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CORRECTIONS TO THE HIPPARCOS PROPER MOTIONS IN DECLINATION FOR 807 STARS

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SUMMARY: We used the data on latitude variations obtained from observations with 10 classical photographic zenith tubes (PZT) in order to improve the Hipparcos proper motions in declinations μ_δ for 807 stars. Part of observing programmes, carried out during the last century for the purpose of studying the Earth's rotation, were realized by using PZT instruments. These observations were performed within in the intervals (tens of years) much longer than that of the Hipparcos mission (less than 4 years). In addition, the annual number of observations for every PZT-programme star is several hundreds on the average. Though the accuracy of the star coordinates in the Hipparcos Catalogue is by two orders of magnitude better than that of the star coordinates from the PZT observations, the large number of observations performed a much longer time interval makes it possible to correct the Hipparcos proper motions and to improve their accuracy with respect to the accuracy given in the Hipparcos Catalogue. Long term examinations of latitude and time variations were used to form the Earth Orientation Catalogue (EOC-2), aimed at a more accurate determination of positions and proper motions for the stars included. Our method of calculating the corrections of the proper motions in declination from the latitude variations is different from the method used in obtaining the EOC-2 Catalogue. Comparing the results we have established a good agreement between our μ_δ and the EOC-2 ones for the star sample used in the present paper.

Key words. Astrometry – Reference systems

1. INTRODUCTION

At the IAU General Assembly in Kyoto 1997, the International Celestial Reference Frame (ICRF) was adopted to materialize the International Celestial Reference System (ICRS) from the beginning of 1998, and it was based on a catalogue of 608 compact radio sources (Ma et al. 1998).

The Hipparcos ESA mission (ESA 1997) produced two catalogues in optical wavelength, both linked to the ICRF: Hipparcos (118218 stars with coordinate accuracy close to 1 mas at 1991.25, epoch of the catalogue, 1 mas/yr accuracy of proper motions in $\mu_\alpha \cos\delta$ and μ_δ, and very accurate parallaxes and photometry) and Tycho (1058332 stars with 25 mas accuracy of coordinates). As a result of the IAU resolution from 1997 the Hipparcos Catalogue was

Table 1. The informations for PZT instruments.

observatory	instrument	N	period	MJD	$\lambda(^\circ)$	$\varphi(^\circ)$
Mizusawa	MZP, MZQ	137	02.I 1959-21.XII 1991	36570.6-48611.5	141.1	39.1
Mount Stromlo	MS	184	31.X 1957-27.VIII 1985	36142.5-46304.7	149.0	-35.3
Ondřejov	OJP	285	05.II 1973-14.XII 1991	41718.9-48604.7	14.8	49.9
Punta Indio	PIP	165	03.VIII 1971-29.VI 1984	41166.9-45881.1	-57.3	-35.3
Richmond	RCP, RCQ	202	05.XI 1949-12.V 1989	33225.2-47658.1	-80.4	25.6
Washington	WA, W, WGQ	188	28.X 1915-26.XII 1991	20798.2-48616.0	-77.1	38.9

adopted to be the primary realization of ICRS in the optical domain. It contains stars brighter than $V = 12$ (mostly between $V = 7$ and $V = 9$). The Hipparcos stars positions and proper motions are bases of the optical frame HCRF (Hipparcos Celestial Reference Frame).

It is evident that the combinations of Hipparcos and Tycho catalogues and the ground-based ones can improve the positions and proper motions of observed stars. During the last decade, a number of problems concerning the Hipparcos data appeared: a different accuracy of the data for single Hipparcos stars than for double and multiple ones due to the short duration of the satellite mission, different accuracy of the data for different parts of the celestial sphere, more inaccurate apparent star positions due to the errors of proper motions whose influence is linear in time (from the epoch 1991.25) and by now the errors of apparent position attained about 15 mas (one order of magnitude larger than the average position error in Hipparcos Catalogue), etc. All this is the reason that new star catalogues appeared after the Hipparcos one, such as ARIHIP (Wielen et al. 2001), and the Earth Orientation Catalogue (EOC-2) (Vondrák 2004), with more accurate star positions and proper motions than those from Hipparcos.

2. DATA AND CALCULATIONS

Here we use the results of latitude observations made with PZT instruments over a few decades together with the Hipparcos Catalogue data, in order to obtain proper motions in declination more accurate than the Hipparcos ones for 807 stars.

The reduction procedure for the latitude variations φ_i was described by Vondrák et al. (1998). We investigate these latitude variations φ_i with time around the corresponding mean latitudes. The elimination of systematic effects of interest (polar motion, local and instrumental systematic variations) for this investigation is described in the paper by Damljanović (2005).

