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Solar Influence on Chandler Period

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Abstract

The Chandler wobble (CW) is a free rotational mode of the Earth associated with its dynamical ellipticity. In the absence of external force, the CW would have a period of about 433 days. The Chandler wobble is excited by a combination of atmospheric and oceanic processes, with the dominant excitation mechanism being ocean-bottom pressure fluctuations, caused by ocean circulation and variations in temperature, salinity, and winds. The most important energy sources of all atmospheric and oceanic processes are the solar activity cycles, so the solar cycles affect climatic system and angular momentum of atmosphere and ocean, followed by polar motion and Chandler period variations. The Chandler period variations are determined from the coordinates of polar motion for 1860-now from the solution C01 of the IERS. The centennial, decadal and interannual harmonics of solar activity are determined by the Method of Partial Fourier Approximation of time series of the Total Solar Irradiance (TSI), Sunspot Numbers (SSN) and North-South Solar Asymmetry (N-S SA). The long-term variations of CW period are compared with corresponding cycles of N-S SA. The decadal and interannual oscillations with periods above 6yr of CW have good agreement with the TSI cycles in several frequency bands. The short-term CW oscillations have good agreement with SSN cycles in two bands of periodicity between 3 and 4 years. It is remarkable that the CW grand minimum around 1930 is strongly connected with all solar harmonics with dominating influence of long term N-S SA variations (periodicity 78-156yr, CW period decrease - 6d) and TSI variations (periodicity 39-52yr, CW period decrease - 10d). The TSI influence on CW period variations is non-linear and frequency dependent. The value of CW period increase during the warming cycles of solar activity and decrease during some solar minima.

Keywords: Chandler period, TSI, SSN, North-South solar asymmetry.

Introduction

The solar activity affects terrestrial systems by means of direct radiation over Earth surface, influences charged particles of the solar wind, and the solar magnetic field. The solar wind directly affects Earth magnetic field, ionosphere and atmosphere. The sunspot numbers represent both TSI and solar wind variations. The SSN and TSI variations are highly correlated in decadal period bands, and they have some differences in annual period bands. The variations of solar magnetic field modulate solar wind and cosmic rays in the frame of the solar system. The North-South solar asymmetry represents significant part of solar magnetic field variations. The cosmic rays near Earth are modulated by Earth magnetic field variations, too. The TSI and cosmic ray variations affect climate system and motion of ocean and atmosphere, whose small variations stay in the source of Chandler wobble excitation. So, we may expect significant solar influence on Chandler wobble variations, expressed by strong correlation in selected frequency bands between Chandler period value and any of solar activity indices – TSI, SSN or N-S solar asymmetry. The Chandler period variations have two anomalies: in 1926, when the period significantly decrease; and in 2011, when the Chandler oscillation almost disappear from the polar motion.

Data and Methods

a) Solar and terrestrial data

The solar activity variations are presented by several numerical indices (Fig. 1). The most popular of them are indices of sunspot numbers, sunspot area and TSI. The sunspots have been observed during the last 4 centuries, while the real observations of TSI are available only for the last decades.

