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SOLAR EXCITATION OF BICENTENNIAL EARTH ROTATION OSCILLATIONS

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ABSTRACT
The bicentennial variations of the Earth rotation consist of several oscillations with most known periods 178.7a (Jose cycle), 210a and 230a (de Vries cycle); they are driven by the solar cycles which affect climatic variations, followed by global environmental changes. These periods are close to the higher harmonics of millennial Hallstatt cycle (2300a), so the proper separation between the individual bicentennial cycles needs time series longer than 2300a. The bicentennial variations of the Universal Time (UT1) in relation to the Terrestrial Time (TT) are investigated using reconstructed time series of the Total Solar Irradiance (TSI) for the last 9300a. A linear regression model of TSI influence on the UT1 and the Mean Sea Level (MSL) bicentennial variations are created. The parameters and time series of the bicentennial UT1-TT oscillations for the last 9300a are determined

KEYWORDS: Earth rotation, solar activity

1. INTRODUCTION

The irregular and long-term variations of the Earth rotation are mainly caused by the displacements of matter in different parts of the planet whose excitation mechanism is the influence of the Sun and solar activity cycles. The solar cycles can drive great number of geodynamical processes connected with the convections of the Earth fluids on the surface and inside the Earth. Many of climate and weather parameters are affected directly by the variations of the solar activity. The climate response to the solar activity consists of cycles whose periods are close to the well known solar periods of 11a, 22a, 45a, 77a, 200a etc., and their harmonics. The climate variations are mostly due to the Total Solar Irradiance variations (TSI). The TSI variations significantly affect water evaporation and global water cycles. The global water redistribution between the oceans and continental polar ice leads to periodical changes of the principal moment of inertia *C*, followed by the Earth rotation variations, according to the law of the angular momentum conservation. The solar excitation affects biannual, decadal, centennial and millennial cycles of climate and Earth rotation. Another source of decadal oscillation of the Earth rotation is the influence of the liquid core of the Earth, whose frequencies differ from the solar frequencies. The short term of the Earth rotation cycles are mainly due to the influence of zonal tides, atmospheric and oceanic angular momenta changes.

The variations of the Earth rotation are studied either by means of the Length of Day (LOD), that is the difference between the astronomically determined duration of a day and nominal 86400 SI seconds, or by means of the difference between the time scale measured by the rotation of the Earth, Universal Time (UT1), and a uniform time scale, Terrestrial Time (TT). Since both quantities are in a simple interrelation LOD=$-d($UT1-TT$)/dt$, we will use only the UT1-TT, hereinafter refered to as UT1. The modern LOD and UT1 data, based on satellite and Very Long Baseline Interferometer (VLBI) observations is highly accurate, but relatively short and therefore suitable to study rather short-term and interannual LOD and UT1 variations only. The investigation of the decadal Earth rotation variations needs longer time series of UT1 observations. The reliable longest UT1 time series is composed by the modern UT1 determination from the last 3 decades, optical astrometry observations since 1956 and star occultations by Moon since 1623. The time series is suitable to study the solar influence on UT1 variations with periods up to several decades and to separate the oscillations with close frequencies. It has been shown that the phase-shifted 11a oscillations of UT1 are highly-correlated with the sunspot cycles (Chapanov et al., 2008b). Similar results are obtained in Chapanov (2006) and Chapanov and Gambis (2008) by means of the solution C04 of the Earth Orientation Parameters (EOP) of IERS. The time series of UT1 variations reveals strong correlations between the 11a and 22a cycles in the Earth rotation and in the Mean Sea Level (MSL) (Chapanov and Gambis, 2009a, b). Models of the Earth rotation excitation, based on the changes of moments of inertia due to global water redistribution, are suggested in Chapanov and Gambis (2009b). The necessary data to create these models are Total Solar Irradiance (TSI), UT1 and MSL time series containing oscillations near to the solar cycles. The observed UT1 data cover almost 4 centuries and MSL data – 240a. These data allow direct estimation of parameters of a single bicentennial cycle, while the model of the bicentennial UT1 variations consists of several oscillations with close frequencies and the determination of their parameters needs millennial time span data. So, the real centennial UT1 and MSL observations and reconstructed TSI data will be used to prove the existence of common bicentennial solar, climate and Earth rotation cycles and to create simple regression models. These regression models will be used to determine time series of UT1 and MSL from TSI data. The available TSI data for the last 9300a allow the separation of the close bicentennial cycles, the determination of an appropriate model and time variations of the bicentennial parameters.

