ELSEVIER

Journal of Atmospheric and Solar-Terrestrial Physics 66 (2004) 219–227

Journal of
ATMOSPHERIC AND
SOLAR-TERRESTRIAL
PHYSICS

www.elsevier.com/locate/jastp

Periodicities between 6 and 16 years in surface air temperature in possible relation to solar inertial motion

Ivanka Charvátová*, Jaroslav Střeštík

Geophysical Institute AS CR, Boční II, 141 31 Praha 4, Czech Republic

Accepted 12 June 2002

Abstract

The individual and summarised series of surface air temperature from the area of central Europe have been processed. A similarity between the sets of significant peaks (12.8, 10.4 and 7.8 years) in the spectra of surface air temperature and the solar inertial motion (SIM) in the period range 6–16 years especially when computed from the series long 179 years have been revealed. The value of 179 years represents the basic cycle of solar motion. The SIM is computable in advance. Predictive assessments of periodicity behaviour during the future decades were established: various periods with very low amplitudes could occur.

Keywords: Solar motion; Surface air temperature; Climatic change; Periodicities between 6 and 16 years

1. Introduction

Temporal changes of surface air temperature have mostly been studied on the global (NH, SH) temperature series which are available since 1861 only. Besides that some of the individual long European series have been studied, e.g. Benner (1999) who studied Central England series (1659–1997). Intensive statistical effort has also been done to study spatial temperature behaviour during the last decades (e.g. Mann and Park, 1996; Jones et al., 1999). Natural or anthropogenic influences have been considered and evaluated.

There are several natural impact factors which could cause temperature changes: solar motion, solar activity, geomagnetic activity, volcanic activity, etc. In this paper as well as in the former ones (Charvátová, 1990a, 1990b; Charvátová, 1995, 1997a,b, 2000) responses of the solar inertial motion (SIM) as a key, independent, central phenomenon of the solar system, the most important from the external, astronomical forcings, precisely computable into the past and into the future, in the above-mentioned activities and climatic changes are studied. As concerns climatic changes, our first, exploratory results were published in Charvátová and Střeštík (1995). The results of the previous papers showed that above-described approach is carrying, that above-mentioned activities and climate could be influenced (or may be governed) by the solar system.

Eight surface air temperature series from the area of central Europe have been processed and studied in relation to SIM whose basic cycle is 179 years (Jose, 1965; Fairbridge and Shirley, 1987; Charvátová, 1990b). The series are significantly longer than the global (NH, SH) series, they extend back to the 18th century. The annual temperature values were taken from Marietta (1992). These series begin in various years of the 18th century and end there mostly with the year 1990. All the studied series are longer than 179 years. The time series of surface air temperature from Geneve (1753–1988), Berlin–Tempelhof (1753–1990), Basel (1755–1980), Paris (1757–1990), Praha–Klementinum (1775–1990), Wien (1775–1990), Budapest (1780–1988), and München (1781–1990) were processed. The summarised series for central Europe has also been composed and processed by the same way as made and described in Charvátová and Střeštík (1995), but here in the interval from 1753 to 1990 and related to the 1961–1990 average. In several series, missing data up to 2 years were replaced by means of interpolation (of the

---

* Corresponding author. Fax: +420-2-72761549.

E-mail addresses: ich@ig.cas.cz (I. Charvátová), jstr@ig.cas.cz (J. Střeštík).

1364-6826/$ - see front matter
doi:10.1016/j.jastp.2003.10.003

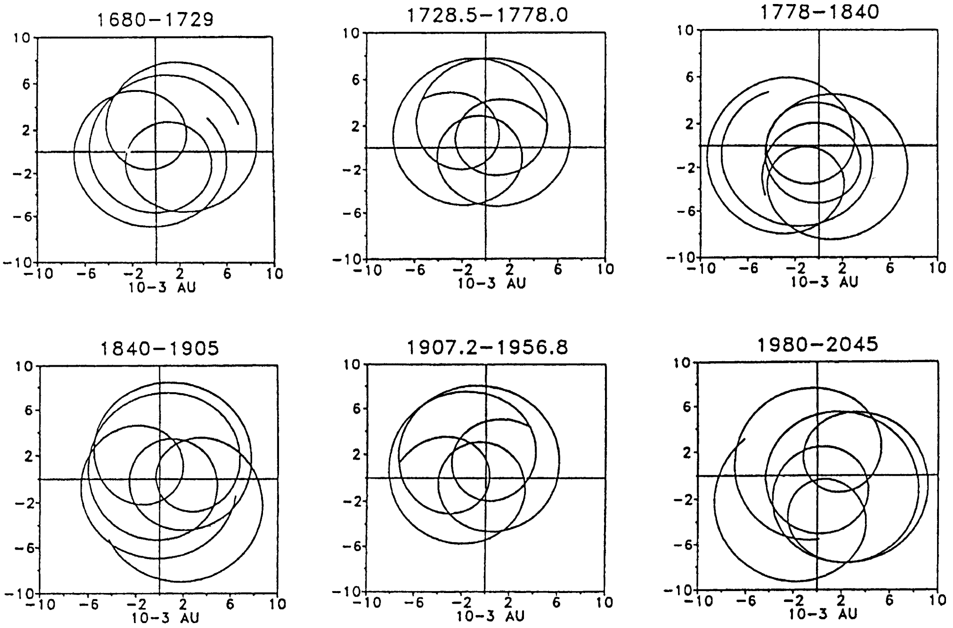

Fig. 1. Solar orbit (in units of 10^{-3} AU, astronomical unit, 150×10^6 km) in 50–65 years segments since 1680. Besides an identity of motion trefoils 1728–1778 and 1907–1957, one can see a similarity (after a rotating) between solar orbit in the years 1840–1905 and 1980–2045.

second order). Since 3 decades after 1750 and the latest decade before 1990 are not covered by all the series, there is an uncertainty at the beginning and at the end of the summarised central European series. This summarised series has been constructed because it is more representative than the individual series and because it is much longer than the global (NH, SH) series, longer than the basic SIM (activity) cycle being 179 years.

