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Long-term variations in the correlation between solar activity and climate

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Abstract. The problem of solar activity influences on climate is controversial - some authors have found positive correlations between solar activity and different meteorological parameters, others negative correlations, still others no correlations at all. On the basis of all available global and zonal averages of surface air temperature, as well as measurements in individual stations with long data records we show that the sign of the correlation is the same in different locations, and changes regularly from one secular solar cycle (SSC) to the other, with the sign depending on the long-term solar activity asymmetry.

Key words. Sunspot cycle, temperature

1. Intoduction

Ever since the sunspot cycle was discovered, attempts have been made to find a relation between solar activity and terrestrial climate. Nevertheless the question remains controversial. There is no commonly accepted physical mechanism, and different authors (and sometimes the same authors), for different locations (and sometimes for the same locations) have found positive, negative or missing correlations between sunspot activity and surface air temperature in the 11-year solar cycle. For example Kőppen (1914) showed that in the 19th century the mean annual global temperature was lower in sunspot maximum and higher in sunspot minimum. The same result was found for the same period separately for tropical and subtropical regions (Kőppen 1873). Troup (1962) continued Kőppen's analysis and found that in the tropical zone the correlation between temperature and sunspot number was indeed negative between 1862 and 1920-1925, but changed to positive afterwards. If the correlation between solar activity and temperature changes randomly, this may mean that the relations found are random coincidences. On the other hand, if there is some regularity in the change in the correlation, most probably the influence is real but there are some additional factors determining how solar activity influences the climate.

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2. Solar activity and temperature in the 11-year sunspot cycle

As a first step, we make a compilation of all available published results. In Fig. 1 the periods for which positive or negative correlations

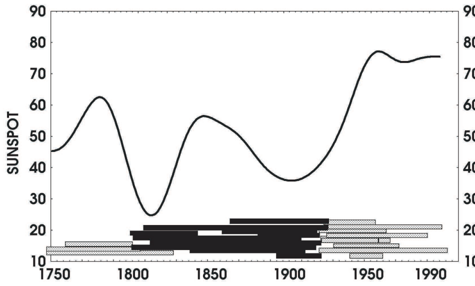

Fig. 1. Published results reporting negative (dark shading) and positive (light shading) correlations between solar activity and surface air temperature in the 11-year solar cycle. Solid line - SSC.

are reported in different papers between surface air temperature and solar activity in the 11-year cycle are presented by dark and light bars, respectively, and the SSC - by a solid line. It can be seen that the cases of positive and negative correlations are fairly well grouped. The sign of the correlation depends only on the period studied and not on the location, and seems to change in consecutive secular cycles (see Fig. 1).

This result is confirmed by reconstructions of global, hemispheric and zonal temperatures (e.g. Vinnikiv et al. 1990) illustrated in Fig. 2: the correlation between sunspot number and temperature is negative until about 1925 and negative afterwards. In the bottom panel of the Fig. 2 the cross-correlation functions for the two periods are presented. Global reconstructions are relatively short, so to study earlier epochs, data from individual meteorological stations with long measurement records were used. In the Global Historical Climatology Network Temperature Database of NCDC (Peterson and Russel 1997), 65 stations were found with almost continuous data records beginning well before the middle of the 19th century. The time series for each station was divided into subseries yielding the best correlation with solar activity. In Fig. 3 the percentage of stations with statistically significant positive and negative correlation (along the positive and negative parts of the axis, respectively) is shown together with the secular solar activity cycle. In the 18th century, in the

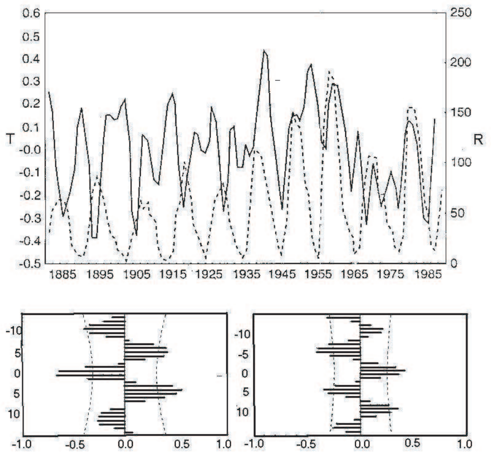

Fig. 2. Upper panel: Mean zonal annual temperature (solid line) and sunspot numbers (dotted line); 5-point runnung mean, detrended; Lower panel: Cross-correlation functions for the periods before and after 1925.

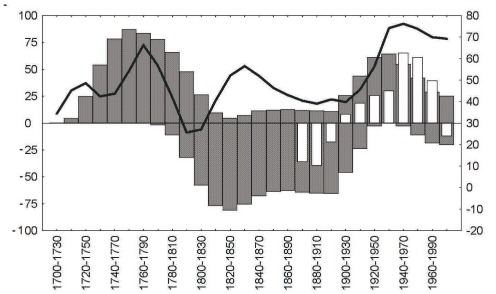

Fig. 3. Dark bars - percentage of stations with statistically significant correlations between solar activity and surface air temperature in the 11-year solar cycle - positive or negative, along the positive and negative Y-axis, respectively; Solid line - SSC; White bars - North-South solar activity asymmetry.

vast majority of the available stations the surface air temperature was positively correlated with solar activity in the 11-year solar cycle, this correlation changed to negative in the 19th century and to positive again in the 20th century.

