

Joint Analysis of the Polar Motion and Celestial Pole Offset Time Series

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Abstract

In this work, we performed a joint analysis of the polar motion (PM) and celestial pole offset (CPO) time series along with time series of two geomagnetic indices, Kp and Dst. Our primary goal was revealing possible connection between the Earth's magnetic field variations and CW and FCN excitation. This study was based on the extraction of the common principal components in the four analyzed series using the Multi-Channel Singular Spectrum Analysis and on their amplitude and phase analysis using the Hilbert transform. Two groups of common principal components (PCs) were found: trends and quasi-harmonic terms with near-Chandlerian frequencies for the PM, Kp, and Dst series and near-FCN frequency for CPO series (both periods are near 430 days). Comparison of the spectra of the investigated series and their amplitude and phase variations showed some interesting common features. However obtained results are still not sufficient to quantify the effects of interconnections of the CW, FCN, and the geomagnetic field.

1. Introduction

The Earth's rotation axis moves with respect to both terrestrial and celestial reference systems in a rather irregular way. These movements with respect to the theoretical models in the terrestrial and celestial reference frames are described by the polar motion (PM) and the celestial pole offset (CPO) respectively. It is important that many irregularities of these movements are caused by the same physical reasons and thus are physically connected. Geomagnetic field variations may be one of these factors. In this paper, we jointly analyze the PM, CPO, and geomagnetic long-term variations. We primarily focus on the investigations of signals with periods of about 1.2 years corresponding to the Chandler wobble (CW) and Free Core Nutation (FCN). Although these signals are related to different components of Earth rotation that are not connected kinematically, some geophysical processes may influence the excitation of both CW and FCN simultaneously.

In previous studies, various authors discussed a possible interconnection of geomagnetic field variations with the CW, see, e.g. [1], and papers cited therein. In this paper, the authors found that the geomagnetic jerks and the CW phase jumps often occurred simultaneously, which can be explained by viscous friction produced at the core-mantle boundary. Gorshkov & Miller [3] jointly analyzed connection between the CW, the geomagnetic field, and solar activity and also found some common behavior in these processes. Much less attention has been paid so far to the impact of the geomagnetic field disturbances on the CPO variations. Some preliminary results were presented in [10]. The authors revealed that a jump in the FCN occurred simultaneously with a large geomagnetic jerk in 1998. So, the joint analysis of all these signals may be of large importance in understanding the CW and FCN excitation.

2. Data Used

As mentioned above, we used four time series for our analysis, Earth orientation parameters (EOP) and geomagnetic indices describing the geomagnetic field variations.

The two EOP series are PM series from the International Earth Rotation and Reference Systems Service (IERS) taken from the IERS Earth Orientation Center at the Paris Observatory¹, and CPO series computed at the Pulkovo Observatory² (see [4], ZM2 model). The latter is based on the IVS combined EOP series³. The PM series consists of the pole coordinates X_p and Y_p , and the CPO series consists of the celestial pole offsets dX and dY .

Series of the two geomagnetic indices, Kp and Dst, were taken from the Kyoto World Data Center for Geomagnetism⁴. Both indices serve to measure the variations of the geomagnetic field, and they can be used as indicators of magnetic storms and jerks. The Kp index serves to quantify the geomagnetic field disturbances. It is computed as an average of fluctuations measured at 13 stations located between 50° and 63° geomagnetic latitude, and it is expressed in decibels. The values of the Kp range from 0 (very quiet) to 9 (very disturbed). The Disturbed Storm Time (Dst) index is a measure of the magnetic field (in nT) created by the equatorial ring current, an electric current carried by charged particles trapped in the Earth's magnetosphere. The index is calculated from measurements at four stations near the equator and referenced to zero on internationally designated quiet days.

The common data interval for all four series was chosen to be 1986.2–2012.0. The start of the interval was determined by the CPO series, because the earlier CPO data are not reliable. For investigation of the fine CW structure, the whole available 170-year interval of PM data was used as was discussed in [9].