Fig. 6 in Charvátová and Střeštík (1995) compares the central European series (1753–1980) smoothed by 21-year running average and surface air temperature of Northern Hemisphere taken from Foland et al. (1990), besides other temperature curves. Both the series are, since 1860, in very good coincidence. Therefore, it is possible to suppose that a coincidence could be very good also before 1860. The temperature curve reconstructed by D'Arrigo and Jacoby (1993) from tree-rings of Arctic region (Alaska, Canada, Fennoscandia, Siberia) since 1689 shows very good coincidence with central European series: the same position of long-term maxima (1750–60 and 1930–40), the same position of long-term minimum in 1840 and further similarities in details. Spring temperature reconstruction based on grapevine sprouts lengths (Střeštík and Verö, 2000) confirmed higher temperatures in the 18th century.

SIM is the central phenomenon of the Solar System caused by varying positions of the giant planets (Jupiter—J, Saturn—S, Uranus—U, Neptune—N) predominantly. It is not negligible in comparison with the Sun, the diameter of the area in which the Sun moves is $4.3r_s$, r_s being solar radius. This value represents 0.02 AU (astronomical unit, 1.5×10^{11} m) or 3×10^6 km. The eccentricity of the Earth's orbit is 5×10^6 km. The velocity of the Sun varies between 9 and 16 m/s (32–58 km/h). The SIM is computable in advance, this point offers to establish predictive assessments of phenomena related, so far of course on the basis of analogies with the mutual relations found for the previous adequate orbital patterns.

The solar orbit was separated into two basic types: the ordered (in a trefoil, in a three-lobed orbital pattern, see Fig. 1, centre), and disordered (Charvátová, 1988, Charvátová, 1990a,b, see Fig. 1, left and right curves). Since this separation, SIM has been discernible and fixed in time. According to Charvátová and Střeštík (1991) and Charvátová (1995, 1997b), the basic 178.7-years cycle in SIM is the time distance between two consecutive orbital trefoils. The solar orbit in the partial intervals long 50–65 years between 1680 and 2045 is plotted in Fig. 1. Two nearly identical trefoils long 50 years are clearly seen in the centre of figure, in the intervals 1728–1778 and 1907–1957. The trefoil orbits are, after a rotation, nearly the same. It is valid on millennial scale (Charvátová, 1990b, 1995). The disordered orbits differ from one to another. In the previous papers, responses of SIM in solar, geomagnetic and volcanic activities have been pointed out (Charvátová-Jakubcová et al., 1988; Charvátová, 1990b, 1997a,b, 2000).

We have at our disposal two properties of SIM which can be employed in searching for possible relations between SIM and above-mentioned activities and climatic changes.

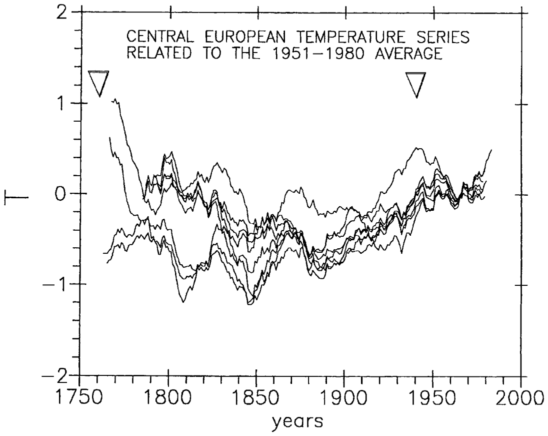

Fig. 2. The individual temperature series smoothed by 21-year running averages. The triangles denote the centres of the trefoil (three-lobed patterns) intervals of solar motion.

The first of them are the positions of the trefoil intervals long 50 years that recur always after the basic cycle of 179 years. The motion character is stable there: The orbital loops lie under about 120°, according to JS motion order, according to the basic order (the "heart") of the Solar System. It was found that the groups of five sunspot cycles that were created by the Sun during nearly the same trefoil motion of the 18th and 20th centuries are very close ($r = 0.81$). (Charvátová, 1990b). Charvátová (1988) estimated that the mean duration of the Sun's motion along one-motion loop (arc) is 9.93 years ($\frac{1}{2}$ JS) and subsequently found (Charvátová, 1995) that solar cycle lengths are stable and equal to 10 years during the whole trefoil intervals. Geomagnetic activity (index *aa*) has linear trend during the trefoil interval. It was shown (Charvátová, 1997a) that volcanic activity has patterns which go in coincidence with the basic patterns of solar motion: during the whole trefoil intervals, Earth's volcanic activity is attenuated, without the great eruptions reaching to the stratosphere. This is stable situation in correspondence with stability of the trefoil SIM there. In the most disordered interval (see Fig. 1 upper, right part), the greatest eruptions occurred (e.g. Tambora in 1815). This was shown since 1500, by means of several volcanic indices (SVI, DVI, AI—the values were taken from Cress and Schönwiese, 1990).

In addition, a similarity of other, shorter disordered parts of the solar orbits sometimes appears. In the studied intervals, they are the intervals 1850–1905 and 1985–2040, see at them after a rotation (Fig. 1). This similarity can be explored for establishing of predictive assessments of the phenomena related.

