Some New Results of the VLBI Data Analysis in the IAA RAS

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Abstract At the Institute of Applied Astronomy, the multi-purpose software package QUASAR created by I. Surkis, V. Gubanov, and S. Kurdubov has been used for processing VLBI observations since 2000. In this paper, some scientific results derived recently by means of QUASAR are presented.

Keywords VLBI, reference frames, Earth rotation

1 Introduction

QUASAR is used mainly for the analysis of 24-h series of VLBI observations in IVS geodetic programs for more precise definition of the CRF and TRF reference frames and for geodynamic investigations. Current variations of unstable Earth rotation and local parameters are determined by independent solutions of each series. Stable parameters are determined from global solutions.

A number of interesting new results have been obtained recently with the help of the software package QUASAR analyzing the 30-year series of VLBI observations in connection with IERS Convention (2010) [1]:

1. It is stated with high reliability that the linear trend of the Retrograde Free Core Nutation (RFCN) phase changed four times during this time, which can be explained by the fact that the period of these oscillations is changeable [3, 4].

2. A complete global adjustment of all available observations has been achieved in order to obtain new versions of terrestrial and celestial coordinate systems as well as Earth orientation parameter series [5].

3. New estimates have been made with an accuracy of 10^{-4} for the integral (not frequency dependent) complex values of Love/Shida tidal numbers and for diurnal and semi-diurnal bands. A new effect has been discovered for 49 VLBI stations—the tidal asymmetry of horizontal displacement in the direction of their tectonic motions [6].

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2 Results

2.1 VLBI Global Solutions

Arc parameters: Earth orientation (Xp, Yp, UT1–UTC, Xc, and Yc), station clock quadratic + stochastic model, station troposphere linear + stochastic model.

Global parameters: source coordinates $\Delta\alpha$ and $\Delta\delta$ and station coordinates and velocities.

NNR for 212 ICRF1 defining sources, NNT/NNR for 15 stations (BR-VLBA, FD-VLBA, FORTLEZA, HN-VLBA, KP-VLBA, LA-VLBA, MATERA, NL-VLBA, ALGOPARK, WESTFORD, WETTZELL, HARTRAO, KOKEE, NYALES20, and ONSALA60). Soft constraint for sources with fewer than 15 observations, no velocity estimation for stations with less than a year of observations. The sum of the clock parameters in each session equals zero. EOP is fixed for low geometry sessions. Velocities for stations at the same site (such as NRAO) are made equal.

Results are presented as tables iaa2012a, iaa2011a, iaa2009b, iaa2008b, and iaa2007b at: http://ivscc.gsfc.nasa.gov/products-data/products.html, ftp://ivs.bkg.

bund.de/pub/vlbi/ivsproducts/trf/iaa2013a.trf.gz, ftp://ivs.bkg.bund.de/pub/vlbi/ivsproducts/trf/iaa2013a.crf.

2.2 Direct Estimations of ICRF2 Systematic Errors

The distribution of systematic errors in the coordinates of 1,217 extragalactic radio sources of the latest version of the International Celestial Reference Frame (ICRF2) has been mapped by processing VLBI observations by geodetic programs spanning the period 1980–2012 [7].

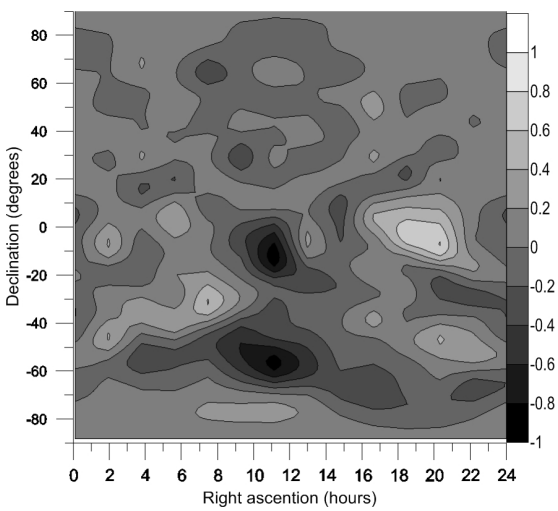

Fig. 1 Map of ICRF2-1217 $\Delta\alpha$ systematic errors.

These errors are shown to reach ± 1.0 mas (milliarcsecond). This accuracy cannot be considered satisfactory, especially in order to determine Earth orientation parameters (EOP). For this task, we must collect a specific list of sources with more accurate coordinates (ICRF-EOP). For example, the list of 752 sources observed more than 100 times may be adopted as system ICRF-752, the systematic errors of which do not exceed ± 0.2 mas (see Figures 3 and 4).

