EARTH ORIENTATION PARAMETERS IN 1899–1992 BASED ON THE NEW EARTH ORIENTATION CATALOGUE

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ABSTRACT. The Earth orientation parameters (EOP), based on optical astrometry observations of latitude and universal time variations and the Hipparcos Catalogue, covering 1899.7–1992.0, were determined in past years at Astronomical Institute in Prague, in close cooperation with the Czech Technical University in Prague, see Vondrák et al. (1998). During the solution it has been discovered that not all Hipparcos stars are suitable for a long-term study; many of them proved to have large errors in proper motions. Recently, the new Earth Orientation Catalogue (EOC) based on the recent star catalogues ARIHIP and TYCHO-2, and also Hipparcos and PPM catalogues, is being prepared by our group. We apply the provisional version of the catalogue to the optical astrometry observations (except for those of the method of equal altitudes) to test the new EOC. The differences of the EOP with respect to the EOP from the solution OA00 (Ron & Vondrák, 2001) are discussed.

1. INTRODUCTION

In the last decade we have used the observations by optical astrometry to derive the Earth Orientation Parameters (EOP) in the International Celestial Reference System (ICRS) which is realized by the reference frame of the Hipparcos Catalogue (ESA, 1997). The solution is described in Vondrák et al. (1998). The last solution denoted as OA00, available at the IERS Product Center as EOP(AICAS) 01 A 01, was described by Ron & Vondrák (2001). The analysis of the residuals proved the insufficient accuracy of some star positions based on the Hipparcos catalogue, caused by errors in proper motions. We corrected about 20% of individual observations by drifts derived from the observations themselves to overcome this imperfection.

Recently, new precise astrometrical catalogues related to ICRS have appeared. The catalogues as ARIHIP (Wielen et al. 2001) or TYCHO-2 (Høg et al., 2000) were derived as combination of the Hipparcos Catalogue (ESA, 1997) with the former ground-based catalogues. Because these catalogues showed to have more reliable proper motion of the stars, we decided to use them in the new determinations of the EOP. Wielen et al. (2001) introduced the star classification – the coefficient K_{ae} called *the astrometrical excellency* – in the scale $0-3$ (the higher the coefficient the better is the star from the astrometrical point of view). We have presented the idea of the new *Earth Orientation Catalogue* (EOC) in Vondrák & Ron (2003). The new catalogue combines the precise star positions of the recent astrometrical catalogues with the long term series of the optical astrometry observations.

2. SOLUTION OF EOP FROM OPTICAL ASTROMETRY

The following parameters were derived in all preceding solutions:

- for each of the 5-day interval:
  - coordinates of the pole in terrestrial reference frame x, y,
  - universal time differences UT1–TAI (after 1956),
  - celestial pole offsets $\Delta\varepsilon, \Delta\psi \sin\varepsilon$,
- for each instrument:
  - constant, linear, annual and semi-annual deviation in latitude A, A_1, B, C, D, E,
  - constant, linear, annual and semi-annual deviation in universal time A', A'_1, B', C', D', E',
  - rheological parameter $\Lambda = 1 + k - l$ governing the tidal variations of the local vertical.

All observations were recalculated to be related to Hipparcos catalogue, and thus also to ICRS. Due to the relatively short mission of the satellite Hipparcos, the proper motions of the stars that are the components of binaries or multi-star systems were not derived with the sufficient accuracy. For that reason the observations of φ, UT0–UTC and δh had to be corrected. The corrections of individual stars (about 20% of the stars) were derived from the residuals of individual observations with respect to 5-day means of the instrument.

The observation equations lead to the system of normal equations that are singular with defect of matrix equal to 18. Therefore it is necessary to add 18 constraints tying together the parameters $A, \ldots, E'$ and fixing thus the terrestrial reference frame defined by the conventional coordinates of the individual instruments (see Tab. 3) and assuring that projection of seasonal residuals is minimized. The solution is described in details in Vondrák et al. (1998).

3. NEW EARTH ORIENTATION CATALOGUE

The first idea to set up the EOC has been presented by Vondrák & Ron (2003), and first version of the catalogue has been presented at the 25th IAU GA in Sydney (Vondrák & Ron, 2004).

