Periodical Regularities of Polar Motion in the Pulkovo Latitude Variations

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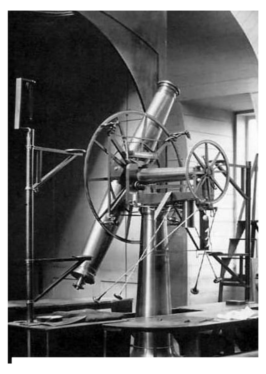
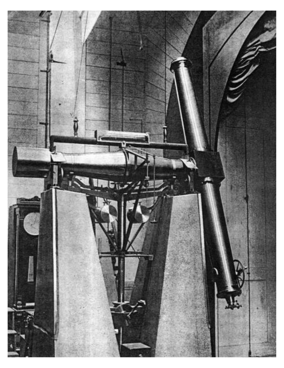


Ertel's VC



Repsold's TIPV

Abstract

The work studies the main component of Polar Motion, obtained from variations in the Pulkovo latitude (1840–2014). We employed different methods of analysis of nonstationary time series - singular spectral analysis, and Fourier and Hilbert transforms. It was shown that time changes in the amplitude and phase of Chandler polar motion can be studied by means of long term observation time series of latitude at a single observatory, even if these observation records have gaps. Six components in the interval of 1.1-1.3 year were found. The first two components possess repeated structural features well apparent during the periods of 1850–1930 and 1930–2010 in the time variations of phase and amplitude. The superimposed epoch method was used to estimate the period of variations in the amplitude with a simultaneous change of phase of this oscillation, which was found to be 80 years. The spectral analysis of the variations of other components sum amplitude showed the existence of harmonicas with the periods of 11, 20, 29, 44 years.

Freiberg-Kondratiev ZTF-135

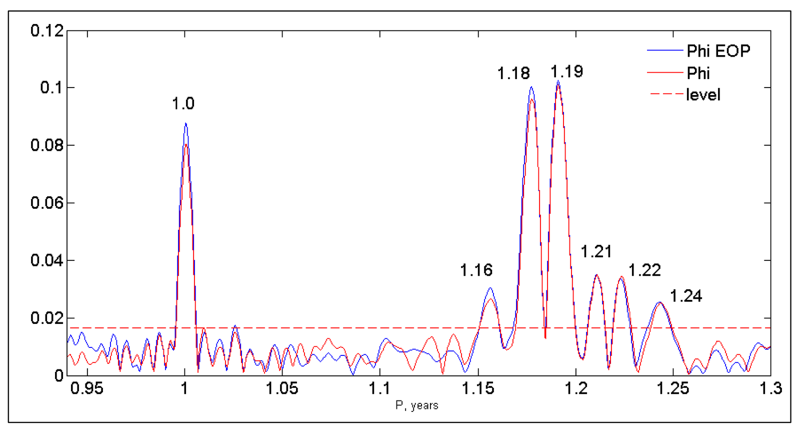


Fig. 2. Fourier analysis of the original time series ***Phi*** and ***Phi$_{xy}$*** for the range of oscillation periods from 0.9 to 1.3 years.

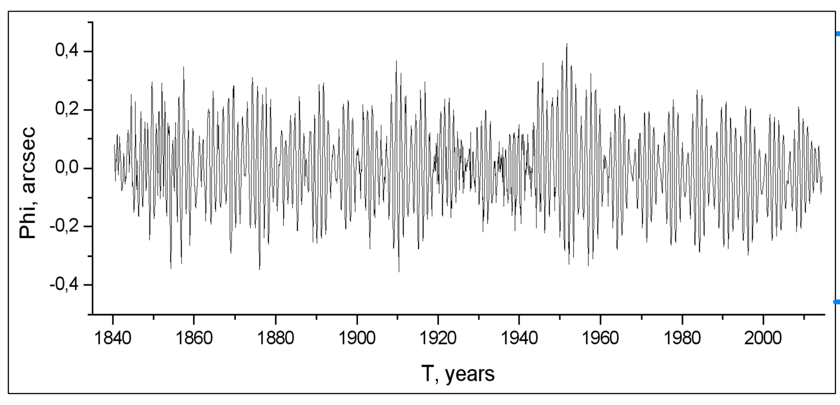


Fig. 1. ***Phi*** - the combined series of Pulkovo latitude variations (1840.4-2014.4).

