A MODEL OF CENTENNIAL OSCILLATIONS OF EARTH ROTATION BASED ON TOTAL SOLAR IRRADIANCE VARIATIONS

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ABSTRACT. The centennial variations of Earth rotation are driven by the solar cycles which affect climatic variations, followed by global environmental changes. The centennial solar cycles consist of several oscillations with most known periods 178.7 a (Jose cycle), 210 a and 230 a (de Vries cycle). These periods are close to the harmonics of the millennial Hallstatt cycle (2300 a), so the proper separation between the centennial cycles needs a model with main period 2300 a. The centennial variations of the Universal Time UT1 and Length of Day LOD are investigated by means of reconstructed time series of the Total Solar Irradiance TSI for the last 9300 years. The parameters of the centennial TSI variations are estimated in 2300-year running windows; time variations of the phases and amplitudes of the centennial cycles are determined. A linear regression model of the TSI influence on UT1 centennial variations is created. The parameters and time series of the centennial UT1 and LOD oscillations for the last 9.3 Ka are determined.

1. INTRODUCTION

The irregular and long-term variations of Earth rotation are mainly caused by the displacements of matter in different parts of the planet with the initial excitation mechanism being the influence of the Sun and the solar activity cycles. The existing long climatic and astronomical time series with centennial and millennial time spans are useful to study interconnection between the centennial cycles of the solar activity and Earth rotation. In Chapanov et al. (2011) the centennial cycles of the solar activity and Earth rotation are investigated by means of the available data of Earth rotation, solar activity and climatic parameters. The used data consist of time series with duration from centuries to several millennia: UT1-TT and LOD for the period 1623–2005; total solar irradiance TSI for the period 843–1961 (Bard et al., 2000); 2.2 Ka time series of North America temperature (Salzer and Kipfmueller, 2005); Mean sea level at Stockholm for the period 1770-2001 (Ekman, 2003); 8 Ka time series of North America precipitation (Hughes and Graumlich, 2000). It has been determined that the centennial cycles of Earth rotation consist of at least three oscillations with significant amplitudes and periods from the interval 171–230 years (Chapanov et al., 2011). The 210-year oscillation has a dominating amplitude, and strong correlation between the 210-year cycles of the UT1, MSL and TSI (Figure 2a,b) exists (Chapanov et al., 2011). The detailed study and separation of the UT1 centennial cycles need data covering more than 2300 a intervals, so time series of TSI with duration 9.3 Ka (Steinhilber et al., 2009) and 11 Ka series of sunspot numbers SSN (Solanki et al., 2004) are used in this work (Figure 1).

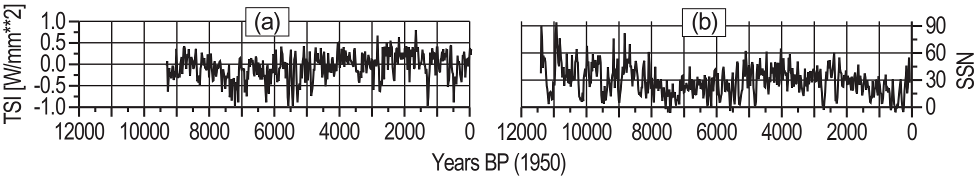

Figure 1: Millennial time series of Total Solar Irradiance TSI (a) and Sunspot numbers SSN (b).

2. LINEAR REGRESSIONS BETWEEN UT1, MSL AND TSI CENTENNIAL VARIATIONS

Real and reliable UT1 observations are available since 1623. The data of Earth rotation variations before 1623 during the Holocene is possible to reconstruct by means of TSI time series. So, the linear regression between UT1 and TSI (Equation 1), 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 (Equation 2) will prove the centennial model of solar-terrestrial energy transfer:

$$\mathrm{UT1} = -15.47\mathrm{TSI} + 0.05, \tag{1}$$

$$\mathrm{MSL} = 2.2\mathrm{TSI} + 0.07, \tag{2}$$

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.

