THE PRESENT STATUS OF PREPARING THE NEW REDUCTION OF THE PAST ASTROMETRIC OBSERVATIONS TO OBTAIN THE EARTH ORIENTATION PARAMETERS IN THE HIPPARCOS REFERENCE SYSTEM

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ABSTRACT. The IAU Working group on Earth rotation in the Hipparcos reference frame, set up by IAU Commission 19 in 1988, is presently preparing the algorithms and collecting the data obtained by optical astrometry since the beginning of the century. The main idea is to use the observations of individual stars rather than group results, all recalculated in the unique system of astronomical constants and algorithms. The final solution will be referred to the celestial reference frame realized by the Hipparcos star catalog presently under preparation. All known geophysical influences (as e.g. solid and oceanic Earth tides or plate tectonic movements) will be included into the model. In addition to traditional Earth rotation parameters (polar motion, universal time), also the pole offset components in the celestial reference frame will be solved for, as well as other relevant parameters (systematic seasonal deviations of the individual stations, instrumental constants etc.). The present status of the solution and the time evolution of its expected accuracy are described.

1. INTRODUCTION

Soon after Chandler's (1891) discovery of polar motion, an international program was established to monitor this motion using optical astrometry observations (ILS,IPMS). After 1955, when atomic clocks became available, the BIH started to coordinate from 60 to 90 astrometric stations and provided their regular analyses until 1987. The analyses included also the relation between Universal and Atomic time. All these past observations have been reduced with respect to different star catalogs and, consequently, to slightly different reference frames, often with relatively low accuracy.

In August 1989, the ESA launched successfully the astrometric satellite HIPPARCOS which would measure the precise positions, proper motions and parallaxes of about 120 000 stars. In spite of the initial problems with placing the satellite into final geosynchronous orbit, the present status of the mission is excellent and one can expect even better positional precision than originally planned ±0.002" (Kovalevsky 1992). Since nearly all the stars used to determine the Earth Orientation Parameters (EOP) by optical astrometry in the past have been included in the Input Catalog of the mission, the necessary steps were taken, before the mission started, to use the HIPPARCOS Catalog to re-reduce the past astrometric observations in a unique, homogeneous and more accurately realized reference frame.

Thus the IAU Working Group on Earth rotation in the HIPPARCOS reference frame was appointed by Commission 19 at the 20th IAU General Assembly in Baltimore (1988) and

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its work prolonged at the 21st IAU General Assembly in Buenos Aires (1991). Its task is to select the most precise instruments, collect the past observations, propose the models and to solve for the EOP since the beginning of the century in the HIPPARCOS reference frame, when it becomes available. The original membership list of 1988 was slightly reorganized in 1991 in order to reflect the fact that theoretical models had already been proposed and to stress the necessity of collecting the observations and creating the reliable input database. The present membership is the following:

B.Archinal (USA), M.Bougeard (France), N.Capitaine (France), F.Chollet (France), V.Gorshkov (Russia), J.Hefty (Slovakia), B.Kolaczek (Poland), A.Korsun (Ukraine), K.Kurzynska (Poland), Z.X.Li (China), J.Luck (Australia), M.Meinig (Germany), V.Naumov (Russia), F.Noël (Chile), J.Popelar (Canada), J.Vondrák (Czech Republic, chair), K.Yokoyama (Japan).

The new reduction of the existing astrometric data will be referred to a better realization of the optical celestial reference frame (unique and more accurate star catalog) as well as to an improved realization of the terrestrial reference frame (corrections for the fluctuations of the vertical and plate motions will be included). The series under preparation will be much longer than the series obtained so far by modern space techniques and, consequently, improvements can be expected mainly in estimation of the long-periodic components of the EOP (Capitaine 1991b).

2. PARTICIPATING OBSERVATORIES AND DATA COLLECTION

After many discussions within the WG, the final list of observatories to be asked to participate in the project has been compounded and published (Vondrák et al. 1992). Only the best instruments, with sufficiently accurate, stable, frequent and long series of observation have been selected. The list comprises 55 different instruments (15 visual zenith telescopes, 1 visual zenith tube, 2 floating zenith tubes, 6 visual and 6 photoelectric astrolabes, 17 photographic zenith tubes and 8 photoelectric transit instruments) working at 37 observatories in 19 states (China 6; Russia and USA 5; Argentina, Canada, France, Japan and United Kingdom 2; Australia, Chile, Czechoslovakia, Finland, Italy, Spain, Switzerland, Turkmenia, Ukraine, Uzbekistan and Yugoslavia 1). All these observatories have been contacted and asked to cooperate; prevailing majority of them have already responded positively. The detailed specification of the data files needed from the observatories was worked out and dispatched to the participating observatories in 1991.