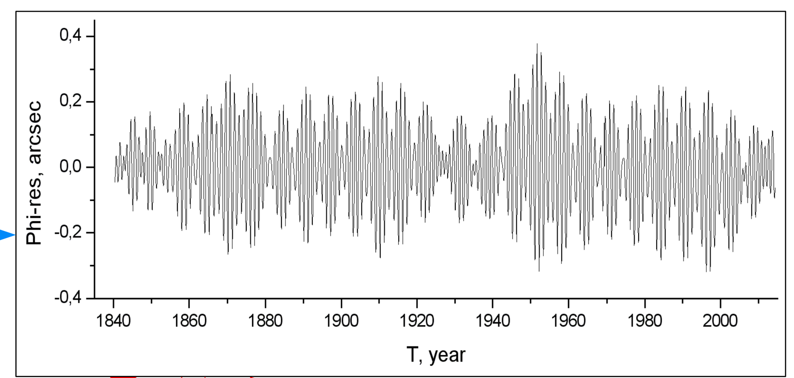


Fig. 3. The SSA reconstruction Phi is made based sum of the nonlinear trend (Fig. 5), the CW (Fig.6) and the annual fluctuation (Fig.7).

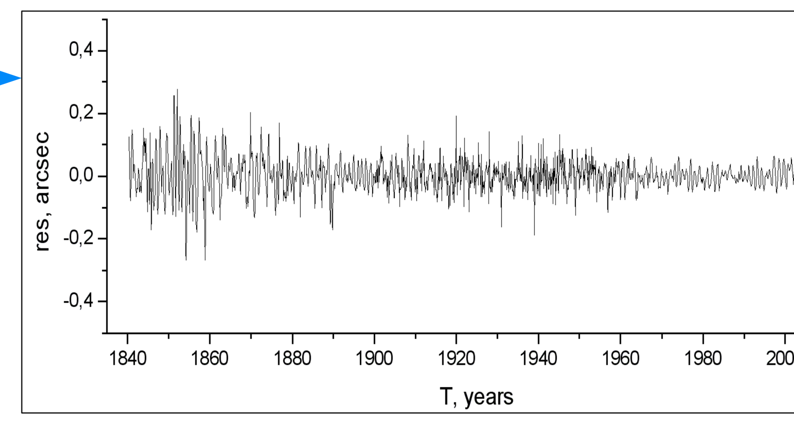


Fig. 4. The residue from SSA reconstruction ***Phi***. Detailed analysis of residues for ***Phi$_{xy}$*** can be found in [14].

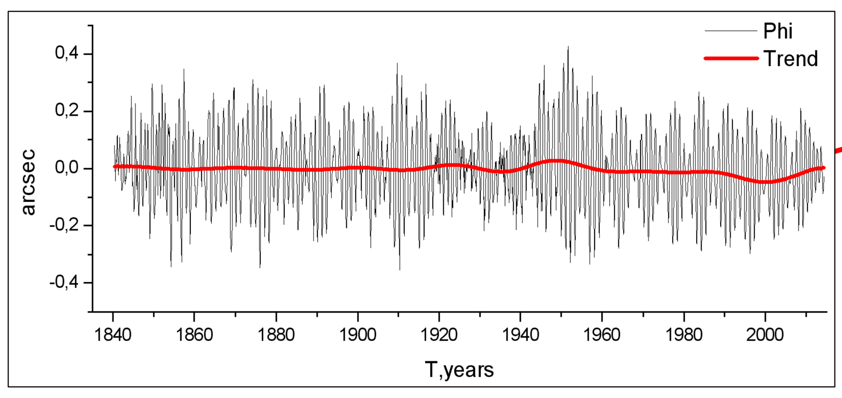


Fig. 5. The trend in the latitude variations ***Phi*** obtained SSA.

