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NEW SOLUTION OF EARTH ORIENTATION PARAMETERS 1900-1992 FROM OPTICAL ASTROMETRY, AND ITS LINKING TO ICRF AND ITRF

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Abstract. In preceding years we collected and re-analyzed the optical astrometry data from 33 observatories, using a unique celestial reference frame. It was realized first by the Hipparcos Catalogue, and then by a group of our own Earth Orientation Catalogs (EOC), being obtained by combining Hipparcos/Tycho data with older ground-based observations. EOC catalogs, that are tied to Hipparcos Catalogue, are given in the International Celestial Reference Frame (ICRF). On the other hand, the underlying terrestrial reference frame is arbitrarily realized by adopted geographic coordinates (latitudes, longitudes) of participating stations. Small additional coordinate biases and drifts of individual stations are estimated in the solution, we also suppose that each station can exhibit apparent annual and semi-annual changes of geographic coordinates due to anomalous refraction. To remove the singularity of the solution, we apply 18 additional constraints, tying the biases, drifts and seasonal changes of individual stations. As a consequence, the terrestrial reference frame of the optical solution can deviate from the International Terrestrial Reference Frame (ITRF) by a constant, linear drift and seasonal (annual, semi-annual) changes, in all three axes. To estimate these deviations, we compare our most recent EOP series, referred to catalog EOC-4, with the one provided by space techniques in the common interval of observations. The deviations found are then applied to our EOP solution to link it more precisely to ITRF.

1. INTRODUCTION

Optical astrometry was, for most of the 20th century, the only technique measuring the Earth Orientation Parameters (EOP). EOP, that are the coordinates of the pole in terrestrial and celestial reference frames, and universal time UT1, respectively, are necessary to compute transformation between the celestial and terrestrial reference frames. The observations comprised the instantaneous values of latitude, and later on (after 1956) also differences between Universal and Atomic time scales. Method of equal altitudes then provided a combination of both, the differences between observed and computed altitude of the stars. We collected and re-analyzed these data using a unique celestial reference frame, close to the International Celestial Reference Frame (ICRF) with the best possible accuracy. It was first realized by the Hipparcos Catalogue, and then by a group of our own Earth Orientation Catalogs (EOC). The latter were obtained by combining Hipparcos/Tycho data with older ground-based observations, in order to improve the proper motions, and in some cases also to derive non-linear motions of a great proportion of the stars. Here we use our most recent catalog, EOC-4 (Vondrák and Štefka, 2010), for more details see the next section.

On the other hand, the underlying terrestrial reference frame is rather arbitrarily realized by adopted geographic coordinates (latitudes, longitudes) of participating stations. In addition, we tied the system to the plate motion model NUVEL-1A (Argus and Gordon, 1991) by correcting the observations for the linear motions of the stations computed for that model. Small coordinate corrections and drifts of individual stations with respect to individual plates are estimated in the solution. We also suppose that each station can exhibit apparent seasonal changes of geographic coordinates due to anomalous refraction. We apply 18 constraints, tying these parameters, to remove singularity of the solution. In all our preceding solutions we tacitly assumed that the selected geographic coordinates were referred to the International Terrestrial Reference Frame (ITRF), and that the average drifts and seasonal deviations of all stations have zero effect on the orientation of our terrestrial frame. If this is not the case, the terrestrial reference frame of the optical solution deviates from ITRF by a constant, linear drift and seasonal (annual, semi-annual) changes, in all three axes. Below we propose how to find corrections to refer our solution to ITRF more accurately.