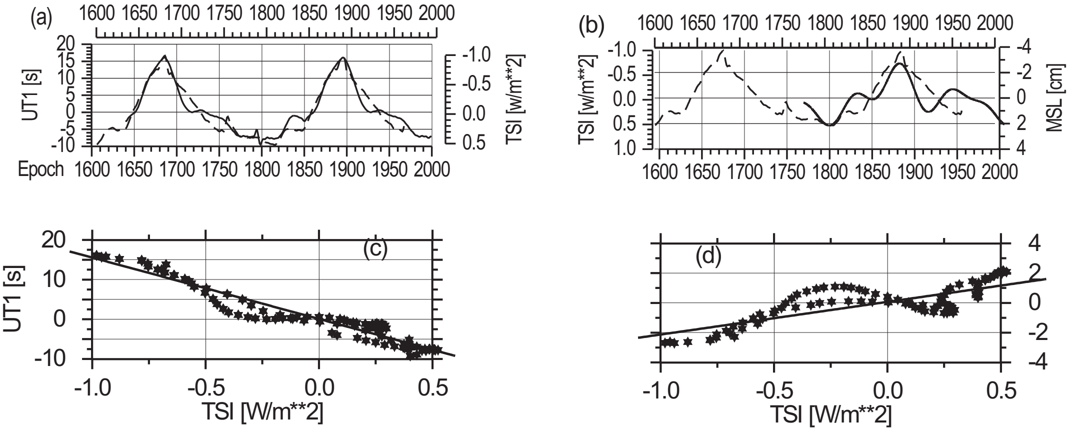

Figure 2: Comparison between UT1 (solid line) and TSI (dashed line) centennial cycles (a) and MSL (solid line) and TSI (dashed line) cycles (b), according to Chapanov et al. (2011). Linear regressions UT1-TSI (c) and MSL -TSI (d).

3. MODELS OF UT1, AND TSI CENTENNIAL VARIATIONS

The simplest model of UT1 and TSI centennial variations is based on Fourier approximation of all data with a main period of 2300 a (Hallstatt cycle) and the first 13 harmonics. This model includes the following harmonics: 10-th with 230 a period (Suess cycle); 11-th with 209 a period (de Vries cycle) and 13-th with shifted Jose cycle (176 a). A more precise model is based on Fourier approximation of all data with a main period of 9200 a and the first 55 harmonics. The centennial oscillations from this model are composed out of the harmonics 39-55 and the periods from the interval 167 a – 235 a.

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 centennial cycles of the TSI are determined by varying the main period from 2280 a to 2400 a with 10-year steps, where the period of the corresponding j-th harmonics of the Fourier approximation also varies with steps equal to 10/j years (Figure 3). 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 208 a and 231 a. The planetary terms and Jose cycle are represented by a common maximum at 183-year period and a few non-matching maxima. So, the base model of centennial UT1 and TSI oscillations includes three oscillations with periods 231 a (Suess cycle), 208 a (de Vries cycle) and 183 a (Jose cycle, 1965). This model have 2100-year maximal beat period between the frequencies. An extended

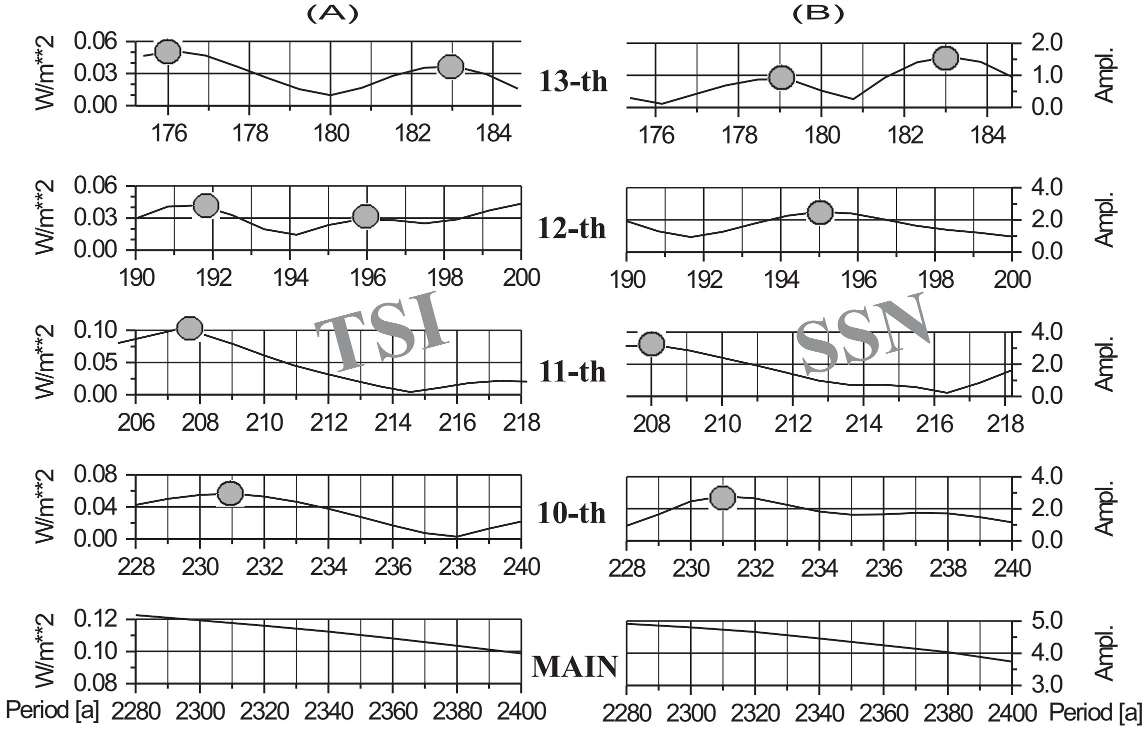

Figure 3: Amplitude maxima of the main oscillation and harmonics 10-13 of the Fourier approximations, determined by varying the main period from 2280 a to 2400 a with 10-year steps from total solar irradiance data (A) and sunspot numbers (B).

model, including six oscillations of centennial UT1 and TSI variations is proposed by adding three terms with periods 171.4 a, 178.8 a and 196 a to the base model. The extended model represents better the variations of the parameters of the centennial UT1 and TSI cycles. This model has 7800-year maximal beat period between the frequencies.