The individual above-mentioned temperature series smoothed by 21-year running average are plotted in Fig. 2. One can see long-term temperature maxima in about 1750–60 and 1930–40 (marked by the triangles). They are coincident with the central parts of the trefoil intervals of the solar motion. A coincidence of the long-term temperature maxima with the centres of trefoil SIM was also found for the summarised central European series (1753–1980) in Charvátová and Střeštík (1995, Fig. 6). The same long-term course of temperature curve from tree-rings since 1689 is possible to see in D'Arrigo and Jacoby (1993). Johnsen et al. (1970) presented the temperature reconstruction by means of ^{18}O in ice cores from Greenland since 1200. Again, the revealed long-term temperature maxima approximately coincide with central parts of the trefoil intervals. These authors also detected the 181-year basic cycle. Jinjun et al. (1993) showed the temperature reconstructed from tree-rings in NW China since 1000. The long-term maxima are again in coincidence with the intervals of the trefoil solar orbit. Similar approximate coincidence since 1000 is seen in Mann et al. (1999, Fig. 6). These authors show palaeoclimatic reconstructions for Northern Hemisphere. A coincidence is of course only approximate, may be due to quality of temperature reconstructions from indirect sources is not perfect.

2. Spectrum of periods in SIM

This paper employs the second property of the SIM being at our disposal, it is its spectrum of periods. Identity (or at least similarity) of the spectrum of the studied phenomenon with the SIM spectrum indicates possible mutual physical relation between the both phenomena.

In Bucha et al. (1985), spectral analyses of many motion parameters, such as the velocity, the acceleration, the radius of curvature, the angular momenta, etc., and their rates of changes from the series 3100 years long have been carried out. Very similar spectra of periods were provided from the individual characteristics. The mean spectrum was calculated. The characteristics are mostly of scalar character, the geometry of solar orbit was not taken into account. The periods in SIM have been found to be the higher harmonics of the basic period of solar motion, the period of 178.7 years, i.e. 84 (U), 60, 45 (SU), 35 (SN), 29 (S),…, 13.8 (JU), 12.8 (JN), 11.9 (J),…, 9.9 ($\frac{1}{2}$ JS),…, 7.8,…, 6.9 (JU/2), 6.4 (JN/2) years. They mostly correspond to the orbital periods of the giant planets (Jakubcová and Pick, 1987).

In this paper, we have studied a periodicity in the period range from 6 to 16 years, this means a periodicity around 10 years ($\frac{1}{2}$ JS). This period range is very important for mutual (SIM—surface air temperature) understanding: The mean duration of SIM along one-orbital loop (arc) is 10 (JS/2) years—see Fig. 1 here and in Charvátová (1990b). Longer periods (30–200 years) have been studied in Charvátová and Střeštík (1995). The significant periods of about 80–90 years and of about 35 years have been detected. The studied range also approximately represents the range of the sunspot cycle lengths. In connection with solar motion, it is without sense to study the periods shorter than 6 years. The motion of the Sun (up to 1×10^{-2} AU) is caused by the

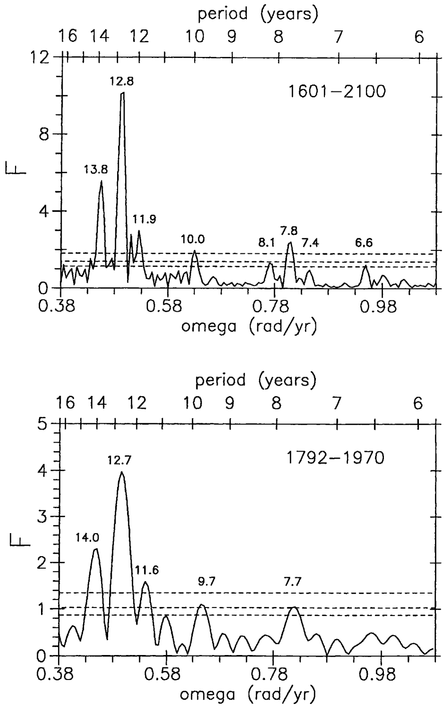

Fig. 3. Top: the Fourier amplitude spectrum of SIM characteristic (here the distance between the centre of the Sun and the centre of mass of the solar system), computed in the time interval 1601–2100. Bottom: the same type of spectra of the same characteristic computed for the 179 years long interval, (1792–1970). The solid horizontal lines represent the confidence levels of 90%, 95%, and 99%.

giant planets, from which the nearest planet Jupiter has the shortest orbital period being 11.9 years.

The orbital periods of the inner planets (Mercury (Me), Venus (V), Earth (E), Mars (Ma)) are shorter. The main period found in SIM due to the inner planets is 6.4 years, the prominent period is 1.6 (VE) years. But contribution of the inner planets is very minute (up to 5×10^{-6} AU). Moreover, the pattern of the Sun's path due to the inner planets differs considerably from the Sun's path due to the giant planets, it is "heart shaped". Possible influence of the SIM due to the inner planets on surface air temperature also in connection with ENSO, NAO, QBO,..., if any, will be subjects of future studies.

Within the period range studied in this paper, two prominent periods of 7.8 and 12.8 have been detected (Fig. 3). Further significant periods of 6.5, 7.4, 8.4, 10.4, 12.0 and 13.8 years have been detected besides them. Fig. 3 (top) shows the Fourier amplitude spectrum of the SIM characteristic (the distance between the centres of the Sun and of the mass centre of the solar system) computed from the time series 500 years long (1601–2100). The same above-mentioned periods have been found. A conspicuous peak lack occurs between 8 and 10 years. Fig. 3 (bottom) shows the same type of spectra computed from the series 179 years long (1792–1970). Using this shorter interval of 179 years, the significant peaks remain on the same positions (SIM is a regular process), they only become broader, the peaks merge together (12.9 and 7.7 years) and their significance in higher frequencies decreases.