2. CATALOG EOC-4

This catalog (Vondrák and Štefka, 2010) is the realization of the celestial frame in which we describe EOP based on optical astrometry. We used about 4.5 million observations of latitude / universal time / altitude variations at 33 observatories all over the world, and combined them with the catalogues ARIHIP (Wielen et al., 2001), TYCHO-2 (Høg et al., 2000) etc… in order to obtain this catalog. These observations are identical with those used to construct the previous version, EOC-3 (Vondrák and Štefka, 2007), but the procedure to obtain it was slightly different. Spectral analysis of ground-based data and comparison with the USNO Sixth Catalog of Orbits of Visual Binary Stars (Hartkopf and Mason, 2006)was used to discover which of the observed objects display periodic motions. The corresponding amplitudes and phases were then estimated in one-step least-squares solution, together with positions and proper motions, which assured the full compatibility of the positions with the Hipparcos/Tycho Catalogues (ESA, 1997) at epochs close to its mean epoch, 1991.25, thus also to ICRF. Unlike in EOC-3, where annual averages were used, we used the individual nightly observations in the solution. The catalog contains 4418 different objects (i.e., stars, components of double stars, photocenters), out of which 599 have significant orbital motions. The procedure that we used also assures that the catalog is referred to ICRF (via the Hipparcos/Tycho Catalogues) with the highest possible accuracy.

3. SOLUTION OF EOP

During the past ten years or so, we made several solutions of EOP, historically the first one being OA97 (which stands for Optical Astrometry and the year of production). This solution, published in Vondrák et al. (1998), was based on the Hipparcos Catalogue, and all procedures and corrections used to derive it are described there in detail. Since that time, the procedures themselves did not change substantially, the subsequent solutions differed mostly in different star catalogs and number of observations used; beginning with OA03 we started to use the new IAU precession/nutation models (McCarthy and Petit, 2004). Our last solution that we call OA09, with catalog EOC-4, is described in Vondrák et al. (2010). All of these solutions are referred to ICRF, but the terrestrial frame is defined by the adopted mean values of geographic coordinates (longitudes, latitudes) of participating observatories. They were selected so that they are given as close as possible in ITRF, but there is still a possibility that their initial estimation was not accurate enough. The coordinates were corrected for the linear motions due to plate motions, using the model NUVEL-1A (Argus and Gordon, 1991). To account for small incompatibilities of the adopted coordinates, for the motion of the station with respect to the plate tectonic model, and also for seasonal refraction anomalies, we included biases, trends and annual/semi-annual deviations in longitude/latitude of each observation site in the list of parameters to be estimated from the solution.

As already mentioned, the data that we use to derive EOP are the following, based on observation of individual stars:

- the difference between instantaneous latitude from its mean value, $\Delta\varphi$;
- the difference between Universal Time 0 and Coordinated Universal Time, UT0–UTC;
- the difference between the computed and observed altitude, Δh. This value is a linear combination of $\Delta\varphi$ and UT0– UTC.

They come from 47 different instruments, working at 33 observatories. They are as follows

- 10 photographic zenith tubes (PZT), providing both $\Delta\varphi$ and UT0–UTC:
  - 3 at Washington; 2 at Richmond and Mizusawa; 1 at Mount Stromlo, Punta Indio and Ondřejov;
- 7 photoelectric transit instruments (PTI), providing only UT0–UTC:
  - 3 at Pulkovo; 1 at Irkutsk, Kharkov, Nikolaev and Wuhang;
- 16 visual zenith-telescopes and similar instruments, providing only $\Delta\varphi$:
  - 7 zenith-telescopes (ZT) at ILS stations (Carloforte, Cincinnati, Gaithersburg, Kitab, Mizusawa, Tschardjui, Ukiah); 2 ZT at Poltava; 1 ZT at Belgrade, Blagovestschensk, Irkutsk, Jósefoslaw and Pulkovo; floating zenith-telescope (FZT) at Mizusawa, visual zenith-tube(VZT) at Tuorla-Turku;
- 14 instruments for equal altitude observations, measuring Δh:
  - 1 Danjon astrolabe (AST) at Paris, Santiago de Chile, Shanghai, Simeiz and Wuhang; 2 photoelectric astrolabes (PAST) at Shaanxi; 1 PAST at Beijing, Grasse, Shanghai and Yunnan; 1 circumzenithal (CZ) at Bratislava, Prague and Pecný.