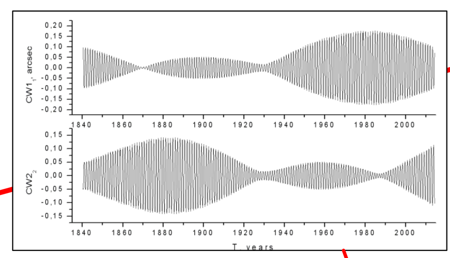


Fig. 11

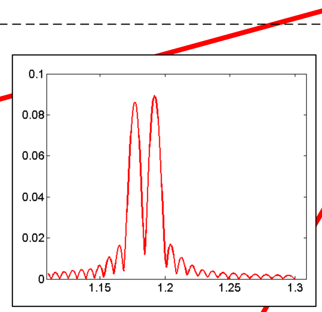


Fig. 13

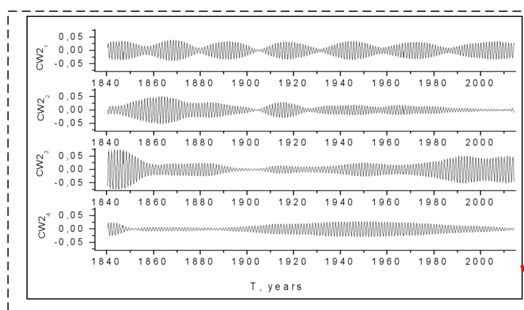


Fig. 12

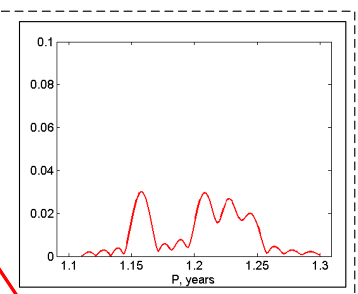


Fig. 14

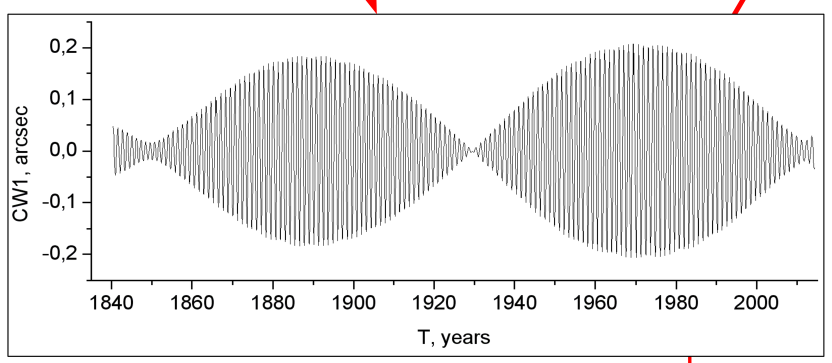


Fig. 9. The ***CW1*** **- main CW component.**

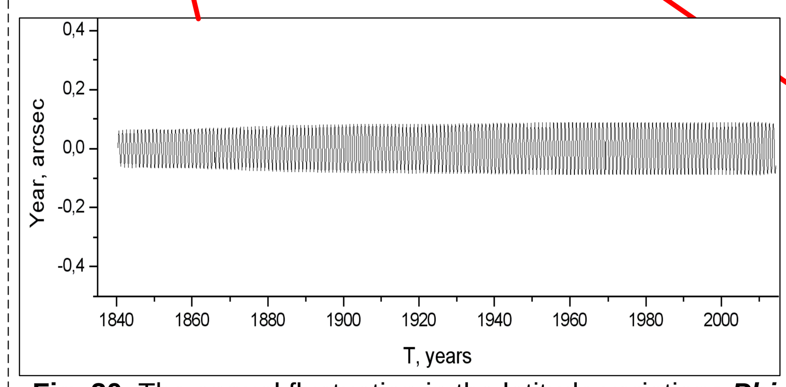


Fig. 20. The annual fluctuation in the latitude variations ***Phi*** obtained SSA.

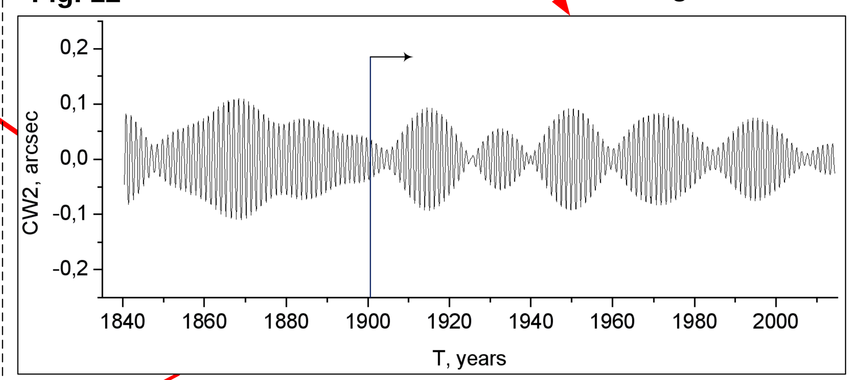


Fig.10. The ***CW2*** component.