Many authors consider the 200a solar cycles as one of the most intensive solar cycles. The periodical variations of solar activity in the past are studied by variation of cosmogenic isotopes 14C and 10Be concentration in terrestrial archives. Vasilev et al. (1999) and Muscheler et al. (2003) determine that the 200a solar activity cycle (de Vries cycle) is a dominant cycle during the Holocene by means of radiocarbon concentration in tree rings. Eddy (1976) considers the grand solar minima as manifestations of the de Vries cycle during the past millennia. Wagner et al. (2001) study the bicentennial periodicity by 10Be concentration in Greenland ice as a proxy for solar activity variations 25Ka-50Ka before present (BP). Sonett and Suess (1984) show correlation between the bicentennial cycles of the isotope 14C concentration and the radial growth of tree rings from eastern California. Schimmelmann et al. (2003) demonstrate the connection between the bicentennial solar cycles and some climatic parameters by means of palaeoclimatic data. Haeberli and Holzhauser (2003) point out the climate response to the grand solar minima based on data of Alpine glaciers expansion. Wiles et al. (2004) make similar conclusion about glacier expansion in Alaska. The bicentennial climatic periodicities are detected in different regions of the Earth. The available palaeoclimatic data confirm the existence of these periodicities in Europe, North and South America, Asia, Tasmania, Antarctica and Arctic, and in the ocean sediments (Sonett and Suess, 1984; Peterson et al., 1991; Anderson, 1992, 1993; Cook et al., 1996; Zolitschka, 1996; Dean, 1997; Cini Castagnoli et al., 1998; Qin et al., 1999; Hong et al., 2000; Hodell et al., 2001; Nyberg et al., 2001; Roig et al., 2001; Yang et al., 2002; Fleitman et al., 2003; Haeberli and Holzhauser, 2003; Hu et al., 2003; Schimmelmann et al., 2003; Soon and Yaskell, 2003; Prasad et al., 2004; Raspopov et al., 2004; Wiles et al., 2004; Wang et al., 2005). The regional bicentennial climatic signals are associated with the global solar forcing, so the climatic response to the solar activity should reveal significant global effects, too. These effects are synchronous bicentennial oscillations of the mean sea level and polar ice thickness and volume, due to global water redistribution between ocean and continental polar ice. The polar ice thickness increases and the mean sea level decreases during the bicentennial cold events, followed by the decrease of the mean Earth radius and the principal moment of inertia relative to the rotational axes. Any change of the principal moment of inertia leads to significant variations of the Earth rotation, due to the conservation of the Earth angular momentum. The time series UT1, LOD and climatic variations give good opportunity to study the long-term oscillations of Earth rotation, corresponding to the sunspots, magnetic and equatorial solar asymmetry cycles of the solar activity with periods of about 11a, 22a and 45a (Chapanov and Gambis, 2008; Chapanov et al., 2008a, b; 2009). These time series are suitable to study interdecadal oscillations with periods up to 3-4 centuries.

The existing long climatic and astronomical time series with bicentennial and millennial time spans are useful to study interconnection between the bicentennial cycles of the solar activity and the Earth rotation. The bicentennial solar cycles consist of several known oscillations. Jose (1965) points out a repeating solar system configuration of the 4 outer planets with period of 178.7a. He suggests this configuration modulates the solar cycles. Sharp (2010) suggests another value - 171.44a, which is the synodic period of Uranus and Neptune. Some authors study solar periodicity 205a-210a (de Vries cycle) and 230a (Suess cycle). The oscillations with periods 210a and 230a may appear as the 10th and 11th harmonics of 2300a Hallstatt solar cycle, so the candidates of the main bicentennial cycles of climatic variations, driven by the solar activity are four oscillations with periods of 171.44a, 178.7a (planetary terms), 210a and 230a (de Vries and Suess cycles).

The model of bicentennial Earth rotation oscillations driven by the solar activity is required to determine the main bicentennial term and the proportions between the amplitudes of the bicentennial terms, to suggest linear regressions between TSI, MSL and UT1 bicentennial variations, and to estimate time variations of the model parameters. Due to the close values of the bicentennial frequencies, it is necessary to use time series longer than 2300a, which is their maximal beat period.

