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Polar Motion from VLBI Measurements

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Abstract

From the reduction of 2893 globally distributed astrometric and geodetic VLBI sessions from August 1979 to December 1998, coordinates of 722 radio sources at J2000.0, coordinates and velocities of 128 stations at J1997.0 and about 20 years Earth Orientation Parameters were estimated. From the analysis of polar motion series the following are demonstrated: (1) During the VLBI data span the Markowitz wobble does not appear. (2) The amplitudes of both annual and Chandler wobble show temporal variations, with the former being more obvious than the latter. (3) Wavelet analysis shows that all the signals in the polar motion series are characterized by temporal variation in amplitudes. If we take any signal as strictly periodic, it is impossible to remove it completely from the polar motion series by least-squares fit because the hypothesis of a constant amplitude conflicts with VLBI measurements. (4) By applying a low-pass filter the secular polar motion was found to be 2.74±0.01 mas/yr towards 83.9±0.3 °W longitude, which is smaller in rate and more westward in direction compared with those determined from optical observations.

1. Introduction

Very Long Baseline Interferometry is so far the sole space geodetic technique to simultaneously provide the celestial reference frame (CRF), the terrestrial reference frame (TRF) and the linking Earth Orientation Parameters (EOP), which permits the unification of CRF, TRF and EOP. Due to the outstanding characteristics of high stability and precision, VLBI has been the principal technique to determine EOP since the 1980s. Astrometric and geodetic VLBI has accumulated nearly 20 years of observations. With the CALC8.2/SOLVE software system we performed a reduction of these observations. The resultant polar motion series were analyzed for the determination of the spectrum structure and the secular polar motion.

2. Data Reduction

Data reduction is performed by applying software system CALC8.2/SOLVE. IERS 1996 Conventions (McCarthy, 1996) are adopted. The terrestrial reference frame is connected to ITRF96 (Boucher et al., 1998) at 1997.0 by applying no-net-horizontal-translation and no-net-rotation constraints to the position adjustments of 12 stations with uniform station weighting for both constraints. The evolution of the TRF is connected to NNR-NUVEL1A (DeMets et al., 1994) by applying no-net-horizontal-translation and no-net-rotation constraints to the velocity adjustments of five stations with uniform station weighting for both constraints. The celestial reference frame is connected to RSC (WGRF) 95 R 01 (Ma and Feissel, 1997) (ICRF95) by applying no-net-rotation constraints to the position adjustments of the 212 ICRF95 defining sources with weighting proportional to the precision of the source positions. The New Mapping Function (Neill, 1996) is used for the correction of troposphere delay with cut-off angle at 7 degrees. Clock behavior and wet troposphere effect are modeled as piecewise linear functions. Station positions and velocities and source positions are estimated as global parameters, Earth Orientation Parameters x, y, UT1, $\delta\psi$ and $\delta\epsilon$ are estimated as arc ones. Axis offset and asymmetric atmosphere effects are considered as well.

From the data reduction, the weighted-root-mean-squares of post-fit residuals is about 25ps. The coordinates of 722 radio sources at J2000.0, the coordinates and velocities of 128 stations at J1997.0 and about 20 years of Earth Orientation Parameters resulted. Comparisons show that the differences in orientation between our solution and ICRF95 are about 0.02 mas. The relative deformation parameters are at the same level of precision and are not significant. The relative rotation angles and their rates of change between our solution and ITRF96 are respectively at the precision level of 0.3 mas and 0.1 mas/yr. The systematic differences and relative drifts between our solution and EOP (IERS) C 04 are respectively at the precision level of 0.4 mas and 0.05 mas/yr.

3. Analysis of the Polar Motion Series

The polar motion series from the VLBI data reduction was smoothed and interpolated into a normal series with a sample interval of 30 days. This series is the basis of the following analysis.

After the normal series was de-trended spectrum analysis and wavelet analysis were applied. The results are shown in Figures 1 and 2, from which it is clear that the spectrum at high frequencies is very complicated. However, the annual and Chandler wobble are easily identifiable. In the spectrum there also exist long periodic terms.

