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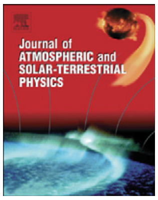

Quantifying and specifying the solar influence on terrestrial surface temperature

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ABSTRACT

This investigation is a follow-up of a paper in which we showed that both major magnetic components of the solar dynamo, *viz.* the toroidal and the poloidal ones, are correlated with average terrestrial surface temperatures. Here, we quantify, improve and specify that result and search for their causes.

We studied seven recent temperature files. They were smoothed in order to eliminate the Schwabe-type (11 years) variations. While the total temperature gradient over the period of investigation (1610–1970) is 0.087 °C/century; a gradient of 0.077 °C/century is correlated with the equatorial (toroidal) magnetic field component. Half of it is explained by the increase of the Total Solar Irradiance over the period of investigation, while the other half is due to feedback by evaporated water vapour. A yet unexplained gradient of −0.040 °C/century is correlated with the polar (poloidal) magnetic field. The residual temperature increase over that period, not correlated with solar variability, is 0.051 °C/century. It is ascribed to climatologic forcings and internal modes of variation.

We used these results to study present terrestrial surface warming. By subtracting the above-mentioned components from the observed temperatures we found a residual excess of 0.31° in 1999, this being the triangularly weighted residual over the period 1990–2008.

We show that solar forcing of the ground temperature associated with significant feedback is a regularly occurring feature, by describing some well observed events during the Holocene.

1. Introduction

In a previous paper (De Jager and Duhau, 2009b) we discussed the relationship between solar activity and average terrestrial surface temperature. A refinement, as compared to earlier investigations of that problem, was that we did not only deal with the correlation of terrestrial surface temperature with the manifestations of the solar toroidal magnetic field component, such as sunspots, the UV radiation emitted by the facular fields, solar flares and CMEs, but that we also considered the possible influence of the poloidal fields. The rationale behind that approach is that the two magnetic field components of the solar dynamo, *viz.* the toroidal and the poloidal ones, are comparable in magnetic flux. Hence there is no *a priori* reason for concentrating on only one of them when studying the possible solar influence on tropospheric temperatures.

On the basis of a study of seven temperature data files we found (De Jager and Duhau, 2009b) that the influence of the poloidal fields cannot be neglected. It was at that time reconstructed to amount to some 30% of that of the toroidal field component. The question which manifestation(s) of solar activity should be put responsible for the sun–troposphere connection was not touched.

We have since been involved in a more detailed recalculation of these results for various reasons: First, we got new *aa*-data. Next we also realized that the use of *aa*-data for the period 1610–1844, being based on extrapolated sunspot numbers could give rise to wrong results. The approach followed in that paper was based on a method comparable to our '*first attempt*', described in Section 2. In that section we will show that this approach yields inaccurate results. Finally we thankfully acknowledge the receipt before publication of a critical paper by Komen (preprint). The outcome of the new study is part of the present paper. Later in this paper we explain the difference with the former results.

In our attempt to identify a solar agency we took into account that the solar variability has several components. Best known are the Schwabe and Hale cycles of ∼11 and ∼22 years, the

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Gleissberg cycle of ~88 years, the De Vries cycle of 205 years, the Hallstatt cycle of ~2300 years (cf. review by De Jager, 2005). Most of these cycles, though, are not constant as some of them, notably the Schwabe and Hale cycles and particularly the Gleissberg cycle vary in length as well as in their time-dependent structure. It seems likely that each of the various components of these cycles may be associated with another solar physical mechanism, which has to be identified. Each of these may or may not be correlated with terrestrial surface temperatures and they may act differently. It is the purpose of this paper also to deal with that problem, in an attempt to identify the solar cycles that contribute to tropospheric warming.

To illustrate the problem we show in Fig. 1 the variation of the temperature with time since 1620. The data file is that of Moberg et al. (2005) extended after 1980 by that of Brohan et al. (2006) and Kennedy et al. (2008). The data have been smoothed with a procedure described by De Jager and Usoskin (2006), which consist in weighing the data with triangularly distributed weights over a time interval of plus and minus 9 years around the central date. Data smoothing is essential for the present problem because the notion ‘climate’ implies the study of terrestrial surface temperatures.

A gradual increase, with a gradient of 0.17° per century, is apparent in the diagram but we notice a change in the gradient after about 1790–1800. Also clear is the still steeper increase after 1970. Roughly one may distinguish between three periods, each with a different gradient $dT(t)/dt$: 1610–1800, 1800–1970 and after 1970.

The average secular temperature gradient of the Moberg–Brohan–Kennedy data, being $dT/dt = 0.17°$ per century, is not typical. All seven temperature data sets that are studied in this paper (cf. the references in Section 2) show a secular increase of temperature. The average value over the seven data sets is 0.087° per century. In these temperature data sets the lowest value, 0.036° per century, is for the data of Mann et al. (1999).

