PRINCIPAL TERM OF NUTATION FROM THE COMBINATION OF VLBI OBSERVATIONS AND OPTICAL ASTROMETRY

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Abstract. The celestial pole offsets (CPO) in provisional HIPPARCOS reference frame determined from the optical astrometry observations since 1899.7 until 1992.0 (Vondrák *et al.*, 1996) and CPO determined from VLBI observations since 1980.0 until 1996.0 (Ma *et al.*, 1996) are combined to get amplitudes of the long periodic nutation terms 18.6 and 9.3 years, respectively. The amplitudes are compared with previous solution based only on VLBI observations (Souchay *et al.*, 1995).

1. Introduction

The determination of the precession and nutation from VLBI observations meets with the problem in the determination of both long periodic terms of nutation 18.6 and 9.3 years respectively due to big correlation between the drift (correction for precession) and amplitudes of the terms. This is due to the fact that the input data do not cover the whole period of the principal nutation term. It was solved by Souchay *et al.* (1995) by using constraints imposed on 9.3, 18.6 year and drift terms.

Optical astrometry was used in the past to determine corrections to certain nutation terms, using different methods than the one used in this paper (e.g., Capitaine, 1980; Feissel and Guinot, 1980; or McCarthy *et al.*, 1980). Here we use the determination of the celestial pole offset from the optical astrometry. The available interval of the input data now covers

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nearly five periods of the principal term of nutation and both terms are not correlated, but the dispersion of the particular values of the offsets is nearly hundred times bigger than in the case of VLBI determination.

Therefore, we combine both the celestial pole offsets from VLBI observations and optical astrometry (OA) to get the adjustment of amplitudes of long periodic nutation terms.

2. Input Data

2.1. CELESTIAL POLE OFFSET FROM OPTICAL ASTROMETRY

We used the solution of EOP (Vondrák *et al.*, 1996) based on the re-reduced individual star observations in the reference frame of the provisional catalog of Hipparcos (H37P). Two previous versions of Hipparcos catalog H37 and H37C, provided by the Hipparcos Science Team (Kovalevsky, 1996), were combined to increase the number of observations ($\approx 10\%$) which has a big influence on the dispersion of the celestial pole offset (Vondrák *et al.*, 1992).

The H37C reference frame was linked to the VLBI reference frame (Lindegren *et al.*, 1995) using the values of Kovalevsky (1996). From the latitude observations the corrections of proper motion of several (260) stars or star pairs were derived, keeping the Hipparcos positions at their mean epoch, 1991.25, and the observations were corrected to avoid the uncertainty of Hipparcos catalog in proper motions. Each of the three steps and the consecutive solution of Earth orientation parameters are described in detail in Vondrák *et al.* (1996).

2.2. CELESTIAL POLE OFFSET FROM VLBI OBSERVATIONS

We have used time series of celestial pole offsets, $\delta\psi$ and $\delta\varepsilon$, derived from VLBI observations, which give the direction of the celestial pole relative to that predicted by the IAU 1980 theory of nutation and the IAU 1976 precession. The series considered here were obtained by Ma *et al.* (1996) over 1980–1995 from practically all existing VLBI observations. They are referred to as EOP(GSFC) 96 R 01, and are computed taking into account the diurnal and semi-diurnal variations in polar motion and universal time.

3. The Analysis

In this section both independent series will be combined to get the unique solution of the selected nutation terms. We concentrate our attention only on the long periodic terms with periods 18.6 yr and 9.3 yr. We did not try to get the terms with shorter period from the combination considering that OA cannot contribute to the determination of short periodic terms of nutation as much as the VLBI observations.

3.1. THE PREPARATION OF THE DATA SETS

In fact, the final HIPPARCOS catalog is not yet available and the drift in celestial pole offset from OA in previous tests does not agree with the drift obtained from VLBI (Souchay *et al.*, 1995), especially in longitude. Therefore, we decided to determine the constant term and the drift for both observation techniques separately. The drift in OA solution is probably hidden in the proper motions of the stars, and its detection and description shall be done in the future.

In the previous analysis we have found the change of the drift in the fifties which can be caused by a radical increase of the number of instruments used after the Second World War, by the change of the system by including new stars and/or by inserting the time observations to the solution after 1956. From various preliminary solutions of drifts we have estimated that the change of the drift occurred at 1956. To exclude the step in the celestial pole offset we determined the drift and the constant term in two steps.

