Consistency Analysis Between EOP Series and Reference Frames

Daniel Gambis, Christian Bizouard

Earth Orientation Center, Observatoire de Paris, Paris, France

1 Background: Consistency of IERS EOP series with ITRF and ICRF

Earth Orientation Parameters (EOP) provide the transformation between the International Terrestrial Reference Frame (ITRF) and the International Celestial Reference Frame (ICRF). The IERS reference series, labelled IERS C04 is obtained from the combination of individual EOP series derived from the various astro-geodetic techniques, mostly VLBI, GPS and SLR. These individual EOP series present mutually systematic errors, generally limited to biases and drifts which can be attributed to the adoption of different reference frames CRF and TRF in the analyses of observations. It is also essential that the reference series C04 be not affected by these individual systematic errors to ensure a long-term stability. However, as the C04 is independently maintained, it is expected that small inconsistencies could appear after some time. This fact already lead in the past to a small adjustment of polar motion (biases and drifts) in 1997. In order to assess whether a correction should again be applied to C04, various consistency studies were carried on, using the IVS pilot project 2001 and the IERS alignment campaign in 2002. It appears that the C04 is for pole components, inconsistent with ITRF2000 at a level of 0.1 to 0.2 milliarcseconds. However, it is premature to apply any correction to it since the level of inconsistency between the different techniques, mostly GPS and VLBI is at the same level. More investigations are needed to identify the reasons of the discrepancies within identical techniques with the same or different packages used and also between the different techniques.

2 Monitoring inconsistency at the Earth Orientation Center: current method

There are different approaches to estimate the consistency of the IERS EOP system with respect to both terrestrial and celestial reference frames. The usual method performed at the IERS since 1991 consists in comparing the individual EOP solutions to the IERS C04 after estimation of the rotation angles between on one hand the individual CRF with respect to ICRF and on the other hand the individual TRF with respect to ITRF. The formalism is described in Zhu and Mueller (1983). Figures 1 to 3 represent, since 1991, the evolution of the inconsistency for the different techniques VLBI, GPS and SLR (Gambis et al., 2002; Bizouard and Gambis, 2002). Note that the mean inconsistency is for the various techniques at the level of 100 µas for polar motion and 20 microseconds for UT1 since the year 2000 (IERS Annual Reports).

This approach using the comparisons of rotation angles from individual frames to ITRF is now not straightforward because of constraints introduced in the determination of the terrestrial and celestial frames; angles between the individual TRF and the ITRF cannot be now easily computed.