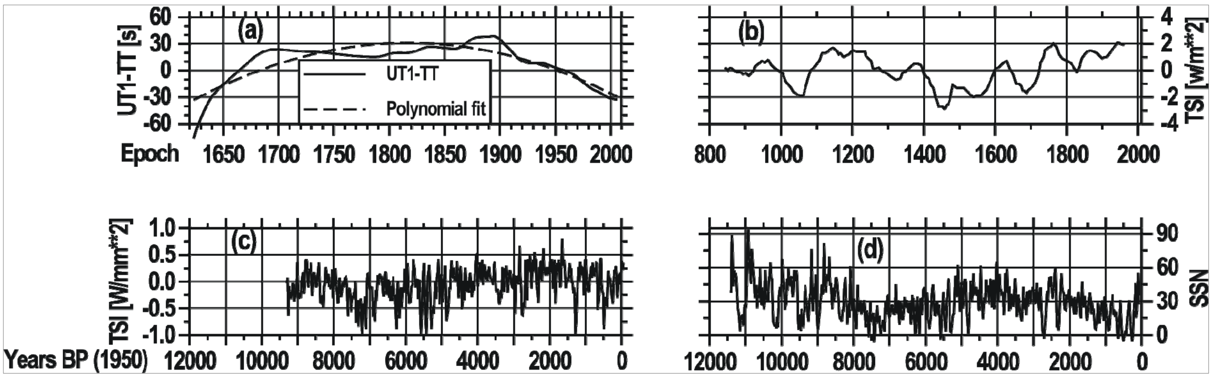

Fig. 1 Time series of the difference between the Universal Time UT1 and Terrestrial Time TT (a), centennial TSI variations (Bard et al., 2000) (b), millennial TSI variations (Steinhilber et al., 2009) (c) and Sun Spot Numbers SSN (d).

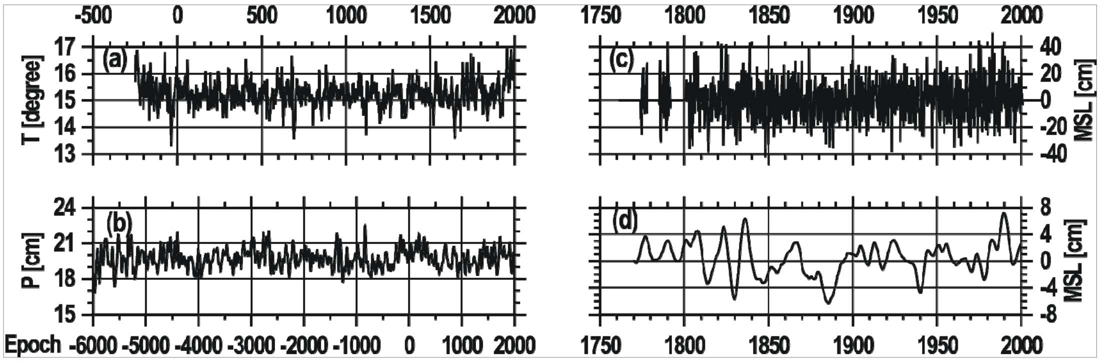

Fig. 2 Time series of North America temperature (a) and precipitation (b), detrended Mean Sea Level (MSL) at Stockholm (c) and 5-year averaged MSL (d).

2. TIME SERIES AND SPECTRA OF EARTH ROTATION, SOLAR AND CLIMATIC DATA

The bicentennial variations of the Universal Time UT1 are investigated by means of studying long centennial and millennial observational series of solar activity, climatic parameters and UT1 variations, which cover time span more than 3 centuries long. The centennial data are used to prove the existence of common bicentennial solar, climate and Earth rotation cycles and to create simple regression models. The detailed study and separation of the UT1 bicentennial cycles requires the data covering intervals longer than 2300a. The used data consist of time series with duration from centuries to several millennia:

- UT1 for the period 1623-2005, (IERS, 2011, Fig. 1, a). The time series contains almost two bicentennial cycles of observed variations of the Earth rotation. The UT1 data are used to prove the existence of common cycles of Earth rotation, sea level and solar activity and to determine the main bicentennial period;
- Total solar irradiance TSI for the period 843-1961(Bard et al., 2000, Fig. 1, b). The time series of reconstructed TSI variations consists detailed decadal and centennial solar cycles (except 11a cycles). The TSI data are used to prove the existence of solar influence on bicentennial MSL and UT1 variations and to determine the main bicentennial period;
- Mean sea level at Stockholm for the period 1770-2001 (Ekman, 2003, Fig. 2, c, d). The longest real MSL observations are used to prove the bicentennial model of solar activity variation – climatic variations – global water redistribution between the ocean and continental polar ice – variations of the principal moment of inertia *C* – Earth rotation variations, according to the law of angular momentum conservation;
- 2200a time series of North America temperature (Salzer and Kipfmueller, 2005, Fig. 2, a). These data are used to determine the spectrum of the bicentennial climate variations and to indicate the existence of planetary terms and de Vries and Suess cycles;
- 8000a time series of North America precipitation (Hughes and Graumlich, 2000, Fig. 2, b). These

