A POSSIBLE LONG-TERM SOLAR IMPACT ON AIR TEMPERATURE IN RELATION TO SOLAR MOTION

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Summary: *Using the long-term relations between solar motion and solar activity, long-term relations between solar activity and air temperature variations on the Earth's surface have been studied. A long-term periodicity in the period range from 25 to 250 years, corresponding to the periodicity of solar motion and solar activity, has been found in four very long European surface air temperature series. The positions of the spectral peaks approximately obey the relation* $p_i = 178{\cdot}7/i$, $i = 1, 2, \ldots$ *. Similar long-term patterns of solar and geomagnetic activity and of global surface air temperature have been found in the years 1861 to 1990. The results indicate that the solar activity impact on the climate could be significant, and that the prolonged minimum of solar activity, predicted from solar motion for the next 2 - 3 decades, could decreace global air temperatures.*

1. INTRODUCTION

The close and stable connection between solar motion round the barycentre of the Solar System and solar variability in the period range from 2200 years to the length of the solar cycle (10 - 12 years) has been confirmed [1-6]. The variability of solar activity has thus very probably been found to be a systemic phenomenon of the solar system as a whole.

On the short-term scale, the results displaying the influence of solar activity on meteorological phenomena are not statistically convincing and conclusive. More hopeful results seem to be achieved on the long-term scale.

The main properties of solar motion as a possible source of solar variability can be employed as a point of view or a "skeleton" for investigating long-term solar-climate relationships.

Let us summarize these main properties: The basic cycle of solar motion is 178·7 years. All solar motion characteristics, e.g., velocity, acceleration, radii of curvature, angular momenta, etc., repeat their patterns always after 178·7 years [7,8]. The periods p_i in these characteristics have been found to be the higher harmonics of the basic period of 178·4 years ($p_i = 178{\cdot}4/i$, $i=1,2, \ldots$) and mostly correspond to the synodic and sidereal periods of giant planets [9] (Periods will be denoted here as p in accordance with [1-4]; the symbol T will be used for temperatures). The amplitudes in the respective periods do not correspond, perhaps because the geometry of the solar orbit not being taken into account.

There are two types of motion: the motion along the Jupiter-Saturn-ordered (in trefoil) orbit and the motion along the chaotic orbit, alternately reoccuring. The Sun returns to the trefoil type of orbit after 178·7 years, on the average. This could be the explanation of the basic cycle of solar motion. The epochs of the JS-ordered, or chaotic, respectively, motion of the Sun coincide with the prolonged maxima, or minima in solar activity. The "bottoms" of the minima reoccur at intervals of 171 years.

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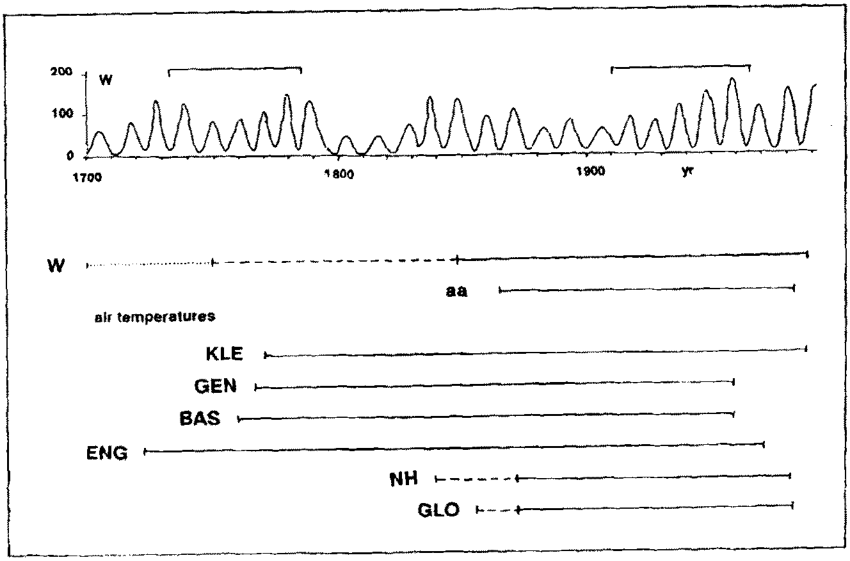