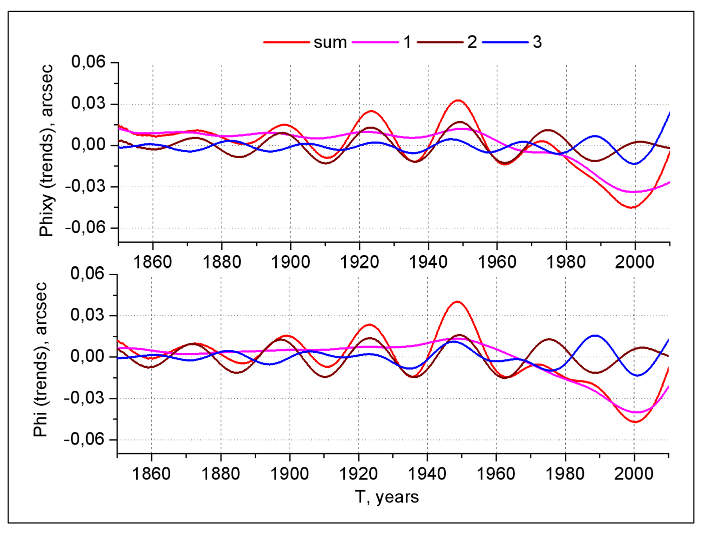


Fig. 6. The comparison of the decomposition SSA of the trends ***Phi*** and ***Phi$_{xy}$***.

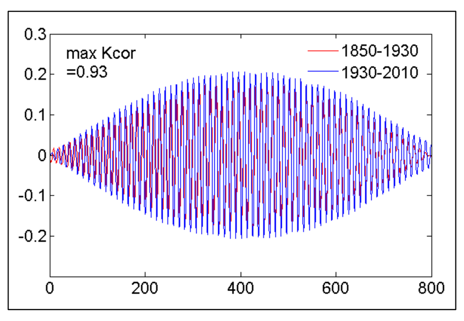


Fig. 18

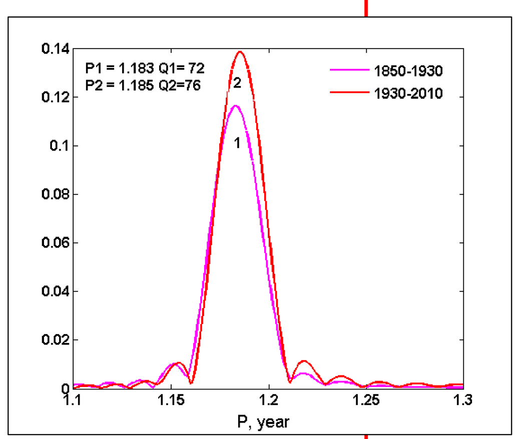


Fig. 19

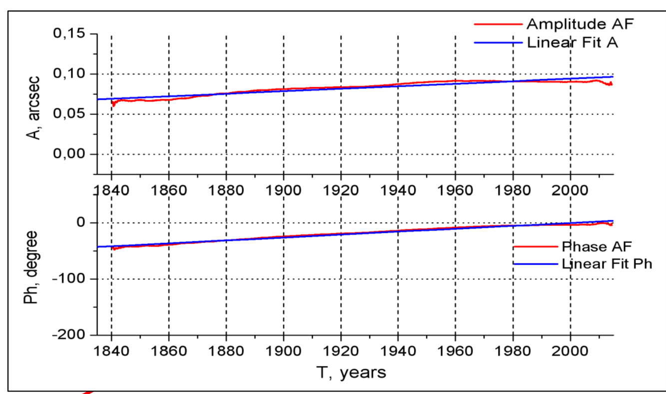


Fig. 21. The variations of the amplitude and phase of the annual fluctuation by SSA and their linear regression trends.

