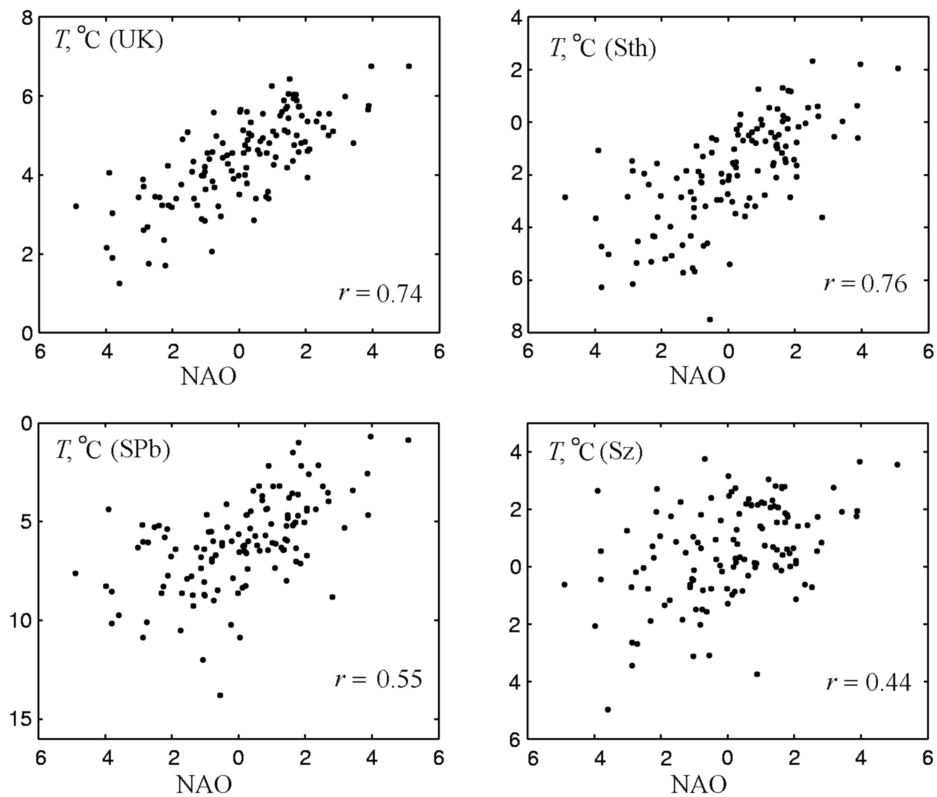

Figure 2. The wintertime temperature variations in the English Midlands (UK), Stockholm (Sth), St.-Petersburg (SPb) and Salzburg (Sz) in dependence on North Atlantic Oscillation index (NAO).

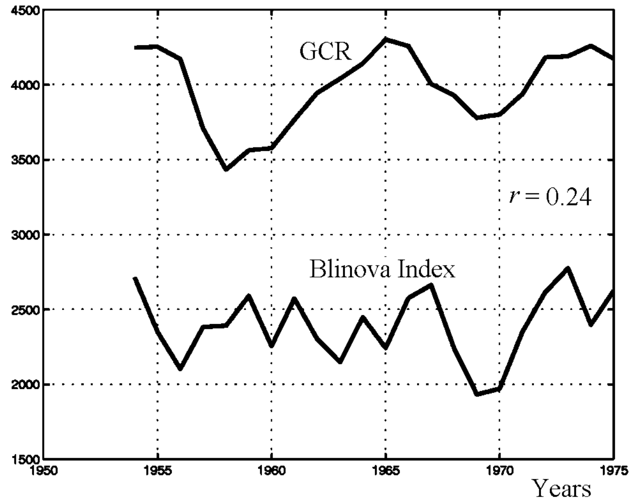

Figure 3. Time variations of Galactic Cosmic Rays (GCR) flux intensity and Blinova Index for winter months (December–March).

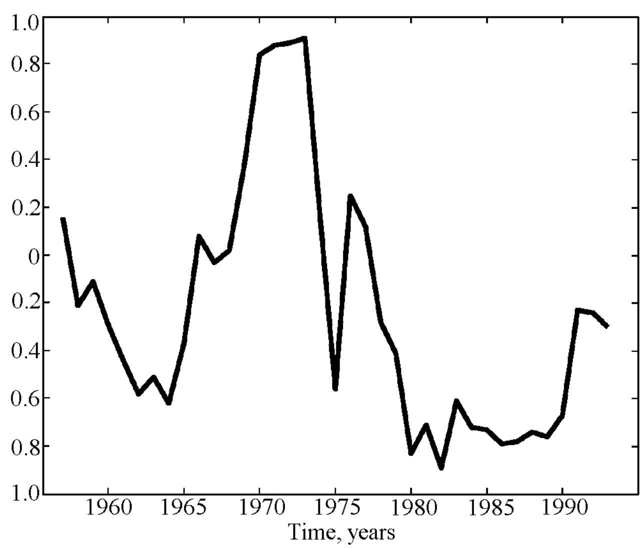

Figure 4. 7-year running correlation coefficient between NAO and GCR flux intensity for wintertime.

