ON THE SYSTEMATICS IN APPARENT PROPER MOTIONS OF RADIO SOURCES OBSERVED BY VLBI

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ABSTRACT. For about twenty years, several authors have been investigating the systematics in the apparent proper motions of radio source positions. In some cases, the theoretical work developed (Pyne et al., 1996) could not be assessed due to the few number of VLBI observations. In other cases, the effects attributed to apparent proper motion could not be related successfully because there were no significant evidences from a statistical point of view (MacMillan, 2005). In this work we provide considerations about the estimation of the coefficients of spherical harmonics, based on a three-step procedure used by Titov et al. (2011) and Titov and Lambert (2013). The early stage of this work has been to compare step by step the computations and estimation processes between the Calc/Solve (http://gemini.gsfc.nasa.gov/solve/) and VieVS software (Böhm et al., 2012). To achieve this, the results were analyzed and compared with the previous study done by Titov and Lambert (2013).

1. INTRODUCTION

The acceleration of the Solar System Barycenter (SSB) in the Universe, which is due, for a large part, to the rotation of the SSB about the Galactic center in 250 Myr, produces a dipolar anisotropy of the extragalactic body proper motion field. Several works analyzed geodetic VLBI observations (Pyne et al., 1996; MacMillan, 2005) and failed to isolate this effect from VLBI noise mainly because of a too small number of observations. Finally, the effect was first detected by Titov et al. (2011) and confirmed in Titov and Lambert (2013). However, other parallel studies led with different methods found a drastically different orientation of the dipole (Xu et al., 2012). In order to understand the possible reasons of these differences and to improve the determination of the SSB acceleration, we reproduce in this study the computation of Titov and Lambert (2013) using an independent geodetic VLBI analysis software package (VieVS). Especially, we focus on the value of constraint on source position, which was identified as a key point by Titov et al. (2011).

2. THE STUDY

Different methods have been applied to estimate the systematics in apparent proper motions. One of them is the three-step procedure applied by Titov et al. (2011) and Titov and Lambert (2013). It has the advantage that almost everything is estimated after the VLBI analysis, thus we have the possibility to check the different steps:

1. Radio source time series are estimated from VLBI analysis
2. Apparent proper motions are fitted to their coordinate time series
3. Spherical harmonics are fitted to the proper motion field

To compare VieVS (1979-Dec/2013) results against results of Calc/Solve (1979-Feb/2013), and assess the consistency of both VLBI softwares, we use the same a priori configuration and parameterization chosen by Titov and Lambert (2013) to analyse the VLBI sessions. In the present study we also excluded sessions which are not suitable for reliable Earth Orientation Parameters (EOP) determination (http://lupus.gsfc.nasa.gov/files_IVS-AC/eop_exclusion.txt), decreasing the initial number of sessions from 5812 to 4677, while the previous study (Titov and Lambert, 2013) provides 5632. For both studies the models followed the IERS Conventions (2010) (Petit and Luzum, 2010).

Radio sources with less than three observations per sessions were excluded, choosing a cut-off elevation angle of 5°. The celestial frame was tied to the current International Celestial Reference Frame (ICRF2, Fey et al., 2009) by applying individual constraint on each source. We estimated four different solutions with VieVS, depending on the weights: $\sigma = 10^{-5}$ rad ($\sim$ 2 as), $\sigma = 10^{-6}$ rad ($\sim$ 200 mas), $\sigma = 10^{-7}$ rad ($\sim$ 20 mas), $\sigma = 10^{-8}$ rad ($\sim$ 2 mas). Titov, et al. (2011) showed that constraining each source using very loose constraint ($\sigma = 2$ as) is equivalent to apply loose NNR constraint with the same weight.