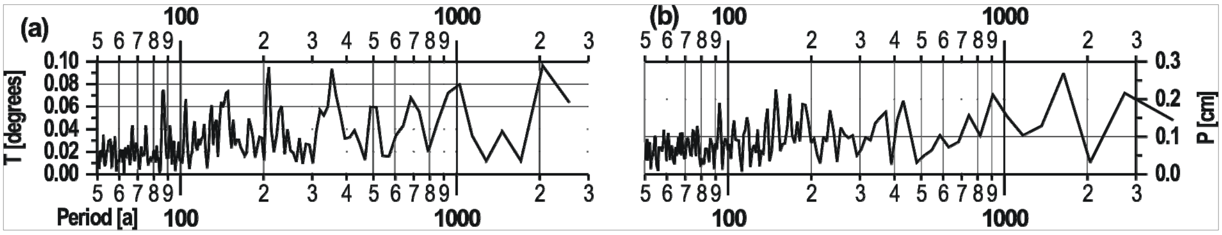

Fig. 3 Amplitude spectra of North America temperature (a) and precipitation (b).

data are used to determine the spectrum of the bicentennial and millennial climate variations and to prove the existence of Hallstatt solar cycle and its harmonics in climate variations. The climate time series serves as an independent source of information on bicentennial cycles;

- Time series of TSI with duration 9300a (Steinhilber et al., 2009, Fig. 1, c). The reconstructed TSI variations are essential to separate and estimate the parameters of planetary terms, de Vries and Suess cycles, because the beat periods between the bicentennial oscillations with close frequencies are between 2300a and 7800a. It is possible to use the TSI data to reconstruct the UT1, LOD, MSL and principal angular moment *C* variations for the last 9300a by means of the model of solar excitation of bicentennial Earth rotation oscillations;
- 11000a series of sunspot numbers SSN (Solanki et al., 2004, Fig. 1, d). The time series serves as independent data to determine centennial and millennial solar cycles and it has been used to compare the bicentennial frequencies in TSI and SSN variations. This comparison is necessary to prove the existence of arbitrary values of estimated bicentennial periods and to exclude possible false signals from solar data.

The amplitude spectra of North America temperature and precipitation show a millennial long-periodical oscillation with the period between 2000a and 3000a (Fig. 3, a, b). This long-periodical oscillation is known as the Hallstatt cycle with period, estimated to fall between 2300a and 2400a in scientific papers. The North America temperature spectrum contains significant oscillations with periods 210a and 230a, which appear as the 10th and 11th harmonics of the 2300a Hallstatt cycle.

So, the main bicentennial cycles of climatic variations, driven by the solar activity are shown in Figure 3.

3. MAIN BICENTENNIAL OSCILLATION AND LINEAR REGRESSIONS BETWEEN UT1, MSL AND TSI VARIATIONS

The main bicentennial oscillation is determined by a model of the solar influences on the bicentennial, decadal and interdecadal oscillation. This model should include all short solar terms with periods equal to or greater than 11a, otherwise they would appear as a high-frequency noise. The value of the dominant period of the main bicentennial cycle of this model is determined among 171.44a, 178.7a (Jose cycle), 210a and 230a (de Vries cycle) by looking for the minimal residuals of UT1, TSI and MSL comparison. For filtering and extracting bicentennial cycles from the observed data we have determined Fourier series with the period of the main first term being equal to one of the bicentennial cycles. The Fourier coefficients have been estimated by the method of least squares applied to all data. So, this method shows to be a modification of the well known Fourier approximation of all data with the main period shorter than the data span and with an appropriate truncation of the number of used terms. The advantages of this method consist in band pass filtering set by the first and last Fourier frequencies used, in exact choosing the involved frequencies (or periods) and in estimating amplitudes, phases and errors of all oscillations from the band by least squares, respectively.

The model of the bicentennial and decadal cycles of the Earth rotation and solar activity is made as a modified Fourier approximation of all TSI, UT1 and MSL data in the form

$$F = f_0 + f_1(t - t_0) + \sum_{j=1}^{N_k} a_j \sin j \frac{2\pi}{P_k}(t - t_0) + b_j \cos j \frac{2\pi}{P_k}(t - t_0) \quad , \qquad (1)$$

where t_0 is the mean epoch of observations F, N_k - the number of harmonics having the frequencies $\omega_k=2\pi/P_k$, which correspond to different bicentennial periods P_k. We will examine four bicentennial models with main periods P_k =171.44a, 178.7a, 210a and 230a. The coefficients f_0, f_1, a_j and b_j in (1) are estimated by the least squares. The number of the harmonics N_k should be greater or equal to $P_k/11+1$, so the approximation (1) includes all solar frequencies with periods from 11 to P_k years. Next the centennial and bicentennial oscillations are separated from the decadal solar terms by using only the first 5 harmonics of Eq. 1 (Figs. 4-6).