From these observations, we solve the following parameters:

- at 5-day intervals:
  - coordinates of the instantaneous pole of rotation in terrestrial frame, x, y;
  - the difference between Universal Time 1 and Coordinated Universal Time, UT1–UTC.
- for each instrument:
  - bias, trend, semi-annual and annual deviations in latitude/longitude, dev_φ, dev_λ;
  - rheological parameter, governing the tidal variations of local verticals, $\Lambda = 1 + k - l$.
- for the whole interval:
  - celestial pole offsets dX, dY with respect to the presently adopted IAU precession/nutation model (McCarthy and Petit, 2004), as a quadratic function of time.

The deviations in latitude/longitude mentioned above have the form

$$dev_{\varphi,\lambda} = A^{\varphi,\lambda} + A_1^{\varphi,\lambda}T + B^{\varphi,\lambda}\sin 2\pi t + C^{\varphi,\lambda}\cos 2\pi t + D^{\varphi,\lambda}\sin 4\pi t + E^{\varphi,\lambda}\cos 4\pi t\ , \quad (1)$$

where T is measured in Julian centuries from MJD=32000 (for latitude) and 43000 (for longitude), t is given in years from the beginning of the preceding Besselian year.

The observation equations for the three types of observations, slightly simplified, then read

$$\begin{aligned}
\Delta\varphi &= x\cos\lambda - y\sin\lambda - dX\cos\alpha - dY\sin\alpha + dev_\varphi + \Lambda D_\varphi,\\
15\cos\varphi(\text{UT0-UTC}) &= 15\cos\varphi(\text{UT1-UTC}) + \sin\varphi(x\sin\lambda + y\cos\lambda) +\\
&+ \cos\varphi\tan\delta(dY\cos\alpha - dX\sin\alpha) + dev_\lambda + 15\Lambda D_\lambda\cos\varphi, \qquad (2)\\
\Delta h &= 15\cos\varphi\sin a(\text{UT1-UTC}) + x(\cos\lambda\cos a + \sin\varphi\sin\lambda\sin a) -\\
-\ y(\sin\lambda\cos a - \sin\varphi\cos\lambda\sin a) &+ dY(\sin q\sin\delta\cos\alpha - \cos q\sin\alpha) -\\
&- dX(\sin q\sin\delta\sin\alpha + \cos q\cos\alpha) + dev_\varphi\cos a + dev_\lambda\sin a +\\
&+ \Lambda(D_\varphi\cos a + 15D_\lambda\cos\varphi\sin a),
\end{aligned}$$

where φ, λ are the observatory's geographic coordinates, α, δ, a and q are right ascension, declination, azimuth, and parallactic angle of the observed star, respectively, and D_φ, D_λ are tidal variations of the local vertical computed for rigid Earth. In case two or more instruments of similar type worked at the same observatory, their results were homogenized (i.e., brought to the same point of the observatory), merged into a single series and treated as a single instrument.

The detailed inspection of the structure of observation equations (2) reveals that the system of normal equations based on them is singular, with deficit equal to 18. Therefore, we apply 18 independent constraints, tying the 12 parameters of Eqs. (1):

$$\begin{aligned}
\sum pA^{\varphi}\begin{pmatrix}\sin\lambda\\ \cos\lambda\end{pmatrix} &= \sum qA_1^{\varphi}\begin{pmatrix}\sin\lambda\\ \cos\lambda\end{pmatrix} = \sum pB^{\varphi}\begin{pmatrix}\sin\lambda\\ \cos\lambda\end{pmatrix} = 0\\
\sum pC^{\varphi}\begin{pmatrix}\sin\lambda\\ \cos\lambda\end{pmatrix} &= \sum pD^{\varphi}\begin{pmatrix}\sin\lambda\\ \cos\lambda\end{pmatrix} = \sum pE^{\varphi}\begin{pmatrix}\sin\lambda\\ \cos\lambda\end{pmatrix} = 0 \qquad (3)\\
\sum pA^{\lambda} &= \sum qA_1^{\lambda} = \sum pB^{\lambda} = \sum pC^{\lambda} = \sum pD^{\lambda} = \sum pE^{\lambda} = 0.
\end{aligned}$$

So far, we applied the indicated summations only to the stations that finished their observations after 1962, in order to tie the terrestrial system to the more recent observations. The weights p, q were proportional to the length of the interval covered by the observations and to its third power, respectively. So, e.g., the trend of the polar motion of the solution is given as a weighted mean of parameters A_1^{φ} of all stations inserted in the summation of Eqs. (3), projected into x, y axes.