3. THREE-STEP PROCEDURE

After time series of the radio sources have been estimated with VieVS, we proceed to compute the proper motions. First, we exclude sessions with RMS larger than 100 ps as well as the 39 special handling sources, whose large structure could affect the harmonics estimation. After that, we apply an outlier elimination algorithm for each time series, that is, data points with distances from the mean larger than T_1 times the uncertainties are removed (where $T_1 = 90$ is the value provided by Titov and Lambert, 2013). Only radio sources with more than ten sessions are chosen for velocity estimation, reducing the number by one-sixth of the total before the iteration ($\sim$ 545 out of $\sim$ 3200). The velocities are estimated by a linear fit to the source positions, weighting the equations by using the inverse of the variance of the offsets ($\sigma^2_{d\alpha cos\delta}, \sigma^2_{d\delta}$). Comparing the velocities of the 49 most observed sources for both softwares, the results are the closest to Titov and Lambert (2013) study when tighter constraints are applied in VieVS ($\sigma = 10^{-7}$ rad). In Calc/Solve we found a stability of the velocities for $\sigma = 10^{-6}$ rad or looser, while in VieVS the singularity level is achieved by $\sigma = 10^{-5}$ rad or looser, that is, strength of the constraint is loose enough to cannot remove the degeneracy.

To estimate the spherical harmonics by fitting to the proper motion field, we apply the equations developed by Mignard and Klioner (2012) to decompose the systematic part of the proper motion field into different harmonics:

$$\Delta\mu_\alpha \cos\delta = -d_1 \sin\alpha + d_2 \cos\alpha + r_1 \cos\alpha \sin\delta + r_2 \sin\alpha \sin\delta - r_3 \cos\delta$$

$$\Delta\mu_\delta = -d_1 \cos\alpha \sin\delta - d_2 \sin\alpha \sin\delta + d_3 \cos\delta - r_1 \sin\alpha + r_2 \cos\alpha$$

where ($\Delta\mu_\alpha \cos\delta$, $\Delta\mu_\delta$) is the systematic part of the proper motion field, (d_1, d_2, d_3) the electric harmonics of degree one (acceleration of the SSB) and (r_1, r_2, r_3) the magnetic harmonics of degree one (global rotations).

To estimate the Vector Spherical Harmonics (VSH), we do a second iterative process to exclude the unstable radio sources, i.e., radio sources with residual velocities larger than T_2 times the residual rms were excluded from the set (where $T_2 = 7$ is the value provided by Titov and Lambert, 2013). Table 1 shows the values estimated for the systematics using the constraints $\sigma = 10^{-6}$ rad, 10^{-7} rad and 10^{-8} rad. The dipole values provided by $\sigma = 10^{-6}$ rad and 10^{-7} rad are the closest to the Titov and Lambert (2013) study for the first two components. However, we obtain strong discrepancies for the third component (that traduces the declination of the dipole) (see Table 1).

VSH [μas/yr]	10^{-6} rad (407 sour.)	10^{-7} rad (388 sour.)	10^{-8} rad (425 sour.)	T and L, 2013 (427 sour.)
d_1	-0.2 ± 1.9	-0.6 ± 0.6	0.0 ± 0.4	-0.4 ± 0.7
d_2	-5.8 ± 1.6	-5.7 ± 0.7	-4.5 ± 0.4	-5.7 ± 0.8
d_3	0.8 ± 1.3	1.1 ± 0.7	0.8 ± 0.4	-2.8 ± 0.9
r_1	0.31 ± 1.5	2.8 ± 0.7	2.5 ± 0.4	-1.1 ± 0.9
r_2	-2.4 ± 1.8	0.6 ± 0.7	0.4 ± 0.4	1.4 ± 0.8
r_3	-20.9 ± 1.5	-2.0 ± 0.5	0.6 ± 0.3	0.7 ± 0.6

Table 1: VSH values depending on the constraint applied.

4. CONCLUSIONS

Using a constraint of 10^{-7} rad leads to a dipole amplitude quite similar to Titov and Lambert (2013). However, though the agreement is good for the amplitude, the orientation of the dipole significantly differs. The present study provides a dipole of amplitude 5.85 ± 0.91, oriented towards $\alpha = 263.82 \pm 6.66^\circ$ and $\delta = 5.85 \pm 7.12^\circ$. Titov and Lambert (2013) provides a dipole of amplitude 6.4 ± 1.1, oriented towards $\alpha = 266 \pm 7^\circ$ and $\delta = -26 \pm 7^\circ$. At this stage, we need a deeper study to find out the reason.

A comparison between different software and approaches for the estimation of very small effects, such as the galactic aberration effect, from VLBI observations is essential. This aims at providing a better understanding of the scientific results. This work has provided such a detailed comparison. Further tests are still necessary.

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