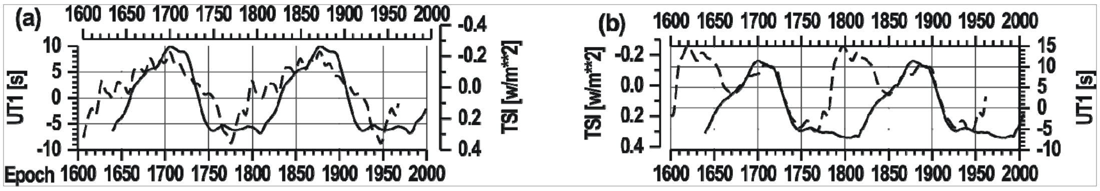

Fig. 4 Comparison between UT1 (solid line) and TSI (Bard's solution, dashed line) bicentennial cycles, determined by 171.44a model (a) and 178.7a model (b).

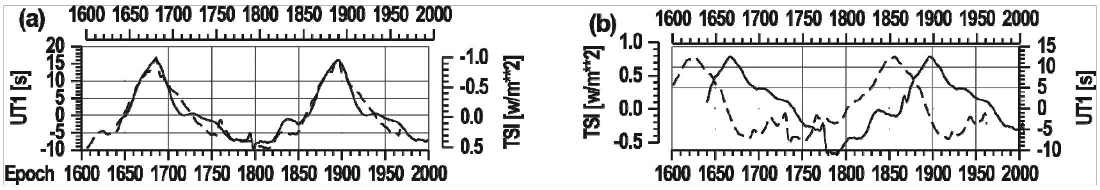

Fig. 5 Comparison between UT1 (solid line) and TSI (Bard's solution, dashed line) bicentennial cycles, determined by 210a model (a) and 230a model (b).

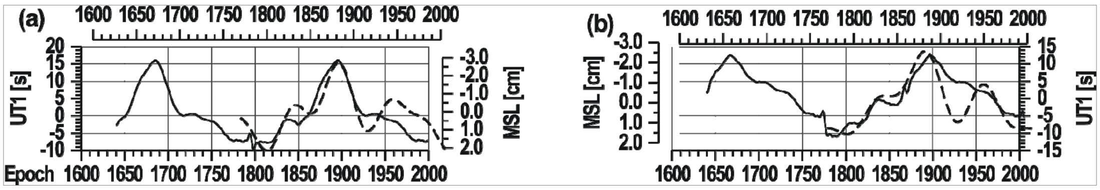

Fig. 6 Comparison between UT1 (solid line) and MSL (dashed line) bicentennial cycles, determined by 210a model (a) and 230a model (b).

First, the UT1variations are reduced by a parabolic fit. Next, the UT1 bicentennial cycles determined by the model (1) are compared with the corresponding TSI cycles from the solution of Bard et al. (2000), which provides smoother curve than other solar indices. The 172a model yields poor agreement between the UT1 and TSI variations (Fig. 4, a). Partial correlation between the UT1 and negative TSI variations exists in the case of 178.7a model (Fig. 4, b), which points out that this oscillation and its harmonics are present in the bicentennial solar-terrestrial influences, but it is not the dominant period. The same conclusion is valid for 230a model (Fig. 5, b), where the TSI and UT1 cycles are significantly shifted. The 210a model yields almost exact match between the UT1 and negative TSI cycles (Fig. 5, a), so the period of about 210a of the bicentennial solar-terrestrial influences is dominating. A relatively good agreement between the UT1 and negative MSL bicentennial cycles exists (Fig. 6), so the most probable source of Earth rotation bicentennial variations are cooling effects of the solar grand minima and corresponding increasing of the polar ice thickness.

The best agreement between the bicentennial cycles of the TSI and UT1 is achieved by 210a model. The amplitude of 210a oscillation is dominating, and a strong correlation between the 210a cycles of the UT1, MSL and TSI (Fig. 5, a; Fig. 6, a) exists. The dependence between the TSI and UT1 bicentennial variations is negative, so the Earth rotation acceleration is connected with the decrease of the MSL, due to the cooling effects of solar grand minima and the corresponding increase of the polar ice thickness.