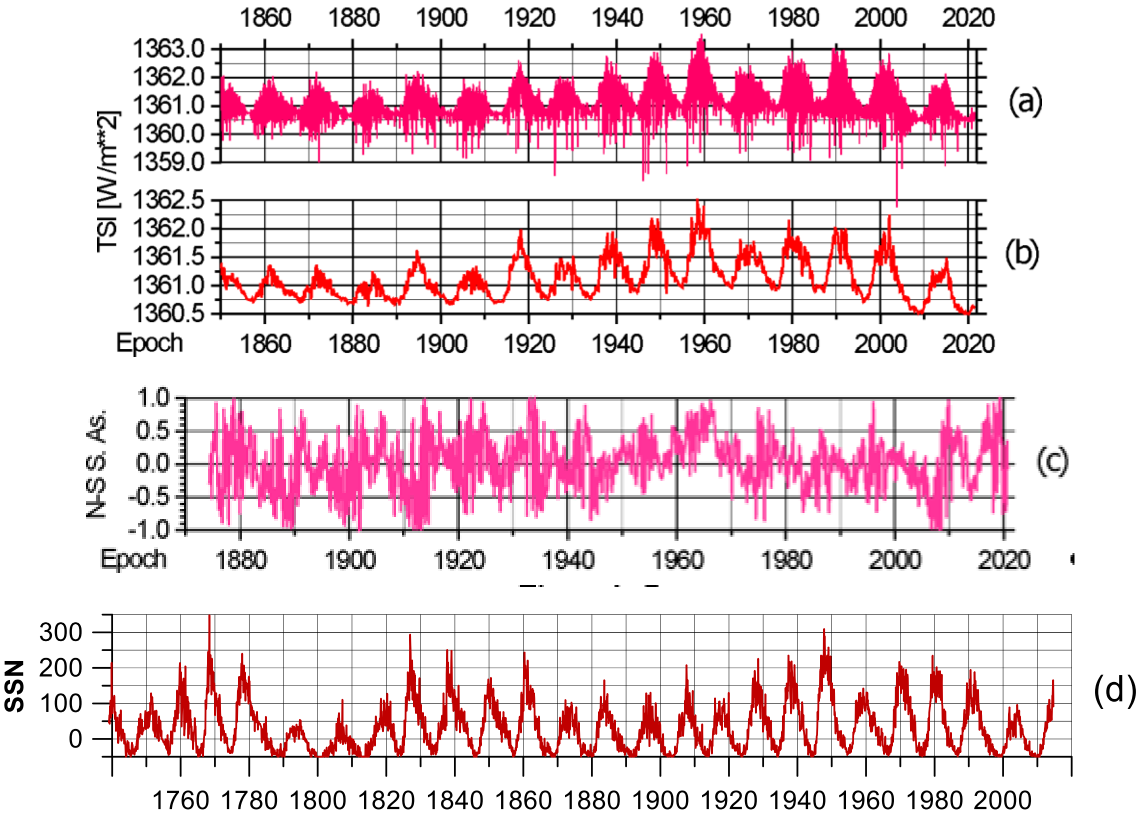

Figure 1. *Time series of solar indices: reconstructed daily values of TSI – (a); 0.1-year normal points of TSI – (b); North-South solar asymmetry – (c); and sunspot numbers – (d).*

The TSI data are presented in Fig.1, a, b. The last version of estimated solar irradiances for the last 400 years is based on the NRLTSI2 historical TSI reconstruction model by J. Lean (Kopp et al., 2016; Lean, 2000, 2010; Coddington et al., 2015). The North-South solar asymmetry (Fig.1, c) is determined from the relation $(S_n\text{-}S_s)/(S_n+S_s)$, where the S_n and S_s are monthly sunspot area on the Northern and Southern solar hemispheres, respectively (in units of millionths of a hemisphere). The data since 1874 are observed by the Royal Greenwich Observatory and merged after 1976 with the US Air Force (USAF) and the US National Oceanic and Atmospheric Administration (NOAA) data by D. Hathaway (https://solarscience.msfc.nasa.gov/greenwch.shtml). The daily and monthly values of SSN are provided by the Royal Observatory of Belgium (Fig.1, d).

The variations of the value of Chandler period (Fig.2) are calculated by the method, described in (Vondrak et al., 2005). The polar motion coordinates (Fig. 3) are from the solution C01 of the IERS. They have two anomalies – in 1926 and 2011, when the Chandler amplitude stands almost zero. In 1926 the Chandler period significantly decrease to 380 days, instead of its mean value of 431 d. In 2011 and next years the estimated Chandler period stays closed to its mean value with the exception in 2018, when it decreases to 390 d (Fig. 2).