3. Solar asymmetry and secular solar cycle (SSC)

The change in the sign of correlation in consecutive SSCs implies that there is some solar parameter determining the way in which solar activity affects climate, which changes in consecutive secular cycles. One parameter which changes in the end of the 19th and the beginning of 20th century is the north-south asymmetry of solar activity (the white bars in Fig. 3). It has been noted earlier that the activity originating from the two solar hemispheres has different effect upon atmospheric parameters. Smirnov (1967) found that when the Earth passes from one sector of the interplanetary magnetic field into another, the sign of the correlation between the solar wind velocity and the atmospheric parameters changes. The sector boundary crossing means changing the solar hemisphere to which the Earth is exposed. Waldmeier (1957) based on data up to the 18th solar cycle, found a close relation between the North-South asymmetry of solar activity and the SSC, and formulated that solar activity dominates in the Northern solar hemisphere during the ascending part of the SSC, in the Southern one during the descending part, and in epochs of secular minima and maxima the asymmetry is small. However, there are at least two episodes when this rule does not hold: the secular maximum in the 20th century when the asymmetry had a maximum rather than a minimum, and the end of the Maunder minimum when the activity was clearly ascending and all sunspots were concentrates in the Southern solar hemisphere. Based on the study of the solar activity effects on climate we have suggested that solar asymmetry changes in consecutive secular cycles, being positive in "even" cycles (if we denote the 20th century secular cycle as even) and negative in odd ones. It has a maximum positive or negative value coinciding with the maximum of solar activity in the secular cycle, and changes sign around secular solar minimum. This leaves no "anomalies" in the available data (Georgieva and Kirov 2000). Therefore, we can speak about a "double secular" (or "double Gleissberg") solar cycle consisting of two secular cycles one in which more active is the Southern solar hemisphere, and a second one in which more active is the Northern hemisphere, much like the double sunspot (or Hale) cycle consisting of two 11-year cycles with reversing magnetic polarities. The secular cycle in solar activity asymmetry was confirmed by Mursula and Zieger (2001) based on data for geomagnetic activity. Solar rotation is considered a basic element in the solar dynamo mechanism. Gigolashvili et al. (2005) demonstrated that the northern hemisphere rotates faster during the even numbered sunspot cycles (20 and 22) while the rotation of southern hemisphere dominates in odd ones, and conclude that the N-S asymmetry of the solar rotation should cause a difference in activity level between the northern and southern hemispheres. Javaraiah et al. (2005) studied the long-term variations in solar differential rotation and in the strength and length of the sunspot activity cycles, and also found a double Gleissberg cycle consisting of two Gleissberg cycles with different strengths. The first one (corresponding to "odd" secular cycles) is weaker than the second ("even") one. A comparison of solar rotation parameters (Javaraiah et al., 2005) shows that the equatorial solar rotation is faster and the latitudinal gradient of the solar rotation rate are both bigger in odd numbered than in even numbered SSCs which confirms the relation between solar differential rotation and sunspot activity. We can therefore conclude that the secular cycle of solar asymmetry is a real feature, confirmed by data on sunspot activity, sunspot asymmetry, solar rotation rate, geomagnetic activity and climate.

4. Solar asymmetry and solar activity influences on climate

Long-term variations in global temperatures are related to the long-term changes in global atmospheric circulations. Zonal forms of circulation are associated with positive temperature anomalies, while meridional circulation causes cooling over most of America and Eurasia. Therefore, solar activity influence on climate is mediated by its influence on atmospheric circulation. Vitel's (1960) have studied the repeatability of the forms of atmospheric circulation and the number of transformations from one form into another. Combining their results, we come to the conclusion that zonal forms of circulation prevailed in the 19th century and increased solar activity in the 11-year solar cycle transformed them into meridional (leading to cooling), while in the 20th century the prevailing form of circulation was meridional and solar activity transformed it into zonal (leading to warming). Kuznetsova and Tsirulnik (2004) found that even 11-yr solar cycles correspond to enhanced meridional circulation and global cooling while odd ones correspond to zonal circulation and warming. The mechanism they propose is based on the influence of the solar wind electric fields E on the global atmospheric circuit changing the angular momentum of the zonal atmospheric winds. Comparing the odd-even 11-year cycles and the odd-even secular cycles, similar variations are found in solar rotation parameters, atmospheric circulation, and solar activity influences on circulation and temperature anomalies. Most probably all these effects are related to the dynamics of the Solar system (Javaraiah and Gokhale, 1995), however this hypothesis requires much additional investigation.

5. Summary

We have shown that the correlation between solar activity and global temperature is different in different SSCs and depends on solar activity asymmetry. The Gleissbers solar cycle is a part of a double secular cycle consisiting of one Gleissberg cycle in which more active is the Southern solar hemisphere, and a second one with more active Northern hemispohere. The prevailing type of atmospheric circulation and the way in which solar activity transforms it are different in both odd and even 11-year cycles, and in odd and even SSCs. These differences are most probably related to the dynamics of the Solar system.

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