3. Methods of Analysis

In this research, we mainly used the same methods as in our previous studies [5–7, 9, 11]. A preliminary overview of the harmonic components in the analyzed series was made using Fourier analysis (Schuster periodogram) of two complex series $X_p + i Y_p$ and $dX + i dY$ for the PM and CPO correspondingly. This analysis has shown a similar spectral structure for both series: main peaks at the nominal CW (FCN) frequencies at about 1.2 years, and smaller (but mostly statistically significant) ones corresponding, in particular, to the periods 1.1, 1.15, 1.23, 1.26, and 1.29 years for CW and 1.1, 1.15, 1.23, and 1.29 years for FCN. Detailed investigation of these spectra is beyond the scope of this paper. More analysis of the main and weak CW components can be found in [7–9, 11]. Moreover, (quasi)harmonic components with periods close to the Chandlerian one (1.2 years) were also found in the variations of the geomagnetic indices Ap and Dst [3], which was a supplemental motivation for this study.

It should be noted that the classical spectral analysis has serious shortcomings; e.g., it does not allow analysis of the temporal behavior of the components. For this reason, the main tool in this study was Principal Components (PCs) Analysis also known as the Singular Spectrum Analysis (SSA) [2]. The SSA method is based on transformation of the time series into a matrix and its

¹<http://hpiers.obspm.fr/eop-pc/>

²<http://www.gao.spb.ru/english/as/persac/>

³<http://vlbi.geod.uni-bonn.de/IVS-AC/>

⁴<http://dc.kugi.kyoto-u.ac.jp/>

singular decomposition, leading to decomposition of the initial series into additive components. This method involves calculation of the sampling correlation function, whose eigenvalues λ_i are sampling variances of the corresponding PCs. These PCs are determined in the order of decreasing of contribution to the total variance. The percentage contribution V_i is calculated as $V_i = \lambda_i/M \cdot 100\%$, where M is the window width, usually a half of the series length. After the PCs are extracted, they can be investigated in detail separately or grouped. In our case we can merge the components around the CW or FCN frequency, or the trend components, etc.

In this study we made use of the Multi-Channel SSA mode (M-SSA), which is well suited for investigation of the common component in several time series. It is important for the method that the similar PCs in all the series have compatible amplitude and contribution to the total variance V_i . To provide this, we standardized each input series using the transformation $x' = (x - x_m)/\sigma$, i.e., by centering it and dividing by the STD.

Finally, the amplitude and phase of the PCs found with the SSA were independently analyzed using the Hilbert transform.

4. Results and Discussion

The main results of the SSA analysis are presented in Figure 1. In this figure the PCs are shown extracted from the four analyzed series in the frequency band of about 0.83 ± 0.035 cpy (a period of about 1.2 ± 0.06 years.). For PM and CPO series, PCs for both coordinates were processed independently, i.e., in fact, from a mathematical point of view, six time series were analyzed by the M-SSA method.

One can see in Figure 1 some interesting details in the PCs' behavior. First, it confirms a strong decreasing of the CW amplitude in the 2000s reported earlier by the authors [6]. A new interesting result is a nearly synchronous amplitude variation of the FCN and geomagnetic indices, which may confirm the earlier suggestion on the impact of the geomagnetic field variations on FCN [10].

Figure 2 presents the amplitude and phase variations of the PCs components depicted in Figure 1. The computations were made by means of the `hilbert` function from the Matlab Signal Processing Toolbox. In the left panel, the amplitude variations are shown, which mostly quantifies the result that can be seen by eye in Figure 1. However, the phase variations shown in the right panel are an important contribution to the understanding of the interconnection between the geomagnetic field and Earth rotation. Similar to amplitude analysis, one can see nearly synchronous phase variations between the geomagnetic indices and FCN. The interconnection between geomagnetic field and CW variations is more questionable. However, one should keep in mind that the CW amplitude varies with a period of about 75–80 years [6, 9], and the current minimum of the CW amplitude is happening in our days. So, several more years of data are needed to specify the epoch of CW minimum, which would allow us to make a more definite conclusion about the geomagnetic field.

