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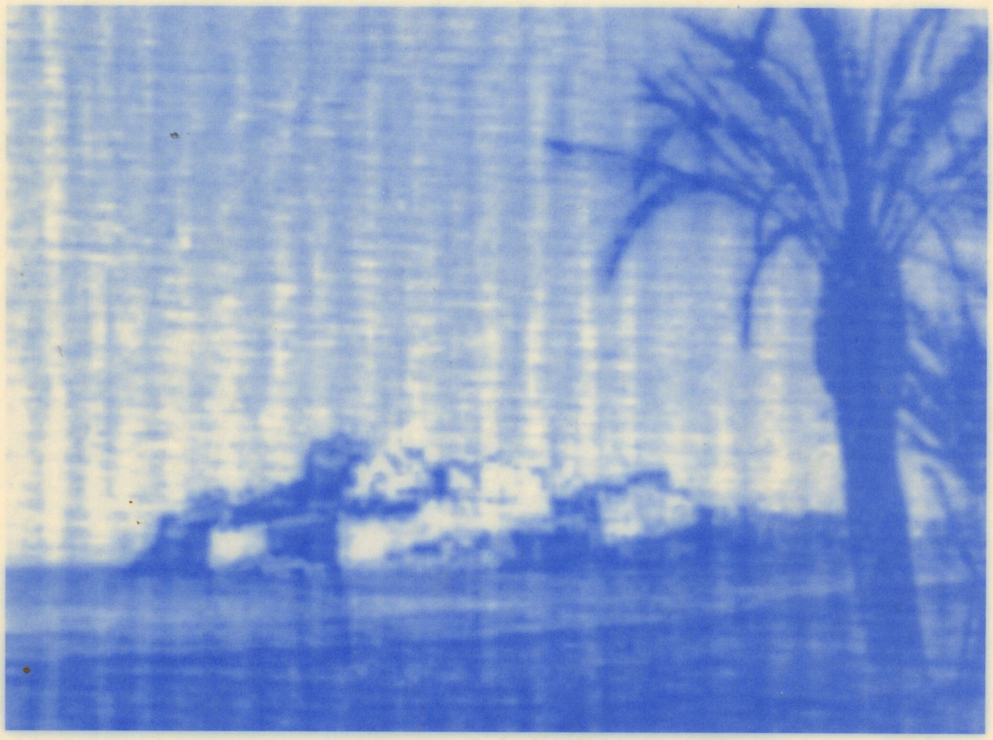

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SELECTED MINOR PLANET OBSERVATION PROGRAM: ITS POTENTIAL AND REAL OBSERVATIONS PROCESSING

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Abstract. The numerical experiments with fictitious observations concerning the 1991–2000 selected minor planet (SMP) observation program demonstrate that even at dense and uniform coverage of the $\pm 100^d$ opposition centred arcs of the planetary trajectories by observations there exist rather strong correlations between the Earth's longitude and some catalogue error parameters as well as between the parameters themselves. So, the full set of the parameters can not be determined reliably from the observations of this program only.

The real photographic observations of the SMP made at the Nikolaev observatory (Ukraine) were processed to obtain the improved orbits of these planets as well as the FK5 catalogue zero-point corrections. The results are in agreement with those ones obtained by other authors.

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1. Introduction

In 1933–1935 B. V. Numerov (1933, 1935) and D. Brouwer (1935) published their programs of observation of the selected minor planets (SMP) aimed at correcting the zero-points of the fundamental star catalogues. These programs were approved by Commissions 4, 8 and 20 of the IAU at the General Assembly of the IAU in 1935 in Paris. The first observations of the SMP were made before the World War II. During the war the work on the SMP–program was practically interrupted, and only after the war the observation work was resumed in the full scale.