4. LINKING THE SOLUTION TO ITRF

Our first idea was to simply compare our optical astrometry solution (x, y, UT1–UTC) with the one based on space geodetic techniques (provided by the International Earth Rotation and Reference Systems Service – IERS), and derive the deviations (bias, drift, and seasonal deviations) from the differences found by estimating all parameters of formula (1) in a least-squares fit. We however found soon that this was not the ideal procedure in case of the drift. The common interval of optical astrometry and space geodesy is relatively short, the differences have large dispersion, and they exhibit long-periodic changes. As a result, the drifts found are determined with large inaccuracies and the values found heavily depend of the time interval chosen for the comparison. Therefore, we chose a different approach, only for the case of the drift.

Our preceding solution OA09 (Vondrák et al., 2010) provided coefficients $A_1^{\varphi,\lambda}$, giving the drifts of individual stations with respect to the plates moving with the velocities of NUVEL-1A model. They are depicted, together with their error bars, in Figs. 1, 2 from which we see that they are mostly concentrated around zero, but some of them differ from the others significantly. This is namely true for Ondřejov (OJP), Bratislava (BRC), Prague (PRD) and Shaanxi (SXB). We decided to link the drift to the stable stations, i.e., all but the outlying ones mentioned above, by means of modifying the constraints (3). We apply them only to the stable stations, with weights p, q computed from the formal standard errors of the corresponding parameters of the solution OA09.

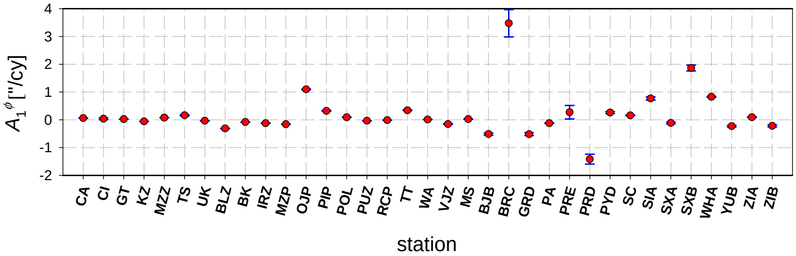

Figure 1. Observed drifts of individual stations in latitude, wrt NUVEL-1A.

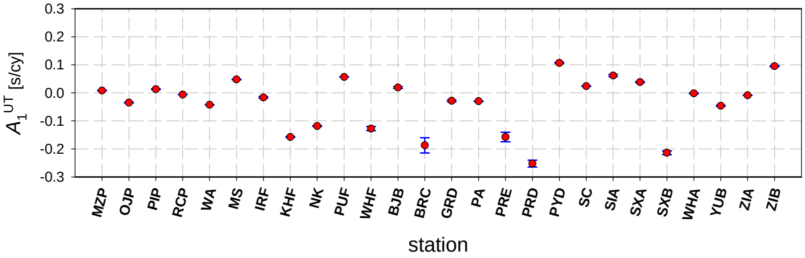

Figure 2. Observed drifts of individual stations in longitude, wrt NUVEL-1A.

Table 1 gives the list of the stable instruments, fixing the drift of the solution to NUVEL-1A plate model, and thus also to ITRF. From the dispersion of the drifts and their uncertainties we estimate that our solution is fixed to ITRF with the uncertainty of about $0.0095''/cy$ in x, $0.0075''/cy$ in y, and 0.0090s/cy in UT.

So we computed the solution again, with the newly defined constraints, and made comparison of the values x, y, UT1–UTC with the IERS solution C04, in the interval 1962.0 – 1992.0. The differences (in the sense C04 minus optical astrometry) are shown in Figs. 3 – 5 as black points for each five days.

