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MORE ACCURATE PROPER MOTIONS IN DECLINATION THAN THE HIPPARCOS CATALOGUE ONES BY USING OPTICAL LATITUDE DATA

G. DAMLJANOVIĆ

Astronomical Observatory, Volgina 7, 11060 Belgrade 38, Serbia
E–mail: gdamljanovic@aob.bg.ac.yu

Abstract. In 1995, Commission 19 (Earth Rotation) of IAU established the Working Group on Earth Rotation in the Hipparcos Reference Frame (WG ERHRF) to collect the optical observations of latitude and universal time variations, made during 1899.7 – 1992.0 in line with the Earth orientation programmes (to derive Earth Orientation Parameters – EOP). About 4.4 million observations of latitude/universal time variations made at 33 observatories were collected.

Nowadays, it is customary to correct the positions and proper motions of stars of Hipparcos Catalogue using ground-based observations of the same stars. In this PhD thesis I use the latitude observations made with several types of classical astrometric instruments: visual and floating zenith-telescopes (ZT and FZT), visual zenith tube (VZT) and photographic zenith tube (PZT), i. e. a total of 26 different instruments located at 19 observatories all over the world. I received the data from Dr. Vondrák (head of WG ERHRF).

The task was to improve the Hipparcos proper motions in declination of the observed stars. The original method was developed. It consists of removing from the instantaneous observed latitude all known effects (polar motion and some local and instrumental errors). The corrected latitudes are then used to calculate the corrections of the Hipparcos proper motions in declination by using the Least Squares Method (LSM) with the linear model. The newly obtained values of proper motions in declination are substantially more precise than those of the Hipparcos Catalogue. It is because the time interval covered by the latitude observations (tens of years) is much longer than the Hipparcos one (less than four years), and because of the great number of ground-based observations made during this interval. The calculated results were compared with ARIHIP and EOC-2 data, and I found a good agreement. The main result of the thesis is a catalogue of proper motions in declination of 2347 Hipparcos stars. Here, some results and main steps of the method are presented.

1. INTRODUCTION

During 1997 two important catalogues at optical wavelengths, Hipparcos and Tycho, appeared (ESA 1997). Both were linked to the International Celestial Reference Frame (ICRF). The ICRF was adopted to materialize the International Celestial Reference System (ICRS) from the beginning of 1998.

The Hipparcos Catalogue contains 118218 stars and was adopted to be the primary realization of ICRS at optical wavelengths. The epoch of the catalogue is 1991.25.

There are some problems concerning the Hipparcos data. The accuracy of the data for single stars from the Hipparcos Catalogue is better than for double and multiple ones because the satellite mission was short (less than four years). There is a different accuracy of the data on different parts of the celestial sphere. The error of apparent position has attained about 15 mas until now because the influence of proper motions is linear in time from the moment 1991.25. The value 15 mas is one order of magnitude larger than the average position error in the Hipparcos Catalogue. So, there are a lot of reasons to improve the Hipparcos values of proper motions. Also, the combinations of satellite data (Hipparcos and Tycho ones) with the ground- based ones of common stars can improve the accuracy of positions and proper motions of mentioned stars. I used the data concerning the latitude variations obtained from observations with 26 classical instruments (14 ZT, 1 FZT, 1 VZT and 10 PZT instruments) to improve the proper motions in declination μ_δ of stars from the Hipparcos Catalogue, and I did it for 2347 stars. Some star catalogues appeared after the Hipparcos, such as ARIHIP (Wielen et al. 2001) and the Earth Orientation Catalogue – EOC-2 (Vondrák 2004), with more accurate stellar positions and proper motions than the Hipparcos ones.

2. DATA AND METHOD

The mentioned 26 instruments located at 19 observatories with which observing programmes were performed during the last century are:

- 7 ZT stations of the International Latitude Service – ILS (Carloforte – CA, Cincinnati – CI, Gaithersburg – GT, Kitab – KZ, Mizusawa – MZZ, Tschardjui – TS, Ukiah – UK),
- 6 ZT independent stations (Belgrade – BLZ, Blagoveschtschensk – BK, Irkutsk – IRZ, Poltava – POL, Pulkovo – PU/PUZ, Warsaw – VJZ),
- 1 FZT independent station (Mizusawa – MZL),
- 1 VZT independent station (Tuorla-Turku – TT),
- 6 PZT stations (Mizusawa – MZP/MZQ, Mount Stromlo – MS, Ondřejov – OJP, Punta Indio – PIP, Richmond – RCP/RCQ, Washington – WA/W/WGQ); more informations can be found in PhD thesis (Damljanović 2007). The codes (CI, GT, etc.) are from the monograph by Vondrák et al. (1998).

