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Short Communication

Episodes of relative global warming

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ABSTRACT

Solar activity is regulated by the solar dynamo. The dynamo is a non-linear interplay between the equatorial and polar magnetic field components. So far, in Sun–climate studies, only the equatorial component has been considered as a possible driver of tropospheric temperature variations. We show that, next to this, there is a significant contribution of the polar component. Based on direct observations of proxy data for the two main solar magnetic fields components since 1844, we derive an empirical relation between tropospheric temperature variation and those of the solar equatorial and polar activities. When applying that relation to the period 1610–1995, we find some quasi-regular episodes of residual temperature increases and decreases, with semi-amplitudes up to ~0.3 °C. The present period of global warming is one of them.

1. Introduction

The question of the relation between the average tropospheric temperature and solar activity is a matter of debate. There are, however, indications that some relationship does exist. During the Maunder Minimum (1650–1710) the level of solar activity was low while the same was the case for the mean temperature. In Holland there were indications for low winter temperatures from recorded data on frozen canals (De Jager, 1981). Not without reason the term Little Ice Age is used for the period ~1500–~1850. Over longer time intervals there is abundant indication of Sun-related temperature variation in biological sediments (cf. review by Versteegh, 2005, with many references to earlier investigations). An attempt to quantify that relationship (De Jager and Usoskin, 2005) showed a clear dependence of the tropospheric temperatures on equatorial activity, as manifested by the Group Sunspot Number. In addition, a less pronounced relation was found between the open solar magnetic flux and tropospheric temperatures. Krivova and Solanki (2003) studied the relation between tropospheric temperature and solar parameters including the terrestrial cosmic ray flux and found that the relation, if existent, was not significant after 1970.

The source of solar activity is the solar dynamo (cf. review by De Jager, 2005), the basis of which is seated in the tachocline, a relatively thin layer at a depth of some 200,000 km below the solar surface. There, strong toroidal magnetic fields originate from an initially poloidal configuration, by internal shearing motions. When these have sufficiently increased in strength, parts of them detach, whereupon they rise and appear at the surface as sunspot groups. During the Schwabe cycle, which is the well-known ~11 years cycle of solar activity, a toroidal field thus originates from an initially poloidal one. Part of this toroidal field thereupon gives rise to fields with a poloidal character, which show themselves mainly in solar polar areas. Although the surface polar fields are less strong than those in the sunspot belt, the total magnetic fluxes of the polar and equatorial fields are comparable (Callebaut, priv. comm.).

In the studies mentioned above, as well as in all other hitherto published investigations related to Sun–climate relationships, it is always implicitly assumed that the solar mechanism that might influence tropospheric temperatures had to be looked for in the equatorial, sunspot-related, magnetic field regions. That mechanism could either be the total solar irradiance directly influencing the troposphere, the UV flux from facular areas around sunspots by their influence on the terrestrial stratosphere, or else it might be based on the flux of magnetized plasma, affecting the rate of cloud formation by the modulation of the incoming flux of cosmic radiation on the Earth (see for this last aspect Krivova and Solanki, 2003). A proxy for both mechanisms is the number of sunspots, or the number of sunspot groups. These are related to the toroidal component of the Sun's magnetic field.

In this paper, we investigate empirically whether those manifestations of solar activity that are related to the polar areas may also contribute to terrestrial climate and to what degree. From data since 1844 we derive an empirical relation. Thereafter, we use that relationship to compare tropospheric temperatures of the past four centuries with the expected temperatures. We find some significant episodes of relatively higher and lower

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temperatures. They last for times of the order of a Gleissberg cycle. The present episode of global warming appears to be one of them.

2. Relation between solar activity and tropospheric temperatures

The toroidal component of the solar magnetic fields shows itself in the solar activity regions, with its many manifestations: sunspots, facular fields, solar flares, coronal mass emissions, prominences are the most important components. A generally used proxy for these activities is the number of sunspots. This proxy remains, though, an approximation, but so far it seems to be the best. Fig. 1 shows the smoothed Group Sunspot Number (Hoyt and Schatten, 1998) over the past four centuries. We choose this number for the proxy for the solar activity regions, because it represents the number of sunspot groups. The difference between the sunspot group number and the usual Zürich sunspot numbers is small, though. The group sunspot number is known from 1610 onward. These data have been smoothed with a 21-year triangular smoothing function, as described by De Jager and Usoskin (2005). Therefore, the first data point of the diagram is for 1620.

