Global consistency of IERS Earth orientation with the ITRS and ICRS: span 1988–2003

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Abstract. In this technical note we present the problem of global consistency of EOP series, determined from VLBI, GPS, SLR observations. It is possible to quantify the level of consistency of two EOP series if the relative rotation between the reference frames to which they referred, is known. After recalling the way the „consistencies" are estimated, we derived them for the last global VLBI solutions received during the year 2004 at the Earth Orientation Center

1 Introduction

The Earth Orientation Parameters (EOP) are routinely provided by three techniques: VLBI, GPS, SLR. One of the tasks of the IERS, committed to the care of the EOP Centre of Paris since 1988 is to check the consistency of these series. Nowadays the time variations of the EOP agree from a series to an other at the level of 60 microarcseconds (μas): for polar motion, 15 microseconds for UT1 and 100 μas for nutation. But these same series can present larger systematic shifts, modelled as linear time function. These systematic offsets are not surprising when considering the fact that these series are referred to different reference frame (terrestrial and celestial). Indeed any rotation between these systems induce biases between the corresponding EOP. The consistency of two EOP series is granted if their bias is fully explained by the rotation angles between the terrestrial (or celestial) frames to which they are referred. From practical point of view biases and trend are computed with respect to combined series of the EOP Centre (C01), which is given in principle in the International Terrestrial Reference Frame (ITRF) and International Celestial Reference Frame (ICRF).

Consistencies were studied since 1988, and reported in the frame of the IERS annual report. The inconsistencies reached in this epoch 1-2 milliarcseconds (mas). They are now reduced to a few tenths of mas. This is too large with respect to the precision of the EOP.

2 Theory

Let us consider two series of EOP (x, y, UT1, dψ, dϵ) and (x', y', UT1', dψ', dϵ') respectively. Each of them is referred to a celestial frame defined by the adopted Radio Source Coordinates (RSC) and to a terrestrial frame defined by the adopted Set of Station Coordinates (SSC) and velocities. The celestial reference frames, respectively denoted CRF and CRF' present systematic differences, which can be described by an elementary rotation matrix A. The coordinates in both system, [CRF] and [CRF'] respectively, are linked by the relation:

$$[\mathrm{CRF}] = \mathrm{A}\ [\mathrm{CRF'}]$$

In the same way the terrestrial reference frames, TRF and TRF' respectively, are linked through an elementary rotation:

$$[\mathrm{TRF}] = \mathrm{R}\ [\mathrm{TRF'}]$$

If both EOP series were consistent with their frames, then the systematic differences in the pole coordinates (Δx = x' - x, Δy = y' - y), in the universal time (ΔUT1 = UT1' - UT1), and in the celestial pole offsets ($\Delta\psi = \delta\psi$' - $\delta\psi$, $\Delta\epsilon = \delta\epsilon$' - $\delta\epsilon$) would be only due to the rotation angles (A1, A2, A3) between the two celestial frames and (R1, R2, R3) between the two terrestrial frames. It can be shown that these systematic differences would satisfy the following relationships with an accuracy of a few microarcseconds:

$$\begin{aligned}
\Delta x &= R_2 \\
\Delta y &= R1 \\
f.\Delta UT1 &= -R_3 + A_3 \\
\Delta(\delta\psi) &= A_2/sin(\epsilon_0) \\
\Delta(\delta\epsilon) &= -A_1
\end{aligned} \tag{7}$$

where f is the conversion factor from Universal Time to sidereal time, and ϵ_0 is the obliquity of the ecliptic. It is worthwhile to check to which extent the relationships (1) are satisfied. Each comparison will be made naturally with respect to the same data set (CRF, TRF, EOP), that is the ICRF, the ITRF and the corresponding EOP series of the IERS. The closure of relationships (1) characterises the internal consistency of the set of IERS results, time series and reference frames. In this objective the quantities

$$\begin{aligned}
C(x) &= \Delta x - R_2, \\
C(y) &= \Delta y - R_1, \\
C(UT1) &= f.DUT1 - (-R_3 + A_3), \\
C(\delta\psi) &= \Delta(\delta\psi) - A_2/sin(\epsilon_0), \\
C(\delta\epsilon) &= \Delta(\delta\epsilon) - (-A_1)
\end{aligned}$$

are computed.