Fig. 1. Top: Plot of the Wolf numbers series (*W*) since 1700. The series display prolonged maxima in the 18th and the 20th centuries. Two similar groups of five cycles corresponding to the trefoil orbits of the Sun (1730 - 80 and 1910 - 60) are noted by horizontal lines, the Sabine minimum (SA) in the first third of the 19th century corresponds to the chaotic motion of the Sun (1790-1830). Several high cycles in the middle of the 19th century probably manifest 80-90 years variation in solar activity (motion). Bottom: Horizontal abscissae denote the intervals in which data related to the Wolf numbers (*W*), aa-indices (aa), and air temperatures (KLE - Klementinum, GEN - Geneva, BAS - Basle, ENG - Central England, NH - North Hemisphere, GLO - global) are available. The parts of the intervals in which measurements were less accurate are plotted as dashed and dotted lines.

The last two intervals of the JS-ordered motion of the Sun (in trefoil), coincident with the intervals of prolonged maxima of solar activity, occurred in the 18th century (centred at ~1760) and in the 20th century (centred at ~1940). The last prolonged minimum (the Sabine minimum) occurred in the first third of the 19th century in coincidence with the interval of chaotic motion of the Sun (Fig. 1).

This paper is an introductory study using the above mentioned long-term relations between solar motion and solar variability in searching for possible relations between solar variability and air temperature fluctuations. Climatic changes seem to be a complicated complex problem. Besides greenhouse gases due to human activities, a series of natural phenomena could contribute to global or local climatic changes: variable solar (geomagnetic) activity and volcanic activity, position of geomagnetic poles, changes in the Earth's position relative to the Sun, etc. It is very difficult to distinguish a part of an individual phenomena in the complex. There are also theories explaining fluctuations in climate as a result of external transfers of energy between large reservoirs - the atmosphere, oceans, ice masses. Variations in solar output are geoeffective in the upper layers of the Earth's atmosphere, where satellites orbit [10].

2. DATA SETS AND PROCESSING METHODS

Some individual attempts at daily instrumental measurements of the air temperature had been made in England in the second half of the 17th century. Systematic daily records of the surface air temperature started in the second half of the 18th century only at some points of the European continent, e.g. in Prague (Klementinum) in 1771 [11,12]. These time series are non-uniform - the instruments, the observational times and environmental conditions changed in the course of years. Therefore, they are not quite homogeneous. The grid points have gradually spread over the globe (both over land and sea), and now cover roughly 80 per cent of it.

The relations between solar variability and climatic changes should be studied in a global or North Hemisphere (NH) sense. But the time series of global or NH temperatures could only be estimated since ~1850. The global and NH temperatures have been reconstructed by several groups of authors, e.g. [13-16]. Because of the limited coverage of the Earth in the early decades, there is an uncertainty in these series, especially before 1875 [13,15]. The time series of the Northern Hemisphere surface air temperatures is more representative, because, unlike the Southern Hemisphere, the Northern Hemisphere is covered by large continents.

So far, we have had at our disposal only four point (local) time series: Central England (ENG) 1659 - 1972 (but the temperatures are given in units of 0·1 $^{\circ}$C only since 1723) [17], Prague-Klementinum (KLE) 1771 - 1988 [11,12], Geneva (GEN) 1768 - 1960, Basle (BAS) 1755 - 1960. The geographical coordinates φ, λ of these localities are: ENG 52° 30' - 53° 00' N, 1° 45' - 2° 15' W, KLE 50° 05' N, 14° 25' E, GEN 46° 15' N, 6° 07' E, BAS 47° 33' N, 7° 35' E. The lengths of our series (180-250 years) allows periodicities of about 180 years to be detected, but their numerical values cannot be determined exactly.

The annual means of NH surface air temperatures for 1851 to 1987 [15] have been used as well as the annual means of NH surface air temperatures for 1841 - 1985 [16]. The time series of global surface air temperatures (land and sea) for 1861 to 1990 were taken from Folland et al. [13] in graphic form.