First we solved the drifts and constant terms for intervals 1899–1956 and 1956–1992 (both fixed in 1956.0) independently. Then, the average values of constant terms in 1956.0 were removed from the celestial pole offset (−3.7 mas and 50.1 mas in $\Delta\varepsilon$ and $\Delta\psi$, respectively). Thus, centered data were solved only for drifts in both intervals. The drift in units of mas/yr for interval 1899–1956 is -0.39 ± 0.02 in obliquity and -1.64 ± 0.06 in longitude; for the interval 1956–1992 the values are $+0.27 \pm 0.02$ and -0.96 ± 0.06, respectively.

In order to homogenize the series, the constant term and drifts were also removed from VLBI celestial pole offset. The values fixed at 2000.0 were taken from Souchay *et al.* (1995) — the constant term is (in mas) −5.3 and −44.9, the drift (in mas/yr) −0.26 and −3.21 in obliquity and longitude, respectively.

Then, the values of annual, semiannual and 121-day terms derived in Souchay *et al.* (1995) were removed from both VLBI and OA celestial pole offsets. The series are shown in Figures 1 and 2.

Thus, we obtained relatively homogeneous series of celestial pole offset which were used together in the least-square estimation to derive the amplitudes of the selected nutation terms.

3.2. COMBINATION OF THE CELESTIAL POLE OFFSET FROM OA AND VLBI – THE DETERMINATION OF WEIGHTS

In combining the series with such different mean errors (100 times) we have to clear up the problem of the weights. If we use the standard formula for the determination of weights from mean errors $w_i = (\sigma_0/\sigma_i)^2$ where w_i denotes the weight of the observation equation, σ_0 is the mean error of one observation with the weight 1 and σ_i is the standard deviation of

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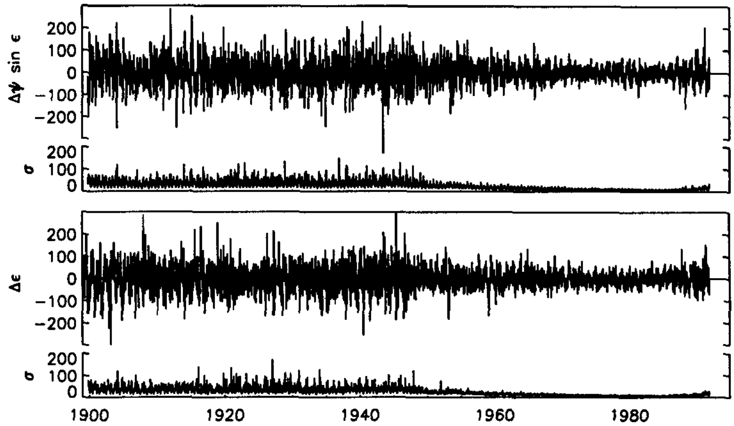

Figure 1. Celestial pole offset and its mean errors (in mas) from OA; the drift, constant term and the terms with periods 365.2, 182.6, 177.3, 121.3 days are removed.

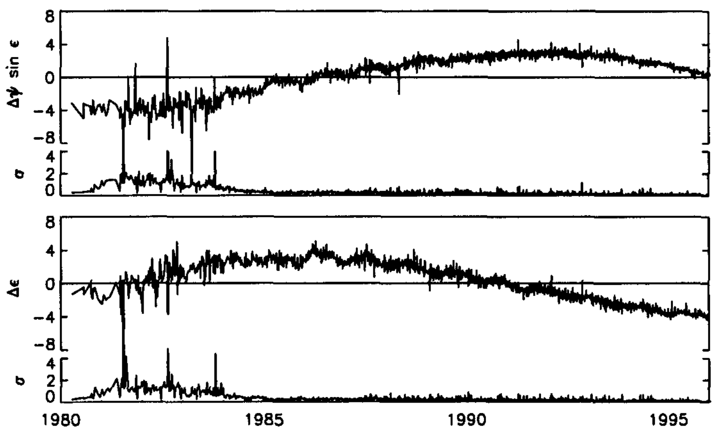

Figure 2. Celestial pole offset and its mean errors (in mas) from VLBI; the drift, constant term and the terms with periods of 365.2, 182.6, 177.3, 121.3 days are removed.

the observation, then the solution depends practically on the VLBI series only. In this case, however, large correlation coefficients appear between Ω and 2Ω terms because of the short interval of VLBI observations, in contrast to the solution from OA observations only where no correlations appear. We have used this fact to find the quotient K by which the weight w_i of OA observation is to be multiplied, to get the *realistically combined* solution. Correlation coefficients between Ω and 2Ω terms, approximately equal to 0.5, indicate that both input series have nearly the same share in the solution. The samples of correlation coefficients for different quotients

TABLE 1. Correlation coefficients for different quotients K.

