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CORRECTIONS OF PROPER MOTIONS IN DECLINATION BY USING ILS DATA

G. Damljanović[1] and N. Pejović[2]

[1]*Astronomical Observatory, Volgina 7, 11160 Belgrade 74, Serbia*

[2] *Department of Astronomy, Faculty of Mathematics, University of Belgrade, Studentski trg 16, 11000 Belgrade, Serbia*

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SUMMARY: There are nowadays numerous astrometric ground–based observations of some stars referred to Hipparcos Catalogue, made at many observatories during the last century. We used the data on latitude variations, covering the period 1899.7 – 1979.0, of visual Zenith Telescopes (ZT) of International Latitude Service (ILS), to improve the Hipparcos proper motions in declination for stars observed at seven ILS stations: Carloforte, Cincinnati, Gaithersburg, Kitab, Mizusawa, Tschardjui and Ukiah. About 15 years elapsed since the HIPPARCOS ESA mission (ESA 1997) observations (1991.25 is the epoch of this catalogue), and with the errors of the Hipparcos proper motions close to 1 mas/yr, the error of apparent places of stars is now more than 15 mas; so that it exceeds the error of the Hipparcos positions by one order of magnitude (which is about 1 mas). Also, for some Hipparcos stars, the errors of proper motions are much larger than the averaged value itself, even not realistic at all (Vondrák et al. 1998); the Hipparcos astronomical satellite mission lasted less than four years, not enough to get a sufficient accuracy of the proper motions. To improve the accuracy of the proper motions for some Hipparcos stars, the ground – based data were used and some new catalogues were published (such as ARIHIP, EOC-2, etc.) during the last decade. Our investigations are in accordance with the Earth Orientation Catalogue – EOC (Vondrák and Ron 2003) one, based on the Earth rotation programmes ground–based data, but we used different method here. Our results yield better proper motions in declination for stars common to ILS and HIPPARCOS, and a good agreement with those from EOC-2.

Key words. Astrometry – Reference systems

1. INTRODUCTION

The HIPPARCOS Catalogue with astrometric data for 118218 stars is the optical counterpart (Kovalevsky et al. 1997) of the International Celestial Reference Frame (ICRF). The standard errors in positions (α and δ) of its stars are around 1 mas at the epoch of the catalogue (1991.25), and the standard errors of its proper motions ($\mu_\alpha \cos\delta$ and μ_δ) are near 1 mas/yr. The stars are brighter than magnitude 12, but most of them are between magnitude 7 and 9. By now several new catalogues have appeared, such as ACT, FK6, GC+HIP, TYC2+HIP, TYCHO-2, ARIHIP, EOC-2, with a better accuracy of the proper motions than in Hipparcos, but as a combination of Hipparcos and/or Tycho with ground–based observations. The main problem for the Hipparcos proper motions accuracy is the period of HIPPARCOS satellite observations which was less than four years; it is not enough to get a good accuracy of proper motions for some stars (such as for double or multiple ones). Also, in some parts of the sky in the Hipparcos Catalogue errors of the proper motion data are larger. Nowadays, 15 years after the epoch of the Hipparcos Catalogue (1991.25), the errors of the Hipparcos proper motions of about 1 mas/yr result in an error of about 15 mas of the calculated apparent positions of the Hipparcos stars; this is close to the ground–based error of the observed positions and an order of magnitude higher than a typical error in a Hipparcos position. Thus, the astrogeodetical observations need a better accuracy of proper motions than that offered by Hipparcos. The aim of some investigations started during the last decade was to improve the Hipparcos proper motions by using ground–based observations covering almost a whole century. As a result, we have several new catalogues of which the ARIHIP (Wielen et al. 2001) and EOC-2 (Vondrák 2004) are of special interest to the present study.

A few years ago, the ground–based astrometric observations of latitude and universal time variations, covering the interval 1899.7 – 1992.0 and made in accordance with the Earth rotation programmes, were included in the investigations aimed at improving the accuracy of the Hipparcos proper motions. Here, we used the data of ZT of ILS and OA00 (Ron and Vondrák 2001) solution of the Earth Orientation Parameters (EOP), but our method was different from that used in EOC-2 (Vondrák 2004). The ILS data cover very long interval (1899.7 – 1979.0) of ZT observations made at seven ILS stations, and by using the ILS latitude variations we determined the corrections of the Hipparcos proper motions in declination with an accuracy close to that of the proper motions given in ARIHIP and EOC-2.

