INFLUENCE OF DIFFERENT STRATEGIES IN VLBI DATA ANALYSIS ON REALIZATIONS OF ICRF

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ABSTRACT. Positions of radio sources which are a realization of International Celestial Reference Frame (ICRF) can be estimated from VLBI observations. In this presentation we discuss different approaches in data analysis and the influence of applied strategy on the results. Application of these strategies are illustrated with a set of radio sources catalogs obtained from VLBI data analysis at the Main Astronomical Observatory (Kiev).

1. INTRODUCTION

In nowadays the International Celestial Reference Frame (ICRF) is realized by positions of extragalactic radio sources which are obtained from data analysis of geodetic and astrometric very long baseline (VLBI) observations. Efforts of many VLBI analysis centers are focused on producing new solutions of sources coordinates in the frame of international project ICRF-2, the second realization of the ICRF (e.g., C.Ma, this volume).

Estimated from VLBI observations coordinates of radio sources are depend on models of astronomical and geophysical effects which were applied in data analysis. Some mis-modeled or ill-modeled effects could increase random errors of source coordinates, another ones – systematic errors. One of well known examples of the last case is an influence of accounting of tropospheric gradients in data analysis on radio sources positions. In this paper we made an investigation of influence of various factors on the coordinates of radio sources.

2. COMPUTATION PROCEDURE

In order to investigate how the effects are distorting the resulting CRF we performed numerical tests. First of all, for selected set of VLBI observations, the data were analyzed and coordinates of radio sources (as well as stations positions and velocities, Earth orientation parameters (EOP), zenith delays and their horizontal gradients, etc.) were estimated. This solution of the CRF was used as the reference one. Then, studying the role of each of effect, the data analysis was performed without taking into account this effect (or option of a model) and resulting coordinates of radio sources were compared with the obtained from the reference solution. For both cases the set of VLBI sessions as well as data analysis procedures were the same.

A comparison of catalogs was performed in the following way: first, the parameters of a model of transformation between the reference and test catalogs were estimated with the least square method. Then, the model was applied to coordinates of the test catalog and weighted root means squares residuals for right ascension and declination were calculated.

We applied a model of transformation similar to that which was used in the IERS Annual Reports (e.g, 1993 IERS Annual Report), with added harmonic terms. The differences in right ascension, $\Delta\alpha$, and declination, $\Delta\delta$, are presented as:

$$\begin{aligned}\Delta\alpha &= A_1\tan\delta\cos\alpha + A_2\tan\delta\sin\alpha - A_3 + D_\alpha(\delta-\delta_0) + C_\alpha\sin(\alpha+\varphi_\alpha)\\ \Delta\delta &= -A_1\sin\alpha + A_2\cos\alpha + D_\delta(\delta-\delta_0) + B_\delta + C_\delta\sin(\alpha+\varphi_\delta),\end{aligned}$$

where A_1, A_2 and A_3 are small angles of global rotations about three axes; D_α and D_δ are slopes in right ascension and declination as functions of the declination; B_δ is a bias in the declination; C_α, φ_α and C_δ, φ_δ are amplitudes and phases of harmonic oscillations in right ascension and declination.

For data analysis all available VLBI observations which are good enough for simultaneous estimation of the Earth orientation parameters, Celestial and Terrestrial reference frames were processed. In total, 4,754,438 dual frequency delays acquired on 2,653 VLBI sessions from 1984 till mid of 2007 were processed.

The reference radio source catalog was obtained with the following assumptions. The VLBI data analysis was performed according to IERS Conventions (2003), with some exceptions: antenna thermal deformation model was not applied (due to lack of data for all stations) and the atmospheric pressure loading was modeled according to Petrov and Boy (2004) ephemeris.

Hydrostatic zenith delay was modeled according to Saastamoinen (1972). Ifadis mapping function (Ifadis, 1986) was used for both hydrostatic and wet components if station meteo parameters were good and NMFw2 (Niell, 1996) mapping function was used if the meteo parameters were suspicious.

Initial values of the CRF were taken from ICRF-Ext.1 catalog (IERS Annual Report, 1999). A priori values of stations positions and velocities were taken from ITRF2000 (Altamimi et al., 2002). The orientation of the CRF was linked by NNR constraint to ICRF-Ext.1; the origin, orientation and time evolution of the TRF were tied to ITRF2000 by NNT and NNR of positions and velocities constraints.