Here is necessary to note again that the spectrum was computed from SIM characteristic mostly of scalar character, not taking the geometry of SIM into account. This can be why the periods around 10 and 7.8 years have significantly lower amplitudes than the periods around 12.8 years—on the contrary to the spectrum of surface air temperature, which will be shown in the next section, where the amplitudes in both the periods are approximately the same.

3. Spectrum of periods in surface air temperature

The standard power spectra (Blackman and Tukey, 1958) of the individual series and of the summarised central European series were computed. This summarised series (1753–1988) has been composed from the data of the above-mentioned stations related to the 1960–1990 average. For the power spectra the window $w = 150$ years has been used. The confidence levels 90%, 95% and 99% have been computed.

Fig. 4 shows power spectrum of the summarised central European series in two versions: In the first one (top) it was computed from the whole available data series (1753–1990), in the second one (bottom) from four selected series 179 years long (1775–1953, 1781–1959, 1792–1970 and 1810–1988, see also Fig. 6). The prominent periods of 7.8 and 12.7 years have been detected together with the periods of 14.1, 10.4, 8.4, 7.4 and 6.4 years. The significant peak lack that occurs between 8 and 10 years corresponding to that of SIM spectrum (see also in Bucha et al., 1985, Fig. 1) is clearly seen. It is here necessary to point out that no significant peak occurs near the period of 11.1 years which is the mean period of the solar activity cycle.

Power spectra of the temperature series from Wien (1775–1988) and München (1781–1990) computed from the whole available series, by the same way, are plotted in Fig. 5 as examples.

Spectra of periods from the series long just 179 years have been also computed. Fig. 6 shows an example of four groups of power spectra of the individual series whose lengths are equal to the basic cycle of solar motion, i.e., 179 years. The spectra were computed in the intervals 1775–1953, 1781–1959, 1792–1970 and 1810–1988. These intervals were chosen according to the appropriate beginnings or ends of the temperature series. The prominent periods of 7.8 and 12.8 years have been detected together with the periods of 14.3, 10.3–10.5, 8.4–8.5, 7.3–7.4, and 6.5 years. A peak lack again occurs between 8 and 10 years.

Fig. 7 represents the power spectra groups computed from the individual series for the partial intervals (1792–1840,

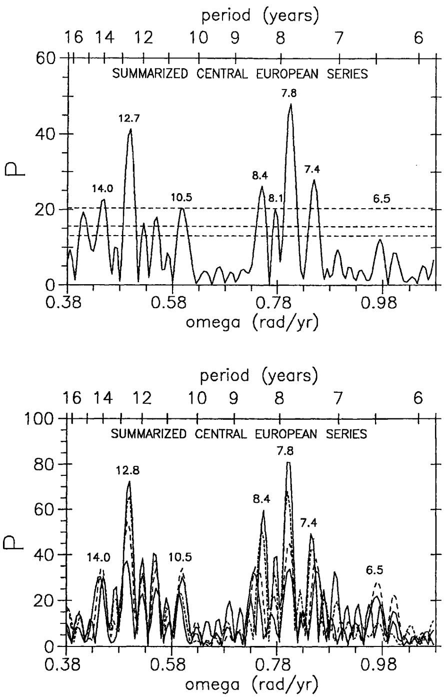

Fig. 4. Top: the power spectrum of summarised central European series (1753–1988). The solid horizontal lines represent the confidence levels of 90%, 95%, and 99%. Bottom: the power spectra computed from the parts of central European series being 179 years long are plotted by solid (1810–1988), long dashed (1792–1970), dashed (1781–1959), and dotted (1775–1953) lines.

1840–1905, 1905–1970). The first of them shows mainly a less pronounced periodicity around 12 and 7.8 years, in the third power spectrum group the period of 7.8 years is the most significant. The second group of the spectra shows various periods with very low amplitudes. It is possible to see there that surface air temperature spectra, i.e., a distribution of the energy into the individual frequency zones, are variable in time. Similar conclusion was presented by Schönwiese (1987).

4. Discussion and conclusion

Solar inertial motion (SIM) has been studied in our Institute since 1984. Two basic tools have been revealed here in this motion which serve in searching for mutual relations between SIM and the individual solar-terrestrial (ST) and climatic phenomena. The first of them is the separation of the SIM into two basic types—the ordered (JS-trefoil like) and the disordered. This has served as the precise and legible basis to which the studies have been related. The Sun enters into the trefoil sections of its orbit every 178.7 years and this type of orbit lasts about 50 years (Charvátová, 1988, 1990b). The second tool is the spectrum of SIM periods (Bucha et al., 1985) computed from the series 3100 years long. The periods detected in the motion characteristics such as the velocity, the acceleration, the radius of curvature, etc., have been found to be the higher harmonics of the basic period of SIM being 178.7 years and mostly correspond to the orbital periods of the giant planets (i.e. the periods of 80–90 (U), 60, 45 (SU), 35 (SN), 29 (S), …, 19.9 (JS), …, 13.8 (JU), 12.8 (JN), 11.9 (J), …, 10. (JS/2), …, 7.8, …, 6.9 (JU/2), 6.4 (JN/2). A correspondence of the basic features of SIM and ST and climatic phenomena found according to these two tools indicates a possible physical relations among them. The basic features of SIM found in all the above-mentioned phenomena can also indicate that SIM plays a driving, controlling or frame role in these phenomena variations.