K		longitude ($\Delta\psi$)				obliquity ($\Delta\varepsilon$)			
		$\sin\Omega$	$\cos\Omega$	$\sin 2\Omega$	$\cos 2\Omega$	$\sin\Omega$	$\cos\Omega$	$\sin 2\Omega$	$\cos 2\Omega$
	$\sin\Omega$	1.00				1.00			
1	$\cos\Omega$	0.09	1.00			0.08	1.00		
(VLBI)	$\sin 2\Omega$	0.17	0.77	1.00		0.19	0.80	1.00	
	$\cos 2\Omega$	0.62	0.06	0.19	1.00	0.64	0.04	0.18	1.00
	$\sin\Omega$	1.00				1.00			
50	$\cos\Omega$	0.14	1.00			0.15	1.00		
(comb.)	$\sin 2\Omega$	0.11	0.49	1.00		0.14	0.53	1.00	
	$\cos 2\Omega$	0.36	0.01	0.06	1.00	0.39	0.01	0.06	1.00
	$\sin\Omega$	1.00				1.00			
1000	$\cos\Omega$	0.03	1.00			0.04	1.00		
(OA)	$\sin 2\Omega$	0.05	0.02	1.00		0.05	0.02	1.00	
	$\cos 2\Omega$	0.08	0.01	0.00	1.00	0.08	0.00	0.00	1.00

are shown in Table 1, where the quotient $K = 1$ roughly corresponds to VLBI-only solution and $K = 1000$ to OA-only solution. From this aspect we have chosen $K = 50$ as the quotient for our combined solution.

The resulting amplitudes of both long periodic terms of nutation for different combinations of VLBI and OA series are displayed in Table 2. For comparison, the solutions of Souchay *et al.* (1995) and the analogical solution based on the new VLBI series Ma *et al.* (1996) are also shown.

4. Conclusions

From this study we can conclude (see Table 2) that there is a good agreement between the principal term in obliquity terms (both in-phase and out-of-phase) as determined from VLBI and OA solutions. The in-phase terms in longitude agree very well whereas the out-of-phase terms are quite different. As far as the 9.3 yr term is concerned, there is only a theoretical correction from Souchay *et al.* (1995) available. The OA solution gives systematically larger amplitudes for its components.

We conclude by stating that the combination of OA and VLBI series leads to a reasonable compromise between the low correlation of the OA solution and higher accuracy of the VLBI solution, and in this respect it is superior to the solutions based on only a single technique.

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TABLE 2. Corrections of the amplitudes of nutation terms 18.6 and 9.3 yr (in mas).

		longitude ($\Delta\psi$)		obliquity ($\Delta\varepsilon$)	
		sin	cos	sin	cos
Ω	IAU 1980	−17199.6			9202.5
	K=1 (VLBI)	−7.38 ± 0.02	2.82 ± 0.04	1.57 ± 0.01	2.85 ± 0.02
	K=50 (comb.)	*−6.95 ± 0.67*	*1.07 ± 0.85*	*2.08 ± 0.27*	*3.31 ± 0.33*
	K=1000 (OA)	−7.62 ± 1.13	−1.56 ± 1.15	2.26 ± 0.44	3.01 ± 0.45
	Souchay *et al.*, 95	−7.53 ± 0.13	2.91 ± 0.07	1.49 ± 0.05	2.86 ± 0.03
	GSFC, 96	−7.33 ± 0.04	2.98 ± 0.03	1.49 ± 0.02	2.75 ± 0.01
2Ω	IAU 1980	206.2			−89.5
	K=1 (VLBI)	1.05 ± 0.03	0.05 ± 0.03	0.09 ± 0.01	−0.35 ± 0.01
	K=50 (comb.)	*0.98 ± 0.72*	*−0.30 ± 0.76*	*0.88 ± 0.28*	*−0.93 ± 0.30*
	K=1000 (OA)	3.59 ± 1.14	−0.64 ± 1.14	1.68 ± 0.44	−1.17 ± 0.44
	Souchay *et al.*, 95	1.23	−0.05	−0.02	−0.24

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