The following parameters were estimated in the solution: positions of sources, coordinates and velocities of stations as global parameters, the EOP on a session basis, clocks offsets, zenith delays and troposphere gradients as stochastic processes (random walk).

3. NUMERICAL TESTS, DISCUSSION

Several numerical tests were performed. We do not tested an influence of troposphere on coordinates of sources because it is well known effect and widely described in publications. The names of tests and their short descriptions are following. **Test-1**: The TRF estimation. In this test the coordinates and velocities of stations were not estimated and kept fixed to their priori values, ITRF-2000. **Test-2**: Polar motion estimation, the corrections of polar motion, p_x and p_y, were not estimated.

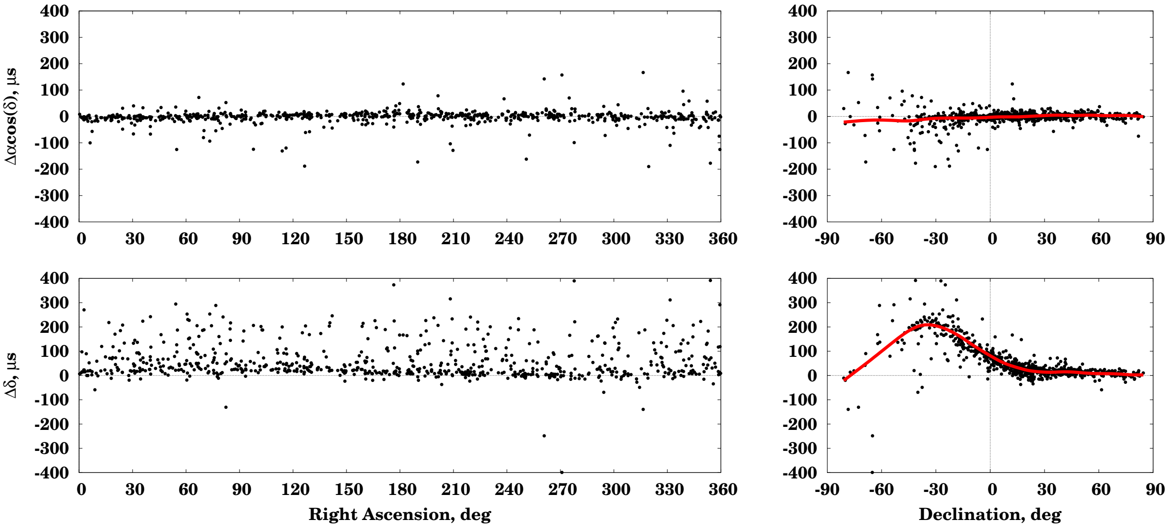

Figure 1: Differences of the catalogs for the **Test-2**, polar motion was held fixed, equal to a priori EOP(IERS)C04 solution.

Test-3: Estimation of subdiurnal Earth rotation parameters. The polar motion and $d(UT1 - UTC)$ were parametrized and estimated on the frequency domains of +1, ±2 and ±3 cycles per day. **Test-4**: Subdiurnal variations in polar motion. The Ray et al. (1994) model of diurnal and semidiurnal p_x and p_y variations due to oceanic tides was turned off. **Test-5**: Subdiurnal variations in the rotation of the Earth, $d(UT1-UTC)$. The same as previous case, but the diurnal and semidiurnal variations of $d(UT1-UTC)$ was turned off. **Test-6**: Change of an ocean loading model. The ocean loading model CSR3.0 (Eanes, 1994) was applied instead of the GOT00.2 (Ray, 1999). **Test-7**: Nutation model, the old IAU-1980 Nutation theory was used instead of recommended by IERS Standards (2003) model IAU-2000.

Test-8: Effects in solid tides, degree 3 and latitude dependence of solid tides model was turned off. **Test-9**: Influence of atmospheric loading, the model of atmospheric loading was not applied.