By definition $\mu_\delta = (\delta_1 - \delta_2)/(t_1 - t_2)$, where δ_1 and δ_2 are two declinations (in the same system) of the same star for the epochs t_1 and t_2, respectively. The error of μ_δ is $\epsilon_{\mu_\delta} = (\epsilon_1^2 + \epsilon_2^2)^{1/2}/|t_2 - t_1|$ where ϵ_1 and ϵ_2 are the standard errors of δ_1 and δ_2, respectively. Then, ϵ_{μ_δ} is proportional to $1/t$ (Eichhorn 1974), and with regard to the long ILS interval t we can get a very good accuracy ϵ_{μ_δ} (better than the Hipparcos one) though the Hipparcos data concerning the star positions are better than the ILS ones.

2. DATA AND CALCULATIONS

During each year of the interval 1899.7 – 1979.0, each ILS star pair was observed from a few to a few hundred times. The accuracy of a ZT observation is about $0''\!.2$, but the time interval a few decades long and numerous observations for each ILS pair during each year of that interval are decisive in attaining a better accuracy, than the Hipparcos one, of proper motions in declination for stars common to ILS and Hipparcos. Combining the ILS values (observations) with the Hipparcos one (for the epoch 1991.25) can yield better results (corrections of proper motions in declination for some Hipparcos stars) than if only the ILS data are used (Damljanović et al. 2006). The accuracy is about one order of magnitude better than $0''\!.2$ for the averaged (over nearly one year observational interval) values of latitude variations.

We used the ZT data (latitude variations φ_i) of 7 ILS stations, at nearly the same latitude of $+39^\circ\!.1$ (see Table 1).

The value $(t - t_1)$ is in centuries, and t_1 is counted from 32000 MJD. The codes (CA, CI, GT, KZ, MZZ, TS and UK) are from the monograph by Vondrák et al. (1998). The longitude λ_W is west of the zero meridian. The tectonic plate motion and mean latitude were removed from the ILS data (Vondrák 2002). More about the ILS data was published by Yumi and Yokoyama (1980). Here, 256 ILS star pairs (out of total 281 ones) are included in our calculation because some of the ILS stars are not in the Hipparcos Catalogue: the 256 pairs were observed at CA, GT and MZZ, 198 ones at KZ, 117 ones at CI and TS, 228 ones at UK. Some stars are included in more than one star pair and there are 486 common ILS and Hipparcos stars.

The latitude variations were used to improve the Hipparcos proper motions in declination (Damljanović and Pejović 2005), but the ZT data give us these corrections for star pairs, because with a ZT instrument always a star pair is observed. We found the way to solve this problem and to separate them; see Eq. (5) below. From $\varphi_p = \delta_S + z_S$ and $\varphi_p = \delta_N - z_N$ (Yumi and Yokoyama 1980), the latitude obtained from a star pair φ_p (for

Table 1. Some informations of ILS stations.

ILS station	λ_W (^{o})	Observed int.	Break	Mean latitude (39°8′+”)	Tectonic plate motion(”/100yr)	t interval (MJD)
Carloforte(CA)	351.7	1899.8-1979.0	1943.3-1946.5	9.157	$0.061(t - t_1)$	14950-43863
Cincinnati(CI)	84.4	1899.8-1916.0		19.437	$0.002(t - t_1)$	14898-20868
Gaithersburg(GT)	77.2	1899.8-1979.0	1915.0-1932.6	13.309	$0.012(t - t_1)$	14928-43880
Kitab(KZ)	293.1	1930.8-1979.0		2.057	$0.001(t - t_1)$	26304-43878
Mizusawa(MZZ)	218.9	1900.0-1979.0		3.687	$-0.045(t - t_1)$	15002-46010
Tschardjui(TS)	296.5	1899.7-1919.3		11.334	$0.004(t - t_1)$	18512-22090
Ukiah(UK)	123.2	1899.7-1961.0		12.161	$0.025(t - t_1)$	14937-37302

the moment of measurement t) is the main ZT equation (following from the Horrebow – Talcott method):