For comparison, Fig. 2 shows the smoothed average Northern Hemisphere tropospheric temperatures for the same period (Moberg et al., 2005). They have been smoothed the same way as the Group Sunspot Numbers. Correlation between these two variables is apparent. They show that both, the number of

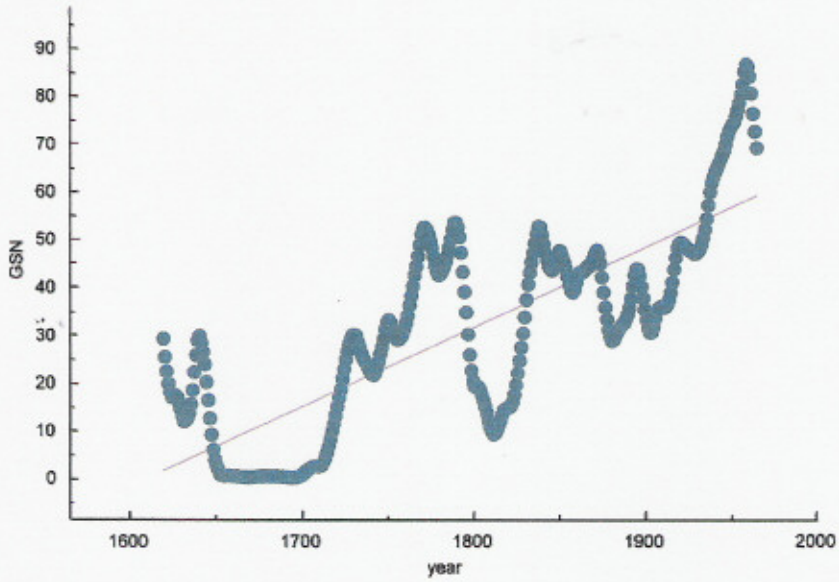

Fig. 1. Smoothed Group Sunspot Numbers for the period 1620–1970. The regression line shows the gradual increase over the centuries. For the smoothing technique reference is made to De Jager and Usoskin (2005).

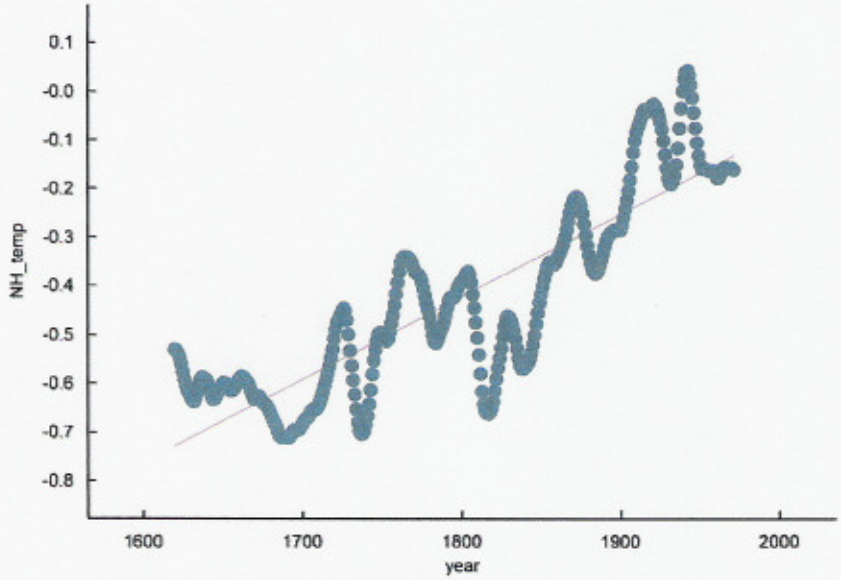

Fig. 2. Smoothed average Northern Hemisphere temperatures according to Moberg et al. (2005) and the regression line. The NH temperature too increased over the centuries.