These observations were used for the purpose of studying the terrestrial rotation. They lasted much longer (tens of years) than those of the Hipparcos mission (shorter than 4 years). The annual number of observations for every observed star is on the average several hundred. So, it becomes possible to obtain corrections in the Hipparcos proper motions. I improved the proper motions accuracy (for a large number of input stars) to be better than the Hipparcos one though the accuracy of the stellar coordinates in the Hipparcos Catalogue is by two orders of magnitude better than the stellar coordinates following from the latitude observations. Also, the EOC-2 has a better accuracy of positions and proper motions of stars than the Hipparcos. My method (Damljanović 2005, Damljanović and Pejović 2006) is different from that used in obtaining the EOC-2 Catalogue (Vondrák 2004). Also my input data are the latitude variations φ_i whereas the EOC-2 is based on latitude and time variations.

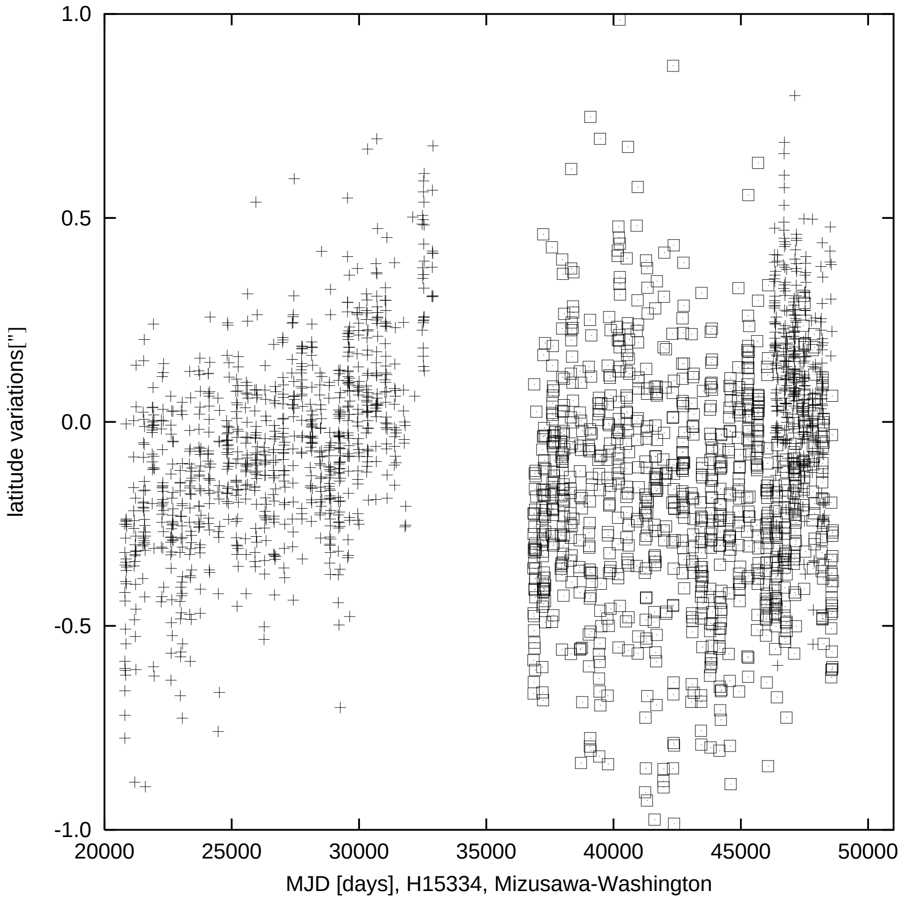

Figure 1: Latitude variations φ_i of Mizusawa (rectangles) – Washington (sign +) data of star H15334 vs. time (MJD).

