PULKOVO COORDINATES FROM ASTROOPTICAL OBSERVATIONS

V. Gorshkov, N. Miller, V. Naumov, E. Prudnikova, N. Shcherbakova

Main (Pulkovo) Astronomical Observatory of RAS
65/1 Pulkovskoye Shosse, 196140 Saint-Petersburg, Russia
e-mail: vigor@gao.spb.ru

The longitude and latitude observations made with two zenith-telescopes and three photoelectric transit instruments of the Pulkovo Observatory during the 20th century were used for coordinates determination. The observations were rereduced in HIPPARCOS reference frame. All known astrometrical reductions and the new model of precession and nutation IAU2000A were used. The longitude (1960–2004) and the latitude (1904–2004) coordinate corrections and their trends were found. The geophysical reasons of detected long-periodical coordinate variations are discussed.

INTRODUCTION

This research was motivated by the following events of the Pulkovo observational history:

- one centenary from the beginning of latitude observations by the Freiberg zenith telescopes (ZTF-135),
- 50 years of the permanent photoelectric Universal Time observations with photoelectric transit instruments (PTI) of the same type,
- forthcoming 80 years of two-side, Pulkovo–Greenwich (Pul–Gr) longitude determination by Ya. Belyaev and N. Dneprovsky with transit instruments (TI).

We reprocess all observation sets in reference to the ICRS catalogues (HiC, ACT, and AriHip) and with use of the IAU2000A precession–nutation model [http://maia.usno.navy.mil/conv2000.html]. All these observations were tied to the center of Pulkovo Round Hall to determine trend and new coordinates of Pulkovo, which was the origin of geodetic net of Russia over a long time.

Two-side longitude determinations were made in 1925 with two Bamberg TI equipped by impersonal micrometer and chronograph. The Rifler clock in Pulkovo and the Short one in Greenwich have been used. The same rhythmic radio time signals from Bordo and Nauen were used for clock comparison. Two observation series (28 days and 36 days) were conducted and were made change of instruments and observers between ones series.

REANALYSIS OF PULKOVO COORDINATE DETERMINATIONS IN THE 20th CENTURY

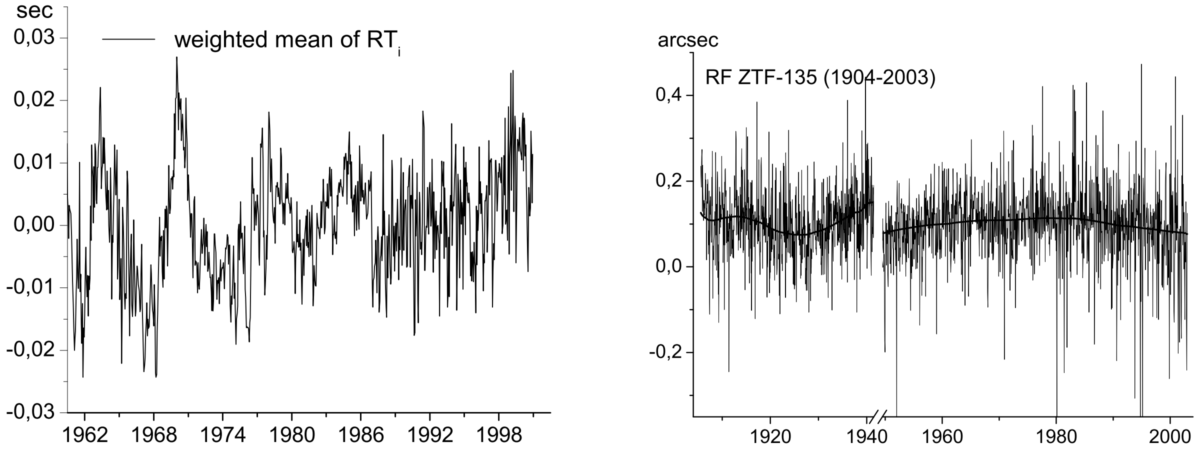
Postwar epoch of longitude (UT0–UTC) determinations in Pulkovo were based on observations by PTI of Pulkovo design. All original observations in Pulkovo were collected in the uniform database and partly have been used for recalculation of EOP (1899.7–1992.0) in international work [3]. In the cited research were used the results of time observations by next photoelectric transit instruments – PUF, PUG and PUH since 1960, when the first atomic clock was established in Pulkovo and two latitude instruments ZTF-135 and ZTL-180. The instrument PUF was established in the same point (West in Table 1), as PUH one which replaced it. All temperature and after 1970 some meteorological (wind effect) influences on results of the observations were investigated and were taken into account.