Finally, we can conclude that our study revealed some interesting common features in the CW, FCN, and geomagnetic field variations which can help to improve understanding of the contribution of the geomagnetic field variations to the Earth rotation. New observations and more detailed analysis, including theoretical modeling, will allow more definite conclusions on the matter.

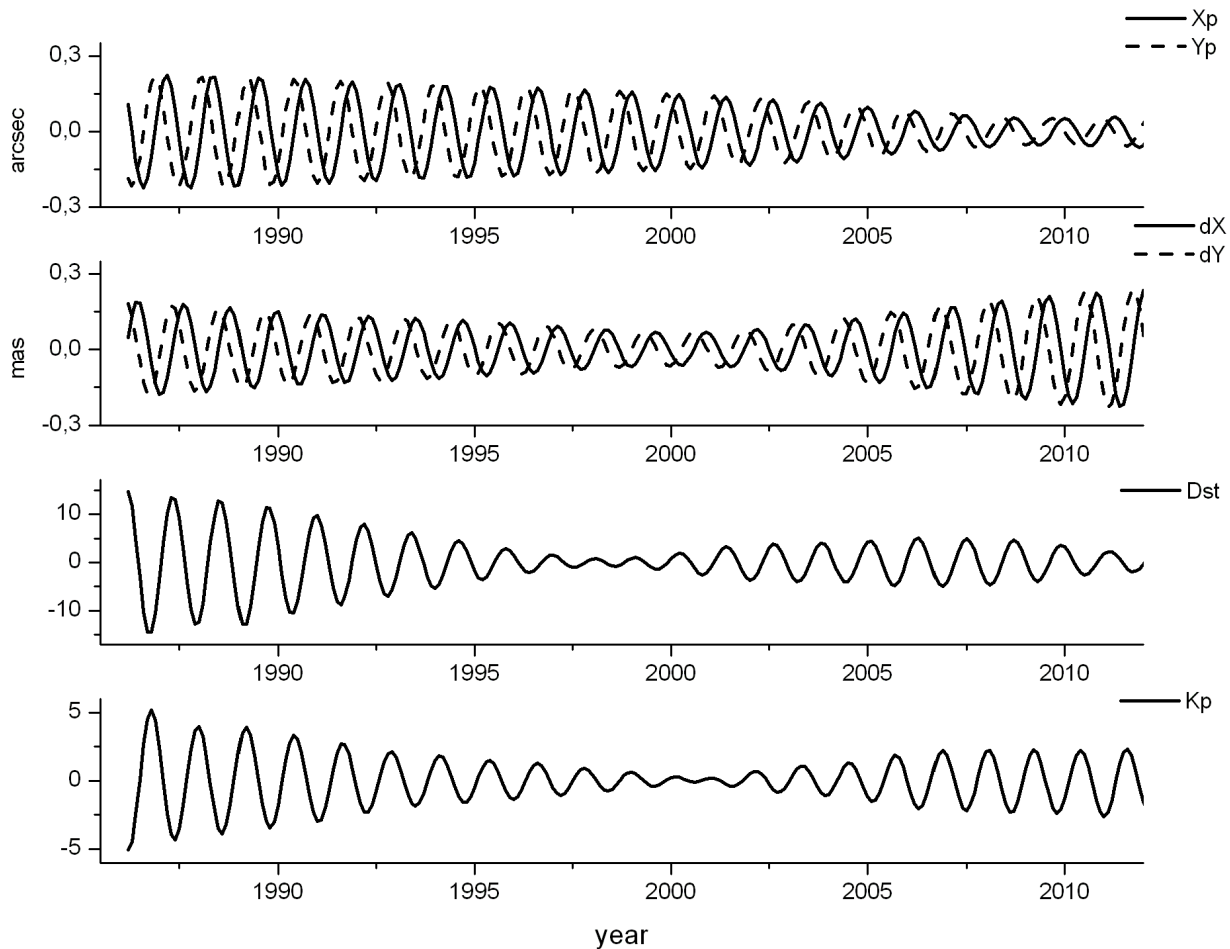


Figure 1. The PCs extracted from the four time series under investigation in the frequency band corresponding to the period of