2.3 Instability of CRF and TRF Objects

The individual stability of many of the extragalactic radio sources and VLBI stations included in the latest versions of ICRF2 and ITRF2005 has been investigated [7]. For example, Figures 5–7 and 8–10 show the displacements in time for the source 0923+392 and the station Pie Town, respectively. The position and proper motion of 0923+392 are $\Delta\alpha = (0.019 \pm 0.002) + (0.131 \pm 0.003)T$, $\Delta\delta = (0.014 \pm 0.002) - (0.041 \pm 0.003)T$, where T is in centuries from the epoch 1997.1. Anomalous shifts reaching ± 20 μas for sources and ± 3 mm for stations have been detected.

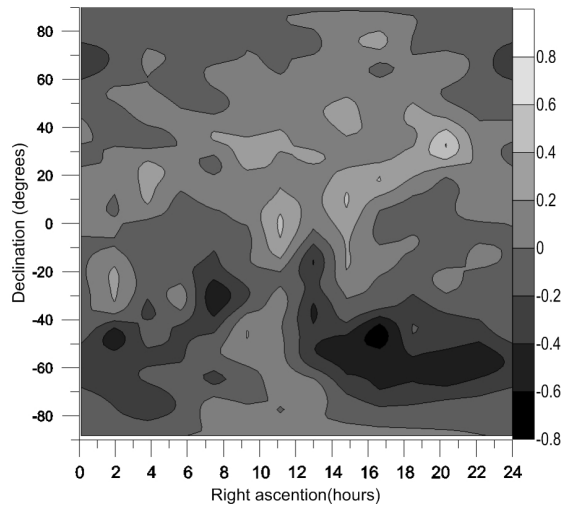

Fig. 2 Map of ICRF2-1217 $\Delta\delta$ systematic errors.

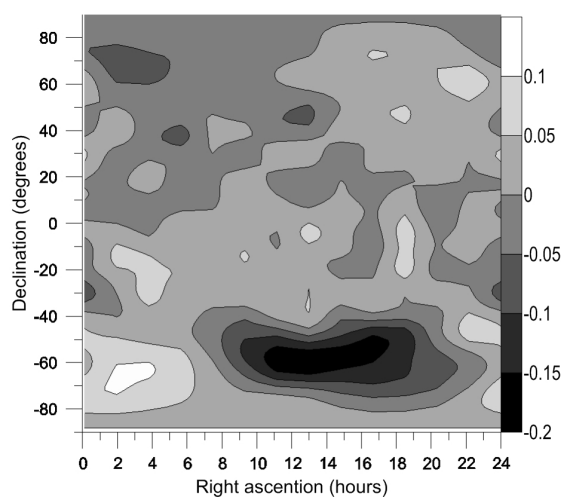

Fig. 3 Map of ICRF2-752 $\Delta\alpha$ systematic errors.

The displacements of the Pie Town station in the directions North and South shown in Figures 8–9 are generally consistent with those obtained in [2].

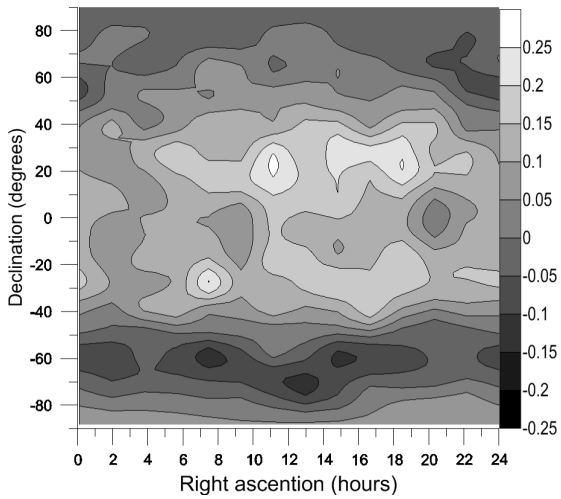

Fig. 4 Map of ICRF2-752 $\Delta\delta$ systematic errors.

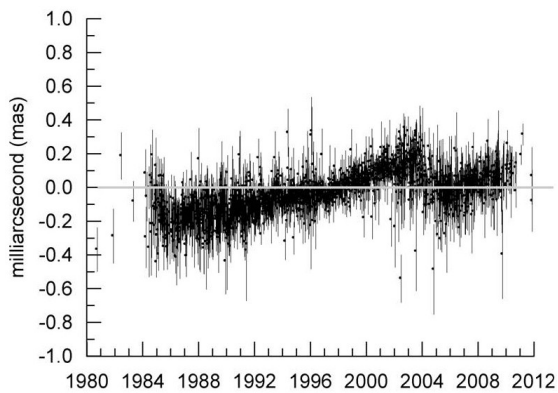

Fig. 5 Displacements of source 0923+392 in α direction.