$$\varphi_p = (\delta_S + \delta_N)/2 + (z_S - z_N)/2, \qquad (1)$$

where δ_S and δ_N are the apparent declinations of stars of the Talcott pair (δ_N for the northern and δ_S for the southern at t, calculated by using Hipparcos Catalogue), $\Delta z = z_S - z_N$ is the measured value of the zenith-distance difference. From the values of the latitude variations, we removed the polar motion component and the systematic variations with time (local, instrumental, etc.), and obtained the residuals with catalogue errors dominant (Damljanović and Vondrák 2005, Damljanović et al. 2006). Thus, one has (Vondrák et al. 1998)

$$\Delta\varphi_p + (d\varphi_p/dt)t \approx (\Delta\delta_S + \Delta\delta_N)/2 +$$

$$+t(\Delta\mu_{\delta_S} + \Delta\mu_{\delta_N})/2\,,$$

where $\Delta\delta_S$ and $\Delta\delta_N$ are corrections of declinations (for S and N star, respectively), $\Delta\mu_{\delta_S}$ and $\Delta\mu_{\delta_N}$ are corrections of proper motions in declination (for S and N stars, respectively), t is time.

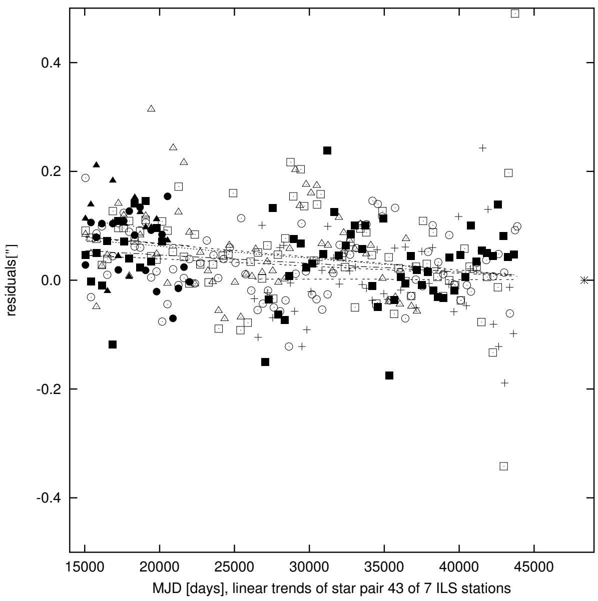

Fig. 1. *Residuals r'_n, linear trend of star pair 43 of each ILS station (CA – open rectangles, GT – solid rectangles, KZ – sign +, MZZ – open circles, TS – solid circles, UK – open triangles, CI – solid triangles), and Hipparcos point (asterisks).*

To calculate the correction of proper motion in declination corresponding to a star pair (of ILS/Hipparcos stars), we use the Least Squares Method (LSM) and linear model (Damljanović 2005, Damljanović and Pejović 2005)

$$r'_n = a + b(t_n - 1991.25), \qquad (2)$$

where r'_n is the star pair residual – about one point per year (residual of latitude variations, without polar motion and the systematic parts, averaged during each year of observational interval), t_n (in years) is the epoch of r'_n, a pertains to $(\Delta\delta_S + \Delta\delta_N)/2$, b pertains to $(\Delta\mu_{\delta_S} + \Delta\mu_{\delta_N})/2$. The values a and b, for each ILS star pair, are in accordance with the epoch of the Hipparcos Catalogue – 1991.25. The points r'_n and the Hipparcos one are taken with appropriate weights (Damljanović et al. 2006). The polar motion and the systematic time changes are calculated and removed from the ILS data in the way presented in an earlier paper (Damljanović 2005). The polar motion part was determined by using the EOP solution OA00 (Ron and Vondrák 2001). The systematic variations of each ILS ZT instrument (local, instrumental and others) were calculated and removed from the ILS data in a similar way as we did in the case of the PZT data (Damljanović et al. 2006).

We have got one equation, $b = (\Delta\mu_{\delta_S} + \Delta\mu_{\delta_N})/2$, but with two unknown quantities ($\Delta\mu_{\delta_S}$ and $\Delta\mu_{\delta_N}$), and we need to introduce another Eq. (3) to solve for the values of $\Delta\mu_{\delta_S}$ and $\Delta\mu_{\delta_N}$,

$$\Delta\mu_{\delta_S} - \Delta\mu_{\delta_N} = (\mu_{\delta_{S1}} - \mu_{\delta_{S2}}) - (\mu_{\delta_{N1}} - \mu_{\delta_{N2}}), \qquad (3)$$

