Paris Observatory Analysis Center OPAR: Report on Activities, January - December 2004

A.-M. Gontier, M. Feissel-Vernier, C. Barache

Abstract

In preparation for the evolution of the definition of the VLBI-based International Celestial Reference Frame (ICRF), we studied the consequences of the status of the terrestrial reference frame in the data analysis, using a set of selected stable radio sources ([2]). We conclude that estimating both the celestial and the terrestrial reference frames in the VLBI global analysis does not impact the quality of the celestial reference frame, and that the use of observations of the proposed set of stable sources collected since 1990 would allow an improvement by a factor of four in the maintenance of the ICRF axes, to reach 5 μas, and by a factor of eight in the source position precision, to reach 30 μas. We also show that the impact of the source selection on the determination of the sidereal orientation of the Earth may reach 300 μas for some low frequency components.

1. Sensitivity of the Celestial Reference Frame to the Terrestrial Reference Frame Status in the Data Analysis

The analysis strategies for deriving a celestial reference frame from multi-year VLBI observations include a number of choices. We consider here the choice that has to be made concerning the definition of the celestial and terrestrial reference frames and their connection in time. Two different approaches are used, as follows. In the derivation of the ICRF and its extensions (Ma et al. [6], Fey et al. [5]), the so-called **CRF** approach was used, namely the stations' positions are set as *arc parameters*, i.e., they are estimated independently for each observing session. In the so-called **TRF** approach, most station positions and velocities are set as *global parameters*, i.e. considered as valid over the total data span.

The **CRF** approach was chosen by the authors of ICRF in order to free the celestial frame solution from systematic errors that may be propagated from terrestrial network deficiencies. We investigated the possible contamination using test solutions based on the 1980.0-2002.7 data, described in Table 1. Data analysis was performed with the CALC-SOLVE software package. The details of the study will be available in [4].

Table 1. Test solutions: status of the sources (Global or Arc) and category of sources considered to define the orientation of the frame (No-net-rotation, NNR).

Frame	Arc srces	Globl srces	NNR	Frame	Arc srces	Globl srces	NNR
TRF approach				**CRF** approach			
cne	unstable	all others	stable	*cnh*	unstable	all others	stable
cn7	none	all	ICRF *defining*	*cn8*	none	all	ICRF *defining*

1.1. Impact on the Orientation of the Celestial Reference Frame

In order to test the possible perturbation of the orientation of the celestial reference frame due to the consideration of a global terrestrial frame, i.e. one set of station positions and velocities, we compute the relative orientations of pairs of celestial frames obtained with the same source categorization, with the **TRF** and the **CRF** approach. The relative orientation of two celestial reference frames is modelled by three rotation angles A_1, A_2, A_3 around the axes of the equatorial coordinate system. These angles are estimated together with the dz parameter, modelling an apparent equator that reflects systematic differences in declination. The relative angles between pairs of celestial reference frames are given in Table 2, for the two pairs of celestial frames described in Table 1. In the case of the conventional source selection (cn7 and cn8), the inconsistency of the axes definition between the **TRF** and **CRF** approaches is smaller than 8 μas, which is well under the published accuracy of the ICRF axes (20 μas). In the case of the selection of stable sources (cne and cnh), it is even smaller (less than 3 μas).

Table 2. Relative rotation angles and equator tilt of celestial reference frames obtained with the **TRF** and **CRF** approaches. Unit: μas.

Pair	A_1	A_2	A_3	dz
Reference sources: Stable ones				
cne-cnh	0.7 ± 0.6	0.2 ± 0.6	-2.3 ± 0.6	0.5 ± 0.9
Reference sources: *Defining*				
cn7-cn8	-6.9 ± 1.0	6.6 ± 1.0	1.7 ± 1.4	-4.2 ± 1.4

1.2. Impact on the Precision of the Celestial Reference Frame

To evaluate the impact of the **TRF** approach on the precision of the source positions, we compare them with two independent celestial frames available at the IERS/ICRS Product Center and that were provided by the IAA and the BKG, respectively. Note that the *cne* and *cnh* frames of Table 1 were aligned onto the ICRS axes using an NNR condition based on the 199 stable sources, while for the *cn7*, *cn8* and the two independent frames, the NNR condition was based on the 212 ICRF *defining* sources. The analysis strategy used to derive the independent celestial reference frames follows the **TRF** approach.

In each comparison, the two frames are rotated to common axes in a least squares adjustment applied to the 206 sources that are common to all reference frames. The variances of the postfit residuals $\Delta\alpha cos\delta$ and $\Delta\delta$ are computed. The three-cornered-hat method is then applied to these variances to derive the individual standard deviations for the reference frames of Table 1, listed in Table 3. The robustness of the estimations was tested by associating the data in various ways. The results remain stable within 2 μas. In the case of the conventional source selection as well as in that of the selection of stable sources, we conclude from the values of Table 3 that the impact on the precision of the source positions is smaller than 3 μas.

2. Terrestrial Reference Frame Status and the Measurement of Precession and Nutation

The computation of the test celestial frames included the estimation of the celestial pole offsets $\Delta\psi$ and $\Delta\epsilon$ for each session, considering only the global sources. These time series are compared to the prediction of the IAU2000 nutation model. Note that the latter was obtained by Mathews et al. ([7]) starting from an analysis of VLBI observations where all sources were considered global,

Table 3. Standard deviations of source positions for celestial reference frames derived by the TRF and CRF approaches. Unit: μas

Source selection	**TRF** approach Standard deviations			**CRF** approach Standard deviations		
	sol.	$\Delta\alpha cos\delta$	$\Delta\delta$	sol.	$\Delta\alpha cos\delta$	$\Delta\delta$
Proposed	*cne*	27.1	21.2	*cnh*	28.0	21.1
Convent.	*cn7*	28.2	27.5	*cn8*	29.4	24.7

and using a source selection scheme analogous to that leading to celestial frames *cn7* or *cn8*.