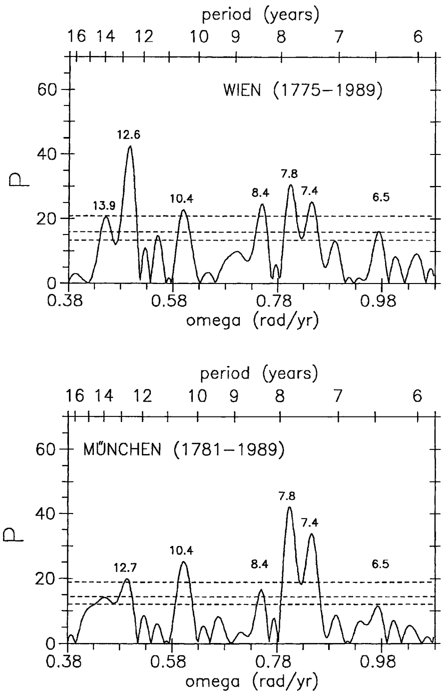

Fig. 5. The power spectra of Wien series (1775–1989) (top) and of München series (1781–1989) (bottom). The solid horizontal lines represent the confidence levels of 90%, 95%, and 99%.

This paper is focused on the second tool. A similarity of the temperature and SIM spectra in the period range 6–16 years has been demonstrated here (Figs. 3–6). The similarity is better in the periods than in the amplitudes. The results for the individual and for the summarised (Fig. 4) series are presented. A closer similarity appeared when the spectra were computed from the series long to 179 years (Fig. 6). Nevertheless, the amplitudes in the period of 7.8 years is always significantly higher in the temperature spectrum than in the SIM spectrum. The prominent period of 7–8 years was detected by Benner (1999) in the Central England temperature series. On this place, it is necessary to mention again

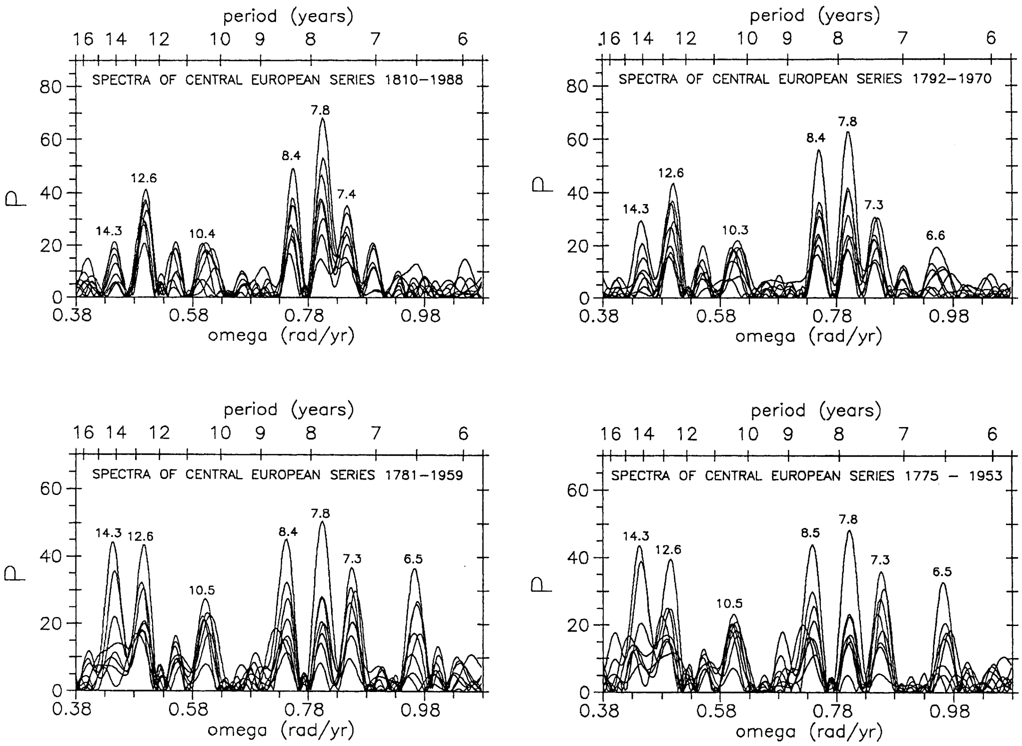

Fig. 6. The power spectra of the individual temperature series being 179 years long 1810–1988 (top left), 1792–1970 (top right), 1781–1959 (bottom left), 1775–1953 (bottom right). This length represents the basic cycle of SIM.

that SIM is so far not processed in the whole—the geometry of SIM is not taken into account. Besides the SIM forcing also other sources of temperature variability can be considered, such as Northern Atlantic oscillation (NAO) or El Niño/Southern oscillation (ENSO). These phenomena also show an evidence of the prominent 7–8 years period (Meko, 1992). But on the contrary, it is a question what is a source of NAO and ENSO (Kestin et al., 1998).

Climatic changes have been mostly considered to be composed of natural (solar, geomagnetic and volcanic activities) and anthropogenic (human-induced factors such as concentration of greenhouse gases) influences. Many attempts have been made to connect climatic changes with variability of solar activity parameters (e.g. Friis-Christensen and Lassen, 1991; Lean et al., 1995; Reid, 1997; Cliver et al., 1998; Haigh, 2001; Lean and Rind, 2001; Lean, 2000; Bond et al., 2001; Shindell et al., 2001), of volcanic activity (in connection with huge volcanic eruptions) (e.g. Robock, 2000). Many efforts are required to separate the signatures of these different forcings in climate records. Sometimes, their parts in climatic changes have been evaluated (e.g. Crowley, 2000). He processed the series since 1000 AD and concludes that during preantropogenic era (before 1850) as much as 41–64% decadal-scale temperature variation was due to changes in solar irradiance and volcanism. Geomagnetic activity has also been taken as one of the impact factors on climate (e.g. Cliver et al., 1998; Bucha and Bucha Jr., 2002). On the contrary, the results presented by Levitus et al. (2001) show that the increase in ocean heat content may largely be due to the increase of anthropogenic gases in the Earth's atmosphere. The anthropogenic influences are also preferred by Barnett et al. (2001).