Figure 1 shows the solar activity (the Wolf sunspot numbers) in the last three centuries. There are prolonged maxima of solar activity in the 18th century and in the 20th century. The Sabine minimum (SA) occurred in the first third of the last century, several higher cycles in the middle of the 19th century probably manifest the ~90 yrs cycle in solar motion and activity. The abscissae in the lower part of the figure demonstrate the time series of solar activity (W) 1700-1990, geomagnetic activity (aa) 1868-1990, point air temperatures (KLE, GEN, BAS, ENG) and NH and global temperatures (NH, GLO). The parts of the intervals which are less accurate are plotted as dashed or dotted lines where known.

Coincident periodicities found in two phenomena indicate a possible physical connection between these phenomena. The mutual comparison of the spectral density in the respective periods provides further information. For this purpose we have used power spectrum analysis [18]. The power spectrum is defined as the Fourier transform of

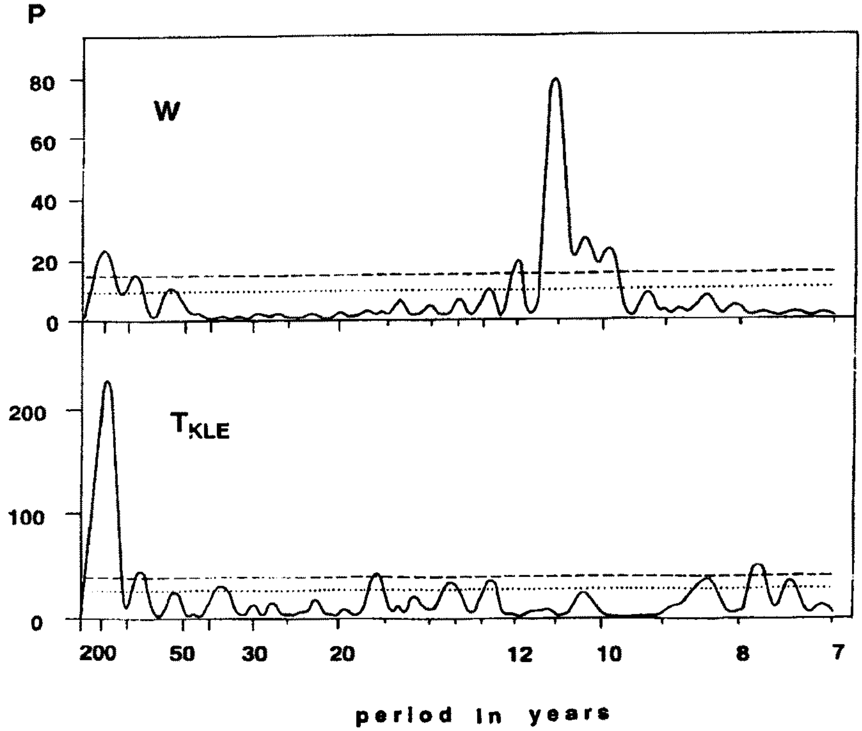

Fig. 2. The power spectra P of the Wolf numbers W (top) and of the Prague air temperature series T_{KLE} (bottom) in the broad period range. Confidence levels for 90% and 99% are plotted.

the autocorrelation function. The integration runs from 0 to θ, where $\theta < \tau$ (τ is the length of the data series) is a suitably chosen window (maximum lag). The algorithm for the numerical evaluation of integrals is described in [19]. The significance of all individual peaks in the computed spectra was tested using the χ^2 -test described in [18] and also used in [20-22]. The 90% and 99% confidence levels are shown in all graphs where spectra are presented.