3. MODELS AND ALGORITHMS TO BE USED

The models and algorithms proposed by the WG for the solution are described in detail elsewhere (Vondrák 1991a, b); therefore only a short description follows. Much more sophisticated procedures will be used in comparison with past practice.

Before the global adjustment, all the observations will be recalculated in order to refer them to the same standards, kept as close as possible to the newest version of the IERS standards (McCarthy 1992). Namely the unique celestial reference frame (realized by HIPPARCOS catalog), the concept of non-rotating origin (Guinot 1979, Capitaine 1990), IAU precession-nutation model (Lieske 1979, Seidelmann 1982), annual aberration (Ron and Vondrák 1986) and Pulkovo refraction tables (Abalakin 1985) will be used, as well as the effects of radial velocity and deflection of light in the gravitational field of the Sun. The relative motions of the local verticals with respect to the terrestrial reference frame will also be modelled, both secular (due to tectonic plate motions after DeMets et al. 1990) and periodic due to solid Earth and oceanic luni-solar tides.

Individual star observations will be used instead of group results used in the past. This approach was chosen because it would enable to recalculate more precisely the original results reported by the observatories into the new standards. It will also ensure better time resolution and enable the addition of two new unknown parameters - celestial pole offsets (or nutation angles) $\mathrm{d}\psi$, $\mathrm{d}\varepsilon$. The observation equations have different form for different methods of observation; for the latitude, universal time and equal altitude observations they are respectively:

$$\begin{aligned}
v_\varphi &= -(1-0.0042\cos 2\varphi_o)(x\cos\lambda_o - y\sin\lambda_o) + \mathrm{d}\varepsilon\sin\alpha + \mathrm{d}\psi\sin\varepsilon\cos\alpha - \mathrm{d}\varphi + (\varphi-\varphi_o)\\
v_T &= -(\mathrm{UT1-UTC}) - 1.0015\tan\varphi_o(x\sin\lambda_o + y\cos\lambda_o) - \tan\delta(\mathrm{d}\varepsilon\cos\alpha - \mathrm{d}\psi\sin\varepsilon\sin\alpha) - \\
&\quad -0.9973\,\mathrm{d}\lambda + (\mathrm{UT0-UTC})\\
v_h &= a(\mathrm{UT1-UTC}) + bx + cy + d\,\mathrm{d}\varepsilon + e\,\mathrm{d}\psi + f\,\mathrm{d}\varphi + g\,\mathrm{d}\lambda - \delta h,
\end{aligned} \tag{1}$$

in which

$$\begin{aligned}
a &= 1.0027\cos\varphi_o\sin A\\
b &= (1-0.0042\cos 2\varphi_o)\cos\lambda_o\cos A + 1.0042\sin\varphi_o\sin\lambda_o\sin A\\
c &= -(1-0.0042\cos 2\varphi_o)\sin\lambda_o\cos A + 1.0042\sin\varphi_o\cos\lambda_o\sin A\\
d &= \sin q\sin\delta\cos\alpha - \cos q\sin\alpha\\
e &= -\sin\varepsilon(\sin q\sin\delta\sin\alpha + \cos q\cos\alpha)\\
f &= \cos A\\
g &= \cos\varphi_o\sin A.
\end{aligned}$$

Here v denotes the residual, φ, UT0−UTC and δh are observed quantities, UT1−UTC, x, y, $\mathrm{d}\varepsilon$, $\mathrm{d}\psi$ are Earth Orientation Parameters to be estimated by the least-squares method, and φ_o, λ_o are approximate geographic coordinates of the observatory; α, δ, A and q denote right ascension, declination, azimuth (reckoned from south) and parallax angle of the observed star. Two sets of unknown parameters, grouped under symbolic denominations $\mathrm{d}\varphi$, $\mathrm{d}\lambda$, contain not only the corrections to the adopted mean geographic latitude and longitude of the observatory, but also personal equations and the systematic seasonal deviations which are supposedly caused by periodic changes in local refraction anomalies with annual and semi-annual period. Observation equations (1) account for the small rotational deformations of the Earth's body (Korsun et al. 1989). For sake of simplicity they do not contain certain parameters that will be also solved for - e.g. some instrumental constants (azimuth for transit instruments, zenith distance for astrolabes etc.), corrections to adopted refraction model (Kurzynska 1991), systematic deformations of the almucantar in case of astrolabes (Pešek 1992), rheological parameter $\Lambda = 1 + k - l$ affecting amplitudes of tidal variations of the local vertical, color and magnitude effects (Hefty 1991), secular drifts of some of the stations that cannot be reliably predicted by the plate tectonic model (those located near plate borders) or the positions and proper motions of the observed stars that are not included in the HIPPARCOS catalog.