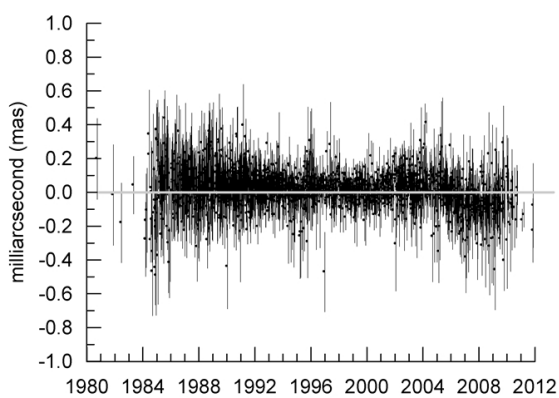

Fig. 6 Displacements of source 0923+392 in δ direction.

2.4 RFCN Parameters

On the basis of available determinations of the Celestial Intermediate Pole (CIP) coordinates (X, Y) from VLBI observations over the last 25 years, a new combined series, gvscomb, has been created [3, 4]. The amplitude-and-phase analysis of this series by Moving Least-Squares filter (MLSF) has allowed the estimation of the Retrograde Free Core Nutation (RFCN) parameters as functions of time to be obtained. It has been shown that during this time interval the period RFCN was not constant $P = -430.21$ solar days as it is adopted in MHB precession-nutation theory but changed a few times. Until 1992.1, it was equal to

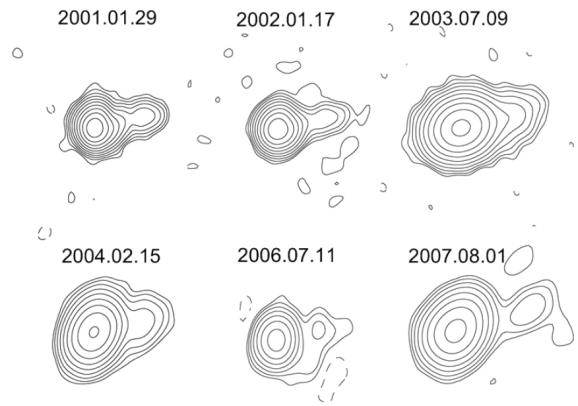

Fig. 7 Images of source 0923+392 by A. Fey (USNO).

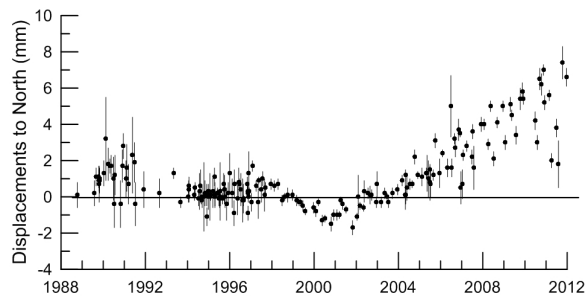

Fig. 8 Displacement of Pie Town VLBI station.

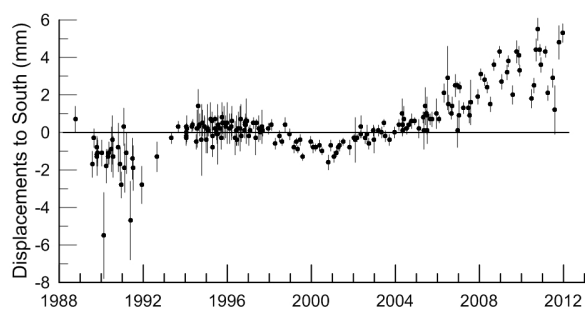

Fig. 9 Displacement of Pie Town VLBI station.

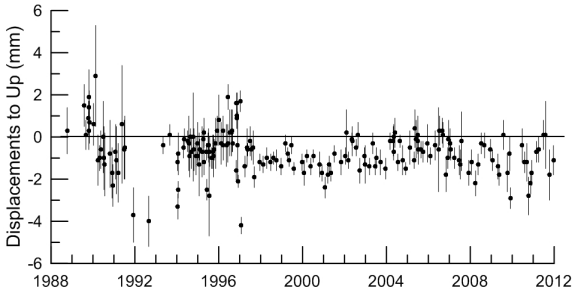

Fig. 10 Displacement of Pie Town VLBI station.

-418.1 ± 0.2 days, and then up to 1999.0 it was equal to -431.6 ± 0.2 days. In 1999 there was almost full damping of CIP oscillation and its reconstruction. Since 2000 the amplitude of this oscillation has begun to increase, and its period has appeared equal to -450.7 ± 0.1 days.