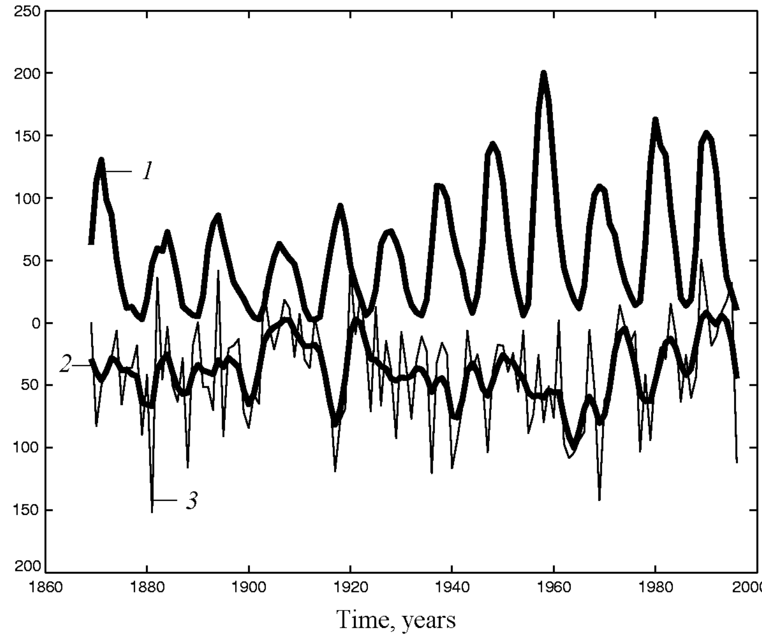

Figure 5. Variations of Wolf numbers (1), NAO indices (2), and 5-year running averaged NAO (3) for 1867–1997.

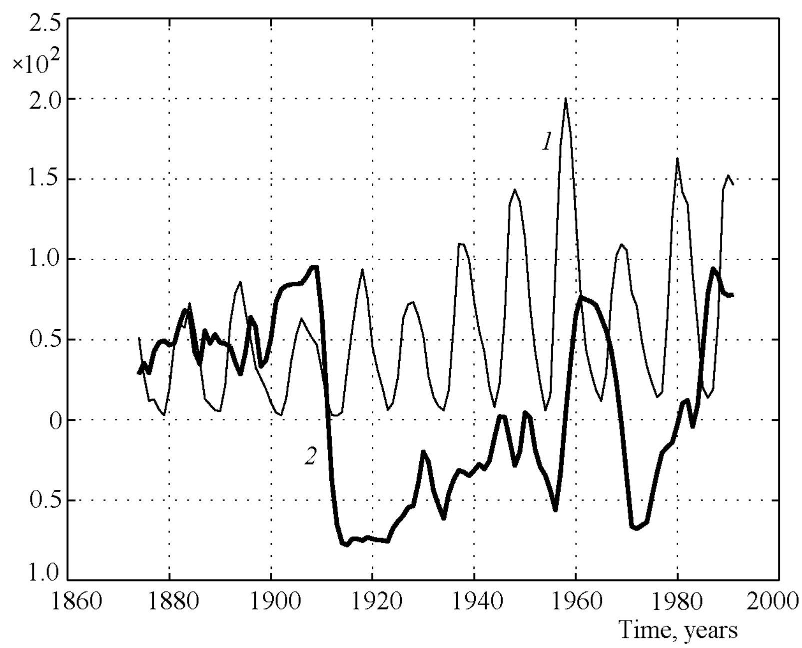

Figure 6. Variations of Wolf numbers and 11-year running correlation coefficient between NAO and W.

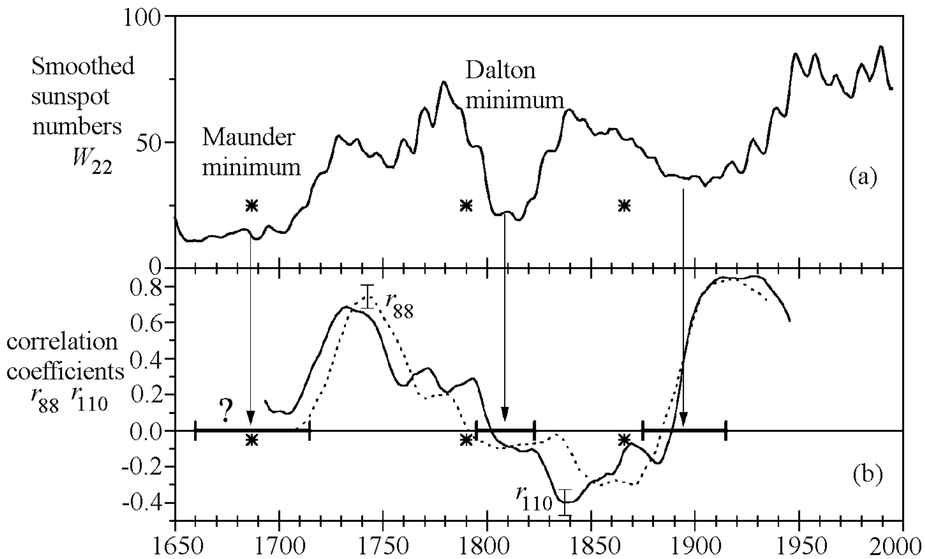

Figure 7. Long-period solar cycles and correlation coefficient between spring temperature in Switzerland and Wolf numbers.