As shown in (Vondrák et al. 1992), the direct use of the celestial pole offsets $\mathrm{d}\psi$, $\mathrm{d}\varepsilon$ in the global adjustment has certain advantage over classical z, w terms used in the past to account for the offset between the pole of the catalog and the axis of Earth's rotation, as well as for the errors in precession-nutation model. In addition, the comparison of these values with the pole offsets obtained from the VLBI observations will yield another possibility of linking optical and radio reference frames. From the structure of Eqs. (1) it is clear that the parameters UT1-UTC, x and y manifest themselves as long-periodic variations of the Earth-bound observed quantities φ, UT0-UTC and δh, while the celestial pole offsets as quasi diurnal variations (right ascensions of the observed stars change, during a night, with a period of one sidereal day). Consequently, in order to obtain the pole offsets independently of the other parameters, the intervals covered by observations in each single session (one night) should be kept as long as possible. The use of single star observations is thus evidently preferable to group means.

The classical system of normal equations based on observation equations (1) is singular; the coefficients standing with the unknowns UT1-UTC, x, y, $d\varphi$ and $d\lambda$ are linearly interdependent. This is the consequence of the fact that the terrestrial system of reference in which the three Earth rotation parameters UT1-UTC, x, y are given has not yet been fixed. Similar dependence and arguments apply also to the systematic seasonal deviations mentioned above; the coefficients standing with the four parameters modelling annual and semi-annual variations in latitude/longitude at each observatory are linearly dependent on the coefficients standing with the other parameters. Therefore, in general 15 additional constraints have to be imposed to make the system of normal equations solvable. They can be formulated in many different ways, but they must fix the coordinate system for the origin of polar motion (2 constraints) and of longitudes (1 constraint). The constraints must also ensure that the influence of local systematic seasonal deviations in observed latitudes on polar motion (8 constraints) and in observed universal time UT0-UTC on UT1-UTC (4 constraints) at annual and semi-annual frequency be minimized. Very probably, the best and most direct way will be to demand that there be no difference between the new solution and a solution based on space techniques at zero, annual and semi-annual frequency, in a sufficiently long interval (i.e. at least one year) of common observations. This leads to a set of constraints:

$$
\begin{aligned}
&\sum_1^n x_i = \sum_1^n \overline{x}_i, \quad \sum_1^n x_i \sin 2\pi t_i = \sum_1^n \overline{x}_i \sin 2\pi t_i, \quad \sum_1^n x_i \cos 2\pi t_i = \sum_1^n \overline{x}_i \cos 2\pi t_i, \\
&\qquad\qquad\qquad \sum_1^n x_i \sin 4\pi t_i = \sum_1^n \overline{x}_i \sin 4\pi t_i, \quad \sum_1^n x_i \cos 4\pi t_i = \sum_1^n \overline{x}_i \cos 4\pi t_i, \\
&\sum_1^n y_i = \sum_1^n \overline{y}_i, \quad \sum_1^n y_i \sin 2\pi t_i = \sum_1^n \overline{y}_i \sin 2\pi t_i, \quad \sum_1^n y_i \cos 2\pi t_i = \sum_1^n \overline{y}_i \cos 2\pi t_i, \\
&\qquad\qquad\qquad \sum_1^n y_i \sin 4\pi t_i = \sum_1^n \overline{y}_i \sin 4\pi t_i, \quad \sum_1^n y_i \cos 4\pi t_i = \sum_1^n \overline{y}_i \cos 4\pi t_i, \\
&\sum_1^n (\mathrm{UT1-UTC})_i = \sum_1^n \overline{(\mathrm{UT1-UTC})}_i, \quad \sum_1^n (\mathrm{UT1-UTC})_i \sin 2\pi t_i = \sum_1^n \overline{(\mathrm{UT1-UTC})}_i \sin 2\pi t_i, \\
&\qquad\qquad\qquad \sum_1^n (\mathrm{UT1-UTC})_i \cos 2\pi t_i = \sum_1^n \overline{(\mathrm{UT1-UTC})}_i \cos 2\pi t_i, \\
&\qquad\qquad\qquad \sum_1^n (\mathrm{UT1-UTC})_i \sin 4\pi t_i = \sum_1^n \overline{(\mathrm{UT1-UTC})}_i \sin 4\pi t_i, \\
&\qquad\qquad\qquad \sum_1^n (\mathrm{UT1-UTC})_i \cos 4\pi t_i = \sum_1^n \overline{(\mathrm{UT1-UTC})}_i \cos 4\pi t_i,
\end{aligned}
\qquad (2)
$$

where t_i is the time (in years) elapsed from the beginning of the running year. The values x, y, UT1-UTC with and without bar refer to space techniques and optical astrometry respectively.