In the Soviet Union the observations of the SMP began in 1948 in great deal owing to the activity of N. S. Samoilova–Yakhontova, who introduced some changes into the initial Numerov's program. The aim of these observations was to improve the zero-points of the fundamental star catalogue, and in all there were observed 10 SMP. In 1976 V. I. Orelskaya offered a more long list of the SMP including 20 planets. The idea of such a change was to ensure sufficiently uniform coverage of the sky band between ±30° of declination by the SMP trajectories. The aim was postulated as determining not only the zero–point corrections but the catalogue periodic errors as well. The proposals of V. I. Orelskaya were approved by several commissions of the IAU in 1976. Later it became clear, however, that some planets from the Orelskaya's list have too weak brightness and they can not be observed over large trajectory arcs using the standard astrographs. So, in 1991, according to the proposal of the Institute of Theoretical Astronomy (ITA), S. Petersburg, Russia, the list of the SMP was changed again: the planets with too weak brightness were excluded and only 15 SMP remained (Batrakov, Shor, 1990). This new plan of observations of the SMP for 1991–2000 was approved by Commission 20 in 1991 during the GA of the IAU in Buenos Aires. To support the work on this plan ITA publishes regularly daily ephemerides of the SMP (Batrakov et al., 1996) which are distributed between observers.

One of the purposes of this paper is to give the results of the numerical experiments aimed at revealing the potential of the 1991–2000 SMP observation program as it concerns the improvement of the catalogue zero–point parameters and the determination of the catalogue periodic errors. Another purpose is to present the results of the real observation processing based on the Nikolaev (Ukraina) series of the SMP photographic observations covering 1974–1995 interval.

2. Numerical experiments

The experimental computations cover the 1991–2000 years interval taking into account every opposition of the 15 SMP. The fictitious observations cover intervals of $\pm 100^d$, centred at every opposition, with 1^d step. The equations of condition are compiled for $cos\delta\Delta\alpha$ and $\Delta\delta$ and their total number is 54270. Each of these equations contains 6 corrections to the non-singular elements of the non-perturbed planetary orbit, correction to the Earth's longitude (the Earth's orbit is also unperturbed) and 30 coefficients of the expressions representing the distribution of the catalogue systematic errors over $\pm 30°$ declination as well as the zero-point corrections. These equations are combined into the normal equations for 121 unknowns, the right hand parts of them being zero. The inverse matrix of these equations multiplied by squared unit weight error is the covariance matrix of the unknowns. As for the unit weight error, it is the parameter of the normal distribution of the observations considered as random values having equal dispersions. It can be chosen a-priori in the experiment computations. The inverse matrix after normalization gives the correlation coefficients. If some of them have absolute values close to 1 one can expect that at least two unknowns are connected by an approximate relation. These unknowns can not be determined reliably and for some of them the fixed zero values are better to take. The analytical expressions for the catalogue errors distribution are taken as follows:

$$\begin{pmatrix}\Delta\alpha\\ \Delta\delta\end{pmatrix} = \sum_{k=0}^{2}\sum_{l=0}^{2} sin^k\delta\left[\begin{pmatrix}a_i\\ b_i\end{pmatrix} cosl\alpha + \begin{pmatrix}a_{i+6}\\ b_{i+6}\end{pmatrix} sinl\alpha\right], \qquad (1)$$

where $i = k + 3l + 1$. In (1) there are 30 catalogue coefficients, a, b, to be included into improvement. The a_1, b_1 coefficients correspond to the zero-point corrections.

The non-singular elements used here are the combinations of the usual Keplerian elements $a, e, i, \Omega, \omega, M_0$, having the form:

$$\begin{aligned} &a, & h &= e\ sin\pi,\\ p &= sin(i/2)sin\Omega, & l &= e\ cos\pi,\\ q &= sin(i/2)cos\Omega, & \lambda &= M_0 + \pi, \end{aligned}$$

where $\pi = \omega + \Omega$. Differential coefficients in the equations of condition for these combinations are taken from (Batrakov, Nikolskaya, 1981).