where the values for $\mu_{\delta_{S1}}$ and $\mu_{\delta_{N1}}$ are from the EOC-2 catalogue, and those for $\mu_{\delta_{S2}}$ and $\mu_{\delta_{N2}}$ are from the Hipparcos one. A similar situation is with the errors $\epsilon_{\Delta\mu_{\delta_S}}$ and $\epsilon_{\Delta\mu_{\delta_N}}$ of $\Delta\mu_{\delta_S}$ and $\Delta\mu_{\delta_N}$, respectively. We have got the equation $(\epsilon^2_{\Delta\mu_{\delta_S}} + \epsilon^2_{\Delta\mu_{\delta_N}})/2 = \epsilon^2_b$, but it is necessary to introduce another one, in our case here it is Eq. (4), to solve the system of equations and to calculate the values of $\epsilon_{\Delta\mu_{\delta_S}}$ and $\epsilon_{\Delta\mu_{\delta_N}}$,

$$\epsilon_{\Delta\mu_{\delta_S}}/\epsilon_{\Delta\mu_{\delta_N}} = \epsilon_{\Delta\mu_{\delta_{S1}}}/\epsilon_{\Delta\mu_{\delta_{N1}}}, \qquad (4)$$

where the values of $\epsilon_{\Delta\mu_{\delta_{S1}}}$ and $\epsilon_{\Delta\mu_{\delta_{N1}}}$ (the errors of S and N stars in ILS star pair, respectively) are from EOC-2.

By using Eqs. (3) and (4), it is possible to calculate the values of $\Delta\mu_{\delta_S}$ and $\Delta\mu_{\delta_N}$ from

$$\Delta\mu_{\delta_S} = (2b + (\mu_{\delta_{S1}} - \mu_{\delta_{S2}}) - (\mu_{\delta_{N1}} - \mu_{\delta_{N2}}))/2,$$

$$\Delta\mu_{\delta_N} = 2b - \Delta\mu_{\delta_S}, \qquad (5)$$

and their errors $\epsilon_{\Delta\mu_{\delta_S}}$ and $\epsilon_{\Delta\mu_{\delta_N}}$ from

$$\epsilon_{\Delta\mu_{\delta_S}} = \epsilon_{\Delta\mu_{\delta_N}}\epsilon_{\Delta\mu_{\delta_{S1}}}/\epsilon_{\Delta\mu_{\delta_{N1}}},$$

$$\epsilon_{\Delta\mu_{\delta_N}} = 2^{1/2}\epsilon_b/(\epsilon^2_{\Delta\mu_{\delta_{S1}}}/\epsilon^2_{\Delta\mu_{\delta_{N1}}} + 1)^{1/2}. \qquad (6)$$

Table 2. Our results ($\Delta\mu_\delta$, μ_δ, ϵ_{μ_δ}), Hipparcos ones (μ_{δ_H}, $\epsilon_{\mu_{\delta_H}}$), and value m (number of ILS points r'_n).[1]

HIP	m	$\Delta\mu_\delta$(mas/y)	μ_δ(mas/y)	ϵ_{μ_δ}(mas/y)	μ_{δ_H}(mas/y)	$\epsilon_{\mu_{\delta_H}}$(mas/y)
19	48	.04	-15.03	.39	-15.07	.45
106	151	-.27	-11.46	.15	-11.19	.47
410	126	-.94	-7.51	.10	-6.57	.47

3. RESULTS

As an example, the calculated values $b \pm \epsilon_b$ for ILS star pair No 43, H29246 and H29650 stars, for the ILS stations are (the Hipparcos point was included, all points are with weights):

- CA, 77 points r'_n, -0.87 ± 0.18 mas/yr,
- GT, 62 points r'_n, -0.57 ± 0.22 mas/yr,
- KZ, 49 points r'_n, -0.03 ± 0.30 mas/yr,
- MZZ, 80 points r'_n, -0.49 ± 0.15 mas/yr,
- TS, 20 points r'_n, -0.87 ± 0.15 mas/yr,
- UK, 61 points r'_n, -0.81 ± 0.17 mas/yr,
- CI, 16 points r'_n, -1.20 ± 0.18 mas/yr, and
- all the seven ILS stations, 365 points r'_n, -0.76 ± 0.11 mas/yr.

Star H29246 is of a magnitude of 5.35 and H29650 of 5.71. The values b for star pair No 43 are presented in Fig. 1; all the linear trends are nearly parallel to one another. Only the value of b for the KZ station (-0.03 ± 0.30 mas/yr, the shortest line in Fig. 1) is a little bit further away from that for all ILS stations (and for the other stations individually) because the KZ station started its activity later (at 1930.8 or 26304 MJD) than the other ILS stations (at about 1900 or near 15000 MJD).