Our input data were the latitude variations obtained by using 10 PZT instruments at 6 observatories. Table 1. contains some basic informations about the observatories and PZT instruments. The columns of Table 1. are: observatory – the name of the observatory, instrument – the codes of the instruments, N – the number of observed stars, period – the dates when observations were started and finished, MJD – corresponding Modified Julian Dates ($MJD = JD - 2400000.5$), λ – the longitude of the observatory and φ – the latitude of the observatory. The codes (MZP, MZQ, etc.) are from the monograph by Vondrák et al. (1998).

The first PZT instrument was WA which started with the observations at the end of 1915. The observatories Punta Indio and Mount Stromlo are nearly at the same latitude, their longitudes different, and because of that there are 157 common stars in their observational programmes. The results for these common stars could be used to check our method (Damljanović 2005) and to compare results for the same stars observed by PZTs in different continents. The similar situation is for the observatories Washington and Mizusawa; there are 71 stars in common. The longitude λ_W of PZT instrument is west of the zero meridian and it is useful here to calculate the polar motion component $\Delta\varphi_i$ (dominant in φ_i) by using the Kostinski's formula $\Delta\varphi_i = x_i \cos\lambda_W + y_i \sin\lambda_W$ (Kulikov 1962).

As a first step of our calculations, we remove the polar motion components $\Delta\varphi_i$ from the values of φ_i. The polar motion coordinates, x_i and y_i, are from Vondrák's file EOPOA00.dat. In this way, we get the residuals (for corresponding observational epochs) $r_i = -(\varphi_i - \Delta\varphi_i)$ for every observed star (Damljanović 2005).

As a second step, we calculate the systematic effects se_i (local, instrumental, etc.) for the observational epochs and get new residuals $r'_i = r_i - se_i$, where the values se_i for each instrument are found by using the values r_i for all stars of the observational programme (Damljanović 2005, Damljanović et al. 2006). After eliminating the polar motion changes and the other systematic effects (local, instrumental, etc.) we assume that the differences r'_i are mostly due to the catalogue systematic errors (influence of proper motions in declination). The unknown corrections of the proper motions in declination are contained in r'_i. We process star by star, using the linear fit $r''_i = a + b(t_i - 1991.25)$, where the unknowns a and b are determined by using the Least Squares Method (LSM), the values r''_i are the averaged values of r'_i over subperiods of 1 year for each star, and the values t_i are the times (in years) corresponding to r''_i. Obviously, the value a is the correction of $\Delta\delta$ and b is the correction of $\Delta\mu_\delta$; both are calculated for the epoch of the Hipparcos Catalogue 1991.25. As an input value for the fit, to the points r''_i we add one more point with the coordinates (1991.25, $0''\!.0$). All points are with suitable weights (Damljanović et al. 2006). We add our calculated corrections b to the corresponding Hipparcos proper motions in declination. In this way we obtain the values μ_δ and their errors.

3. RESULTS

The calculated values μ_δ and ϵ_{μ_δ} for 807 stars are presented in Table 2. Also, in Table 2. we list the values of proper motions in declination and their errors from EOC-2 and Hipparcos catalogues for the purpose of comparison of the results.

The columns of Table 2. are: HIP – the Hipparcos number, m – the number of points r_i'', μ_δ – our proper motions in declination, ϵ_{μ_δ} – the standard errors of μ_δ, $\mu_{\delta_{EOC-2}}$ – the EOC-2 proper motions, $\epsilon_{\mu_{\delta EOC-2}}$ – the standard errors of $\mu_{\delta_{EOC-2}}$, $\mu_{\delta_{\mathrm{HIP}}}$ – the Hipparcos proper motions, $\epsilon_{\mu_{\delta\mathrm{HIP}}}$ – the standard errors of $\mu_{\delta_{\mathrm{HIP}}}$, M – Fig. 1 means that the star is common to Washington and Mizusawa, number 2 that the star is common to Mount Stromlo and Punta Indio and empty field means that the star is observed at only one observatory. For each common star observed at two observatories the value m is approximately equal to the sum of observational periods at both observatories expressed in years. For stars observed at only one observatory m is close to observational period expressed in years. The complete Table 2 is given at the URL: `http://saj.matf.bg.ac.yu/177/pdf/Table2.dat`.

Our best results for μ_δ (313 stars observed for almost 20 and for more than 20 years with errors ϵ_{μ_δ} mostly smaller than the Hipparcos ones) are in the first part of Table 2. The results with errors ϵ_{μ_δ} close to the Hipparcos errors (372 stars observed between 10 and 20 years) are in the second part of Table 2. The results with errors ϵ_{μ_δ} mostly exceeding the Hipparcos errors (122 stars observed for less than 10 years) are in the third part of Table 2.