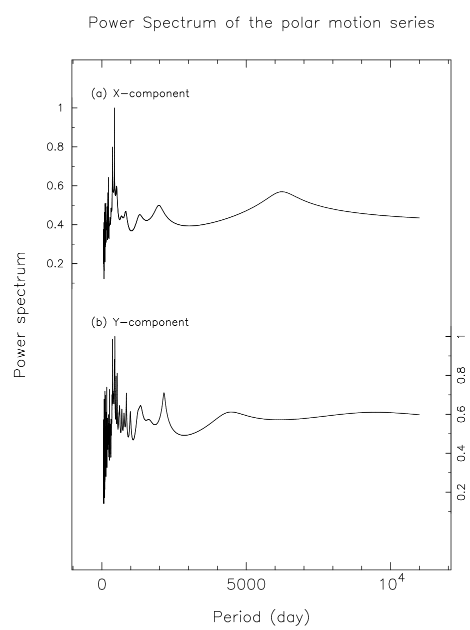

Figure 1. Spectrum analysis of the polar motion series

It is believed that in the polar motion series there exists the Markowitz wobble with period around 25 years and amplitude about 20 mas. There are debates about its existence. For instance, it may be solely associated with errors of star catalogues or the motion of stations. With Hipparcos

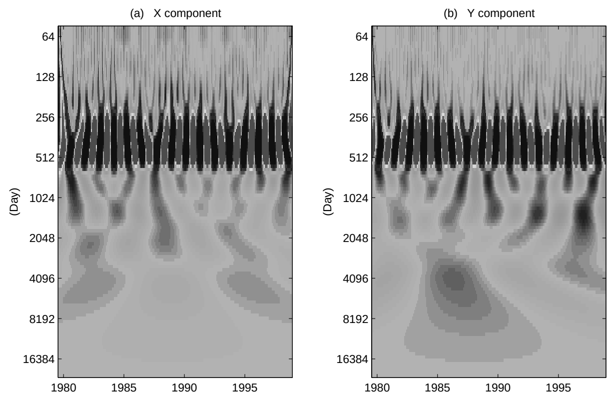

Figure 2. Wavelet analysis of the polar motion series.

catalogue Vondrak (1997) re-reduced the historical optical observations taking into consideration station motions based on plate motion model. The resultant polar motion series is more than 90 years in data span. However, since the observation data span of the Hipparcos catalogue is only 37 months, the average precision in proper motion of stars is about 1 mas/yr. When deducing star positions at the beginning of the 20^{th} century from the mean observation epoch (1991.25) of Hipparcos catalogue, the errors in star position will be magnified. In addition, space geodetic determinations show that the motions of stations are usually different from the predictions of plate motion models at the centimeter level (for instance, the difference for Shanghai VLBI station is about 9 mm/yr). Therefore, the re-reduction of the polar motion series based on Hipparcos catalogue does not fundamentally clear up the suspicions about the existence of Markowitz wobble. As shown in Figure 1 and 2, Markowitz wobble does not appear in the spectrum of the polar motion series from VLBI measurements, which of course still requires further support from future space measurements since the data span utilized here is only about 20 years.

In Figure 3 the characteristics of signals with periods near 400 days are demonstrated by applying wavelet analysis to the polar motion series as shown in a through d corresponding to x-component and e through h for y-component. From top downwards, the signals are respectively (a/e) the full information near the period of 400 days, (b/f) residuals after the removal of annual wobble by least-squares (LS) fit, (c/g) residuals after the removal of the LS solution to Chandler wobble and (d/h) residuals after the removal of LS solutions to both annual and Chandler wobble. In a and e, the beating phenomenon of the annual and Chandler wobble is very clear, which takes place mainly at the annual frequency. In b and f the Chandler wobble is manifested, with relatively slight variation in amplitude. In c and g, it is mainly the annual wobble. Compared with Chandler wobble in b and f, the variation in amplitude of the annual wobble is more obvious. In d and h, since the LS solutions to annual and Chandler wobble are removed, only the variations in amplitudes are shown. It can be seen that the absolute variation in amplitude at the annual frequency is comparable to that at the Chandler frequency. Within the VLBI data span, the amplitudes of annual and Chandler wobble in x- and y-component are respectively 80 mas and 72 mas, 178 mas and 175 mas. Hence, the relative variation in amplitude of the annual wobble is more significant than of Chandler wobble. The annual wobble is usually taken as stable. After its LS solution is removed the residuals are taken as Chandler wobble and so its characteristic parameters are studied. This conflicts with the demonstration in Figure 3.