The TSI variations with periods between 170 a and 2300 a, determined by the 2300 a model (Figure 4a), have a significant cooling effect every 2300 years, when the TSI decrease by 0.4 W/m^2, modulated by three centennial cycles. These variations do not represent the real cooling events, which are non-evenly spaced in time.

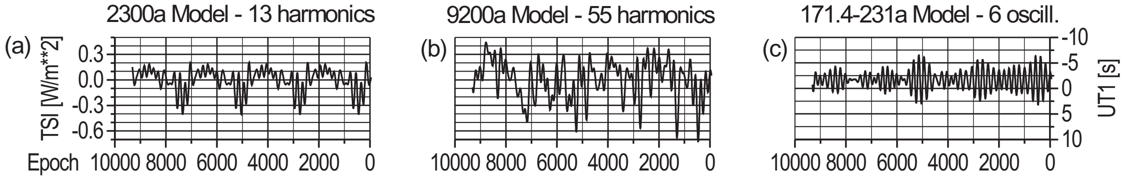

Figure 4: Models of 2300 a (a) and 9200 a (b) TSI variations and UT1 centennial cycles (c).

The TSI variations determined by the 9200 a model (Figure 4b) have significant cooling effects, whose minima are in good agreement with the real cool events, when the TSI decrease by 0.2-0.7 W/m^2, modulated by the centennial cycles. The centennial UT1 variations, determined by the extended six-oscillation model, have variable amplitudes with some amplification during the cool minima (Figure 4c). The UT1 cycles have more stable amplitude after 3000 a BP.

4. TIME VARIATIONS OF THE PHASES AND AMPLITUDES OF THE CENTENNIAL CYCLES IN A 2300-YEAR RUNNING WINDOW

The centennial oscillations of Earth rotation and solar activity have variable amplitudes in time. The variations of the phases and amplitudes of the 231-, 208- and 183-year oscillations from the base model are determined in a 2300-year running window (Figure 5). The amplitude of the 208-year oscillation is dominating during the last 4000 years. For the time interval 4000-8000 a before present the amplitudes of the 208-year and 231-year cycles have almost similar behavior and equal values. The 208- and 231-year cycles have almost opposite phases for the interval 2000–6000 years before present. The amplitudes of the 183-year and 208-year cycles are anticorrelated, so these three oscillations probably have a common excitation source.

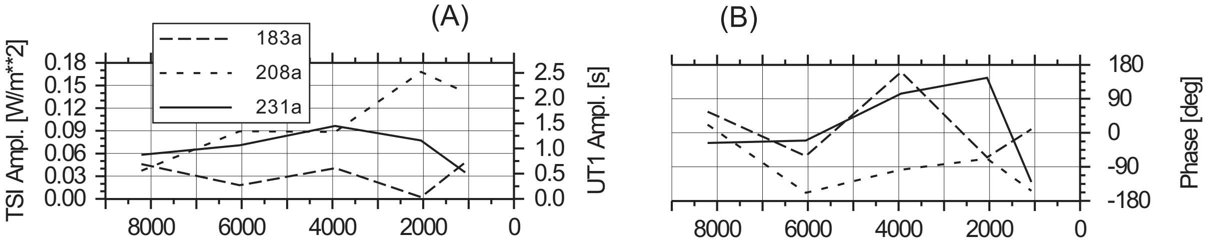

Figure 5: Variations of the amplitudes of the oscillations with periods 183 a, 208 a and 231 a (A) and corresponding phases (B), determined in a 2300-year running window.

5. CONCLUSIONS

The centennial cycles of the solar activity strongly affect Earth's climatic variations, providing a 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's rotation). The cooling effect is amplified significantly by the millennial cycles.

The frequencies of TSI centennial oscillations with maxima of amplitudes are different from the frequencies of 2300-year harmonics. So, the Suess, de Vries and Jose cycles appear to be independent from the 2300-year harmonics and their close frequencies lead to a complex oscillating system with millennial periods.

The time variations of the phases and amplitudes of the centennial cycles in a 2300-year running window show a dominating amplitude of a 208-year oscillation for the last 4000 a and equal 208-year and 231-year amplitudes before, with mostly opposite phases. The amplitudes of the 183-year and 208-year cycles are anticorrelated.

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