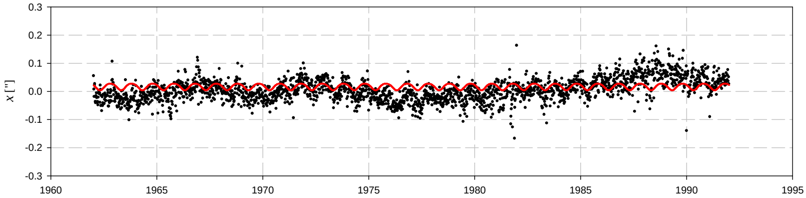

Figure 3. Differences in x-coordinate of the pole between IERS C04 and optical astrometry.

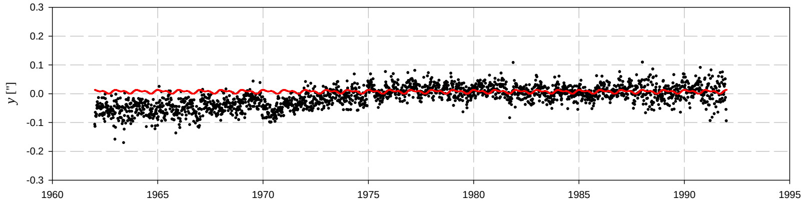

Figure 4. Differences in y-coordinate of the pole between IERS C04 and optical astrometry.

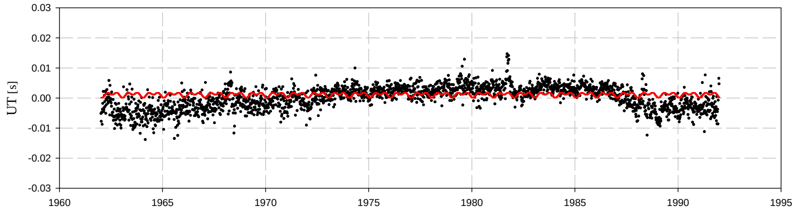

Figure 5. Differences in UT1 between IERS C04 and optical astrometry.

Table 1: Drifts of the stable instruments wrt NUVEL-1A and their uncertainties σ in latitude φ [$''$/cy] and longitude λ [s/cy]

Observatory	instrument	drift in φ	σ	drift in λ	σ
Beijing	BJB (PAST)	–0.5182	0.0374	0.02292	0.00304
Belgrade	BLZ (ZT)	–0.3019	0.0117	–	–
Blagovestchensk	BK (ZT)	–0.0871	0.0071	–	–
Carloforte	CA (ZT)	0.0748	0.0019	–	–
Cincinnati	CI (ZT)	0.0426	0.0346	–	–
Gaithersburg	GT (ZT)	0.0306	0.0028	–	–
Grasse	GRD (PAST)	–0.5050	0.0514	–0.02520	0.00312
Irkutsk	IRZ (ZT), IRF (PTI)	–0.1265	0.0091	–0.01221	0.00278
Jósefoslaw	VJZ (ZT)	0.1424	0.0205	–	–
Kharkov	KHF (PTI)	–	–	–0.15400	0.00186
Kitab	KZ (ZT)	–0.0531	0.0059	–	–
Mizusawa	MZZ (ZT+FZT)	0.0711	0.0019	–	–
	MZP (2x PZT)	–0.1670	0.0094	0.01198	0.00076
Mount Stromlo	MS (PZT)	0.0176	0.0097	0.05066	0.00098
Nikolaev	NK (PTI)	–	–	–0.11505	0.00183
Paris	PA (AST)	–0.1106	0.0113	–0.02657	0.00097
Pecný	PYD (CZ)	0.2717	0.0352	0.11025	0.00232
Poltava	POL (2x ZT)	0.1031	0.0092	–	–
Prague	PRE (CZ)	0.2861	0.2434	–0.15480	0.01697
Pulkovo	PUZ (ZT), PUF (3x PTI)	–0.0218	0.0014	0.06068	0.00183
Punta Indio	PIP (PZT)	0.3305	0.0198	0.01686	0.00187
Richmond	RCP (2x PZT)	-0.0064	0.0039	-0.00326	0.00034
Santiago de Chile	SC (AST)	0.1670	0.0134	0.02771	0.00097
Shaanxi	SXA (PAST)	–0.1180	0.0320	0.04211	0.00231
Shanghai	ZIA (AST)	0.0905	0.0141	–0.00511	0.00091
	ZIB (PAST)	–0.2260	0.0337	0.09874	0.00226
Simeiz	SIA (AST)	0.7781	0.0567	0.06525	0.00376
Tschardjui	TS (ZT)	0.1680	0.0248	–	–
Tuorla-Turku	TT (VZT)	0.3567	0.0173	–	–
Ukiah	UK (ZT)	–0.0364	0.0039	–	–
Washington	WA (3x PZT)	0.0149	0.0017	–0.03980	0.00050
Wuhang	WHA (AST)	0.8257	0.0182	0.00192	0.00107
	WHF (PTI)	–	–	–0.12415	0.00739
Yunnan	YUB (PAST)	–0.2301	0.0314	–0.04235	0.00215