about 1.2 years. From top to bottom: PM series, CPO series, Dst geomagnetic index, and Kp geomagnetic index.

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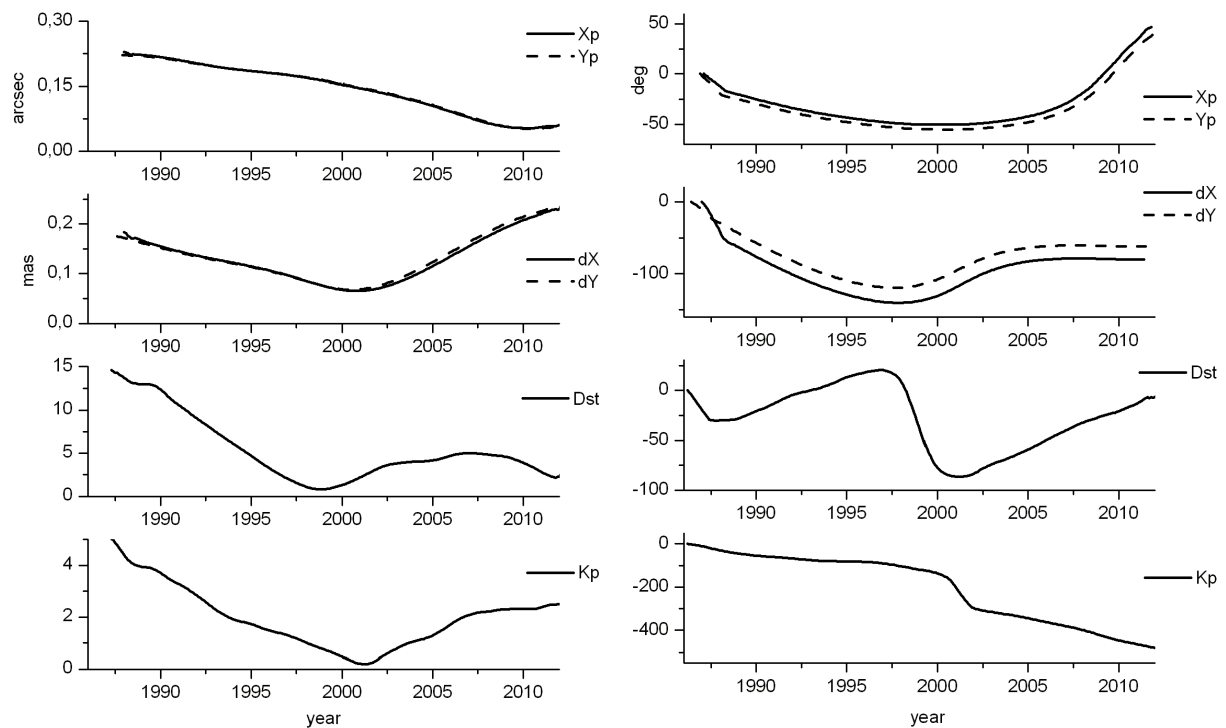


Figure 2. The amplitude (left) and phase (right) variations for the PCs extracted from the four time series under investigation in the frequency band corresponding to the period of about 1.2 years. From top to bottom: PM series, CPO series, Dst geomagnetic index, and Kp geomagnetic index.

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