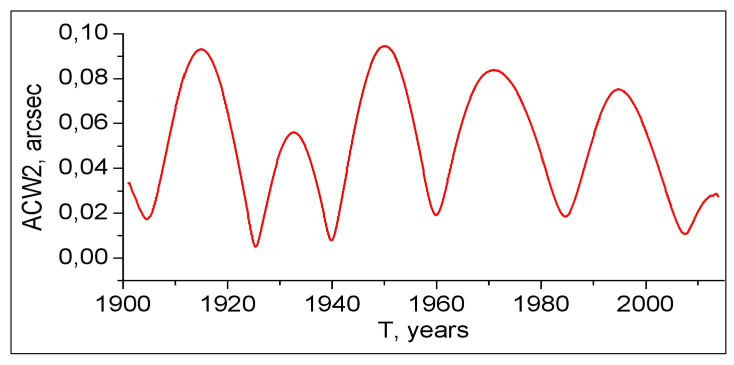


Fig.16. The low frequency variations in the ***CW2*** component amplitude in the interval after 1900.

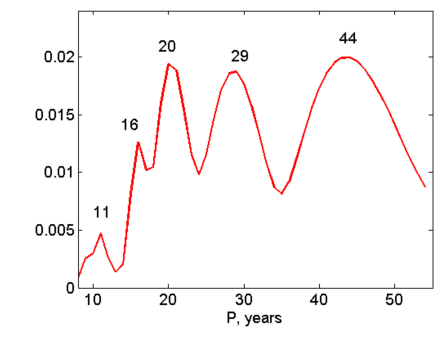


Fig.17. The spectral analysis of the low frequency variations in the CW2 component amplitude.

SCHEME

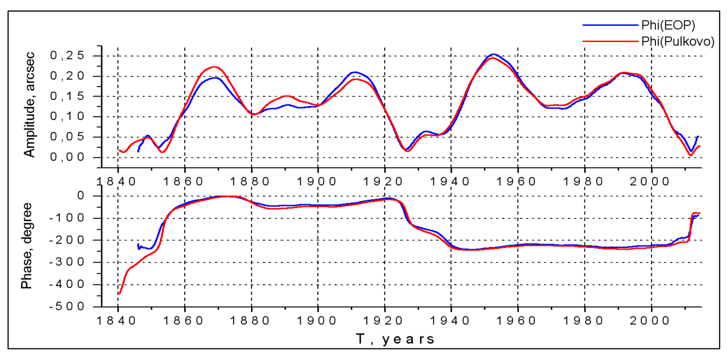


Fig. 8. The CW amplitude and phase variations computed with the SSA.

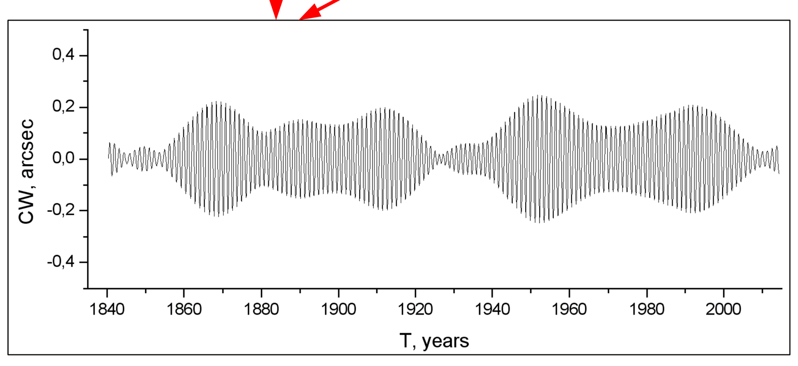


Fig. 7. The ***CW*** (***CW1***+***CW2***) in the latitude variations ***Phi*** obtained by the SSA method.

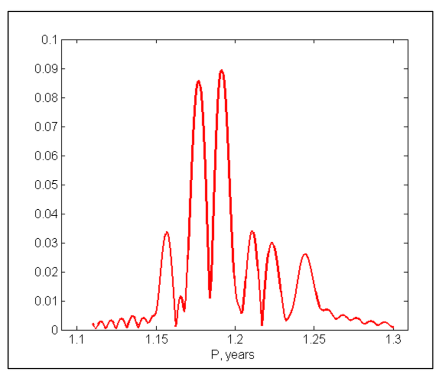


Fig. 15. The power spectra of the CW.