Natural influences on climate have been mostly marginalised by meteorological establishment. The correlations regarding Sun–climate relations have traditionally been attacked for several reasons: The physical mechanism is not known. The very small variations in total solar irradiance up to 0.1% are unlikely to have caused the observed temperature changes (e.g. Kelly and Wigley, 1990). The statistical significance of the Sun–climate relations is poor. Long-term maximum of temperature in about 1940 even leads the long-term maximum of sunspot numbers in about 1960. The conclusive evidence of the detection of the most prominent feature of solar activity, the mean 11.1 years solar cycle, in climatic records has not been still given. An influence of volcanic activity on climate is mostly taken as more possible, because a decrease of surface air temperature after huge volcanic events is always observed.

Gradually, our papers show (Charvátová, 1990b, 1997a, etc.) that both solar and volcanic activity are probably gov-

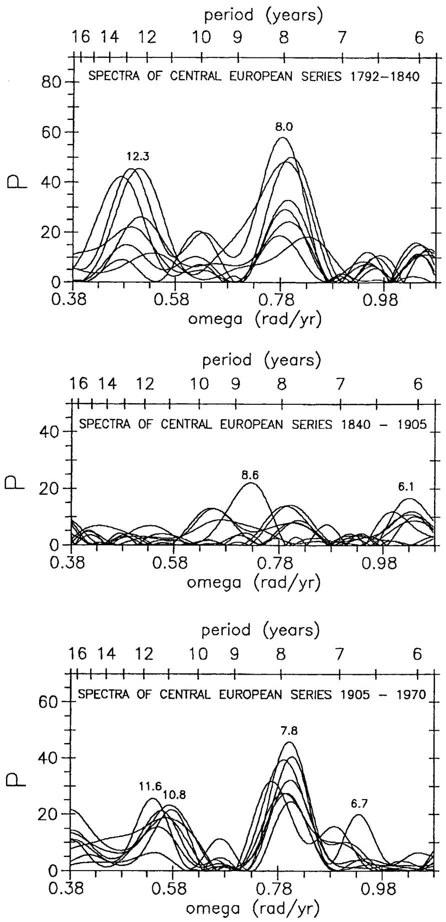

Fig. 7. The power spectra of the individual temperature series computed for the partial intervals 1792–1840 (top), 1840–1905 (centre), and 1905–1970 (bottom).

erned by SIM . The Sun, moving along the same trefoil-like orbits (1734–1785 and 1913–1964), created nearly the same series of sunspot cycles there. Only there, the lengths of sunspot cycles are constant and equal to 10 years. The small deviations can be ascribed to substantially lower quality of data in the 18th century. Volcanic activity is attenuated during the trefoil intervals and huge volcanic events, such as the eruptions of Tambora (1815) or Krakatau (1883), occurred during the intervals of disordered SIM (Charvátová, 1997a). This was shown by means of several volcanic indices. Volcanic acidity index (Cress and Schönwiese, 1990) was employed there since 1500. The mentioned phenomena show a stable character in the intervals of stable character of SIM (in the JS-trefoils). The surface air temperature shows the long-term maxima approximately in the centres of the trefoil intervals of SIM as it is shown by Charvátová and Střeštík (1995) and seen in D'Arrigo and Jacoby (1993) or in Mann et al. (1999).

The period range between 6 and 16 years has here been investigated. The series of surface air temperature in central Europe (the individual and summarised series) have been processed by means of power and Fourier spectral analyses and the resulting spectra have been compared with the SIM spectrum. It is possible to see (Figs. 3–6) that the prominent periods of 12.8 and 7.8 years together with further periods of 13.8, 11.9, 10.3, 8.4, 7.2 and 6.6 years have been detected. The agreement in the periods is very good. The amplitudes, above all in the period of 7.8 years and the adjacent periods, differ. The significant feature of the SIM spectrum, the peak attenuation between 8 and 10 years also occurs accordingly in the temperature spectra. The periods of 13.8, 12.8, 11.9 and 10.2 years were detected also in one of the manifestation of geomagnetic activity, in the aurorae occurrence since 1000 AD (Charvátová-Jakubcová et al., 1988). Longer periodicity, in the period range between 25 and 200 years, have been studied in Charvátová and Střeštík (1995). The significant periods of 35 years and 180 years in accordance with the SIM spectrum have been detected. Our next studies will concern the period range between 16 and 25 years.

The dominant period of solar activity, the period of 11.1 years, has been detected neither in summarised series nor in any individual series. The long-term temperature maxima lead of about 20 years those of solar activity (Charvátová and Střeštík, 1995). It seems therefore that solar activity (solar irradiance) itself does not play a significant role in temperature changes on the Earth surface. This was also partially studied in Charvátová and Střeštík (1994).

As seen in Fig. 7, the temperature spectra depend on the interval from which they were computed. This can be why the results of spectral temperature analyses of different authors being computed for different intervals differ one from another.

During the latest years, it was mostly understood that the global temperature series since 1860 is not sufficiently long and homogeneous (as concerns the number of stations composed it) to represent the basis for well-founded predictions or at least scenarios. The period of 178.7 years in the central phenomenon of the solar system (SIM) can be considered to be the basic natural period. Many efforts have been given to a reconstruction of solar-terrestrial and climatic phenomena on millennial scale (^{14}C in tree-rings, tree-ring widths, ^{10}Be, ^{18}O in ice cores, deep sea or lake sediments, etc.). It is now generally accepted, that there are two prominent natural cycles, the cycle of about 200 (160–210) years and the cycle of about 2400 (2200–2600) years. These cycles have been found in proxy records of nearly all ST and climatic phenomena (e.g. Damon and Sonett, 1991). Charvátová (2000) shows that SIM can be a cause of both the basic natural cycles.