For the analysis of original time and latitude variations the following residuals were calculated:

$$RT_i = (\mathrm{UT0}_i - \mathrm{UTC}) - (\mathrm{UT1R} - \mathrm{UTC}) - (X \sin\lambda_0 + Y \cos\lambda_0)\tan\phi_0/15, \quad (1)$$

$$RF_i = (\phi - \phi_0) - (X \cos\lambda_0 - Y \sin\lambda_0). \quad (2)$$

Earth orientation parameters (X, Y, UT1–UTC) were taken from EOP(IERS)C01 and C04 combined solution. All short-periodic small corrections (tidal time variation up to 35 days, the diurnal lunisolar effect on polar motion and ocean diurnal/subdiurnal tidal effects in local vertical) were taken into account according to models and soft from [http://iers.eop-ps.fr].



a) Weighted residuals (RT_i) of Pulkovo PTI

b) Residuals (RF_i) of ZTF-135

Figure 1. Residuals of Pulkovo time and latitude series

Figure 1 shows residuals of Pulkovo series (averaged for all PTI). Table 1 gives the main statistical parameters of the instrumental series, corresponding to coordinates corrections and their linear trends. The external accuracy (S_{ext}) was obtained by residuals from global solutions of EOP(IERS)C01 for latitude and C04 for longitude after taking into account the corrections of coordinates (λ_0, ϕ_0). The external accuracy (S_e) was calculated after removing linear trend and low frequency filtering of RT_i. The internal standard deviations of stars (S_s) were reduced to the equator and zenith of observatory by

$$S_{int} = S_s \cos\delta_s (\cos z)^p,$$

where $p \approx 0.5$ is the parameter estimated by least square method from each set.

The ZTL-180 observations are consist of two principally different programs and this fact is shown in Table 1 by the two values of accuracy. The results of the first program represent by the latitudes while the second series consists of latitudes without declination corrections because the improvement of declinations was a purpose of this program.

The new estimation of absolute longitude determination in 1925 year gives value $2^h01^m18.5607^s \pm 0.0036^s$. The longitude observations by PTI for last 45 years after reducing to 2000.0 give $2^h01^m18.5616^s \pm 0.0024^s$. The estimation of latitude for the 20th century by ZTF-135 after reducing to 2000.0 gives $59°46'18.656'' \pm 0.006''$. According to NUVEL-1 model the motion of EURA plate in Pulkovo for both coordinates are next:

$$d\lambda/dt = 0.096 \text{ ms/yr (22 mm/yr) and } d\phi/dt = 0.34 \text{ mas/yr (10 mm/yr)}.$$

Weighted mean of Pulkovo longitude trend from Table 1 is following:

$$d\lambda/dt = 0.45 \pm 0.10 \text{ ms/yr } (103 \pm 22 \text{ mm/yr}).$$

Table 1. The statistics of the sets

LONGITUDE	PUF(W)	PUG(E)	PUH(W)	Pul–Gr, 1925
Span (mean epoch)	1961.1–1971.4 (1967.1)	1971.2–1985.4 (1977.8)	1971.8–2003.0 (1987.4)	1925.6–1925.9 (1925.7)
Stars (days)	43918 (992)	61772 (1523)	133201 (3304)	1074 (64)
S_{int}/S_{ext} (S_e) (ms)	±10.0 ± 14.8 (±7.2)	±10.4 ± 12.0 (±7.0)	±12.3 ± 14.5 (±10.2)	±32.9 ± 20.6
Long. correction (ms)	3.12 ± 4.14	26.57 ± 1.43	-0.55 ± 0.42	
Lin. trend (ms/yr)	0.09 ± 0.12	0.89 ± 0.07	0.40 ± 0.03	
LATITUDE	ZTF-135	ZTF-135	ZTL-180	ZTL-180
Span (mean epoch)	1904.7–1941.5 (1923.1)	1948.7–2003.8 (1978.8)	1967.4–1974.7 (1971.1)	1975.0–1990.1 (1982.6)
Lat. pairs (days)	55199 (4131)	102018 (7350)	8020 (571)	8118 (1054)
S_{int}/S_{ext}(mas)	±166 ± 149	±185 ± 171	±202 ± 147	±373 ± 362
Lat. correction (mas)	102 ± 22	95.9 ± 5.1	144 ± 25	
Lin. trend (mas/yr)	-0.032 ± 0.029	-0.028 ± 0.018	-0.031 ± 0.071	