By using formulae (5) and (6), for H29246 star (of ILS star pair 43), we get $\Delta\mu_\delta = -0.67 \pm 0.08$ mas/yr, and for the H29650 (the same star pair) $\Delta\mu_\delta = -0.85 \pm 0.14$ mas/yr; our corrections $\Delta\mu_\delta$ can be added to the corresponding Hipparcos values. There are similar results also for the other ILS/Hipparcos stars which are presented in Table 2. Complete Table 2 (408 Hipparcos stars) is given at the website http://saj.matf.bg.ac.yu/173/pdf/Table2.pdf.

Using Table 2, we compared our errors of proper motions in declination with the Hipparcos ones (cases of ILS star pairs observed for more than 10 years): from 204 ILS star pairs (408 Hipparcos stars), the averaged value of the standard errors ϵ_{μ_δ} is 0.21 mas/yr, and it is about 36% of the averaged Hipparcos values $\epsilon_{\mu_{\delta_H}}$ (0.58 mas/yr, that is three times better than Hipparcos values). Thus $\epsilon_{\mu_\delta} \approx \epsilon_{\Delta\mu_\delta}$, because we just added our corrections $\Delta\mu_\delta$ to the corresponding Hipparcos values μ_{δ_H} to get the values μ_δ.

4. CONCLUSIONS

By using the ILS data it is possible to obtain proper motions in declination with a better accuracy than those of the Hipparcos. From 408 Hipparcos stars observed for more than 10 years at the ILS stations, we get an accuracy about three times better than the Hipparcos one. It is evident that the ILS ZT ground–based data are useful and can improve the reference frame (via improvement of Hipparcos proper motions in declination).

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[1]Full Table is available at http://saj.matf.bg.ac.yu/173/pdf/Table2.pdf.

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ПОПРАВКЕ СОПСТВЕНИХ КРЕТАЊА У ДЕКЛИНАЦИЈИ ДОБИЈЕНЕ ИЗ ILS ПОДАТАКА

G. Damljanović[1] and N. Pejović[2]

[1]*Astronomical Observatory, Volgina 7, 11160 Belgrade 74, Serbia*

[2] *Department of Astronomy, Faculty of Mathematics, University of Belgrade, Studentski trg 16, 11000 Belgrade, Serbia*

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Претходно саопштење

Постоји обиман астрометријски материјал добијен из посматрања звезда посматраних са Земље током прошлог века на многим опсерваторијама, а сада обрађен коришћењем података из Хипаркос каталога. У овом раду су коришћени подаци ширинских промена у периоду 1899.7 – 1979.0, добијени из посматрања на визуелним зенит телескопима Међународне службе за ширину (*International Latitude Service* – ILS), да би побољшали тачност Хипаркос сопствених кретања у деклинацији за Хипаркос звезде посматране на седам ILS станица (*Carloforte, Cincinnati, Gaithersburg, Kitab, Mizusawa, Tschardjui, Ukiah*). Од посматрања Хипаркос сателитом (ESA 1997), има око 15 година (1991.25 је епоха каталога), што са грешком Хипаркос сопствених кретања од око $0''.001$/god уноси грешку у рачун привидних положаја већу од $0''.015$, што је за ред величине веће од грешке Хипаркос позиција (око $0''.001$). За неке Хипаркос звезде, грешка сопствених кретања је много већа од просечне вредности или није реална (Vondrák et al. 1998), јер су астрометријска посматрања Хипаркос сателитом трајала краће од четири године (недовољно за решавање неких проблема добијања сопствених кретања, што се сада уочава). За добијање тачнијих сопствених кретања неких Хипаркос звезда, користе се класична посматрања са Земље, и током протекле деценије појавили су се нови каталози (као што су ARIHIP, EOC-2 и др.). Наша истраживања и резултати су у складу са резултатима каталога *Earth Orientation Catalogue* – EOC (Vondrák and Ron 2003), који је добијен коришћењем података посматрачких програма рађених са Земље за истраживања Земљине ротације, при чему смо применили другу методу. Приказани резултати су тачнија сопствена кретања Хипаркос звезда које су посматране на ILS станицама, и у складу су са EOC-2 сопственим кретањима.