The results of the numerical experiments are given below at supposition that the unit weight error is $0.2''$; if one wants to use some other unit weight error ϵ'', the σ−estimates below must be multiplied by $\epsilon''/0.2''$.

Case 1. All 121 unknowns are determined from the normal equations. The following errors are the most significant ones: $\sigma(\Delta\lambda_E) = 0.28''$, $\sigma(a_1) = 0.26''$, $\sigma(a_{11}) = 0.12''$, $\sigma(b_4) = 0.11''$. Other errors of the a_i, b_i coefficients are less than $0.005''$. Strong correlations exist between $\Delta\lambda_E$, $\Delta\lambda_i$, a_1, a_{11} and b_4 unknowns. Here $\Delta\lambda_E$, $\Delta\lambda_i$ are the corrections of the longitudes of the Earth and the SMP correspondingly.

Case 2. $\Delta\lambda_E$ is excluded. The most significant errors are $\sigma(a_6) = \sigma(a_{12}) = \sigma(b_{12}) = 0.05''$. Other errors are less than $0.04''$.

Case 3. $\Delta\lambda_E$ and a number of a_i, b_i coefficients are excluded. Only a_1, a_4, a_{10}, b_1, b_4 and b_{10} coefficients are included into the improvement procedure. The greatest errors are $\sigma(a_1) = \sigma(a_4) = \sigma(a_{10}) = 0.006''$; other errors are smaller than these ones.

So, when excluding the Earth's longitude from the improvement one obtains noticeably better conditioning of the normal equations and more reliable estimates for the SMP elements and the catalogue coefficients.

3. Real observation processing

The Nikolaev photographic observations of the SMP were obtained with the zonal astrograph ($F = 2044\ mm$, $D = 120\ mm$, $Field : 5^\circ \times 5^\circ$). Tests of the astrograph and the measure equipment confirmed their high quality. The list of observations covers the interval of 1961 – 1995 and include 12 SMP (NN 1, 2, 3, 4, 6, 7, 11, 18, 39, 40, 532, 704). The total number of observations is 2343, all comparison star positions were taken from the PPM catalogue. The way of producing the observations and their reduction were kept unchanged during all this interval. Some information about these observations is given in Table 2.

The equations of motion of these SMP were integrated by Everhart method taking into account the perturbations from all major planets and five minor planets $(1, 2, 4, 7, 324)$ according to the DE200/LE200 ephemeris. The relativistic corrections were included in the equations of motion. The variation equations were integrated along with the equations of motion. The equations of condition include the corrections for the initial rectangular coordinates and velocities of the SMP (6 for every planet) and 6 catalogue correction coefficients. The expressions for the catalogue corrections are as follows:

TABLE 1. Observations of the SMP in Nikolaev during 1961-1995

Number of planet	Name of planet	Number of observations	Number of oppositions	σ
1	Ceres	211	21	$0.15''$
2	Pallas	259	25	0.17
3	Juno	244	24	0.18
4	Vesta	232	22	0.18
6	Hebe	220	22	0.18
7	Iris	196	19	0.20
11	Partenope	192	19	0.20
18	Melpomene	209	19	0.19
39	Laetitia	238	24	0.20
40	Harmonia	209	21	0.22
532	Herculina	68	9	0.21
704	Interamnia	65	7	0.18
	Total	2343	232	

$$\Delta\alpha = \Delta\alpha_0 + a_1 cos\alpha + a_2 sin\alpha,$$
$$\Delta\delta = \Delta\delta_0 + b_1 cos\alpha + b_2 sin\alpha.$$

The observations were reduced for phase using formulae (Sveshnikov, 1985) $\Delta\alpha_p = P(I)sinQ$, $\Delta\delta_p = P(I)cosQ$, where $P(I)$ corresponds to the Lommel–Seeliger law of the light scattering by the asteroid surface, and Q is the angle between the Sun and a planet as seen from the Earth. The correction to the Earth's longitude was not included into the solution.