3.1 *The version EOC-0*

In order to assure the most accurate positions and proper motions we searched for the stars first in the catalogue ARIHIP (Wielen et al., 2002) where we found 2995 stars, then in catalogue TYCHO-2 (Høg et al., 2000) with 1250 stars, in Hipparcos catalogue (ESA, 1997) with 146 stars and finally in the PPM catalogue (Roeser & Bastian, 1991, Bastian & Roeser, 1993) with 28 found stars. Only three stars were not found in any of the catalogues and their positions and proper motions were taken from the local catalogue of the instrument.

3.2 *The version EOC-1*

In the first approximation only the observations made in the local meridian (i.e., all observations except those of astrolabes and circumzenithals) were used to improve the catalogue EOC-0. First we derived the positions of the observed stars with respect to the astrometrically excellent stars as follows:

- all available observations of latitude and universal time were re-computed into the reference system of the catalogue EOC-0, using new IAU2000A model of precession-nutation (Mathews et al., 2002);

- the differences of latitude and/or universal time were computed from the mean values of the same night based on astrometrically excellent stars only;
- the differences for the same star at different epochs were subject to linear regression;
- the stars with significant deviations were checked for multiplicity (in the Hipparcos Catalogue), and in a positive case the displacement of the reference point (very often photocenter) from the catalogue entry estimated;
- the individual observations were recomputed with the modified catalogue EOC-0 and the residuals of individual observation with respect to the mean of night (using only the astrometrically excellent stars) were derived again.

Then the combination of the individual observations with original catalogue has been done to improve the positions and proper motions. The time series of observations of a star from all instruments were combined with three virtual observations, corresponding to the catalogue entry. These were chosen so that the weighted linear regression made through these three points returns exactly the same values t_0, σ_0 and σ_μ as given in the input catalogue. If the central epoch is identified with the one of the input catalogue $t_2 = t_0$, $t_1 = t_0 - 90$y and $t_3 = t_0 + 10$y this approach leads to standard deviations of virtual observations at three epochs

$$\sigma_1^2 = 9000\sigma_\mu^2, \qquad \sigma_2^2 = \frac{\sigma_0^2}{1 - (\sigma_0/\sigma_\mu)^2/900}, \qquad \sigma_3^2 = 1000\sigma_\mu^2. \tag{1}$$

The values of σ_i in mas were used to compute the weights of the three virtual observations (each of these 'observed' values being set to zero) as $p_i = (200/\sigma_i)^2$. The weights of all 'real' observations of the same star are all equal to 1, under the assumption that their accuracy is 200mas.

In the preliminary version EOC-1 we used the observations made in local meridian, i.e., all observations except those by the method of equal altitude. The total number of stars observed by these instruments is 3784. The result of the combination of the catalogue EOC-0 with these observations forms the new preliminary version of the catalogue EOC-1.

Medians of standard deviations in positions (mas) and proper motions (mas/y) are shown in Tab. 1 (star denotes the value multiplied by $15\cos\varphi$), separately for the stars that were observed by Hipparcos (HIP) and that were not (not HIP). The third row (other comp.) gives the values for the stars whose reference point is different from the Hipparcos entry.

Table 1: The statistics of the catalogue EOC-1.

Type	n	$\sigma_\alpha^\star$	$\sigma_{\mu\alpha}^\star$	σ_δ	$\sigma_{\mu\delta}$
HIP	3643	0.67	0.51	0.50	0.31
Not HIP	85	8.00	1.40	7.10	1.01
Other comp.	56	7.50	0.90	4.00	0.90

The improvement of EOC-1 with respect to the EOC-0 is demonstrated in Tab. 2, where global characteristics of both catalogues are compared. Median values are displayed again.

4. NEW SOLUTION OF EOP IN THE REFERENCE SYSTEM OF EOC

The new solution of EOP (called OA03) is referred to the preliminary version EOC-1. Because the final version of EOC is not yet prepared, we did not use the observations made by the method of equal altitude (astrolabes and circumzenithals). All observations were re-computed using the

Table 2: The comparison of the catalogues EOC-0 and EOC-1.