Partial correlation exists between the 180a and 230a cycles of the time series of solar and climatic indices, and UT1. The solar grand minima are irregular in time and the time intervals between them are not multiples of the examined periods, so the appropriate model of the bicentennial cycles of the Earth rotation should combine 180a, 210a, 230a oscillations and their harmonics.

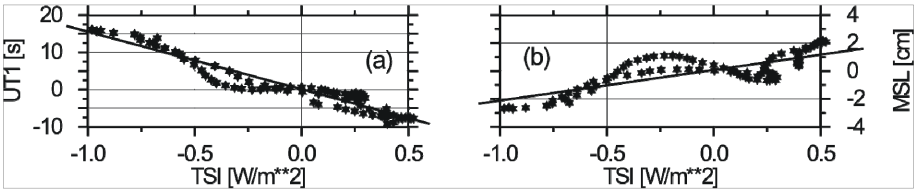

Fig. 7 Linear regressions UT1-TSI (a) and MSL-TSI (b).

The real and reliable UT1 observations are available since 1623. The data of the Earth rotation variations before 1623 during the Holocene is possible to be reconstructed by means of TSI time series. So, the linear regression between UT1 and TSI (2), based on the real UT1 data, will be used to transform the TSI variations into UT1 variations and the linear regression between MSL and TSI variations (3) will prove the bicentennial model of solar-terrestrial energy transfer (Fig. 7):

$$UT1 = (-15.474 \pm 0.255) \times TSI + (0.05 \pm 0.11) \text{ [s]}, \quad (2)$$

$$MSL = (+2.200 \pm 0.134) \times TSI + (0.07 \pm 0.06) \text{ [cm]}, \quad (3)$$

where the universal time UT1 is expressed in seconds, the mean sea level MSL in centimeters and the total solar irradiance in W/m^2. The root mean squares of the residuals of models UT1/TSI and MSL/TSI calculated on their common periods are equal to ±2.00s and ±0.80cm, respectively.

The model of solar excitation of bicentennial Earth rotation oscillations is based on synchronous cycles of TSI, UT1 and MSL variations. This model has been tested on the real UT1 and MSL observations from the last centuries. The equations (2) and (3) give the mutual dependence of UT1, MSL and TSI. Supposing that correlations between that quantities have not changed in last millenia substantially there is a possibility to calculate time series of UT1 and MSL for the last 9300a and to estimate amplitudes of their bicentennial terms.

4. MODELS OF UT1 AND TSI BICENTENNIAL VARIATIONS

The simplest model of UT1 and TSI bicentennial variations is based on Fourier approximation of all data with main period 2300a (Hallstatt cycle) and first 13 harmonics. This model includes the following harmonics: 10th with 230a period (Suess cycle); 11th with 209a period (de Vries cycle) and 13th with shifted Jose cycle (176a). More precise model is based on Fourier approximation of all data with main period 9200a and first 55 harmonics. The bicentennial oscillations from this model are composed of harmonics 39-55 and periods from the interval 167a-235a. The values of the periods of Hallstatt, de Vries and Suess cycles are rather rounded. Even the planetary periods may appear in the observed data with shifted values, due to their superposition with high-frequency terms. The proper values of the bicentennial cycles of the TSI are determined by varying the main period from 2280a to 2400a with 10a steps, where the period of corresponding j-th harmonics of the Fourier approximation also varies with steps equal to $10j^{-1}$ years (Fig. 8). The amplitudes of the Fourier harmonics have maxima when the periods are close to their real values.

The amplitudes of de Vries and Sues cycles have common maxima for TSI and SSN data, while their periods are 208a and 231a. The planetary terms and Jose cycle are represented by a common maximum at 183a period and a few non-matching maxima. So, the basic model of bicentennial UT1 and TSI oscillations includes 3 oscillations with periods 231a (Suess cycle), 208a (de Vries cycle) and 183a (Jose cycle). This model have 2100a maximal beat period between the frequencies. An extended model, including 6 oscillations of bicentennial UT1 and TSI variations is proposed by adding 3 terms with periods 171.4a, 178.8a and 196a to the basic model. The extended model represents better the variations of the parameters of the bicentennial UT1 and TSI cycles. This model have 7800a maximal beat period between the frequencies.

The TSI variations with periods between 170a and 2300a, determined by the 2300a model (Fig. 9, a), have significant cooling effect every 2300a, when the TSI decreases by $0.4W/m^2$, modulated by 3 bicentennial cycles. These variations do not represent the real cooling events, which are unevenly spaced in time.