Data and methods

A detailed study of Pulkovo combined time series of latitude ***Phi*** (1840.4–2014.0) (Fig. 1) was carried out in this work. The rate of sampling is 0.1 yr.

The latitude observations at Pulkovo began in 1840. The Ertel vertical circle and the Repsold transit instrument in the first vertical were used for the purpose. W. Struve in 1840-1856 and X. I. Peters in 1842-1849 were the first observers on these instruments. The latitude variations obtained from X. I. Peters's observations with Ertel vertical circle by A. A. Ivanov and from V. J. Struve's observations with Repsold transit instrument in the first vertical by B.Wanah were used to develop a time series ***Phi*** (1840 –1848) [1]. The latitude variations obtained observations with ZTF-135 were used to develop a time series ***Phi*** (1904-1941, 1948-2006). In addition, the longest records of pole coordinates (IERS C01) for 1846–2009 and 2010-2014 (IERS C04) were used.

Measurements of the Pulkovo latitude (***Phi$_{xy}$***) were calculated by the IERS time series of pole coordinates ***Xp***, ***Yp*** according to the formula

$$Xp \cos\lambda - Yp \sin\lambda = 0.8631\, Xp - 0.5049\, Yp,$$

where λ is the longitude of the ZTF-135 Pulkovo.

The Singular Spectrum Analyses (SSA) [2] method was used for the investigation time series ***Phi***, ***Phi$_{xy}$***. The SSA method is based on transformation of the time series into matrix and its singular decomposition on components. This method involves calculation of the sampling correlation function, which eigenvalues (λi) are sampling variances of the corresponding principal components. This transformation does not change the sum of the dispersion and just redistributes it so that the first components have the largest dispersion.

The percentage contribution is calculated from $Vi = \lambda i / M \times 100\%$, where M is the length of the window, and λi is the eigenvalue. Works [3; 4; 5] demonstrated the advantages of this method for analysis of time series of Earth's rotation parameters.

The comparisons of Fourier transformation results are given (Fig. 2). The Chandler wobble amplitude and phase variations were examined by means of the Hilbert transformation.

Decomposition SSA

We obtained by SSA the following main components of the polar motion: trend (1.96%), Chandler (63.67%) and annual (19.62%) wobbles. The total reconstruction of the main components contributes ~90% for ***Phi$_{xy}$*** time series and ~85% for ***Phi*** (Fig. 3). Results of SSA decomposition and reconstruction, FFT analysis of the components are shown in the scheme.

Table 1		*Phi*			*Phi xy*	
№ in sch.	V %	*P*	*A*	*V %*	*P*	*A*
1	0.76			32.35		
2	0.91	26	0.057	0.25	26	0.047
3	0.26	21.5	0.003	0.41	21.5	0.003
		34.5	0.002		32	0.002
sum	1.96			33.01		

Trend

One of the main features of the SSA method is the possibility of detecting even weak, but significant trends. The comparison of time series ***Phi*** and ***Phi$_{xy}$*** was made in the work [5] and showed good consistency in the analysis of Chandler and annual components. Results of research are shown in the Fig.5, Fig.6 and Table 1.

Chandler Wobble

The Chandler wobble (CW) is one of the main components of of the Earth's rotation axis relative to the Earth's surface, also called Polar motion. Since discovery of CW, numerous papers were devoted to analysis of this phenomenon. The results are summarized in [6, 7, 8]. Between other interesting CW peculiarities, a phase jump of about 180° occurred in 1925s. It was evidently for the first time detected by Orlov [9]. The name of the Chandler wobble refers to all frequencies in the range of 1.12 - 1.3 years in this paper.

The scheme shows the results SSA of the decomposition and reconstruction of the investigated time series and their spectra. Fig. 2 presents the Fourier analysis of the time series ***Phi*** and ***Phi$_{xy}$*** for the range of oscillation periods from 0.9 to 1.3 years. The spectral analysis of both time series identifies two regions with maximum frequencies: two main peaks near by CW and four small peaks in the same frequency range in the CW spectrum.