Some of the mentioned observatories are nearly at the same latitude, but the longitudes differ significantly and they had a lot of common stars in their observing programmes. I can use these stars to check the results and method (Damljanović 2005). For example, the latitude variations following from observations of star H15334 (made at Mizusawa and Washington) are presented in Fig. 1. It is seen from this figure that there are a lot of observations (latitude variations) per year where the polar motion changes with the other systematic effects (local, instrumental, etc.) are included. Because of this, the first step of my method is to remove the polar motion components $\Delta\varphi_i$ and systematic (local, instrumental) changes se_i with time to get the residuals r'_i. The polar motion coordinates (x_i, y_i) are from Vondrák's file EOPOA00.dat. The MJD is Modified Julian Date $MJD = JD - 2400000.5$.

The values r'_i are with systematic catalogue effects which are of interest here. For each star, the values r'_n are the averaged values of r'_i over subperiods of about 1 year (Damljanović and Pejović 2006, Damljanović et al. 2006). In this way I can use the

Least Squares Method (LSM) with the linear model

$$r'_n = a + b(t_i - 1991.25)$$

and get the corrections b to the proper motions in declination for observed Hipparcos stars. The values t_i are the times (in years) corresponding to r'_n. The value a is the correction of $\Delta\delta$ and b is the correction of $\Delta\mu_\delta$; both are referred to the epoch 1991.25.

The residuals r'_n of star H15334 are presented in Fig. 2. The linear trends are very similar to each other; this means that my method is a good one. The points r'_n and the Hipparcos one (1991.25, 0.″0) are with the suitable weights (Damljanović et al. 2006).

This procedure is valid for PZT and VZT observations, but for ZT and FZT ones there are some additional steps in order to obtain the values of a and b by using the observations of star pairs (Damljanović and Pejović 2006, Damljanović 2007).

3. RESULTS

The calculated values μ_δ and ϵ_{μ_δ} for 2347 stars are presented in my PhD thesis (Damljanović 2007).

The best results are for stars observed for more than 10 years (with better accuracy than the Hippacos ones) and for about 10 years (our values ϵ_{μ_δ} are close to the Hipparcos ones). If I use the F-test (on 313 PZT stars and with $\alpha = 0.05$) for verification of the results (Damljanović and Pejović 2008), I need the ground-based observations with nearly 20 and more than 20 years to get better results than the Hippacos ones. It is because this test is stronger than a simple comparison of the averaged accuracy values concerning my work and the Hipparcos values of ϵ_{μ_δ}.

For example, the calculated value $b \pm \epsilon_b$ for star H15334 is -0.44 ± 0.15 mas/yr and it follows $\mu_\delta = -17.13 \pm 0.15$ mas/yr.

From EOC-2: $\mu_\delta = -17.29 \pm 0.12$ mas/yr.

From Hipparcos: $\mu_\delta = -16.69 \pm 0.62$ mas/yr.

So, the presented result is in a good agreement with the EOC-2 one. Also, it is a similar situation for the other results (Damljanović 2007).

If I compare the average values of ϵ_{μ_δ} of stars observed at each observatory separately, I get (for PZT instruments, for example):

- Richmond, 165 stars, 0.39 mas/yr and from the same Hipparcos stars it is 0.74 mas/yr,
- Washington and Mizusawa common 46 stars, 0.41 mas/yr and from the same Hipparcos stars it is 0.71 mas/yr,
- Punta Indio and Mount Stromlo common 144 stars, 0.57 mas/yr and from the same Hipparcos stars it is 0.82 mas/yr,
- Washington, 84 stars, 0.66 mas/yr and from the same Hipparcos stars it is 0.67 mas/yr,
- Mizusawa, 58 stars, 1.14 mas/yr and from the same Hipparcos stars it is 0.77 mas/yr,
- Ondřejov, 187 stars, 1.48 mas/yr and from the same Hipparcos stars it is 0.92 mas/yr.