The TSI variations determined by the 9200a model (Fig. 9, b) have significant cooling effects, whose minima are in good agreement with the real cool events, when the TSI decrease by 0.2-$0.7W/m^2$, modulated by the bicentennial cycles. The determined minima occur around 1820, 1680, 1480, 1290, 1050, 660, –370, –780, –1450, –2900 etc. First four minima correspond to the so-called Dalton (1805), Maunder (1680), Spörer (1470) and Wolf (1305) minima, respectively. The other unnamed minima are centered over the years: 1040, 685, –360, –765, –1390, –2860 etc., according to Usoskin (2008) and only a few of

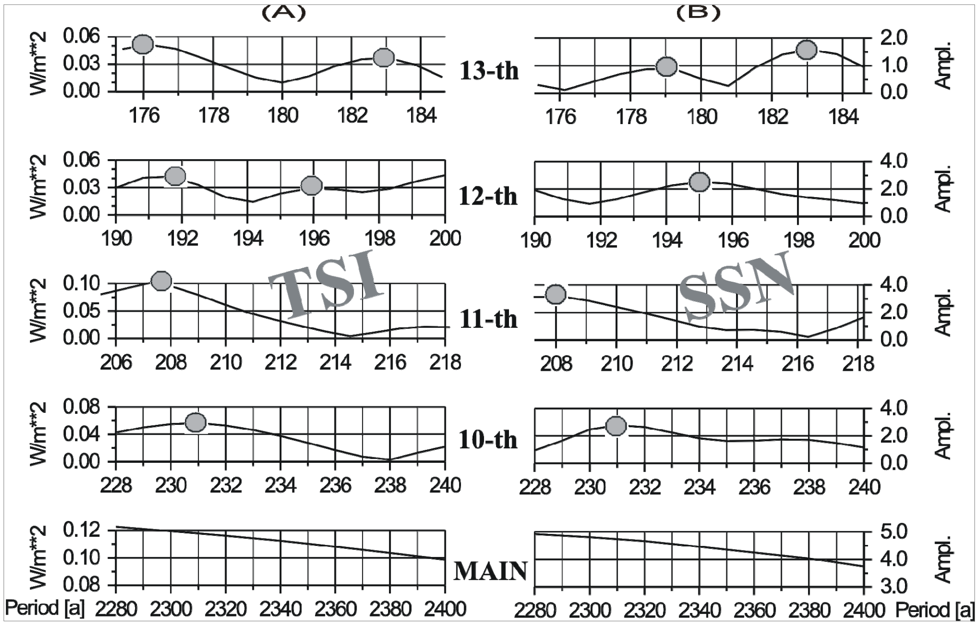

Fig. 8 Amplitude maxima of the main oscillation and harmonics 10-13 of the Fourier approximations, determined by varying the main period from 2280a to 2400a with 10a steps from total solar irradiance data (A) and sunspot numbers (B).

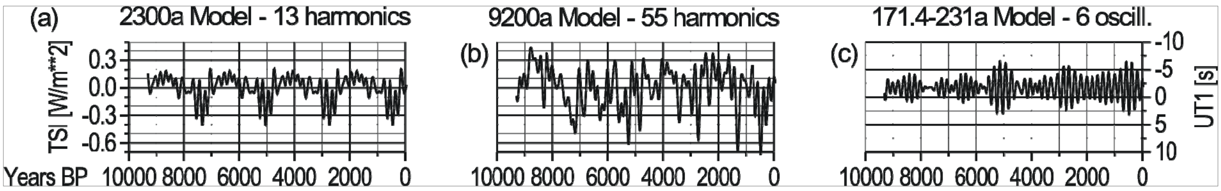

Fig. 9 Models of 2300a (a) and 9200a (b) TSI variations and UT1 bicentennial cycles (c).

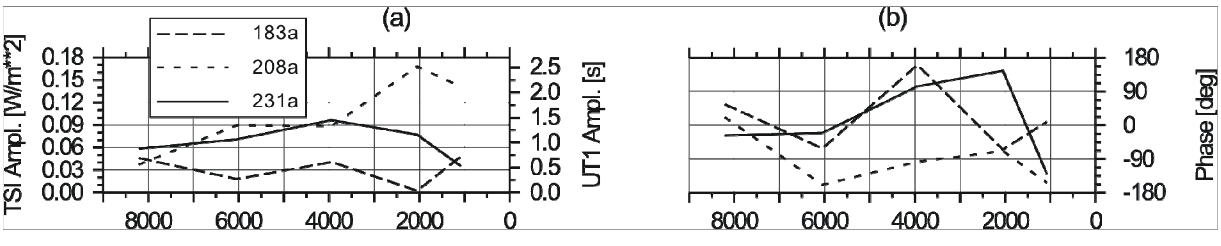

Fig. 10 Variations of the amplitudes of the oscillations with periods 183a, 208a and 231a (a) and corresponding phases (b), determined in running 2300a window.

them are not included in the Usoskin's review. The bicentennial UT1 variations, determined by the extended 6-oscillation model, have variable amplitudes with some amplification during the cold minima (Fig. 9, c). The UT1 cycles have more stable amplitude after 3000a BP.