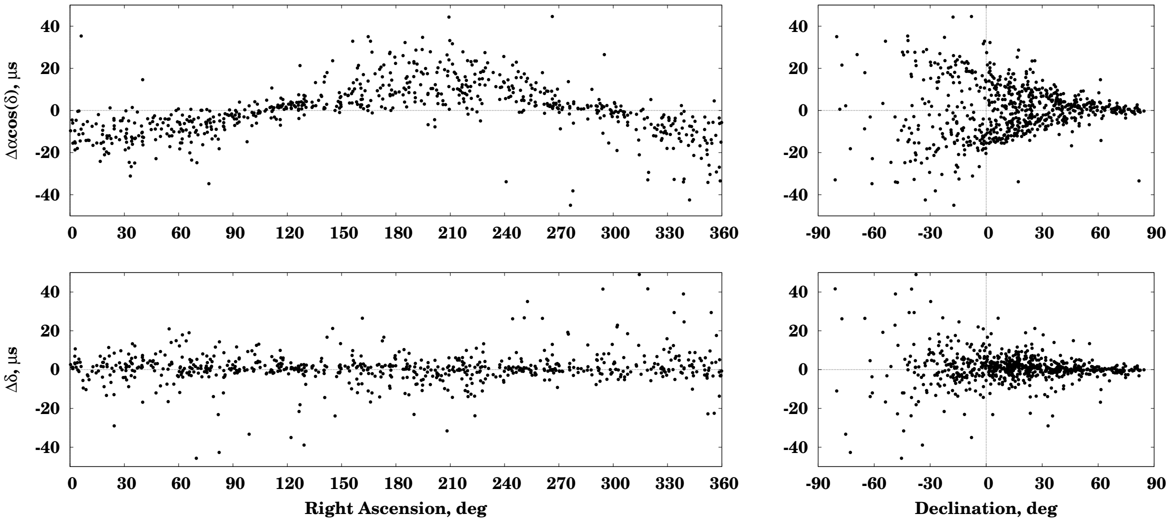

Figure 2: Differences of the catalogs for the **Test-7**, new nutation model IAU-2000 versus old theory IAU-1980.

Differences of sources coordinates between test catalog and the reference one are shown on the Figures 1 and 2 for the **Test-2** and **Test-7** cases. On the figures the standard deviations are not shown because they are greater than the differences in coordinates.

Name	A_1	A_2	A_3	D_α	D_δ	B_δ	C_α	φ_α	C_δ	φ_δ	ν_α	ν_δ
Test-1	13.6	10.2	24.1	71.5	112.4	−155.8	19.9	15.3	17.1	299.6	25.7	65.8
	9.5	9.8	7.9	13.2	7.3	6.6	9.8	24.0	11.7	34.8		
Test-2	−9.7	−0.6	4.4	11.2	−23.2	34.9	0.8	128.2	5.4	173.8	5.6	43.6
	3.1	3.2	2.6	4.3	2.4	2.3	2.7	238.8	3.6	38.6		
Test-3	−4.1	−4.3	−0.2	−1.2	−4.0	6.0	9.0	99.6	7.7	98.8	9.6	10.4
	1.5	1.5	1.2	2.0	1.2	1.1	1.3	9.6	1.8	12.4		
Test-4	3.1	13.5	0.1	−2.3	20.6	−23.2	12.0	193.4	19.2	256.8	12.3	19.3
	2.6	2.7	2.2	3.6	2.1	1.9	2.6	10.7	3.0	9.1		
Test-5	−20.4	−34.5	−2.8	13.0	0.6	−2.8	84.6	50.3	38.4	104.9	19.9	17.0
	3.0	3.1	2.5	4.2	2.4	2.2	3.0	1.9	3.7	5.1		
Test-6	0.3	−0.1	−0.1	−0.4	0.1	−0.1	1.2	241.5	0.5	9.0	0.6	0.7
	0.1	0.1	0.1	0.2	0.1	0.1	0.1	5.1	0.1	16.4		
Test-7	5.8	1.1	−1.4	−1.8	2.2	−1.6	14.3	252.6	5.2	349.2	3.0	3.5
	0.6	0.6	0.5	0.9	0.5	0.5	0.6	2.5	0.7	8.1		
Test-8	−10.5	−6.8	−0.7	−0.5	−3.4	3.7	7.2	66.8	17.1	155.6	2.6	7.6
	0.9	1.0	0.8	1.3	0.7	0.7	0.9	7.1	1.1	3.6		
Test-9	0.2	−0.0	−0.0	−0.1	0.1	−0.0	0.7	258.4	0.1	13.3	0.2	0.2
	0.0	0.0	0.0	0.1	0.0	0.0	0.0	2.8	0.0	25.7		