Catalogue	n	Ep_{α}	$\sigma^{\star}_{\alpha}$	$\sigma^{\star}_{\mu\alpha}$	Ep_{δ}	σ_{δ}	$\sigma_{\mu\delta}$
EOC-0	4422	1991.25	0.69	0.60	1991.26	0.55	0.57
EOC-1	3784	1991.18	0.68	0.52	1991.10	0.50	0.32

new precession-nutation model IAU2000A (Mathews et al., 2002). The celestial pole offsets with respect to the new model are less than 0.2mas and they are undetectable by the optical astrometry. For that reason we abandoned the determination of the celestial pole offsets in 5-day intervals. The observation equations become simpler and the number of determined unknown parameters decreases significantly. For 5-day intervals we determine only three unknowns (x, y, UT1−TAI) and before 1956 only two (x and y) because the atomic time TAI was not defined yet. The smaller rank of the diagonal matrices for the 5-day intervals led to smaller condition numbers and so to the bigger number of the determined 5-day intervals because it was not necessary to connect so many intervals to assure the diagonal blocks of the normal equations to be positive definite, see Vondrák et al. (1998).

We used the observations of the observatories listed in Tab 3. where the coordinates defining the terrestrial system and the secular drifts of the stations caused by the movements of the lithospheric plates derived from the model NUVEL-1 NNR (DeMets et al., 1994) are shown.

The derived values of the terrestrial coordinates of the pole in the interval 1899.7–1992.0 and the excess of the length of day in the interval 1956.0–1992.0 including their standard deviations in 5-day intervals are shown in Fig. 1.

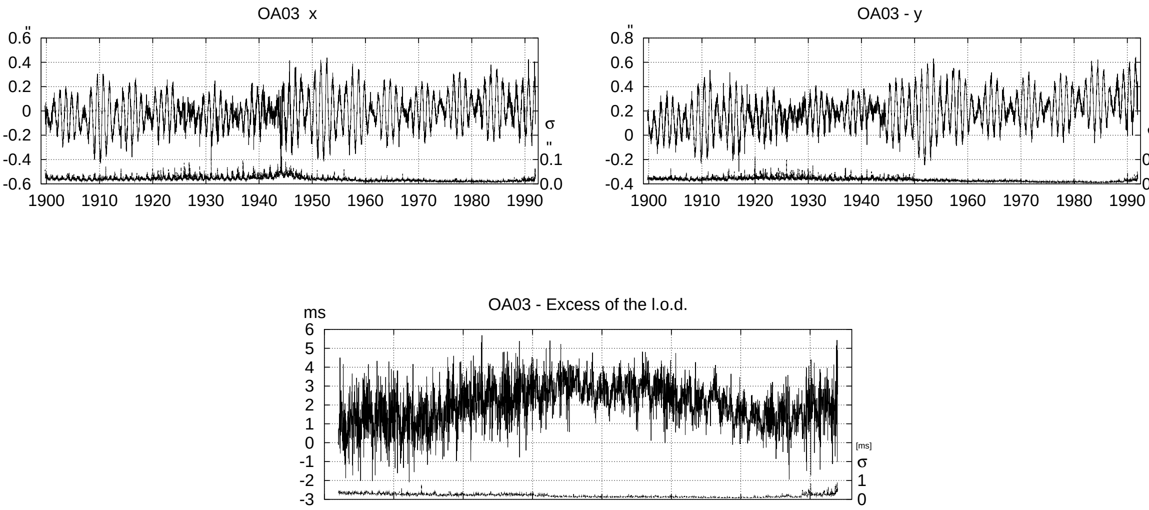

Figure 1: Polar motion at 5-day intervals and excess of the l.o.d. over the nominal value 86400s and their standard errors. The short-periodic tidal variations in l.o.d. ($P < 35$ days) are removed.

Table 3: The coordinates φ_0 and λ_0 of the instruments used in the solution OA03, referred to the mean epoch MJD_0 32000 for the latitude and 43000 for the time observations; $\dot{\varphi}$ and $\dot{\lambda}$ are the secular drifts of the stations, v are the weights used in the solution.