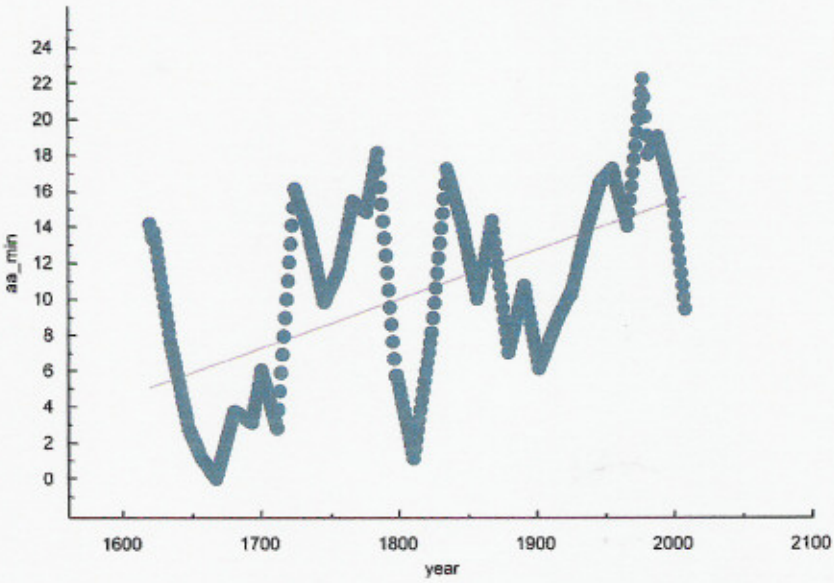

Fig. 3. Smoothed values of aa_{min} since 1610, and the regression line.

sunspots as well as the average NH temperature gradually rose, though with large fluctuations, during the last four centuries. Note that in these two diagrams the last data point is for 1960. That was done in order not to include the recent period of global warming in this part of our study, thus restricting this part of the investigation to the period during which the Sun–climate relationship was not yet sensibly influenced by antropogenic effects.

The polar solar activity has various manifestations, among which 'polar faculae' and 'bright points'. They are related to the poloidal component of the dynamo. The maximum of this field precedes that of the sunspot number by about half a Schwabe cycle. A proxy for its maximum value is aa_{min}, the geomagnetic aa index during sunspot minimum (Russell, 1975; Russell and Mulligan, 1995; Hathaway et al., 1999; Duhau and Chen, 2002). Fig. 3 presents the smoothed values. The data points after 1844 are based on direct observations (Mayaud, 1972; Nevalinna and Kataja, 1993), while those from before that year are derived by a wavelet-based extrapolation by Nagovitsyn (2006). Although the way of deriving these latter extrapolated values is fairly sophisticated, a fundamental weakness is that they are partly based on the sunspot numbers for that period, thus introducing some degree of correlation with the sunspot number. And although a closer study of the data shows that these extrapolations are satisfactory (Duhau and De Jager, 2008), we ultimately decided to restrict the analysis of the Sun–climate relationship to the period 1844 to present. The drawback of this decision, a shorter baseline of our study, was compensated by the fact that thus the investigation is based on direct observations. This led to more precise resulting data.

With the data now at hand we investigate the relation between solar activity and temperature for the period after 1844. To that end we perform a least-squares solution of the equation:

$$T = a + bR + caa, \tag{1}$$

where T stands for the observed average tropospheric temperatures, R for the Group Sunspot Numbers, aa for the aa_{min} values. The symbols a through c are the unknown constants. The constant a is physically uninteresting since it is just a zero-point reference constant. Initially we also introduced a term dt in the equation, where d is a constant and t is the time, in order to cover a possible non-solar, or in any case a non-magnetic component of the temperature variation, but in the course of our investigation we invariably found that this term can be neglected. Hence only the constants b and c are of interest for the present investigation. The NH temperature, Group Sunspot Numbers and the polar variables were made dimensionless and normalized by dividing them by their average values over the period of time under investigation. As stated above, we restricted ourselves to the period 1844–1960, i.e. the time when direct observations were available and during which antropogenic global warming was not yet significant. The investigation is based on the same seven temperature data sets that were used by De Jager and Usoskin (2005): Overpeck and Hughen (1997), Jones et al. (1998), Mann et al. (1999), Briffa (2000), Crowley and Lowerly (2000), Mann and Jones (2003), and Moberg et al. (2005). The resulting average values of the parameters and their mean errors are: $b = 0.144 \pm 0.031$ and $c = 0.043 \pm 0.009$.

The above result shows that, next to the equatorial component, the polar component also influences tropospheric temperature. Its contribution is about 30% of that of the equatorial component. We are not yet able to state quantitatively what fraction of the tropospheric temperature variation has a solar origin, but it is clear that the solar contribution is significant. The immediately arising question, which of the equatorial and polar activities is the physical contributor, is a matter for intriguing solar studies and is reserved for a later investigation.

3. Residual temperature fluctuations

The relation (1) yields the opportunity to examine to what extent it describes the full variation of temperature with time. In other words: do residuals exist, how important are they and how to explain them.