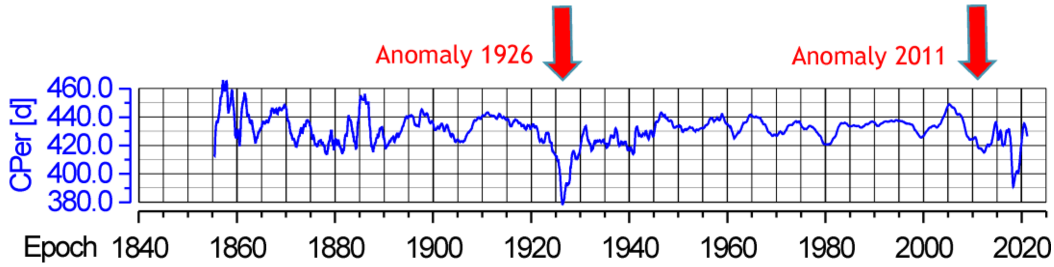

***Figure** 2. Variations of Chandler period value since 1850.*

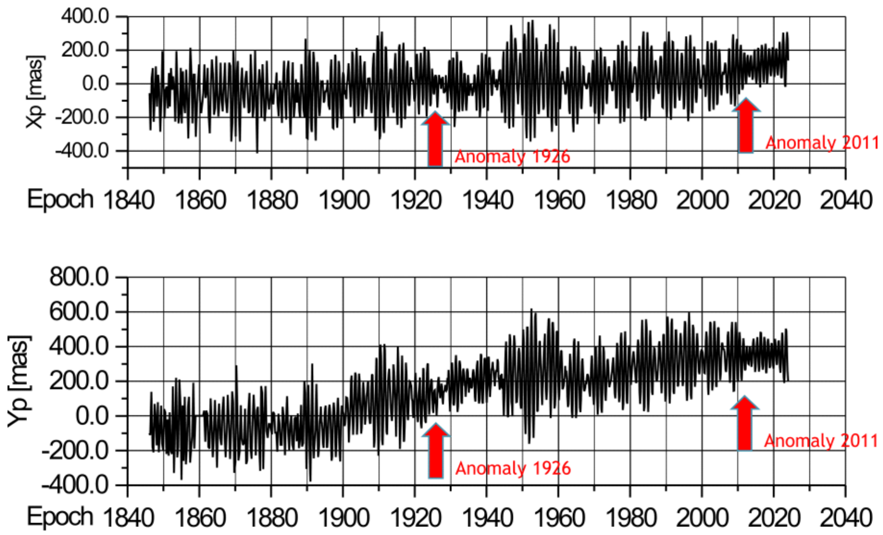

***Figure 3.** Coordinates of polar motion Xp and Yp for the period 1860-now from the solution C01 of the IERS.*

b) Method of Partial Fourier Approximation

The periodical variations are derived from the data by means of partial Fourier approximation based on the Least-Squares (LS) estimation of Fourier coefficients. The Partial Fourier approximation $F(t)$ of discrete data is given by

$$F(t) = f_0 + f_1(t-t_0) + \sum_{k=1}^{n} a_k \sin k\frac{2\pi}{P_0}(t-t_0) + b_k \cos k\frac{2\pi}{P_0}(t-t_0), \tag{1}$$

where P_0 is the period of the first harmonic, t_0 - the mean epoch of observations, f_0, f_1, a_k and b_k are unknown coefficients and n is the number of harmonics of the partial sum, which covers all oscillations with periods between P_0/n and P_0. The application of the LS estimation of Fourier coefficients needs at least $2n+2$ observations, so the number of harmonics n is chosen significantly smaller than the number N of sampled data f_i. The small number of harmonics n yields to LS estimation of the coefficient errors. This estimation is the first essential difference with the classical Fourier approximation. The second difference is the arbitrary choice of the period of first harmonic P_0, instead of the observational time span, so the estimated frequencies may cover the desired set of real oscillations. This method allows a flexible and easy separation of harmonic oscillations into different frequency bands by the formula

$$B(t) = \sum_{k=m_1}^{m_2} a_k \sin k \frac{2\pi}{P_0}(t - t_0) + b_k \cos k \frac{2\pi}{P_0}(t - t_0), \quad (2)$$

where the desired frequencies ω_k are limited by the bandwidth

$$\frac{2\pi m_1}{P_0} \le \omega_k \le \frac{2\pi m_2}{P_0} \quad (3)$$

After estimating the Fourier coefficients, it is possible to identify a narrow frequency zone presenting significant amplitude, and defining a given cycle. Then this cycle can be reconstructed in time domain as the partial sum limited to the corresponding frequency bandwidth. Doing this for terrestrial and solar time series, we shall identify their respective cycles, isolate and compare the common ones.

Results

Common cycles of Chandler period variations and solar indices are determined in several narrow frequency bands (Figs. 4-6). The SSN affects short-term oscillations with periods below 4 years (Fig. 4). The N-S solar asymmetry correlates with long-term Chandler oscillations with time lag equal to the 22-year Hale magnetic solar cycle (Fig. 5). The Anomaly 1926 starts when the decadal cycles of TSI have local minima (Fig. 6).

