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 $\mu_\delta$ 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 $\mu_\delta$ 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 $\mu_\delta$, 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.

<table>
<thead>
<tr>
<th>observatory</th>
<th>instrument</th>
<th>$N$</th>
<th>period</th>
<th>MJD</th>
<th>$\lambda(\circ)$</th>
<th>$\varphi(\circ)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mizusawa</td>
<td>MZP, MZQ</td>
<td>137</td>
<td>02.I 1959-21.XII 1994</td>
<td>36570.6-48611.5</td>
<td>141.1</td>
<td>39.1</td>
</tr>
<tr>
<td>Mount Stromlo</td>
<td>MS</td>
<td>184</td>
<td>03.IX 1957-27.VIII 1985</td>
<td>36142.5-46304.7</td>
<td>149.0</td>
<td>-35.3</td>
</tr>
<tr>
<td>Ondřejov</td>
<td>OJP</td>
<td>285</td>
<td>05.II 1973-14.XII 1991</td>
<td>41718.9-48604.7</td>
<td>14.8</td>
<td>49.9</td>
</tr>
<tr>
<td>Punta Indio</td>
<td>PIP</td>
<td>165</td>
<td>03.VIII 1971-29.VI 1984</td>
<td>41166.9-45581.1</td>
<td>-57.3</td>
<td>-35.3</td>
</tr>
<tr>
<td>Richmond</td>
<td>RCP, RCQ</td>
<td>202</td>
<td>05.XI 1949-12.V 1989</td>
<td>33225.2-47658.1</td>
<td>-80.4</td>
<td>25.6</td>
</tr>
</tbody>
</table>

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 $\lambda_W$ 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 $\varphi_i$) 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 $\varphi_i$. 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 $s_i$ (local, instrumental, etc.) for the observational epochs and get new residuals $r_i' = r_i - s_i$, where the values $s_i$ 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′′). 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 $\mu$ and their errors.

3. RESULTS

The calculated values $\mu$ and $\epsilon_{\mu}$ 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 $r_i''$, $\mu_b$ - our proper motions in declination, $\epsilon_{\mu_b}$ - the standard errors of $\mu_b$, $\mu_{\text{EOC-2}}$ - the EOC-2 proper motions, $\epsilon_{\mu_{\text{EOC-2}}}$ - the standard errors of $\mu_{\text{EOC-2}}$, $\mu_{\text{HIP}}$ - the Hipparcos proper motions, $\epsilon_{\mu_{\text{HIP}}}$ - the standard errors of $\mu_{\text{HIP}}$. $M$ - 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 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 $\mu$ (313 stars observed for almost 20 and for more than 20 years with errors $\epsilon_{\mu}$ mostly smaller than the Hipparcos ones) are in the first part of Table 2. The results with errors $\epsilon_{\mu}$ 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 $\epsilon_{\mu}$ mostly exceeding the Hipparcos errors (122 stars observed for less than 10 years) are in the third part of Table 2.

For example, the calculated value $b \pm \epsilon_b$ for a common Mizusawa and Washington star H30695 (8.33 mag) is $0.06 \pm 0.15$ mas/yr, with $m = 110$ points $r_i''$, and we thus got $\mu = 10.20 \pm 0.15$ mas/yr. The values $r_i''$ and the linear trend are presented in Fig. 1.

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

From Hipparcos: $\mu_b = 9.24 \pm 0.76$ 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 $\epsilon_{\mu}$ 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 $\epsilon_{\mu}$ 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 $\mu$ 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 $\epsilon_{\mu}$ 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 $\mu$ 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

$$F = \frac{S_1^2}{S_2^2}$$

where $S_1^2$ is the averaged value obtained by using $\epsilon_{\mu_{\text{HIP}}}$, and $S_2^2$ by using $\epsilon_{\mu_{b}}$. 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 $H_0 (\epsilon_{\mu_{b}}^2 = \epsilon_{\mu_{\text{HIP}}}^2)$ can be rejected. This means that the values $\epsilon_{\mu_{b}}$ are smaller than the $\epsilon_{\mu_{\text{HIP}}}$ ones, and our results on $\mu$ 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

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

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).
This means that the values $\epsilon_{\mu_\delta}$ 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 $\epsilon_{\mu_\delta}$:
- 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 $\epsilon_{\mu_\delta}$ 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 $\epsilon_{\mu_\delta}$ 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 $\epsilon_{\mu_\delta}$ 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 (Vondrak et al. 1998).

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


Table 2. The values $\mu_\delta$ and $\epsilon_{\mu_\delta}$ for 807 stars: ours, EOC-2 and Hipparcos ones, $M$ corresponds to the observatory.1

<table>
<thead>
<tr>
<th>HIP</th>
<th>m</th>
<th>$\mu_\delta$ (mas/yr)</th>
<th>$\epsilon_{\mu_\delta}$ (mas/yr)</th>
<th>$\mu_{\text{EOC-2}}$ (mas/yr)</th>
<th>$\epsilon_{\mu_{\text{EOC-2}}}$ (mas/yr)</th>
<th>$\mu_{\text{Hip}}$ (mas/yr)</th>
<th>$\epsilon_{\mu_{\text{Hip}}}$ (mas/yr)</th>
<th>$M$</th>
</tr>
</thead>
<tbody>
<tr>
<td>167</td>
<td>60</td>
<td>-3.30</td>
<td>.18</td>
<td>-3.41</td>
<td>.14</td>
<td>-4.37</td>
<td>.61</td>
<td>1</td>
</tr>
<tr>
<td>630</td>
<td>40</td>
<td>-57.69</td>
<td>.25</td>
<td>-56.55</td>
<td>.20</td>
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<td>.64</td>
<td>2</td>
</tr>
<tr>
<td>732</td>
<td>37</td>
<td>-10.82</td>
<td>.39</td>
<td>-11.37</td>
<td>.29</td>
<td>-12.15</td>
<td>.53</td>
<td>2</td>
</tr>
</tbody>
</table>

1The 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 $\mu_\delta$ за 807 звезда. Део посматрачких програма рађена 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 већи 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 $\mu_\delta$ за коришћени узорак звезда.