We distinctly see in Fig. 7, Fig. 8, Fig. 9 two intervals where CW structure is similar and three intervals where CW strongly decreases in amplitude and simultaneously changes in phase. The first minimum is at the beginning of the series (around 1850). The second well-known minimum is around 1930, and a sharp damping in the CW amplitude is observed at the end of the series (around 2010). The CW behavior is described in more details in [5,10].

The time variations ***Phi$_{cw}$*** (Fig. 7) in the amplitude and phase (Fig. 8) were identified with the help of the Hilbert transform.

The CW splits in two ***CW1*** (Fig. 9) and ***CW2*** (Fig.10) components, the first corresponds to two maximal peaks of the Fourier spectrum (Fig.1), and the second corresponds to four minor spectral peaks.

Six initial components were obtained at the CW frequency using the SSA. The CW1 component (Fig.11) contributes 52.9%, and CW2 component (Fig.12) contributes - 10.77%.

The result of spectral analysis for ***CW1, CW2*** and ***CW*** (***CW1***+***CW2***) shown in Fig. 13, Fig. 14 and Fig. 15. The spectral analysis of the low frequency (Fig. 17) variations in the ***CW2*** component amplitude in the interval after 1900 has been executed Fig. 16.

The first component ***CW1*** has a recurrent structure. Fig. 18 presents the CW signal divided into two intervals of similar behavior, 1850–1930 and 1930–2010. Fig. 19 presents spectra of CW signal computed for both intervals. From these plots one can clearly see that the CW amplitude variations are similar for both intervals. This result can provide an evidence of a new CW period of 80 ± 0.2 yr.

The period $P1$ = 1.183; $P2$ = 1.185 yr., maximum amplitude ($A1$ = 0.183"; $A2$ = 0.207") and $Q1$ = 72; $Q2$ = 76 were calculated for each of the two span 1850-1930 and 1930-2010 separately. To obtain the Q of the oscillations of the Earth pole was used ***CW1***. Moreover, calculations were carried out across the width of the spectral line separately for the two intervals with a known constant phase.

Many authors analyzed CW parameters variations for the period 1840–1860, e.g., S. Chandler, A. Ivanov, B. Wanach, H. Kimura (11), S. Kosnisky, A. Vasiliev, A. Orlov (12), N. Sekiguchi (13). Their results showed decreasing of the CW amplitude down to about 0.08" and a change in the CW phase [1].

Annual fluctuation (AF)

The annual components determined by SSA are shown in Fig 20. The variations of amplitude and a phase of the annual components were calculated with the help of Hilbert transformation. Their linear regression are shown in Fig 21. There is small increase of the amplitude on 0.003" and phase on 45 dg. for 174 years.

Analysis of the residue

The residual series (14%) were found after exclusion of all components described above. The residual series (Fig. 4.) are well approximated by a random process. This means that the bulk of regular components are already excluded. This process is non-stationary (the variance is reduced), but has a constant persistence (***H***). This may indicate the presence of two processes: reduction in time with the observational errors, which has in any selected time range of the Gaussian distribution and the physical noise, which can be represented by the Brownian process with persistence ***H*** = 0.7 [14].

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Conclusion

1. The full research of fine structure of pole movement obtained by SSA is presented on the scheme by the time series variations in the Pulkovo latitude (1840–2014).
2. We have found two epochs when the CW amplitude decreased near 1850 and 2010, which are also accompanied by a large phase jump, similar to well known event in 1930s. This result can provide an evidence of a new CW period of 80 ± 0.2 yr. Unfortunately, we can't finally confirm this result as both periods of the phase disturbances described in this example are located at the edges of the interval of the studied time series.
3. The parameters (P = 1.183;1.185 y., A=0.18;0.21", Q=72;76) CW were calculated for each of the two spans: 1850-1930 and 1930-2010 - separately. Moreover, calculations were carried out across the width of the spectral line separately for the two intervals with a known constant phase.
4. The periods of 11, 16, 20, 29, 44 years were found in the amplitude of the second component of the CW after 1900.
5. There is increase of the amplitude by 0.03" and phase by 45 dg. during 174 years in annual fluctuation.
6. The main trend has peculiarities of behavior after 1980.