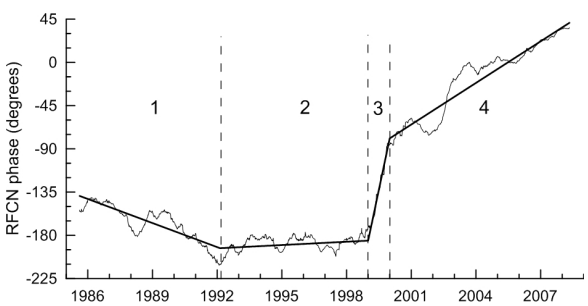

Fig. 11 RFCN phase variation.

Uncertainties of 3,216 points on the thin line in this figure are in the range of two to six degrees.

The discovered instability of the RFCN frequency indicates the presence of quasi-regular disturbances for which a geophysical explanation has not yet been found. They may be connected with unstable electromagnetic and coupling forces on the border of the Earth's liquid core and lower mantle or existence of the scale convection of the matter in this envelope.

2.5 Frequency Independent Love/Shida Numbers and Tide Lag

The partial derivatives of the total tidal displacement $\Delta\vec{s}$ with respect to the nominal Love/Shida numbers are [6]

$$\frac{\partial(\Delta\vec{s})}{\partial h^{(0)}} = H\frac{3p^2-1}{2}\widehat{r}, \quad \frac{\partial(\Delta\vec{s})}{\partial l^{(0)}} = 3Hp(\widehat{R}-p\widehat{r}),$$

where $\widehat{R}$ is the geocentric unit vector to the Moon or Sun, $\widehat{r}$ is the geocentric unit vector to the VLBI station, $p = (\widehat{R}\cdot\widehat{r})$ is the scalar product, H is the amplitude total tidal displacement in meters, and $h^{(0)}, l^{(0)}$ are the nominal Love and Shida numbers independent of latitude.

The partial derivative of the total tidal displacement with respect to tidal phase lag is the following:

$$\frac{\partial(\Delta\vec{s})}{\partial\theta} = 3H\{[(h_2-2l_2)p\widehat{r}+l_2\widehat{R}](\boldsymbol{L}\widehat{R}\cdot\widehat{r})+l_2p\boldsymbol{L}\widehat{R}\},$$

where $\boldsymbol{L}$ is a 3×3-matrix with rows: $(0,-1,0),(1,0,0),(0,0,0)$.

Values from a global solution for nominal tidal numbers and phase lag are [6]

$$\Delta h^{(0)} = +0.00348 \pm 0.00027,$$
$$\Delta l^{(0)} = -0.00039 \pm 0.00006,$$
$$\Delta\theta = -0.^\circ110 \pm 0.^\circ014.$$

2.6 Asymmetry of Horizontal Tidal Displacement

Intuitively, one would expect that some point on the Earth's surface, moving under the action of horizontal tectonic forces has an additional degree of freedom, and its displacement in this direction under tidal action will be somewhat larger than in all other directions. Assuming tidal forces act on a point equally in all directions, the movement of the point of these forces will not occur in a circle, but in an ellipse, whose major axis is elongated along the tectonic movement of the point. The compression of the ellipse is called the asymmetry parameter. The hypothesis is confirmed, if the parameter is positive. If it is negative or zero, then the hypothesis is rejected. Figure 12 shows that the expressed proposal is confirmed in 49 cases out of 72 (68 percent), which is not too bad [6].

2.7 Frequency Dependent Tidal Numbers

Based on an analysis of the VLBI observations performed in 1985–2010 within the framework of IVS

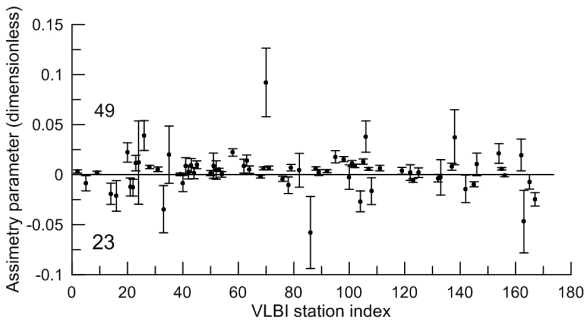

Fig. 12 Asymmetry parameters for 72 VLBI stations.

geodetic programs on global networks, we have obtained the parameters of lunisolar tides as the nominal complex Love/Shida numbers without considering diurnal resonance effects [6]. The new estimates of such "integral" values of these numbers (in 10^{-4}) are for:
total tides:

$$h^{(0)} = (6113 \pm 3) - (33 \pm 2)i,$$
$$l^{(0)} = (843 \pm 1) - (5 \pm 2)i,$$

diurnal tides:

$$h^{(0)} = (6106 \pm 3) - (10 \pm 6)i,$$
$$l^{(0)} = (843 \pm 1) - (8 \pm 1)i,$$

semi-diurnal tides:

$$h^{(0)} = (6106 \pm 3) - (24 \pm 3)i,$$
$$l^{(0)} = (843 \pm 1) + (3 \pm 1)i\ .$$

Acknowledgements

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