Linear trend of ZTF-135 latitude is next:

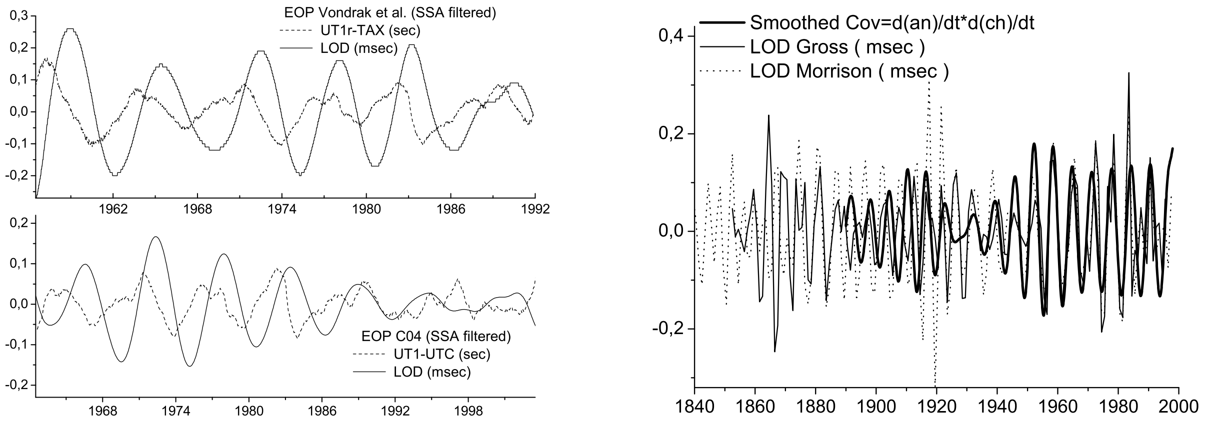
$$d\phi/dt = -0.031 \pm 0.071 \text{ mas/yr } (-1 \text{ mm/yr}).$$

Very small part of $d\lambda/dt$ and $d\phi/dt$ excess could be explained by postglacial rebounding of Fennoscandia. Qualitative estimation of local vertical motion on south-east remote areas of Fennoscandia should be the same as we have observed.

ANALYSIS OF UT SERIES

The most interesting feature of RT_i sets is 5–7 years variations with amplitudes up to 10–20 ms in many series of PTI observations from our data base. These variations could not be caused by any observational and reference catalogues errors as these errors should generate mainly secular or seasonal changes. In the paper [3], where EOP were estimated by best astrometric instruments for 1959–1992, these variations were revealed in UT1–TAX (TAX is TAI modified by taking into account polynomial terms) as a smoothed effect of initial ($UT0_i$–UTC) observations (upper plot of Fig. 2a).

In this connection we also researched combined series EOP(IERS)C04 and revealed these slightly diminished variations in this solution. It was done by singular spectrum analysis (SSA) [1] of UT1–TAI after removing linear trend (LinFit) from series. The most powerful main components (99.86% of residual) belong to slowly varying so-called decadal variations (usually explained by core-mantle interaction) and seasonal ones (explained by atmospheric dynamics). The same calculation was done for length of day (LOD) variations. The differences between initial values of UT1–TAI–LinFit and LOD on the one hand and decadal and seasonal components on the other hand are offered in the bottom plot of Fig. 2a. As it shown in the bottom plot these quasi-six-year variations decreased a lot after 1985 when astrometric instruments had stopped observations.



a) EOP series [3] and IERS C04

b) EOP series from [http://hpiers.obspm.fr/eop-pc/]

Figure 2. Near six-year oscillations of sets calculated by SSA in UT1–TAI and LOD and envelope function $Cov = d(an)/dt \cdot d(ch)/dt$ (thick line on the panel (b))