The system of normal equations based on the least-squares method with constraints is schematically shown in Fig. 1. The part denoted as "intervals" refers to the five EOP, estimated for each interval (preliminarily five days long), "stations" denotes the local parameters specific for each observatory and "common" denotes the parameters which are supposed to be constant in time and common to all observatories. The matrix is expected to be rather sparse; considering 5-day intervals, each year will yield as much as 72 intervals containing 5x5 submatrices each (see upper left corner of the matrix). The form of the matrix thus enables to use numerical methods of solving the system based on decomposition of the matrix and demanding less space of the computer memory.

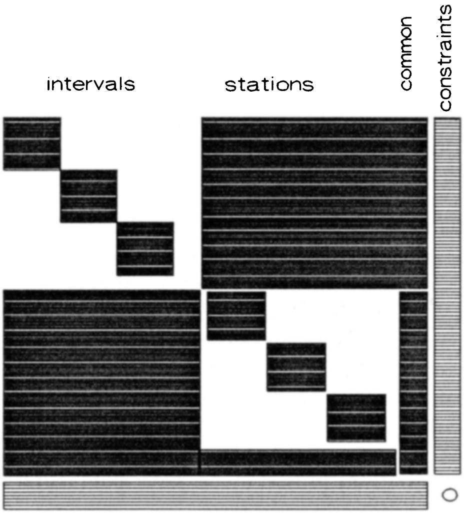

Fig. 1 *Scheme of the normal equations matrix*

Another problem is the identification and elimination of the outliers. Here we are going to use either repeated application of the least-squares method, or a single application of the more robust L_1 procedure (Bougeard 1988). Statistical tests of significance of some of the unknown parameters by means of stepwise regression at a certain level of significance (Bougeard 1992) are also considered.

4. PRESENT STATUS OF THE SOLUTION, CONCLUSIONS

The collection of data have already begun, though not as quickly as we hoped. Since the main philosophy of the prepared solution is to use the observations of individual stars instead of group results used in the past, there obviously arise problems with converting the data (often rather bulky) into machine-readable form. As a consequence, the data flow from the observatories to the center is very slow and, taken into consideration that the people familiar with this type of observations are getting old and retiring, this appears to be a crucial point of the prepared solution. Some of the problems connected with the rapidly decreasing amount of astrometric observations during the last decade are discussed by Li et al. (1991).

The expected accuracy and correlations of the prepared solution have been studied by Vondrák et al. (1992). Based on today's knowledge of the accuracies and time distribution of the observations at individual observatories and on the expected accuracy of the HIPPARCOS catalog, 5-day solution of polar motion can be known to ±0.030" in the first half of the century and ±0.009" after 1960; universal time can be determined to ±0.0008s after 1960. As for the position of the Earth's rotation axis in space (celestial pole offset), its expected uncertainty is of the order of ±0.02"-0.08" at the beginning of the century and ±0.01" during the last two or three decades. The expected uncertainties have significant seasonal character, mainly due to seasonally changing density of observations. In addition, the error ellipse of the celestial pole offset is highly elliptic (major to minor axis ratio of 2.5-3.0). It rotates with annual period; due to the fact that the observations are centered around local midnight its minor axis directs always towards the Sun.

The analysis of some of astrolabe observations (Paris, Santiago de Chile) began. Namely we are searching for possible almucantar deformations, discovered recently by Pešek (1992) in Prague circumzenithal observations. Preliminary results show that there exist systematic deformations of the order of 0.1"-0.2" at both observatories. The deformations show significant seasonal changes. Although a part of these effects can be ascribed to catalog errors, we estimate that at least 50 per cent of them are caused by local azimuth-dependent refraction anomalies. Consequently we conclude that these deformations should be a part of the model used for the adjustment.

Software package to solve the system of normal equations (of the expected form displayed in Fig. 1) has been worked out; it is based on Cholesky decomposition of the matrix. At present, the software is being tested with simulated data.

The theoretical part of the solution is thus proceeding smoothly, without serious problems. The models are constantly being improved and the expected accuracy of the final solution is promising, provided the observations from all the selected observatories will become available. Nevertheless, there is a danger that some of the valuable observations might be lost if the database is not created soon. Certain motivation for the participating observatories might be the priority access to the central data bank for their own analyses and to the final solution, and also co-authorship of preliminary analyses published in course of the solution. International support of the project by the IAU, both moral and financial (even a modest one) might help a lot.

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