3. THE RESULTS

It was found that in the whole range from 7 to 200 years the period of 180 years is dominant in air temperature (with the exception of ENG) and the 11-year period is dominant in solar activity (Fig. 2). While the dominant periods in the Wolf numbers are concentrated near 11 years, there are several groups of periods with approximately the same significancy (17-23, 10-15, 7-9 years) in temperatures in the period range from 7

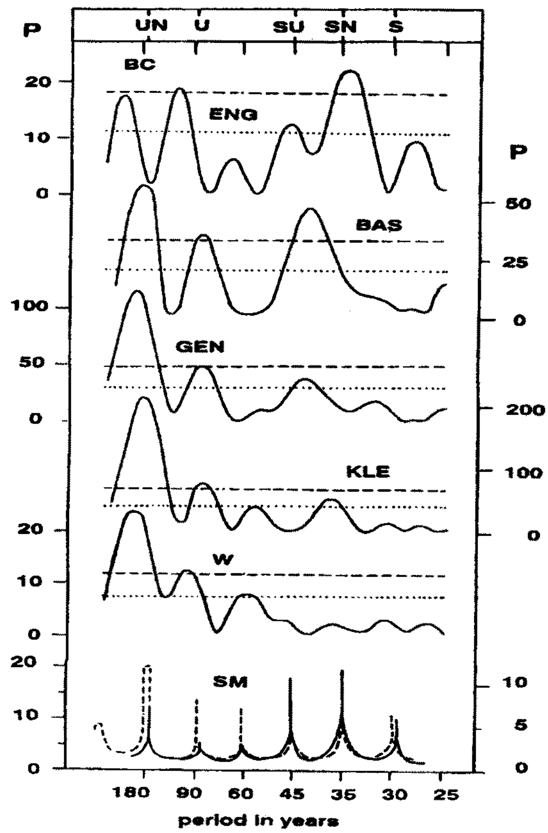

Fig. 3. The power spectra P of solar motion (SM) (the solid line and left-hand scale apply to that derived from motion characteristics, the dashed line and right-hand scale to that derived from the deviations from the JS-ordered motion), of solar activity (W: 1700 - 1990), of point temperatures (KLE: 1776 - 1989, GEN: 1768 - 1960, BAS: 1755 - 1960, ENG: 1723 - 1974). The vertical lines mark the higher harmonics of the basic period of 179 years ($p_i = 178{\cdot}7/i$, i = 1,2,...) in solar motion, mostly corresponding to the orbital periods of planets (S - Saturn, U - Uranus, N - Neptune). Confidence levels for 90% (dotted line) and 99% (dashed line) are plotted.

to 25 years. These relations will be the object of further studies. This is also why the degree of smoothing is different for the Wolf numbers and for the temperatures.

Figure 3 shows the power spectra in the period range from 25 to 200 years: the spectrum of solar motion (SM), solar activity (W) and of point temperatures (KLE, GEN, BAS, ENG). One can see similar features in all the spectra. A slight dissimilarity of the ENG spectrum as compared with the others might be caused by the oceanside position of the British Isles. Most of the periods belong to the pattern of the higher harmonics of the basic period of about 180 years. A similar periodicity (180, 80 - 90, 57, 45 - 35, 28 years) has also been found in [23] for the point temperature series of St. Peterburg. In the BAS, GEN and KLE air temperature series the peaks in the longest periods are dominant in the period range from 25 to 200 years (Fig. 3).

Most of the periods in all phenomena correspond to the sidereal and synodic periods of the outer planets (see top of Fig. 3). Moreover, Fourier spectral analysis of the respective time series shows that the longest periods of about 180 and 80 - 90 years in the temperature series are in phase with those in the Wolf numbers with respect to common origin.

A significant group of periods ranging from 30 to 45 years has been found in all point temperatures. Significant periods of 80 - 100 years and periods of ~45 and 28 years have been detected in the NH temperature time series [16] as well as in the series of Wolf numbers, both for the time interval 1841 - 1985 (Fig. 4). The power spectrum for the NH temperature time series [15] is very similar to that in Fig. 4. Folland et al. [13] detected a period of 83 years in world marine temperature series.