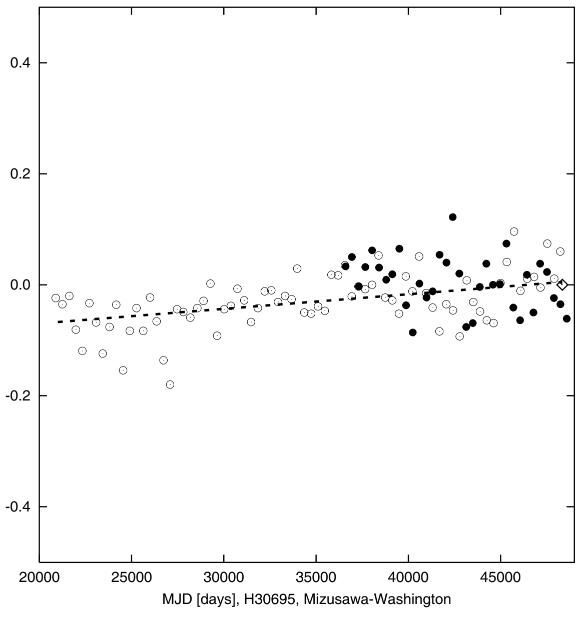

Fig. 1. *Star H30695. Linear trend and residuals r_i'' of Mizusawa (solid circles) and Washington (open circles) observations vs. time (MJD), and the Hipparcos point (open rectangle).*

For example, the calculated value $b \pm \epsilon_b$ for a common Mizusawa and Washington star H30695 (8.33 mag) is $+0.96 \pm 0.15$ mas/yr, with $m = 110$ points r_i'', and we thus got $\mu_\delta = 10.20 \pm 0.15$ mas/yr. The values r_i'' and the linear trend are presented in Fig. 1.

From EOC-2: $\mu_\delta = 10.05 \pm 0.10$ mas/yr.

From Hipparcos: $\mu_\delta = 9.24 \pm 0.76$ mas/yr.

The results with similar errors for the other stars are presented in the first part of Table 2.

4. DISCUSSION

For $m \geq 10$ (685 stars from the first and second parts of Table 2.), the average value of ϵ_{μ_δ} is 0.80 mas/yr (similar to the Hipparcos one for the same stars). For $m \geq 20$ (313 stars of the first part of Table 2.), the average value of ϵ_{μ_δ} is 0.40 mas/yr (0.74 mas/yr is the Hipparcos value for the same stars). This means that, by observing with PZT instruments for 10 or more years, we can get the results μ_δ with similar errors to the Hipparcos ones. If m is greater than 20, our results are much better than the Hipparcos ones. Vice versa, if m is less than 10 (122 stars of the third part of Table 2.), the average value of ϵ_{μ_δ} is 1.87 mas/yr (0.78 mas/yr for the same Hipparcos stars). So, with less than 10 years of PZT observations, it is not possible to get the results μ_δ with errors comparable to the Hipparcos ones.

The further verification of these results is carried out by applying the F-test. The test statistics is

$$F = S_1^2 / S_2^2$$

where S_1^2 is the averaged value obtained by using $\epsilon^2_{\mu_{\delta\mathrm{HIP}}}$, and S_2^2 by using $\epsilon^2_{\mu_\delta}$. If $F \geq F_{f_1,f_2;\alpha}$, one concludes that S_2^2 is smaller than S_1^2.

For the case $m \geq 20$ ($n = 313$ stars, $f_1 = f_2 = 312$, $\alpha = 0.05$) we obtain $S_1^2 = 0.61$ and $S_2^2 = 0.21$, so that

$$F = 2.9 > 1.2 = F_{312,312;0.05}.$$

The hypothesis $H_0(\epsilon^2_{\mu_\delta} = \epsilon^2_{\mu_{\delta\mathrm{HIP}}})$ can be rejected. This means that the values $\epsilon^2_{\mu_\delta}$ are smaller than the $\epsilon^2_{\mu_{\delta\mathrm{HIP}}}$ ones, and our results on μ_δ are better than the Hipparcos ones.

For the case $m \geq 10$ ($n = 685$ stars, $f_1 = f_2 = 684$, $\alpha = 0.05$) we obtain $S_1^2 = 0.81$ and $S_2^2 = 1.09$, so that

$$F = 0.7 < 1.1 = F_{684,684;0.05}.$$

Table 2. The values μ_δ and ϵ_{μ_δ} for 807 stars: ours, EOC-2 and Hipparcos ones, M corresponds to the observatory.[1]

HIP	m	μ_δ (mas/yr)	ϵ_{μ_δ} (mas/yr)	$\mu_{\delta_{\mathrm{EOC-2}}}$ (mas/yr)	$\epsilon_{\mu_{\delta\mathrm{EOC-2}}}$ (mas/yr)	$\mu_{\delta_{\mathrm{HIP}}}$ (mas/yr)	$\epsilon_{\mu_{\delta\mathrm{HIP}}}$ (mas/yr)	M
167	60	-3.30	.18	-3.41	.14	-4.37	.61	
630	40	-57.69	.25	-56.55	.20	-56.82	.64	
732	37	-10.82	.39	-11.37	.29	-12.15	.53	2

This means that the values $\epsilon^2_{\mu_\delta}$ are not better than, but rather similar to the Hipparcos ones.