The amplitude of bicentennial oscillations of the Earth rotation and solar activity are varying in time. The variations of the phases and amplitudes of the 231a, 208a and 183a oscillations from the basic model are determined in 2300a running window (Fig. 10). The amplitude of the 208a oscillation is dominating during the last 4000a. For the time interval 4000a-8000a BP the amplitudes of 208a and 231a cycles have almost similar behavior and equal values. The 208a and 231a cycles have almost opposite phases for the interval 2000a-6000a BP. The amplitudes of 183a and 208a cycles are anti-correlated, so these 3 oscillations probably have common excitation source.

5. CONCLUSIONS

The bicentennial cycles of the solar activity strongly affect Earth climatic variations, providing significant cooling effect especially over the polar ice, leading to decreasing the MSL and the principal moment of inertia *C* during the solar grand minima (acceleration of the Earth rotation). The cooling effect is amplified significantly by the millennial cycles. The existence of common bicentennial solar, climate and Earth rotation cycles has been proved by the real UT1 and MSL observations and reconstructed TSI data. The bicentennial solar cycles consist of several oscillations with periods from interval 171a-231a, where the de Vries cycle (208a) and the Suess cycle (231a) are dominating. These periods are close to the harmonics of millennial Hallstatt cycle (2300a), so the proper separation between the bicentennial cycles requires a model with minimal main period 2300a.

The recent bicentennial oscillations of the TSI, UT1 and MSL are highly correlated and synchronized in case of de Vries cycle and its harmonics. Linear regression models of TSI influence on the UT1 and MSL bicentennial variations are created and these models are used to reconstruct the time series of UT1 variations for the last 9300a.

The proper values of the periods of bicentennial cycles are determined by varying the main period from 2280a to 2400a with 10a steps, where the period of corresponding j-th harmonics of the Fourier approximation also varies with steps equal to $10j^{-1}$ years. The bicentennial amplitudes have common maxima in TSI and SSN series for the oscillations with periods 183a, 208a and 231a. The frequencies of TSI bicentennial oscillations with maxima of amplitudes are different from the frequencies of 2300a harmonics. So, the Suess, de Vries and Jose cycles appear as independent from the 2300a harmonics and their close frequencies lead to complex oscillating system with millennial periods.

The parameters of the bicentennial TSI variations are estimated in running 2300a window and time variations of the phases and amplitudes of the bicentennial cycles are determined. The time variations of the phases and amplitudes of the bicentennial cycles show dominating amplitude of 208a oscillation for the last 4000a and equal 208a and 231a amplitudes before, with mostly opposite phases. The amplitudes of 183a and 208a cycles are anti-correlated. The 2300a model does not represent the real cold events, corresponding to the solar grand minima, while the 9200a model yields more realistic behavior. The bicentennial cycles of the solar activity and Earth rotation, corresponding to the last model, consist of 16 harmonics of the Fourier approximation with numbers 39-54 and oscillations with periods ranging from 170.4a to 235.9a. The maximal amplitudes of the bicentennial oscillations are 0.3 W/m^2 for TSI and 4.6s for UT1.

The model of solar excitation of bicentennial Earth rotation oscillations is based on common synchronous cycles of TSI, UT1 and MSL variations. The extracted time series of bicentennial variations from the real UT1 and MSL data are highly correlated with the corresponding variations of TSI in the last two centuries. A linear dependence exists between these time series, according to the bicentennial model. So, the regression models between the TSI, UT1 and MSL bicentennial variations formulated in equations (2) and (3) are sufficient substitutes to determine Holocene time series of UT1 and MSL variations with rather dense time steps. The significance of the reconstructed UT1 bicentennial variations is that these cycles represent the long term Earth rotation variations and the behavior of time variations of their parameters and they are a step toward creating a common oscillatory model of the Earth rotation and its connection with the solar cycles. The reconstructed time series of MSL variations derived from the Holocene sediments represent mostly the trends of the fast sea level rising and almost no periodic terms, so the proposed linear dependence (3) between MSL and TSI is the sufficient tool to determine bicentennial periodic terms and their harmonics in the Holocene with rather dense time steps.

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