As follows from our results, though they are not complete, our SIM approach to climatic changes, from the point of view of the central phenomenon of the Solar System, seems to give a key to the problem solution or at least opens new possibilities. SIM is computable in advance. So, its ability to provide predictive assessments of the phenomena related, so far of course on the basis of the results for the previous similar orbital sections, is of basic importance. Astronomical forcing (SIM) could represent a frame in which the ST and climatic variations develop.

The results allow us to pronounce, very cautiously, on the basis of analogy only, predictive assessments for spectral temperature behaviour in future decades. Since SIM in the years 1840–1905 and 1980–2045 (after a rotating) are similar (Fig. 1), similar could also be the respective spectra of periods in surface air temperature. Spectra of periods up to 2045 could be adequate to the spectra of periods computed for the interval 1840–1905 (Fig. 7, centre): Varying periods with low amplitudes for the individual temperature series could occur.

Statistical and spectral processing of the respective series is needed before any mechanism is considered; without a thorough knowledge of properties of the studied phenomena and the relations between them, no mechanism can be established.

The Sun moves around the centre of mass of the solar system. It is obvious that the distance between the Sun and the Earth also depends on the position of the Sun with regard to the centre of mass of the solar system. The difference in the distance between the Sun and the Earth varies between 0 and 8×10^6 km. Lowered amount of heat spreading from the more distant Sun to the Earth could lower surface air temperature. Such considerations and computations belong to our future research and could serve as the starting points for the future establishment of a proper physical mechanism.

Anthropogenic influences were minute in the 18th century. Nearly the same heights of the long-term temperature maxima in about 1750–60 and 1930–40 are seen in Fig. 2 or in Charvátová and Střeštík (1995, Fig. 3). Their time positions coincide with the centres of the trefoil intervals. This can be seen also further to the past (D'Arrigo and Jacoby, 1993; Mann et al., 1999; etc.).

In the end, the successful prediction of the sunspot cycle No. 23 height on the basis of the SIM is accented. Charvátová (1988, 1990a,b) predicted that the cycle No. 23 should be lower than the cycle No. 22 (max annual Wolf number $R_{\max} = 158$). Charvátová (2000) predicted that the Sun moving up to 2040 along the disordered orbit which is similar to that of the second half of the 19th century, should create a series of lower solar cycles ($R_{\max}$ from 65 to 140). In the other papers (see in Charvátová, 2000), the cycle No. 23 was predicted to be high or extremely high ($R_{\max}$ between 140 and 225). The reality: The cycle No. 23 height is only 120.

Acknowledgements

The authors thank the referees for their valuable comments and suggestions. This research was made under the support of Grant Agency of the Czech Republic, Grant Number 205/97/0921.

References

Barnett, T.P., Pierce, D.W., Schnur, R., 2001. Detection of anthropogenic climate change in the world's oceans. Science 292, 270–274.

Benner, T.C., 1999. Central England temperatures: long-term variability and teleconnections. International Journal of Climatology 19, 391–403.

Blackman, R.D., Tukey, J.W., 1958. The Measurement of Power Spectra. Dover Public Inc., New York.

Bond, G., Kromer, B., Beer, J., Muscheler, R., Evans, M.N., Schowers, W., Hoffmann, S., Lottz-Bond, R., Hajdas, I., Bonani, G., 2001. Persistent solar influence on North Atlantic climate during the Holocene. Science 294, 2130–2152.

Bucha, V., Bucha Jr., V., 2002. Geomagnetic forcing and climatic variations in Europe, North America and in the Pacific Ocean. Quaternary International 91 (1), 5–15.

Bucha, V., Jakubcová, I., Pick, M., 1985. Resonance frequencies in the Sun's motion. Studia Geophysica et Geodetica 29, 107–111.

Charvátová, I., 1990a. The relations between SIM and solar variability. Bulletin of the Astronomical Institutes of Czechoslovakia 41, 56–59.

Charvátová, I., 1990b. On the relation between SIM and solar activity in the years 1730–1780 and 1910–1960 AD. Bulletin of the Astronomical Institutes of Czechoslovakia 41, 200–204.

Charvátová, I., 1995. Solar-terrestrial and climatic variability during the last several millenia in relation to solar inertial motion. Journal of Coastal Research, Holocene Cycles, Climate, Sea Levels, and Sedimentation 17, 343–354.

Charvátová, I., 1997a. Solar-terrestrial and climatic phenomena in relation to solar inertial motion. Surveys in Geophysics 18, 131–146.

Charvátová, I., 1997b. Solar motion (main article). In: Shirley, J.H., Fairbridge, R.W. (Eds.), Encyclopaedia of Planetary Sciences. Chapman & Hall, New York/London/Tokyo/Weinheim/Melbourne/Madras, pp. 748–751.

Charvátová, I., 2000. Can origin of the 2400-year cycle of solar activity be caused by solar inertial motion? Annales Geophysicae 18, 399–405.

Charvátová, I., Střeštík, J., 1991. Solar variability as a manifestation of the Sun's motion. Journal of Atmospheric and Terrestrial Physics 53, 1019–1025.

Charvátová, I., Střeštík, J., 1994. The solar systemic features in ST-phenomena and surface air temperature during the last centuries. In: Brázdil, R., Kolář, M. (Eds.), Contemporary Climatology. Masaryk University, Brno, pp. 136–141.