The parameters investigated are precession and obliquity rate corrections, and corrections to the 18.6-year nutation, estimated over the 1984.0-2004.7 time span.

2.1. Precession, Obliquity Rate and 18.6-year Nutation

The estimations of precession and obliquity rate corrections from the four data sets under study are listed in Table 4. As already noted by Dehant et al. ([1]) and Feissel-Vernier et al. ([3]), the impact of the source selection, i.e. *cne* vs *cn7* or *cnh* vs *cn8*, is at the level of 40-50 μas/year in precession, while it is small on the obliquity rate. Compared to that effect, the impact of the terrestrial frame status, i.e. *cne* vs *cnh* or *cn7* vs *cn8* (2 μas), is barely significant.

The estimations of the 18.6-year nutation corrections are also listed in Table 4. The same remarks apply: while the impact of the source selection is quite large (up to 50 μas in $\Delta\psi sin\epsilon_0$), the impact of the terrestrial frame status (10 μas) is statistically insignificant.

Table 4. Precession, obliquity rate and 18.6-year nutation corrections: role of the terrestrial reference frame status and of the source selection

Source selection	Precession μas/year	Obliqu. rate μas/year	18.6-yr $\Delta\psi$ (μas) sine	cosine	18.6-yr $\Delta\epsilon$ (μas) sine	cosine
TRF approach						
Proposed (*cne*)	-56.3 ± 4.8	-31.6 ± 1.8	252 ± 23	150 ± 26	-12 ± 9	19± 10
Conventional (*cn7*)	-17.6 ± 4.2	-28.5 ± 1.7	80 ± 20	163 ± 24	-46 ± 8	31± 10
CRF approach						
Proposed (*cnh*)	-58.2 ± 4.6	-32.4 ± 1.7	266 ± 22	135 ± 25	-6 ± 8	19 ± 9
Conventional (*cn8*)	-15.4 ± 4.0	-27.0 ± 1.6	71 ± 19	139 ± 23	-47 ± 7	39 ± 9

2.2. Residual Noise

Statistics of the residual noise in the comparisons of VLBI series of $\Delta\psi$ and $\Delta\epsilon$ with the IAU2000 model are shown in Table 5. Compared to the **CRF**-type solutions, the level of the residual noise of the **TRF**-type solutions, is larger by less than 5%. We therefore may consider that the difference in treating the station coordinates only slightly affects the high frequency noise of the nutation determinations.

Table 5. Agreement of the IAU2000 Precession-Nutation model, corrected for a bias and the terms listed in Table 4, with VLBI results derived with various analysis approaches. Unit: μas

Reference frame	**TRF** approach Standard Dev. (μas)			**CRF** approach Standard Dev. (μas)		
		$\Delta\psi sin\epsilon_0$	$\Delta\epsilon$		$\Delta\psi sin\epsilon_0$	$\Delta\epsilon$
Proposed	*cne*	254	239	*cnh*	244	229
Convent.	*cn7*	236	239	*cn8*	228	233

3. Sidereal Orientation of the Earth and Stability of the VLBI Celestial Reference Frame

The impact of the source selection on the estimation of precession and nutation components was investigated over the time span 1984-2002 ([3]). The precession correction to the IAU2000 value that is obtained when excluding the unstable sources reaches 49 ± 5 μas/year, to be compared to 12 ± 5 μas/year using the current conventional celestial frame. The determination of the obliquity rate is unaffected and remains at the level of 27 ± 2 μas/year. The observed correction to the 18.6-year nutation amplitude using the current conventional celestial frame are sizeably corrupted by the unstable sources. After accounting for this effect, the estimations relative to both sets of reference radio sources confirm a discrepancy with the IAU2000 nutation model with a total amplitude of 320 ± 100 μas for the observed nutation in longitude, to be compared to the 80 μas discrepancy found by Mathews et al. ([7]). The discrepancy in obliquity amounts to 50 ± 16 μas. The effect of source instability is shown to have an impact on the determination of universal time at the one microsecond level. The high and medium frequency nutation terms (up to periods of a few years) are impacted only in the early years of the program.

References

[1] Dehant, V., Feissel-Vernier, M., de Viron, O., Ma, C., Yseboot, M., Bizouard, C., 2003, JGRB, 108, 2275.

[2] Feissel-Vernier, M., 2003. A&A, 403, 105.

[3] Feissel-Vernier, M., Ma, C., Gontier, A.-M., Barache, C., 2005, A&A (in press).

[4] Feissel-Vernier, M., Ma, C., Gontier, A.-M., Barache, C., 2005, IERS Technical Note, C. Ma (ed.) (in preparation).

[5] Fey, A.L., Ma, C., Arias, E.F., Charlot, P., Feissel-Vernier, M., Gontier, A.-M., Jacobs, C.S., Li, J., MacMillan, D.S., AJ 127, 3587.

[6] Ma, C., Arias, E.F., Eubanks, T.M., Fey, A.L., Gontier, A.-M., Jacobs, C.S., Sovers, O.J., Archinal, B.A., Charlot, P., 1998, AJ 116, 516

[7] Mathews, P. M., Herring, T. A., Buffett, B. A. 2002, JGRB, 107, 1029