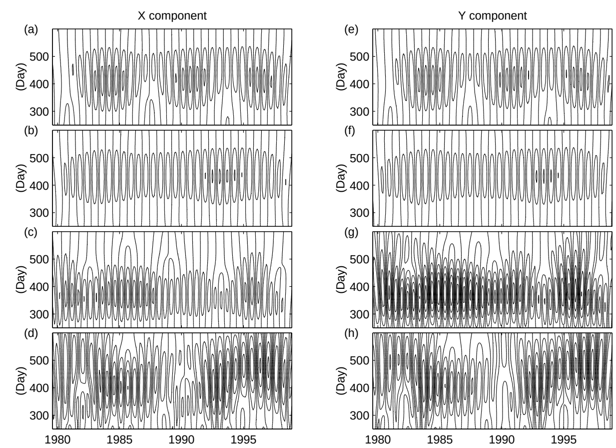

Figure 3. Wavelet analysis of phenomena nearby 400 day period.

Table 1. Estimations of the secular polar motion

Observations	Data span	Rate (mas/yr)	Direction (Degree W)	Reference
International Latitude Service	1899-1979	3.52±0.09	80.1±1.6	Dickman, 1981
Optical	1900-1992	3.51±0.01	79.2±0.2	Gross & Vondrak, 1999
Space geodetic	1976-1994	3.39±0.53	85.4±4.0	McCarthy & Luzum, 1996
Optical and space geodetic	1899-1994	3.33±0.08	75.0±1.1	McCarthy & Luzum, 1996
Latitude	1900-1978	1.6	70	Zhao et al., 1986
Latitude	1900-1978	3.51	79	Zhao & Dong, 1988
Optical	1899-1992	3.31±0.05	76.1±0.8	Schuh et al., 2000
VLBI	1979-1999	2.74±0.01	83.9±0.3	This analysis

LS fit is widely used in the analysis of polar motion series. When we remove a signal at a specified frequency by LS fit, the a priori hypothesis is that the signal is constant in amplitude. However, it is demonstrated by wavelet analysis in Figure 2 that all the signals have some temporal variations in amplitudes. It is easy to understand that under such circumstances, after the removal of the LS solution to a signal at a specified frequency, there still exists signal with almost the same frequency in the spectrum of the residuals. When we solve the LS solutions to two or more signals within narrow frequency span, it is hard to overcome the singularity of normal equation, which leads to unstable solutions. This is a commonly encountered problem in the analysis of signals characterized by temporal variation in amplitude. In view of this, we applied a filter to determine the secular polar motion. By referring to Figure 1 and 2 the cutoff period was set at 8000 days and a low pass filter was applied to the polar motion series. The secular polar motion was found to be 2.74±0.01 mas/yr towards 83.9±0.3°W longitude. From a comparison of results in Table 1 it can be seen that the secular polar motion determined here is smaller in rate and more westwards in direction than those from optical observations.

In conclusion, from the analysis of the VLBI observed polar motion series the following are demonstrated: (1) During the VLBI data span the Markowitz wobble does not appear. (2) The relative temporal variation in amplitude of the annual wobble is more obvious than that of the Chandler wobble. (3) All the signals in the polar motion series are characterized by temporary variation in amplitudes. (4) A low-pass filter was used to estimate the secular polar motion, which is 2.74±0.01 mas/yr towards 83.9±0.3°W longitude.

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