Charvátová, I., Střeštík, J., 1995. Long-term changes of the surface air temperature in relation to solar inertial motion. Climatic Change 29, 333–352.

Charvátová-Jakubcová, I., Střeštík, J., Křivský, L., 1988. The periodicity of aurorae in the years 1001–1900. Studia Geophysica et Geodetica 32, 70–77.

Charvátová, I., 1988. The solar motion and the variability of solar activity. Advances in Space Research 8 (7), 147–150.

Cliver, E.W., Boriakoff, V., Feyman, J., 1998. Solar variability and climate change: geomagnetic *aa* index and global surface temperature. Geophysical Research Letters 25, 1035–1038.

Cress, A., Schönwiese, C.-D., 1990. Vulkanische Einflüsse auf die Bodennahe und stratosphärische Luftemperatur der Erde. Berichte des Instituts für Meteorologie und Geophysik der Universität Frankfurt/Main, Nr. 82.

Crowley, T.J., 2000. Causes of climate change over the past 1000 years. Science 289, 270–277.

Damon, P.E., Sonett, C.P., 1991. Solar and terrestrial components of the atmospheric ^{14}C variation spectrum. In: Sonett, C.P., Giampapa, M.S., Matthews, M.S. (Eds.), The Sun in Time. The University of Arizona, Tucson.

D'Arrigo, R., Jacoby, G.C., 1993. Secular trends in high northern latitude temperature reconstruction based on tree-rings. Climatic Change 25, 163–177.

Fairbridge, R.W., Shirley, J.H., 1987. Prolonged minima and the 179-yr cycle of the solar inertial motion. Solar Physics 110, 191–220.

Foland, C.K., Karl, T.R., Vinnikov, K.Z., 1990. Observed climate variations and change. In: Houghton, J.T., Jenkins, G.J., Ephraums, J.J. (Eds.), Climate Change. Cambridge University Press, New York, pp. 195–238.

Friis-Christensen, E., Lassen, K., 1991. Length of solar cycle: an indicator of solar activity closely associated with climate. Science 254, 698–700.

Haigh, J.D., 2001. Climate variability and the influence of the Sun. Science 294, 2109–2111.

Jakubcová, I., Pick, M., 1987. Correlation between solar motion, earthquakes and other geophysical phenomena. Annales Geophysicae 5B, 135–142.

Jinjun, Ji., Petit-Maire, N., Zhongwei, Y., 1993. The last 1000 years: climatic change in arid Asia and Africa. Global and Planetary Change 7, 203–210.

Johnsen, S.J., Dansgaard, W., Clausen, H.B., 1970. Climatic oscillations 1200–2000 AD. Nature 227, 482–483.

Jones, P.D., New, M., Parker, D.E., Martin, S., Rigor, I.G., 1999. Surface air temperature and its changes over the past 150 years. Review of Geophysics 37, 173–186.

Jose, P.D., 1965. Sun's motion and sunspots. Astronomical Journal 70, 193–200.

Kelly, P.M., Wigley, T.M.L., 1990. The relative contribution of greenhouse and solar forcing to observed trends in global mean temperature. Nature 347, 460–464.

Kestin, T.S., Karoly, D.J., Yano, J.I., Rayner, N.A., 1998. Time-frequency variability of ENSO and stochastic simulations. Journal of Climate 11, 2258–2272.

Lean, J., 2000. Evolution of the Sun's spectral irradiance since the Maunder minimum. Geophysical Research Letters 27, 2425–2428.

Lean, J., Rind, D., 2001. Earth's response to a variable Sun. Science 292, 234–236.

Lean, J., Beer, J., Bradley, R., 1995. Reconstruction of solar irradiance since 1610: implications for climate change. Geophysical Research Letters 22, 3195–3198.

Levitus, S., Antonov, J.I., Wang, J., Delworth, T.J., Dixon, K.W., Brocolli, A.J., 2001. Anthropogenic warming of Earth's climate system. Science 292, 267–270.

Mann, M.E., Park, J., 1996. Joint spatiotemporal modes of surface temperature and sea level pressure variability in the Northern Hemisphere during the last century. Journal of Climate 9, 2137–2162.

Mann, M.E., Bradley, R.S., Hughes, M.K., 1999. Northern Hemisphere temperatures during the past millennium: inferences, uncertainties and limitations. Geophysical Research Letters 26, 759–762.

Marietta, M., 1992. The Global Historical Climatology Network: Long-term Monthly Temperature, Precipitation, Sea Level Pressure, and Station Pressure Data. Oak Ridge National Laboratory, Tennessee, UT.

Meko, D.M., 1992. Spectral properties of tree-ring data in the United States Southwest as related to El Niño/Southern Oscillation. In: Diaz, H.F., Markgraf, V. (Eds.), El Niño. Cambridge University Press, Cambridge, pp. 227–241.

Reid, G.C., 1997. Solar forcing of global climate change since the mid-17th century. Climate Change 87, 391–405.

Robock, A., 2000. Volcanic eruptions and climate. Reviews of Geophysics 38, 191–219.

Schönwiese, C.-D., 1987. Moving spectral variance and coherence analysis and some applications on long air temperature series. Journal of Climatology and Applied Meteorology 26, 1723–1731.

Shindell, D.T., Schmidt, G.A., Mann, M.E., Rind, D., Waple, A., 2001. Solar forcing of regional climate change during the Maunder minimum. Science 294, 2149–2152.

Střeštík, J., Verö, J., 2000. Reconstruction of the spring temperatures in the 18th century based on the measured lengths of wine sprouts. Idöjárás 104, 123–136.