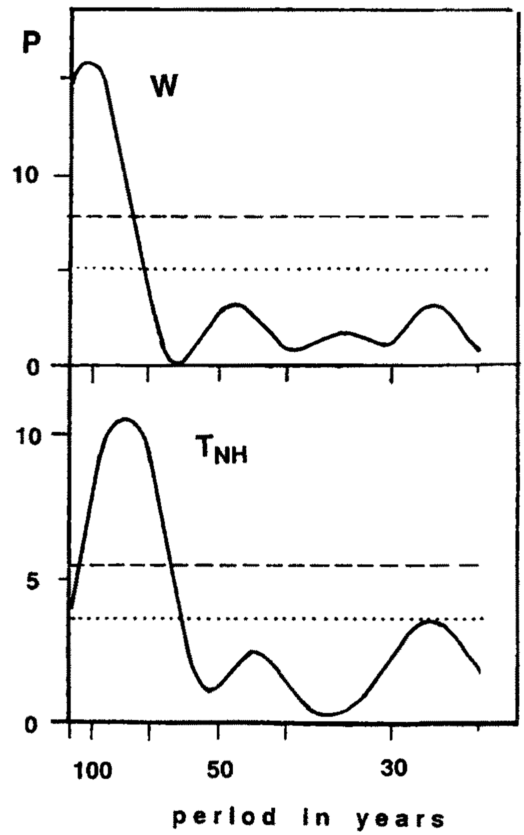

Fig. 4. The power spectra *P* of Wolf numbers *W* and NH temperatures (land) T_{NH} from 1841 to 1984 [16]. Beside the dominant period of about 80 - 100 years also periods of about 28 (S) and 45 (SU) years were detected in both the phenomena. Confidence levels for 90% (dotted line) and 99% (dashed line) are plotted.

The annual means of the Wolf numbers (*W*) from 1841 to 1990 and of *aa*-indices from 1868 to 1990 have been smoothed by 21-year running averages. The smoothed curves are plotted in Fig. 5 (bottom). The upper curves *T* in the same figure are taken from Folland et al. [13]. The solid curve demonstrates the annual means of global temperature and the dashed curve of the NH-temperature (both land and sea) smoothed by a low-pass binomial filter with 21 terms [13]. These curves are nearly identical with the curves of the annual means smoothed by 11-year running averages.

One can see the similar long term pattern of all three

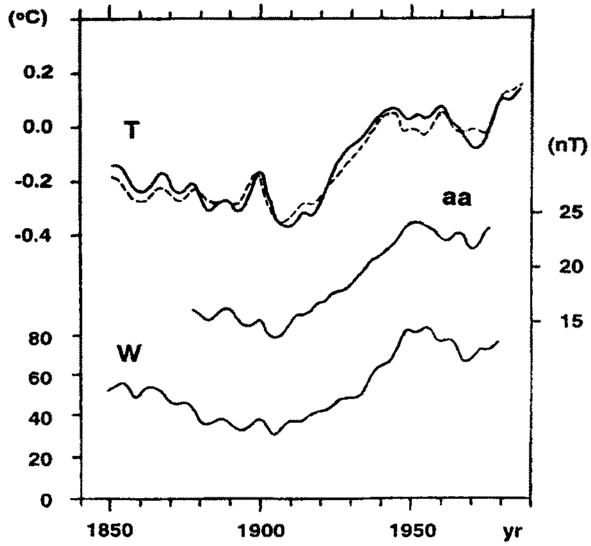

Fig. 5. The annual values of Wolf numbers (*W*) in the interval from 1841 to 1990 and of aa-indices (aa) from 1868 to 1990 smoothed by 21-year running averages are plotted in the lower part of the figure. The curves *T* in the upper part of the figure demonstrate the smoothed annual values [13] of global (dashed curve) temperature and of NH (solid curve) temperature from 1851 to 1990, relative to 1951 - 1980.

phenomena. The coefficients of correlation between these smoothed data series are: $r_{T,W} = 0{\cdot}85$, $r_{T,aa} = 0{\cdot}90$.

Figure 6 shows the time series of the annual means of *W* and *aa* smoothed twice [25] and of global and NH temperature smoothed by 41-year running means for the years 1880 - 1970. The resulting curves for all the phenomena are very similar, their minima near 1900 and maxima near 1950 coincide.