The first step was to obtain solutions for every planet separately. The obtained values of the mean square errors σ (the last column of the Table 2) do not exceede $0.22''$ which demonstrates that the Nikolaev observations are of very good quality. The range of the values of σ is rather small, from $0.15''$ to $0.22''$, therefore we suppose later on that all observations have equal weight.

The results of the combined solution of the normal equations are given in Table 3 for 78 and 74 unknowns. In all 58 equations of condition were excluded from the combined solution according to 3σ–criterium.

The results of determination of the equinox and equator corrections, ΔA, ΔD, to the FK5 from minor planet observations obtained by some

TABLE 2. The corrections obtained (The last column gives results obtained with no phase correction)

Number of unknowns	74		78		78	
σ_0	0.188″		0.187″		0.187″	
$\Delta\alpha_0$	−0.006″	± .027″	−0.000″	± .028″	−0.006″	± .028″
$\Delta\delta_0$	−0.059	.004	−0.059	.005	−0.060	.005
a_1	-		0.019	.020	0.013	.019
a_2	-		−0.115	.022	−0.121	.022
b_1	-		0.028	.018	0.027	.018
b_2	-		−0.034	.018	−0.031	.018

TABLE 3. Comparison of the equinox and equator corrections of the FK5 obtained from minor planet observations (The Earth's longitude correction is not determined)

Author	Object Interval, number of observations	ΔA	ΔD
Branham, Sanguin, 1996	21 minor planets photographic obs. 1909 - 1993, 4518	+0.186″ ± .086″	+0.021″ ± .016″
Yagudina, 1997	8 near-Earth asteroids 1934 - 1995 1722 photogr. obs. 131 radar obs.	+0.126 ± .057	+0.057 ± .037
This paper	12 SMP photographic obs. 1961 - 1995, 2343 (with phase correction)	+0.000 ± .028	+0.059 ± .005

other authors are given in Table 4 (ΔA, ΔD are connected with $\Delta\alpha_0, \Delta\delta_0$ through the relations: $\Delta A = -\Delta\alpha_0$, $\Delta D = -\Delta\delta_0$).

It worths noticing that the photographic observations of minor planets used in (Branham and Sanguin, 1996) and (Yagudina, 1998) have ordinary accuracy about 1″, the reference star positions were taken from different catalogues. The observations were reduced to the FK5, if they were not given in that system already, by adding the systematic differences between the catalogues. The observations were obtained using different telescopes and measuring equipment. It results in rather big errors of the equator and equinox corrections as compared with the Nikolaev observations processing results.

All values of the equator correction ΔD are in good agreement, and conclusion can be done that the FK5 equator needs correction about $+0.05''$.

The range of the values of ΔA and their errors is more considerable, and it is difficult to give preference to some of the results in Table 3: the result obtained in this paper has the smallest error, but the Nikolaev observations can have some systematic errors which influence the results.

4. Conclusions

- The numerical experiments demonstrate that even at ideal distribution of observations there exists correlation between the longitude of SMP, the longitude of the Earth, and a_1 coefficients. This correlation can be diminished only by excluding the Earth longitude from the set of unknowns.
- The processing of the Nikolaev observations shows that these observations are of very good quality. They allow to obtain a number of parameters characterizing the orientation and some of the periodic errors of the catalogue. The FK5 and dynamical equinox (defined by the ephemerides DE200/LE200) agree closely. The FK5 equator needs small correction $+0.06''$.

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5. References

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Discussion

Tel'nyuk-Adamchuk: Did you obtain zero-point corrections to the reference catalog using each minor planet separately?

Answer: Yes, we obtained these solutions. Corrections to $\Delta\alpha_0$ have big range, but to $\Delta\delta_0$ practically coincide for all planets. Our conclusion: $\Delta\alpha_0$ should be obtained from all observations of all SMP.