The solution C04 is based on a mixture of observational techniques: optical astrometry at the beginning of the interval that is, step by step, replaced by modern space geodetic techniques (Very Long-Baseline Interferometry – VLBI, Satellite Laser Ranging – SLR, and Global Positioning System – GPS), so that the new techniques provided hundred percent of information at the end. Roughly saying, space techniques started to dominate after 1978. We suppose that the modern data are linked to ITRF, so we use only the data after 1978.0 to estimate systematic differences (bias, semi-annual and annual term) between optical astrometry and space techniques. Least-squares estimation yields the following results (in arcseconds for x, y, in seconds for UT1):

$$\begin{aligned}
\Delta x &= \quad 0.0176 - 0.0111 \sin 2\pi t + 0.0040 \cos 2\pi t + 0.0012 \sin 4\pi t + \\
&\quad +0.0010 \cos 4\pi t \pm 0.0013 \ \pm 0.0019 \ldots \\
\Delta y &= \quad 0.0076 + 0.0031 \sin 2\pi t + 0.0036 \cos 2\pi t - 0.0022 \sin 4\pi t + \\
&\quad +0.0024 \cos 4\pi t \pm 0.0008 \pm 0.0011 \ldots \\
\Delta \mathrm{UT} &= \quad 0.00116 - 0.00016 \sin 2\pi t - 0.00050 \cos 2\pi t - 0.00029 \sin 4\pi t - \\
&\quad -0.00047 \cos 4\pi t \pm 0.00012 \pm 0.00017 \ldots \, .
\end{aligned} \tag{4}$$

These values are plotted, as full lines, in Figs. 3 – 5. In the next and last step, we subtracted them from the solution, the result being our most recent solution denoted as OA10. It is graphically presented in Fig. 6 (polar motion) and 7 (length-of-day, computed from UT1–UTC as its negatively taken time derivative). In both figures, the formal uncertainties are also given (σ in lower plot, two-times enlarged scale on the right).

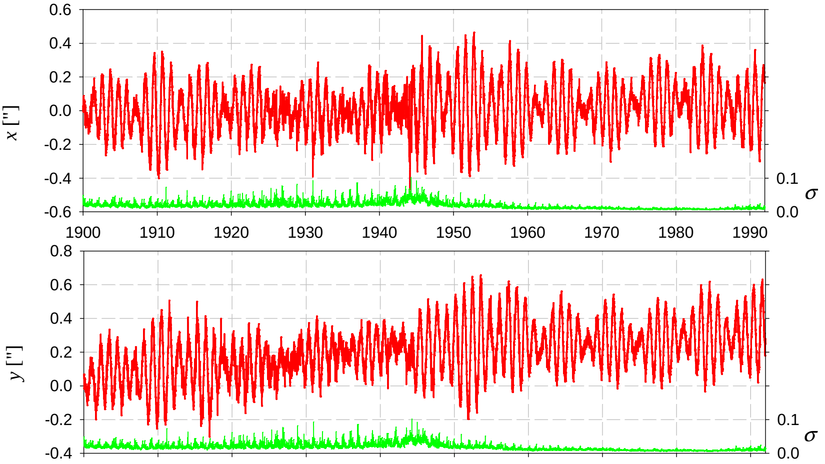

Figure 6. Polar motion.