3 Time evolution of the IERS EOP series relative to ITRF

We consider two terrestrial frames, each one having its own velocity field. The series of EOP, the relative drifts between the corresponding series of EOP can be predicted by relationships (2), obtained as the time derivatives of the first three relationships (1):

$$\begin{aligned}
d(\Delta x)/dt &= d(R2)/dt \\
d(\Delta y)/dt &= d(R1)/dt \\
f.d(\Delta UT1)/dt &= -d(R3)/dt
\end{aligned} \tag{8}$$

where d(R1)/dt, d(R2)/dt, d(R3)/dt are the rates of change of the rotation angles between the two terrestrial reference frames. These relationships are used to compare the drifts of the EOP series relative to EOP(IERS)C01 with their predicted values based on the definition of the corresponding terrestrial velocity field.

4 Results for the EOP VLBI series over the time span 1988–2003

Since the year 1998, the angles between the individual TRF and the ITRF97 have not been computed by the terrestrial frame section of the Central Bureau (located at the Institut Géographique National, France). For that reason consistency analyses for polar motion and UT1 is only pertinent for the series referred to the ITRF (angles R1, R2, R3 equal to zero). That is the case of some VLBI series.

Our analysis is restricted to the last VLBI EOP series, for which we had valuable information on their reference Radio Source Coordinates. They are listed in the Table 1.

Table 1. Analysed EOP VLBI series. We give the time span of the analysis and specify the reference frames to which are referred those series as well as the possible rotation between their associated radio source catalogue and the ICRF. Unit for angles is milliarcsecond.

VLBI EOP Series	Years considered	CRF	TRF	Organization
AUS 04 R 01	1988–2003	ICRF	?	Geoscience Australia
BKG 02 R 01	1988–2001	BKGI 02 R 01 A1 = 0.029±.010 A2 = -0.002±.009 A3 = -0.017±.011	ITRF2000	Bundesamt für Kartographie und Geodäsie
GAOUA 03 R 01	1988–2002	GAOUA 03 R 01 T A1 = 0.008±.011 A2 = -0.047±.010 A3 = -0.017±.012	?	Glavnaya Astronomicheskaya Observatorya Ukraini (MAO)
GSFC 02 R 01	1988–2002	GSFC 02 R 01 A1 = 0.011±.010 A2 = -0.015±.010 A3 = -0.036±.012	?	Goddard Space Flight Center, Washington
IAA 02 R 03	1988–2001	IAA 02 R 03 A1 = 0.003±.012 A2 = -0.012±.011 A3 = -0.007±.014	ITRF2000	Institut of Applied Astronomy Saint-Petersburg
MAO 03 R 02	1988–2002	ICRF	ITRF2000	Main Astronomical Observatory, Ukraine
SHA 04 R 01	1988–2002	ICRF	?	Shanghai Observatory

The present consistency analysis consists in two steps:

- The first step is the computation of the biases and slopes of the individual EOP parameters (nutation in longitude, nutation in obliquity) with respect to the combined parameters of the series EOP(IERS)C01. To this aim the individual series are averaged and interpolated with 0.05-year interval.
- The second step is the comparison, given hereafter, between these biases and those theoretically produced by the rotations between the reference frames, as already explained.

Table 2 gives the evaluations of the internal consistency for data sets involving celestial pole offsets series and RSC, till the date 2003.0. The data before 1988 are not considered because they are considered to be of lower quality. Biases and trends have been computed with respect to the epoch 1997.0.

Table 2. CONSISTENCY OF VLBI EOP SERIES WITH CELESTIAL REFERENCE FRAMES, BASED ON THE ROTATION ANGLES RELATIVE TO ICRF (slope and bias computed at the epoch 1997). The data span is given. Unit are mas (0.001"). For each series the first line gives the second member of consistency relation (1), the second line gives the second member of consistency relation (1), and the third line the consistencies themselves. The satisfactory ,,consistencies" are written in green, the ,,inconsistencies" or badly determined consistencies in red.