In the present paper we want to study the solar influence on the Earth’s lower troposphere and notably on the surface temperature. In this introductory section we briefly summarize results from other authors that found correlation between solar activity and physical parameters of the troposphere, notably the ground temperatures. Coughlin and Tung (2004) found an 11-year sun-correlated signal in the lower troposphere. Usoskin et al. (2004b, 2004c) studied the correlation between solar activity and surface temperature over the last 1150 years and found a correlation coefficient of 0.7–0.8 with a significance level ranging between 94% and 98%. De Jager and Usoskin (2006) studied the correlation between the Moberg et al. temperatures and the Group Sunspot Number for the period 1620–1960. Their diagram (their Fig. 3) shows significant correlation, the correlation coefficient being 0.77 (+0.10/−0.17) with a significance level of 99.8%. Scafetta (2009) found a significant solar contribution in the period before 1980. Le Mouël et al. (2008, 2009) detected a good correlation between some aspects of earth temperature variation and solar variability. According to Benestadt and Schmidt (2009) the sun contributed for 7% to the temperature increase in the 20th century while its contribution is negligible since 1980. Usoskin et al. (in press) found significant, though geographically separated solar effects on tropospheric ionisation.

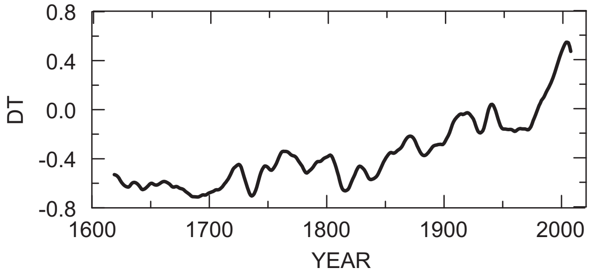

Fig. 1. Smoothed average terrestrial surface temperatures according to Moberg et al. (2005). Data from Brohan et al. (2006) and Kennedy et al. (2008), from 1980 onward are pasted to it.

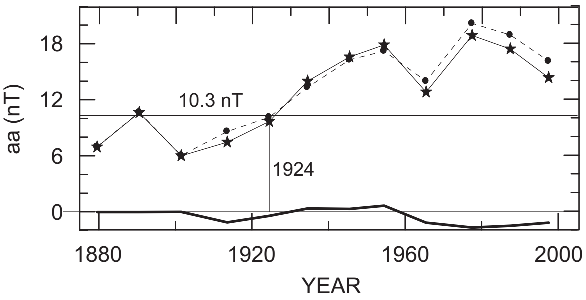

Fig. 2. The homogeneous (Lockwood, stars and thin solid line) and the standard (Mayaud; points, dotted line) aa geomagnetic index time series and the difference between both (thick line). The straight line at the 10.3 nT level indicates the ordinate of the Transition Point (TP). In 1924 the amplitude of the polar cycle was very near to the Transition Point value.

Next, we describe the proxies used here. Following usual practice, the time series of sunspot cycle maxima $R_{\max}$ and of the minima of the geomagnetic index $aa_{\min}$ have been used as proxies for the amplitude modulation of the solar dynamo magnetic field in the toroidal and poloidal components, respectively. This is done because direct observations of the two field components are only available for the past few solar cycles. For the *aa* index we used the Mayaud (1975) data as recently corrected by Lockwood et al. (submitted for publication). The difference between these two data sets is shown in Fig. 2. These differences appear to be relatively small, but since the $R_{\max}$ and the $aa_{\min}$ data are correlated to a large extent, these small differences may result in large differences in the outcome of investigations, like the present one, that are based on a least squares treatment of four variables. We recall that at phase transitions between Grand Episodes the values of $aa_{\min}$ and $R_{\max}$ assume unique values, of 93.4 sunspot numbers and 10.34 nT, respectively (Duhau and De Jager, 2008). These co-ordinates identify the so-called Transition Point. The upper horizontal line in Fig. 2 at 1924 is drawn at that value. The vertical line in Fig. 2 at 93.4 is drawn at the Transition Point value for $R_{\max}$. The $aa_{\min}$ curve crossed the 1924 line during the phase transition of 1923–1924.

2. A reanalysis of the sun–climate connection

We investigate the relation between the annually averaged terrestrial surface temperature T and the toroidal and poloidal fields. Observations (Fig. 1) show that T increased gradually from the Maunder Minimum till the 20th century Grand Maximum. The same applies to $R_{\max}$ as indicated by De Jager and Duhau (2009b; cf. their Figs. 2 and 1). It also applies to $aa_{\min}$ (Fig. 3 of De Jager and Duhau, 2009b). Assuming these relationships to be linear, which is the simplest assumption in the absence of a physical theory, we write:

$$T = xR_{\max} + y\, aa_{\min} + z\, time + const \tag{1}$$

Here, the z-term is introduced to represent an assumed gradual rise of temperature with time that is not correlated with solar variability and that might be due to climatologic phenomena. With Eq. (1) we wish to determine the constants x, y and z in such a way that the resulting fit follows the interdecadal