Table 1: Estimated parameters of transformation models and weighted post fit residuals of coordinates, ν_α and ν_δ. Units: A_1, A_2, A_3, B_δ, C_α, C_δ, ν_α and ν_δ are in μas; D_α and D_δ are in μas/rad; φ_α and φ_δ are in degrees. The standard deviations of the model parameters are shown on the second lines.

The results of estimations of transformation model parameters are summarized in the Table 1. In the table also displayed the post fit residuals in right ascension and declination of radio sources (i.e., after removing the systematic effects).

The first two cases, **Test-1** and **Test-2**, look very close to that which was obtained by Tesmer (2007). It is interesting to note that if geophysical effect which was checked here has periodic (or quasi periodic) oscillations on the frequency −1 cpd with respect to the crust of the Earth, then omitting the model of this effect in data analysis would systematically distort the resulting Celestial reference frame. In this case, the systematic effect has significant harmonic terms in $\Delta\alpha$ and $\Delta\delta$.

4. CONCLUSIONS

In the conclusions we would like to emphasize that there is at least one geophysical effect which is not included in VLBI data analysis (due to lack of meteo parameters) and which has quasi periodic influence on stations coordinates, it is thermal deformation of radio telescope antennae. Omitting this effect (or incorrect modeling, which is worse) is systematically affecting the CRF on the level of 0.1–0.2 mas.

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5. REFERENCES

Altamimi, Z., Sillard, P., & Boucher, C., 2002, "ITRF2000: A new release of the International Terrestrial Reference Frame for earth science applications", J. Geophys. Res. , 107(B10): 2114, doi: 10.1029/2001JB000561.

Eanes, R.J., 1994, "Diurnal and semidiurnal tides from TOPEX/POSEIDON altimetry", Eos Trans. AGU, 75(16):108

IERS Annual Report 1993, 1994, eds. M. Feissel, N. Essaïfi, Observatoire de Paris, Paris, France

IERS Annual report 1998, 1999, First extension of the ICRF, ICRF-Ext.1, Chapter VI, ed. D. Gambis, Observatoire de Paris, p. 87–114.

IERS Conventions (2003), IERS Technical Note 32, eds. D.D. McCarthy and G. Petit, Bundesamt für Kartographie und Geodäsie, Frankfurt am Main.

IVS: International VLBI Service data available electronically at http://ivscc.gsfc.nasa.gov

Ifadis, I.I., 1986, "The Atmospheric Delay of Radio Waves: Modeling the Elevation Dependance on a Global Scale", Technical Report No. 38L. – Chalmers U. of Technology, Göteburg, Sweden.

Ma, C., 2007, "Progress in the 2nd Realization of the ICRF", this volume.

Niell, A.E., 1996, "Global mapping functions for the atmosphere delay at radio wavelengths", J. Geophys. Res. , 101(B2), 3227–3246.

Petrov, L., Boy, J.-P., 2004, "Study of the atmospheric pressure loading signal in VLBI observations", J. Geophys. Res. , 109(B03405), doi:10.1029/2003JB002500.

Ray, R.D., Steinberg, D.J., Chao, B.F., and Cartwright, D.E., 1994, "Diurnal and Semidiurnal Variations in the Earth's Rotation Rate Induced by Oceanic Tides" Science, 264, pp. 830–832.

Ray, R.D., 1999, "A Global Ocean Tide Model From TOPEX/POSEIDON Altimetry: GOT99.2", NASA Technical Memorandum 209478.

Tesmer, V., 2007, "Effect of various analysis options on VLBI-determined CRF", Proc. of the 18th European VLBI for Geodesy and Astrometry Working Meeting, 12-13 April 2007, edited by J. Boehm, A. Pany, and H. Schuh, Geowissenschaftliche Mitteilungen, Heft Nr. 79, Schriftenreihe der Studienrichtung Vermessung und Geoinformation, Technische Universitaet Wien, ISSN 1811-8380.