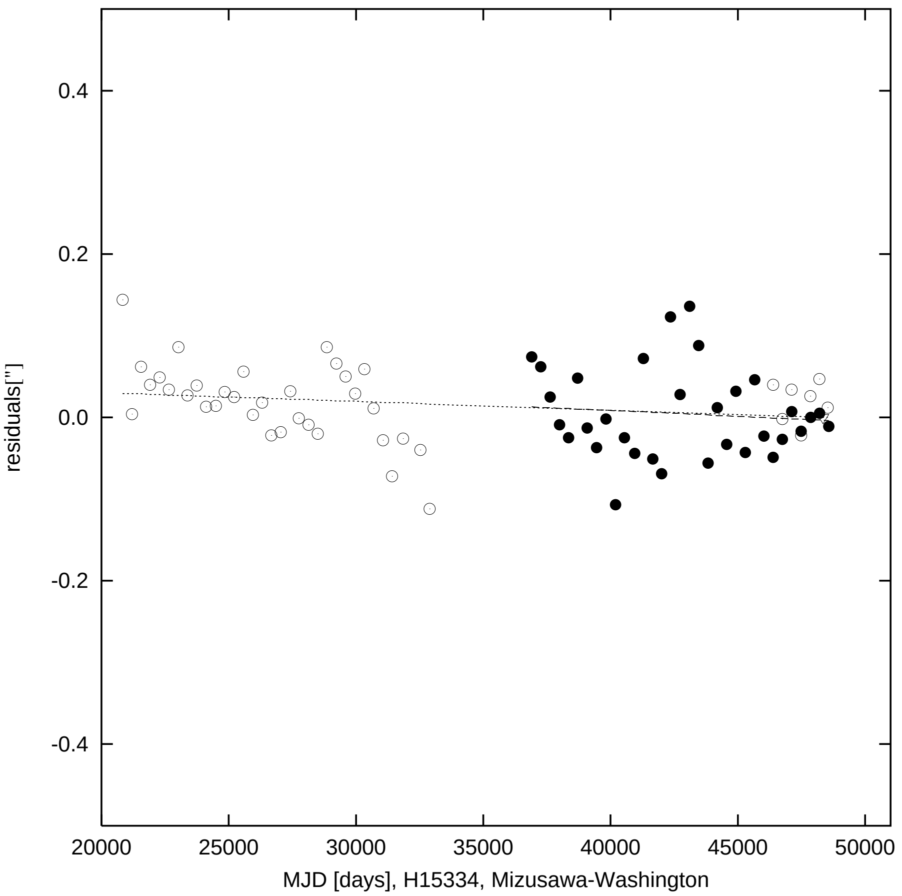

Figure 2: Residuals r'_n (Washington-open circles, Mizusawa-solid ones) and very similar linear trends of Washington (dotted line) and Mizusawa (dashed line) data of star H15334 vs. time (MJD).

It is evident that in the case of the PZT instruments the best results are achieved with the Richmond instruments. This is not the case with the Mizusawa and Ondřejov PZT instruments, because Mizusawa is a very active seismic region and the Ondřejov observing programme contains a lot of double and multiple stars. Also, the high values of the Ondřejov systematic (local, instrumental, etc.) errors are well known (Vondrák et al. 1998). The results for the common Washington and Mizusawa stars are much better, etc.

From 408 stars (204 star pairs) of the ILS visual zenith-telescopes, one finds the average value of ϵ_{μ_δ} to be 0.21 mas/yr, and from the same Hipparcos stars, it is 0.58 mas/yr. In the case of star pairs observations, my method of calculations of values μ_δ for each star separately is a little bit different (Damljanović and Pejović 2006) from that used for PZT and VZT stars.

From the independent stations (other stations except the ILS and PZT ones), it is:
- Blagoveschtschensk, 174 stars (87 star pairs), 0.36 mas/yr and from the same Hipparcos stars it is 0.61 mas/yr,
- Irkutsk, 64 stars (32 star pairs), 0.34 mas/yr and from the same Hipparcos stars it is 0.58 mas/yr,
- Pulkovo, 386 stars (193 star pairs), 0.37 mas/yr and from the same Hipparcos stars it is 0.70 mas/yr, etc.

The results of the other instruments are presented in (Damljanović 2007).

4. CONCLUSIONS

I have used the latitude variations data obtained with 26 instruments (at 19 observatories all over the world) in order to improve the proper motions in declination for 2347 Hipparcos stars. To these data I applied an original method which yields results similar to those given in other catalogues (ARIHIP, EOC-2).

I find that it is necessary to have ground-based observations carried out at least for ten years in order to obtain the results μ_δ with the accuracy close to the Hipparcos one. If observations lasting at least 20 years or more than 20 years are available, then my method offers the possibility of obtaining an accuracy of proper motions in declination even exceeding the Hipparcos one. The F-test is a little bit stronger: instead of 10 years I need about 20 years of ground-based latitude observations to match the Hipparcos accuracy of proper motions in declination. This means that I need data covering a long time interval to get good results.

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