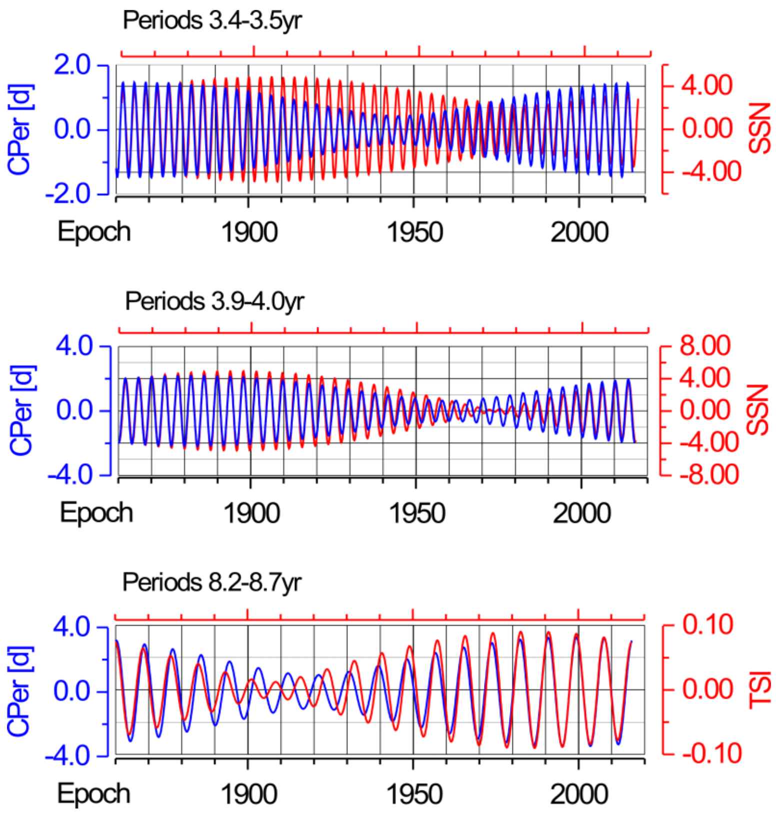

Figure 4. *Subdecadal variations of Chandler oscillation with periodicity 3.4 – 8.7 year.*