SERIES	1 2 3	R_2 Δx C(x)	R_1 Δy C(y)	$-R_3 + A_3$ $f.\Delta UT1$ C(UT1)	$A_2/sin(\epsilon_0)$ $\Delta\delta\psi$ C($\delta\psi$)	$-A_1$ $\Delta\delta\epsilon$ C($\delta\epsilon$)
	1	?	?	?	0.000±0.025	0.000±0.010
EOP(AUS) 4 R 01	2	0.007±0.010	0.035±0.009	-0.113±0.015	0.022±0.019	-0.036±0.008
1988-2003 1997.00	3	?	?	?	0.022±0.032	-0.036±0.013
	1	0.000±0.000	0.000±0.000	-0.017±0.011	-0.005±0.023	-0.029±0.010
EOP(BKG) 2 R 01	2	-0.137±0.010	0.181±0.009	0.008±0.012	-0.036±0.016	-0.055±0.007
1988-2001 1997.00	3	-0.137±0.010	0.181±0.009	0.025±0.016	-0.031±0.028	-0.026±0.012
	1	?	?	?	0.118±0.025	-0.008±0.011
EOP(GAOUA)3 R 01	2	-0.081±0.010	0.144±0.009	-0.030±0.011	0.107±0.016	-0.027±0.007
1988-2002 1997.00	3	?	?	?	-0.011±0.030	-0.019±0.013
	1	?	?	?	-0.038±0.025	0.011±0.010
EOP(GSFC) 2 R 01	2	-0.200±0.009	0.064±0.007	0.003±0.009	-0.096±0.014	-0.013±0.006
1988-2002 1997.00	3	?	?	?	-0.058±0.029	-0.024±0.012
	1	0.000±0.000	0.000±0.000	-0.007±0.014	0.030±0.028	0.003±0.012
EOP(IAA) 2 R 03	2	0.037±0.012	-0.002±0.013	0.662±6.415	-0.065±0.021	-0.033±0.010
1994-2001 1997.00	3	0.037±0.012	-0.002±0.013	0.669±6.415	-0.095±0.035	-0.036±0.016
	1	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.010
EOP(MAO) 3 R 02	2	-0.088±0.011	0.144±0.009	-0.027±0.011	0.111±0.016	-0.034±0.007
1988-2002 1997.00	3	-0.088±0.011	0.144±0.009	-0.027±0.015	0.111±0.030	-0.034±0.012
	1	?	?	?	0.000±0.025	0.000±0.010
EOP(SHA) 4 R 01	2	-0.157±0.010	0.188±0.007	0.012±0.009	0.087±0.019	-0.048±0.009
1988-2002 1997.00	3	?	?	?	0.087±0.032	-0.048±0.013

4.1 Nutation offsets consistency

For celestial pole offsets $\delta\psi sin(\epsilon_0)$ and $\delta\epsilon$ the inconsistencies does not stretch over 50 μas. The mean consistency is about 30 μas. This an encouraging result, in the sense that the standard deviation between time series is typically two times more. For some series (BKG, GAOUA, GSFC) the angles between celestial frames explain partly the bias between series.

4.2 UT1 consistency

Three VLBI series allow us to establish consistency for UT1: BKG for which the value is perfectly acceptable, IAA for which the consistency remain poorly known probably because of the shortness of the series which begins in 1994, and MAO showing excellent consistency. Most often VLBI series are determined from sub-network of the ITRF, and it is not a clear issue whether this sub-network has a significant rotation with respect to the ITRF or not. This may be a major source of inconsistency in UT1.

4.3 Polar motion consistency

The inconsistencies in polar motion can be computed for 4 VLBI series. Globally their values are up to 200 μas, except for IAA series. We note that their mean values (for x: -60 μas, for y: 100 μas), are comparable to that ones associated with VLBI series determined from the VLBI-GPS Pilot Campaign 2001, but globally smaller.

5 Conclusion

We can measure the progress achieved in 10 years: in 1995 the mean consistencies were about 300 μas for x, 800 μas for y, 650 μas for the rotation angle, -150 μas for $\delta\psi sin(\delta\epsilon_0)$ and 50 μas for $\delta\epsilon$. The gain is up to 5 for some EOP, inconsistencies tend to the level of the uncertainties of the EOP parameters.