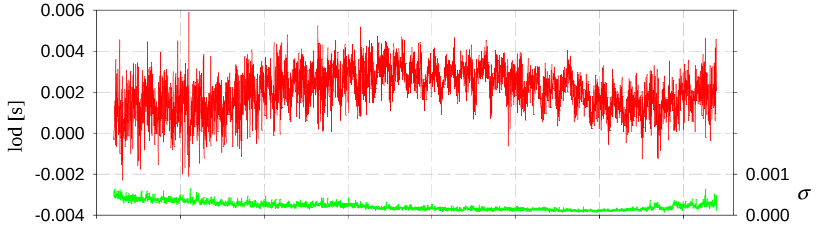

Figure 7. Length-of-day changes.

The celestial pole offsets are derived as quadratic function of time (in milliarcseconds); the third row gives the uncertainties of the coefficients:

$$\begin{aligned} dX &= -7.4 + 29.0T + 29.0T^2 \\ dY &= -6.1 + 8.9T - 1.2T^2 \\ \sigma_{X,Y} &= \pm 0.4 \ \pm 1.1 \ \pm 3.4 \ , \end{aligned}$$

where T runs in Julian centuries from 1956.0.

The solution contains also the small additions A^φ, A^λ to the originally adopted geographic coordinates of individual instruments, $\varphi_\circ, \lambda_\circ$. If combined with the biases $\delta x, \delta y, \delta\mathrm{UT}$ (constant parts of Eqs. (4)), we arrive at the definitive coordinates, defining the terrestrial frame to which the EOP solution is referred:

$$\begin{aligned} \varphi &= \varphi_\circ + A^\varphi + \delta x \cos\lambda_\circ - \delta y \sin\lambda_\circ \qquad (5) \\ \lambda &= \lambda_\circ + 15(A^\lambda + \delta\mathrm{UT}) + (\delta x \sin\lambda_\circ + \delta y \cos\lambda_\circ)\tan\varphi_\circ . \end{aligned}$$

They are displayed in Table 2, where only values rounded to whole arcseconds are given for the instruments that do not measure the respective coordinate.

As a by-product of the EOP solution, we also calculated the rheological parameter $\Lambda = 1 + k - l$, which is given as a combination of Love and Shida numbers. It expresses the reaction of non-rigid Earth to tidal forces exerted by the Moon and the Sun that cause small variations of the local verticals. Our solution provides the values of Λ for each instrument. In Fig. 8 we show the values for each observatory, together with their error bars. In case more instruments worked at the same observatory, the weighted average is displayed. The results are arranged by increasing geographic longitudes of the observatories, so that we can immediately see if there are some systematic differences among continents. Theoretical value of Λ is around 1.2, so the observed values seem to confirm it, although their dispersion is evidently larger than their formal errors. The values are practically the same for all continents.

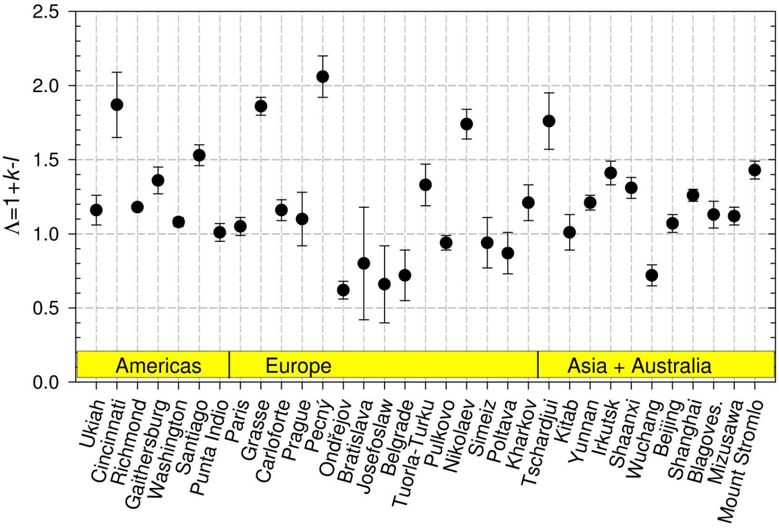

Figure 8. Rheological parameter $\Lambda = 1 + k - l$.