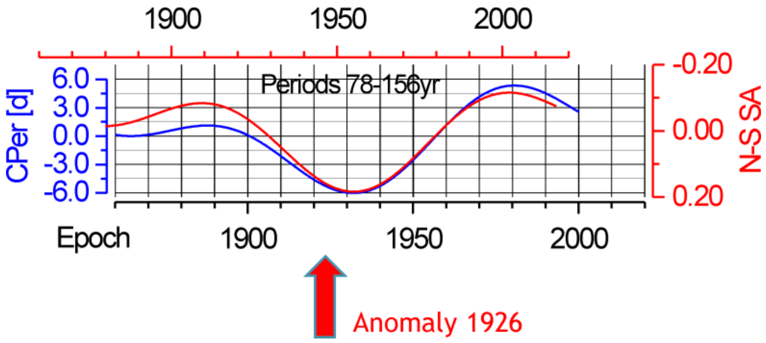

***Figure** 5. Long-term variations of Chandler period with minimum after the anomaly 1926.*

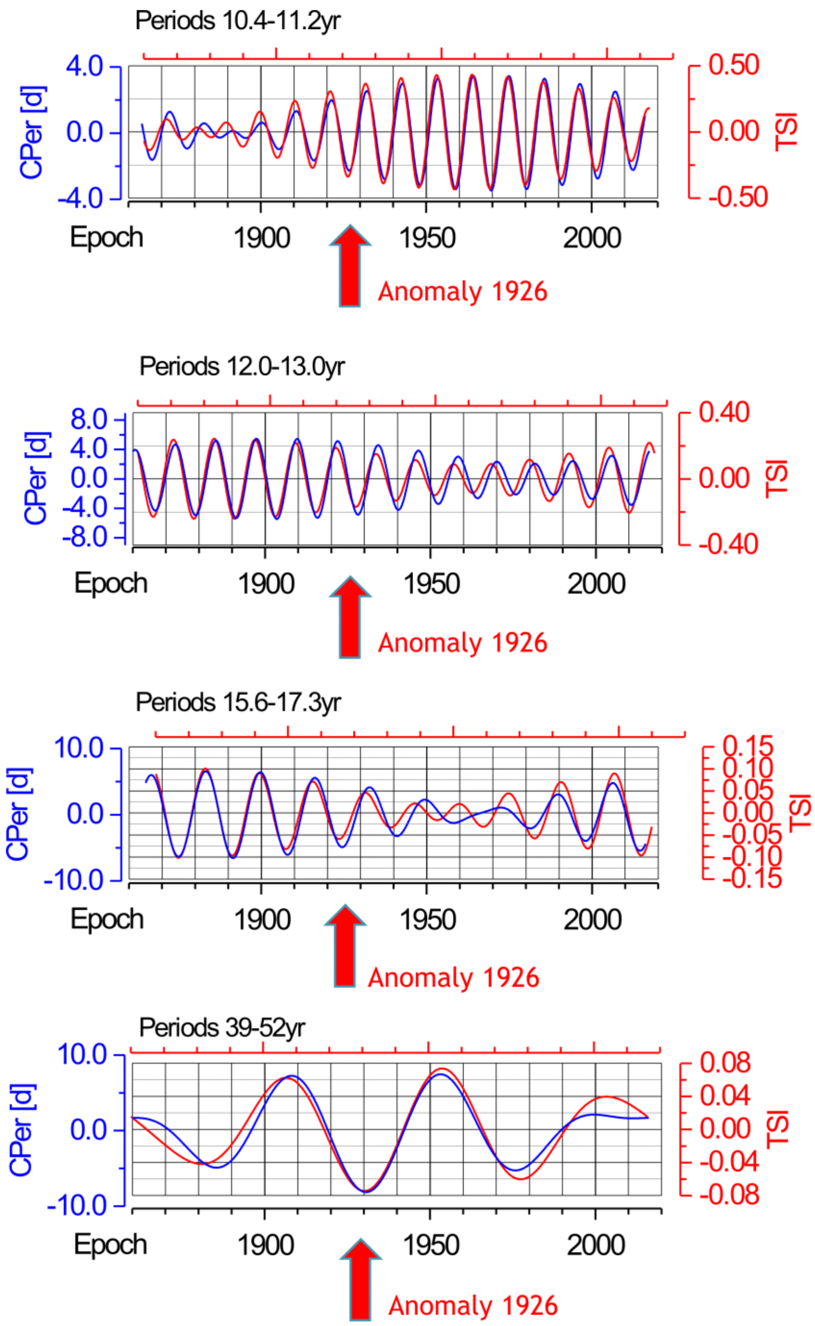

***Figure 6.** Common decadal cycles of TSI and Chandler period. The Anomaly 1926 occurs during local minima of TSI cycles.*

Conclusions

The time series variations are separated in several interannual and decadal frequency bands by PFA with periods 3.4-3.5yr; 3.9-4.0yr; 6.2-6.5yr; 8.2-8.7yr; 10.4-11.2yr; 12.0-13.0yr; 15.6-17.3yr; 39-52yr and 78-156yr, where good correlation exists between solar indices and Chandler period variations. The long-term variations of the Chandler period are affected by N-S solar asymmetry, where the time lag is equal to the 22-year Hale magnetic solar cycle. Excellent agreement between TSI and Chandler period variations exists for oscillations with periodicities 39-52yr and all cycles with periods between 6 and 17 years. The interannual oscillations with periods below 4 years are affected by the SSN variations.

The CW grand minimum in 1926 is strongly connected with all solar harmonics with dominating influence of long-term N-S SA variations (periodicity 78-156yr, CW period decrease - 6d) and TSI variations (periodicity 39-52yr, CW period decrease - 10d; periodicity 15.6-17.3, CW period decrease – 5d; periodicity 12-13yr, CW period decrease – 4d). The TSI influence on CW period variations is non-linear and frequency dependent. The value of CW period increase during the warming cycles of solar activity and decrease during some solar minima. This result means that the solar activity significantly affects the polar motion and CW variations by intermediate climatic variations in ocean and atmosphere.

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