The similar investigations (for $m \geq 10$), but for the stars of each observatory separately, gave us the following average values of ϵ_{μ_δ}:
- Richmond (165 stars), 0.39 mas/yr (0.74 mas/yr for the same Hipparcos stars),
- Washington/Mizusawa (46 stars), 0.41 mas/yr (0.71 mas/yr),
- Punta Indio/Mount Stromlo (144 stars), 0.57 mas/yr (0.82 mas/yr),
- Washington (84 stars), 0.66 mas/yr (0.67 mas/yr),
- Mizusawa (58 stars), 1.14 mas/yr (0.77 mas/yr),
- Ondřejov (187 stars), 1.48 mas/yr (0.92 mas/yr).

The best results are those of the Richmond PZTs. The averaged value of ϵ_{μ_δ} is about 53% of the value from the Hipparcos Catalogue. The PZT observations made at the Richmond Observatory cover about 40 years. The results for the Mizusawa Observatory are mostly with higher values of ϵ_{μ_δ} than the Hipparcos ones even though the observed period is longer than 30 years. In combination with the Washington observations (for the common Washington/Mizusawa stars) the results are much better. The errors of the results of the Ondřejov data are similar to the Mizusawa ones. The reason for poor results in the case of Mizusawa is that this is a very active seismic region, but for the Ondřejov ones it is the observational programme with a lot of double and multiple stars (the average value of $\epsilon_{\mu_{\delta\mathrm{HIP}}}$ is 0.92 mas/yr which exceeds the values of the other observational programmes). The high values of the Ondřejov systematic errors (local, instrumental, etc.) are well known (Vondrák et al. 1998).

We also compare our results with those from EOC-2. We calculate the average values of the modulus of the differences $(\mu_\delta - \mu_{\delta\mathrm{EOC-2}})$ to find:

0.82 mas/yr for $m \geq 10$ (685 stars),

0.35 mas/yr for $m \geq 20$ (313 stars),

2.16 mas/yr for $m < 10$ (122 stars).

This means that our results are in good agreement with the EOC-2 ones, especially for $m \geq 10$ and $m \geq 20$.

5. CONCLUSIONS

We have calculated the proper motions in declination for 807 stars observed with 10 PZT instruments.

Our results are in good agreement with the EOC-2 ones although different methods are used.

In general, if $m \geq 10$ (stars are observed 10 or more than 10 years) our results are close to the Hipparcos ones, if $m \geq 20$ (stars are observed 20 or more than 20 years) our results are better than the Hipparcos ones. The F-test leads to the same conclusion. To obtain good results it is necessary to have data covering a long time interval of PZT observations.

It is evident that PZT data are useful and can improve the reference frame (via improvement of proper motions in declination of Hipparcos stars).

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[1]The complete Table 2 is given at the URL: `http://saj.matf.bg.ac.yu/177/pdf/Table2.dat`.

ПОПРАВКЕ HIPPARCOS СОПСТВЕНИХ КРЕТАЊА ПО ДЕКЛИНАЦИЈИ ЗА 807 ЗВЕЗДА

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Оригинални научни рад

Користили смо промене ширине добијене из посматрања са 10 класичних фотографских зенитних туба (PZT) да бисмо израчунали поправке Hipparcos сопствених кретања по деклинацији μ_δ за 807 звезда. Део посматрачких програма рађених због изучавања Земљине ротације током прошлог века реализован је помоћу PZT инструмената. Ова посматрања рађена су у много дужим временским интервалима (десетине година) него што је временски интервал Hipparcos мисије (краћи од 4 године). Осим тога, годишњи број посматрања сваке звезде PZT програма је неколико стотина. Иако је тачност координата звезда у Hipparcos каталогу за два реда величине боља од тачности координата звезда добијених из посматрања PZT инструментима, велики број посматрања урађен у много дужем интервалу времена омогућава да се добију поправке Hipparcos сопствених кретања и да се побољша њихова тачност у односу на тачност дату у Hipparcos каталогу. Дугогодишња испитивања промена ширине и времена послужила су за израду Earth Orientation Catalogue (EOC-2) чији је циљ било тачније одређивање положаја и сопствених кретања посматраних звезда. Наш метод рачунања поправки сопствених кретања по деклинацији из промена ширине разликује се од метода коришћеног при добијању EOC-2 каталога. Из поређења резултата установили смо добру сагласност наших и EOC-2 μ_δ за коришћени узорак звезда.