Table 2. The definitive geographic coordinates of the instruments, defining the terrestrial frame

	Code	latitude			longitude E		
		°	′	″	°	′	″
Photographic zenith telescopes	MZP	39	8	02.797	141	7	51.978
	OJP	49	54	55.122	14	47	09.177
	PIP	-35	20	40.622	-57	17	08.408
	RCP	25	36	47.046	-80	22	55.960
	WA	38	55	17.220	-77	3	55.985
	MS	-35	19	17.449	149	0	19.472
Photoelectric transit instruments	IRF	52	16	44	104	20	41.949
	KHF	50	0	00	36	13	58.093
	NK	46	58	18	31	58	28.151
	PUF	59	46	18	30	19	38.042
	WHF	30	32	29	114	20	41.668
Visual zenith telescopes	CA	39	8	09.160	8	18	44
	CI	39	8	19.430	-84	25	00
	GT	39	8	13.287	-77	11	57
	KZ	39	8	02.094	66	52	51
	MZZ	39	8	03.693	141	7	51
	TS	39	8	11.293	63	29	00
	UK	39	8	12.136	-123	12	35
	BLZ	44	48	10.463	20	30	50
	BK	50	19	09.610	127	30	00
	IRZ	52	16	44.369	104	20	43
	POL	49	36	13.086	34	32	53
	TT	60	24	57.509	22	27	00
	VJZ	52	5	56.211	21	0	00
	PUZ	59	46	05.651	30	19	40
Astrolabes and circumzeniths	BJB	40	6	03.970	116	19	41.015
	BRC	48	9	17.772	17	7	11.865
	GRD	43	44	55.389	6	55	37.167
	PA	48	50	09.275	2	20	15.461
	PRE	50	4	40.007	14	42	00.875
	PRD	50	6	20.402	14	23	20.816
	PYD	49	54	55.618	14	47	20.139
	SC	-33	23	56.869	-70	32	42.584
	SIA	44	24	12.388	33	59	48.789
	SXA	34	56	43.528	109	33	04.808
	SXB	34	20	35.782	109	8	05.362
	WHA	30	32	29.143	114	20	42.071
	YUB	25	1	45.334	102	47	40.441
	ZIA	31	11	25.136	121	25	37.604
	ZIB	31	11	26.174	121	25	39.246

5. CONCLUSIONS

The new solution OA10 is based on 4 505 442 optical astrometry observations of individual stars, covering the interval 1899.7–1992.0. The solution is linked to the ICRF via the star catalog EOC-4, and to the ITRF via the solution based on modern space techniques (SLR, VLBI, GPS) in the interval 1978.0–1992.0. We expect that the link of the new solution to ICRF is given with the same uncertainty as the Hipparcos Catalogue, i.e. 0.6 mas in bias and 0.25 mas/a in rotation around all three axes (Kovalevsky et al., 1997). The link to the ITRF, established in the present study, is estimated to be given with uncertainty of about 1–2 mas in bias, 0.09 mas/a in rotation around x, y axes and 0.9 mas/a around z-axis. Much worse link in rotation around z- axis is caused by the shortness of observations of Universal time (about one half of that of polar motion), and also by larger dispersion of the drifts (compare Fig. 1 with 2).

The total number of parameters, estimated from the least-squares solution, are 16 463 (5-day values of x, y, UT1-UTC, systematic deviations in latitude and/or longitude and rheological parameters for each instrument, 6 parameters for celestial pole offsets and 18 Lagrange coefficients for the constraints). The solution yields slightly better results than the ones based on previous versions of EOC catalog: the average standard error of one star observation is $\sigma_\circ = 0.184''$ (former value with EOC-3 was $0.190''$). The solution OA10 will be used to further analyze the rotational behavior of the Earth in the 20th century.

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