Code	latitude φ_0	$\dot{\varphi}$	longitude λ_0	dλ	$\dot{\lambda}$	weights	
	° ' "	["/cy]	° ' "	[s]	[s/cy]	v_φ	v_T
Visual zenith telescopes							
CA	39 08 09.148	+0.061	8 18 44.0			1.19	
CI	39 08 19.427	+0.002	−84 25 00.0			1.04	
GT	39 08 13.289	+0.012	−77 11 57.0			0.85	
KZ	39 08 02.076	+0.001	66 52 51.0			0.72	
MZZ,MZL	39 08 03.709	−0.045	141 07 51.0			0.89	
TS	39 08 10.973	+0.004	63 29 00.0			0.86	
	39 08 11.337	+0.004	63 29 00.0			MJD>18512	
UK	39 08 12.157	+0.025	−123 12 35.0			0.89	
BLZ	44 48 10.444	+0.041	20 30 50.0			0.87	
BK	50 19 09.553	−0.048	127 30 00.0			1.54	
IRZ	52 16 44.313	−0.033	104 20 42.7			0.82	
POL	49 36 13.049	+0.031	34 32 52.0			0.84	
PU	59 46 15.622	+0.034	30 19 39.0			1.02	
PUZ	59 46 15.628	+0.034	30 19 39.0			0.98	
TT	60 24 57.496	+0.040	22 27 00.0			1.95	
VJZ	52 05 56.207	+0.041	21 00 00.0			0.66	
Photoelectric transit instruments							
IRF	52 16 44.0		104 20 42.0	−0.0061	+0.0084		0.85
KHF	50 00 00.0		36 13 58.0	+0.0039	+0.0083		0.85
NK	46 58 18.0		31 58 28.0	+0.0086	+0.0078		0.95
PUF,PUG	59 46 18.0		30 19 38.0	+0.0009	+0.0096		1.24
PUH							
WHF	30 32 28.9		114 20 41.4	+0.0176	+0.0060		0.76
Photographic zenith tubes							
MZP,MZQ	39 08 02.736	−0.045	141 07 52.0	−0.0032	−0.0005	0.72	0.74
OJP	49 54 55.145	+0.044	14 47 09.0	+0.0107	+0.0072	1.20	1.28
PIP	−35 20 40.563	+0.036	−57 17 09.0	+0.0373	−0.0005	1.82	1.79
RCP,RCQ	25 36 47.098	+0.008	−80 22 56.0	+0.0026	−0.0027	1.17	1.05
WA	38 55 17.263	+0.012	−77 03 56.0			1.28	
W,WGQ	38 55 17.308	+0.012	−77 03 56.0	+0.0018	−0.0044	0.97	0.85
MS	−35 19 17.486	+0.182	149 00 19.0	+0.0316	+0.0049	1.00	0.86

Table 4: The comparison of statistics of the solutions OA00 and OA03.

	OA00	OA03
number of observations	4447400	3262496
number of unknowns	29809	16285
number of 5-day intervals	6693	6715
number of instruments	41	27
standard deviation σ_0	±0.188″	±0.177″
mean square difference wrt IERS C04 (1962-1992)	±0.047″	±0.050″

5. CONCLUSIONS

The new catalogue shows significant improvement with respect to all of the catalogues used so far in the derivation of the Earth orientation parameters. The improvement can be seen both in version EOC-0 (that only takes over the best from the current catalogues) and EOC-1 (where the catalogue EOC-0 is combined with observations of the 33 instruments observing in the local meridian). The best improvement is achieved in proper motions in declination, thanks to a long history of latitude observations. The final solution of EOC is under preparation.

In the new solution of the Earth orientation parameters OA03 only the observations with the instruments working in the local meridian (VZT, PTI, PZT) were used, in the reference system of the catalogue EOC-1. In contrast to the solution OA00 the new model of precession-nutation was used, and therefore we abandoned the determination of the celestial pole offsets. The results of the solution OA03 even with the less number of used observations (73%) with respect to OA00 are comparable with this solution.

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