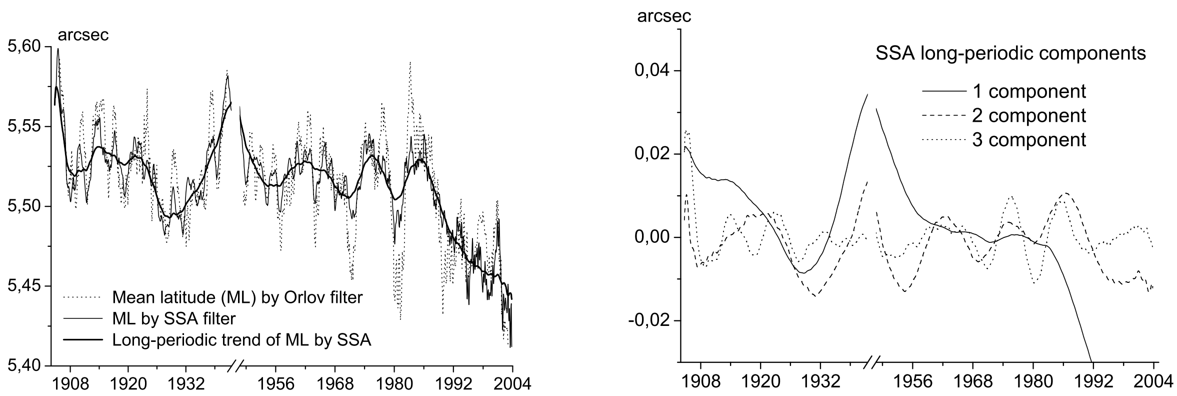
We proposed that discovered oscillation is a really Earth rotation variation. Therefore, we investigated two (Stephenson & Morrison and R. Gross) long-term series of LOD [http://hpiers.obspm.fr/eop-pc/] for testing these variations on the others observation series (lunar occultation). As it can be seen in Fig. 2b the same quasi-six-year variations of LOD present in both series. It is obvious that i) series are in phase after beginning homogeneous ILS observations in 1896, ii) the damping of process took place in the past as like as in the current time, iii) these variations present at whole interval of precise observations.

It allows to rise problem about excitation (or stimulation) of this process. It is most evident the coincidence of this period with pole oscillations composition. Commensurability of annual (an) and chandlerian (ch) oscillations of pole has the same period. The function $Cov = d(an)/dt \cdot d(ch)/dt$ expresses the modulation envelope of these oscillations (thick line in Fig. 2b). If these oscillations (an, ch) are in phase then LOD increases. When they are in opposite phase, the Earth rotation velocity is increasing as we can see in Fig. 2b. Here components an and ch were reconstructed by SSA from EOP(IERS)C01.

This correlation is especially evident after 1920, when the change of phase of Chandler pole wobble was registered after its attenuation. The character of this LOD variations as a whole (the damping of amplitude and the phase change) corresponds to polar motion dynamic in the time. This can be consequence of the interconnection of these processes or the presence of a mutual reason of their modulation. The obtained variations can be caused for example by the interactions of internal shells of the Earth reacting nonlinearly on the phase correlation of seasonal and Chandler polar variations [2]. But the discussion of this mechanism is out of this work.

ANALYSIS OF LATITUDE SERIES

The ZTF-135 latitudes were joint in normal points with the step of 0.05 year and the gap caused by war was filled by the values from global solutions EOP(IERS)C01. So, we obtained the unbroken series. It permitted to investigate long-periodical latitude components during 100-year interval.



a) Mean latitude variations and their SSA trends

b) SSA trend components

Figure 3. The comparison between the ZTF-135 mean latitude (ML) variations obtained by SSA and Orlov filter. Low frequency ML components

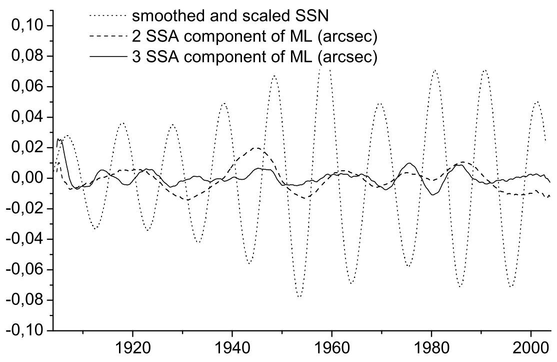


Figure 4. Comparison between the ZTF-135 mean latitude low frequency variations and SSN

Figure 3a shows mean latitude variations (added to $59°46'10''$) obtained by SSA and by Orlov filters. It should be admitted that SSA really gives the mean latitude (ML) variations as this method permits to choose the components certainly free from periodical variations (Chandler, annual and semiannual oscillations). Besides, this method gives the possibility to choose from SSA decomposition the components which are required for problem under consideration.