To that end we derived

$$\Delta T = T_{obs} - T_{cal}, \tag{2}$$

where T_{obs} refers to the smoothed temperatures and T_{cal} is derived with Eq. (1) where the values for b and c are given above. We have subtracted the physically uninteresting constant value a. Fig. 4 is mainly based on the data set from Moberg et al. but these data

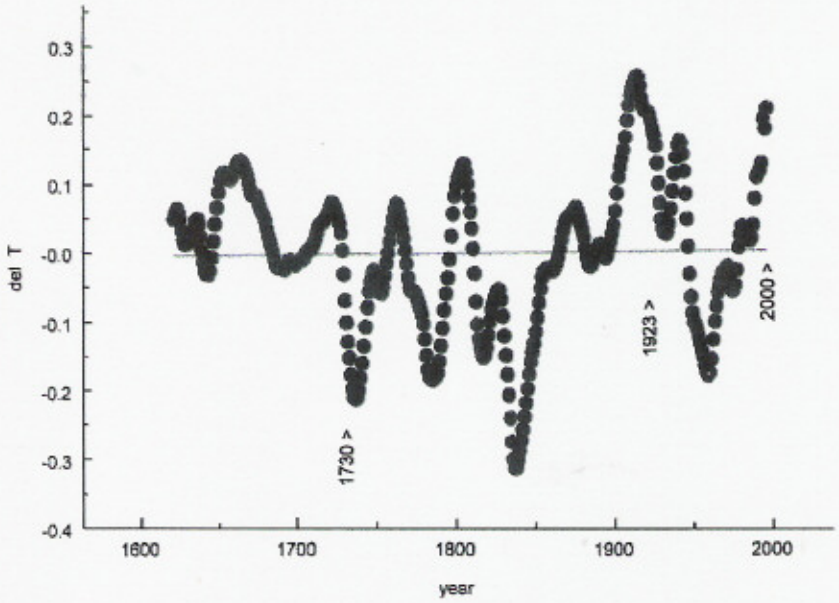

Fig. 4. Differences ΔT, according to Eq. (2) for the period 1620–1995. The diagram refers to the data sets from Moberg et al. (2005) and Brohan et al. (2006).

only go to 1980, and, after smoothing, only to 1970. Therefore, we have extended it with the data set from Brohan et al. (2006) that extends to 2005. The adaptation of this latter data set to the former demanded a minor adaptation constant (−0.007 °C).

Fig. 4 show both positive and negative excursions of the relative temperature. Not all peaks are significant, in the sense that they appear in all seven studies. Apart from the present period of global warming, some significant peaks occurred around 1650, 1715 and 1920. Significant downward peaks, of the same order of magnitude, appeared around 1730 and 1835. It is tempting to speculate on the causes of these peaks, particularly when realizing that 1650 was the onset of the Maunder Minimum, 1835 was in the Dalton Minimum, that around 1720 solar activity changed from a Grand Minimum into a period of Regular Oscillation, while in 1923 the 20th century Grand Maximum started (Duhau and Chen, 2002; Duhau and De Jager, 2008). We reserve such speculations for another paper. We also draw attention to small dips that may be associated with large volcanic eruptions, those of 1815 (Tambora), 1883 (Krakatoa) and 1980 (Mt. St. Helens). They are visible in spite of the fact that the temperature data were strongly smoothed.

Interestingly, the amplitude of the present period of global warming does not significantly differ from the other episodes of relative warming that occurred in earlier centuries. That it actually shows high-temperature excursions in absolute measure is due to the fact that this episode of relative warming is superimposed on a relatively higher level of solar activity than the others, and from that point of view this observation may be a reason for claiming that the present period of global warming is exceptional.

4. Conclusions

The three main results of this study are the following: first, there exists a relation between solar activity and average tropospheric temperatures. Next, this relation depends both on the toroidal and the poloidal component of solar magnetism. The seven temperature sets that we studied here, evidently give different results but it is gratifying that they agree qualitatively in confirming the dependence of tropospheric temperature on both components of solar activity. The third result is that a comparison of observed with calculated temperatures shows residual peaks and valleys. Some of these are significant, appearing in all seven data sets studied here.

These results may be of importance for understanding the solar mechanism(s) that influence(s) climate. The refereed literature contains 15 global or NH temperature data sets. Obviously all must be studied in order to further check the above results. It is also necessary to discuss the heliophysical and climatologic aspects of these findings. Such a study is presently underway with colleagues.

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