4. CONCLUSION

The variable output of the Sun could influence the "energetic" balance of the Earth's atmosphere from without. Volcanic activity could disturb and influence it by dust and gases coming from the Earth's interior. Both the activities seem to be governed by the solar system [9]. One can see also from [26-29] that a significantly lower volcanic activity occurred in the epochs of ordered motion of the Sun (~1730-1780, ~1910-1960) than in the epochs of chaotic motion. It was also found that the temperature periodicity pattern [30] or prevailing type of climate [12,31] in the ~18th century was similar to that in the ~20th century and that they were quite different from the pattern in the ~19th century - in approximate accordance with the alternation of two types of solar motion - ordered and chaotic [1-6].

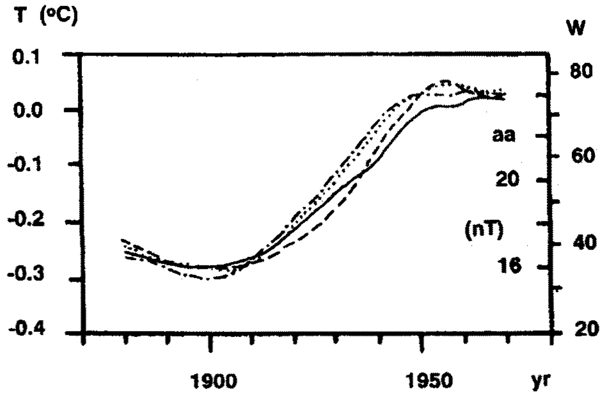

Fig. 6. The pattern of Wolf numbers (dashed curve) and aa-indices (dotted curve) after smoothing according to [25], and the patterns of global temperature (solid curve) and NH temperature (dot-dashed curve) after smoothing by 41-year running averages in the years 1880 to 1970, relative to 1951-1980.

The similar long-term patterns of global and NH temperarure, of solar activity and of geomagnetic activity (Figs. 5 and 6) indicate that the solar activity impact could be significant for surface air temperature fluctuations. Unfortunately, the global temperature time series (land and sea) cannot be reconstructed before ~1860. Only European point temperature series describe the end of the prolonged maximum of solar activity in the 18th century. These European time series thus provide the only direct evidence of the temperature at the Earth at that time. In all four series, which we have at our disposal, the temperatures in the 18th century approximately reached the normal (1951 - 1980) level. The lowest temperatures were recorded in the course of the 19th century [31,32].

Even earlier, the records in Czech chronicles, describing long series of significantly warmer and long series of significantly colder years (Křivský and Pejml, [33]) also support the idea that long-term changes of climate reoccur in a basic cycle of ~180 years in coincidence with the alternation of prolonged maxima and minima of solar activity. Johnsen et al. [34] detected dominant periods of 181 and 78 years for the temperature changes manifested by oxygen-18 values of increment of an ice core from Greenland in the time interval from 1200 to 1970. Stuiver [35] detected similar dominant periods in some indirect temperature indices (e.g. tree-ring width) of the current millennium. The increase in the average level of Wolf numbers from 30 near 1900 to 85 near 1950 correspnds to a mean global warming of about 0·5°C (Fig. 5).

The last decade has brought global warming (Fig. 5) higher than would correspond just to solar activity, expressed by the Wolf numbers. Foukal and Lean [36], considering a total solar irradiance model based on the Wolf numbers with the facular contribution, give one of the possible natural explanations of this warming.

Our results thus seem to indicate that climatic (temperature) changes could still retain their natural level corresponding to the solar activity impact. Injection of dust and gases from great volcanic eruptions could have a significant, but short term (<25 years) influence on air temperatures. The influence of anthropogenic factors (greenhouse gases) still seem to be low.

Low solar activity has been predicted for the next 2-3 decades [1-4] from the relations between solar motion and solar activity. A more accurate pattern of the predicted prolonged minimum of solar acitivity cannot be drawn until the proper "mechanism" is established. Our preliminary results, which are incomplete due to the lack of data, indicate the possible decrease of global temperature in the next decades to the level of 1900 or lower. This could reduce the prospective greenhouse effect.

Similar periodicities found both in solar activity and in the temperature series (Figs. 2, 3 and 4) corresponding to the periodicity of solar motion, also indicate that air temperature variations could be a systemic phenomenon. Our preliminary results will be checked using further data as it becomes available.

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