Figure 3b shows decomposition of low frequency component (thick line) from Fig. 3a. It is obvious that their second and third components have the periodical character near to the solar activity period but in opposite phase as it can be seen in Fig. 4. We placed here scaled (1:2000) sunspot numbers (SSN) and second and third SSA components of ML from Fig. 3b. The direct FFT filtering of ML (0.06–0.20 cpy) are also compared with scaled cosmic rays data from Climax station in Fig. 5. The similar effect is also found in ZTL-180 observations.

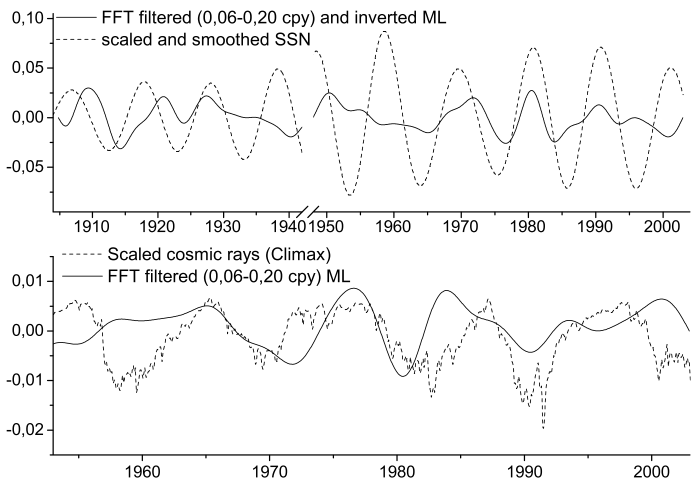


Figure 5. Comparison between filtered and inverted ZTF-135 ML and SSN (upper plot). Comparison between filtered ML and Cosmic rays (bottom plot)

Very likely that the solar activity shows itself in systematic influence on local conditions of latitude observations. For instance, solar activity can influence on latitude variations by the temperature inversions in the atmosphere which can cause local refractional anomalies. The creation of the model of such mechanism requires to prolong the investigations.

CONCLUSION

- The complete recalculation of Pulkovo coordinate observations by the photoelectric transit instruments and zenith telescopes in terms of the new precession-nutation model IAU200A and ICRS catalogues gives the following estimation of coordinates and their trends:

$$\lambda = 2^h01^m18.5616^s \pm 0.0024^s, \qquad d\lambda/dt = +0.45 \pm 0.10 \text{ ms/yr},$$
$$\phi = 59°46'18.6560'' \pm 0.0060'', \qquad d\phi/dt = -0.031 \pm 0.071 \text{ mas/yr}.$$

  This linear trend reflects EURA plate motion as well as probable postglacial rebounding of Fennoscandia and other changes of various fields (refractive, gravimetric).

- Long-term quasi six-year variations in time observation series are in a good accordance with the polar Chandler and annual pulses (combined oscillations). These six-year variations of length of day present in all appropriate series of EOP. Earth rotation accelerates when Chandler and annual oscillations are in opposite phase and vice versa.

- Long-term latitude variations of Pulkovo zenith telescopes reveal negative correlation with sunspot numbers. This dependence could be explained by Sun excitation of regional atmospheric processes.

Acknowledgements. Authors appreciate scores of Pulkovo astronomers whose observations for hundred years permit to create priceless data base for further science researches.

[1] *Goliandina N, Nekrutkin V., Zhigljavsky A.* Analysis of Time Series Structure. SSA and Related Techniques.– Chapman & Hall, 2001.–P. 320. [`http://vega.math.spbu.ru/`].

[2] *Gorshkov V., Vorotkov M.* Dynamics of polar motion and longperiodic Earth rotation variations // Izvest. GAO.– 2002.–N 216.–P. 415–425.

[3] *Vondrak J., Pesek I, Ron C., Cepec A.* Earth orientation parameters 1899–1992 in the ICRS based on the HIPPARCOS reference frame // Publ. Astron. Inst. Acad. Sci. Czech Rep.–1998.–N 87.–P. 53.