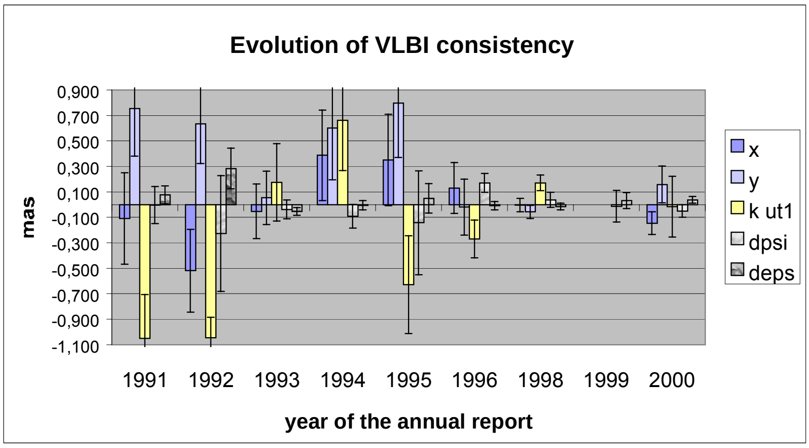

Fig. 1 Evolution of the consistency of VLBI solutions since 1991

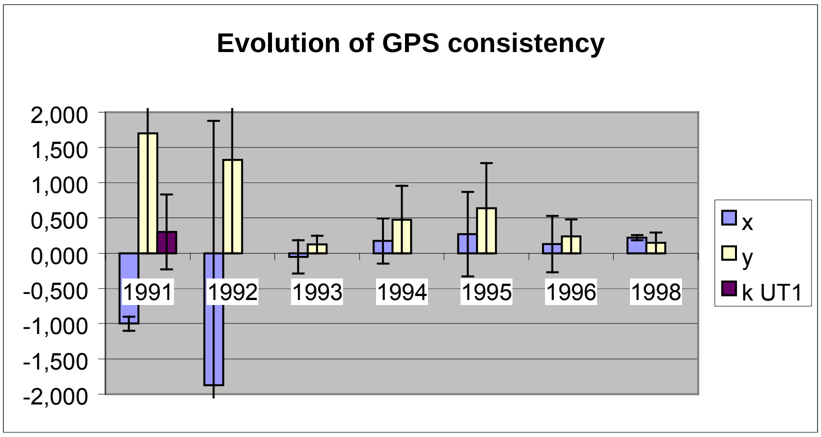

Fig. 2 Evolution of the consistency of GPS solutions since 1991

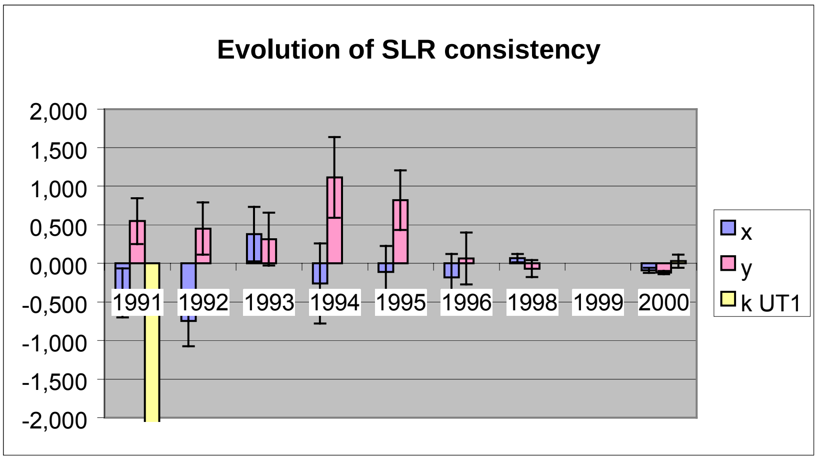

Fig. 3 Evolution of the consistency of SLR solutions since 1991

A more satisfying method to monitor the consistency, so far not realized within the IERS is based on a rigorous computation of both frames, CRF, TFR and EOP parameters. This approach, beyond the scope of the present paper is carried on progressively at the IERS. So far only preliminary results were obtained.

An intermediate approach for a better understanding of the origin of inconsistencies is based on 2 analysis campaigns: the second IVS pilot campaign (Nothnagel, 2001) and the IERS alignment campaign (Rothacher, 2002). In the frame of these campaigns, analysis centers were asked to derive EOP series with high constraints concerning both terrestrial and celestial reference frames. For the IERS alignment campaign, we limited our analyses to series for which terrestrial and celestial reference frames were held fixed to respectively ICRF-Ext.1 and ITRF2000.

3 IVS Pilot 2001

Eleven Analysis Centers submitted EOP series for the second IVS pilot project. These series were derived from all available NEOS-A 24hr VLBI sessions over 1999 and 2000. In these solutions, the celestial and the terrestrial reference were fixed respectively to ICRF-Ext.1 and to ITRF2000 with the associated velocity field.Estimated parameters include the pole components X-Pole, Y-Pole, UT1–UTC and the nutation offsets dPsi, dEps with respect to IAU 1980 model.The individual VLBI series are compared to IERS C04 together with the operational GPS series also referred to ITRF2000 through the IGS realization.

Tables 1 and 2 give the statistics concerning the systematic biases the mean values of which were computed. Units are µas for polar motion and nutation µs for UT1.

Table 1 Systematic biases between VLBI EOP series and the reference IERS C04

VLBI	AUS	BKG	CAN	DGFI	GSFC	IAA	IGG	JPL	OSO	OSO2	SPBU	Mean*	rms
xpole (µas)	–58	–16	–94	–114	–55	–143	–161	–220	62	55	–86	**–60**	76
ypole (µas)	367	330	–403	312	328	286	319	696	330	311	347	**326**	24
UT1 (µs)	6	8	7	8	8	6	10	13	14	16	7	9	3.4
dψ (µas)	28	–90	36	–17	9	15	90	851	96	108	31	–12	58
dε (µas)	49	43	0	3	21	86	–19	–2764	96	116	38	48	34

* CAN and JPL are excluded for polar motion; JPL for nutation

It appears from these tables that for X-Pole, biases are not homogeneous ranging from –16 µas (BKG) to –220 µas (JPL), the standard deviation being in the range of 100 to 200 µas. The mean bias, CAN and JPL excluded, is -60 ± 76 µas. For Y-pole biases are much more homogeneous than for X-pole with a mean value of 326 ± 24 µas. For UT1 biases are ranging between 5 and 25 microseconds. Again JPL presents anomalous rms. For nutation offsets, biases and rms are much less homogenous than for the other parameters. Mean values are respectively –12 ± 58 µas and 48 ± 34 µas for dψ and dε.

4 Biases of GPS operational EOP series

For comparison, the same analyses were conducted for the 7 GPS operational series, over 1999–2000. Biases and rms are reported in Table 2.

Table 2 Systematic biases between GPS EOP series and the reference IERS C04

GPS	CODE	JPL	GFZ	ESOC	NOAA	SIO	EMR	Mean *	rms*
xpole (µas)	20	–47	–70	–29	–85	–39	–23	**–45**	24
ypole (µas)	186	180	184	257	158	207	148	**188**	36
LOD (µs)	8	–7	–5	–33	–29	0	–19	–12	15

It appears that these series are mutually more consistent than for the IVS Pilot series (mean values are –45 ± 24 µas and 188 ± 36 µas respectively for X-and Y-pole. However significant inconsistency of about 150 µas exist in Y-pole when compared to VLBI series. This could be expected from the fact that GPS series are referred to a realization of the ITRF2000 which present significant small rotation with respect to the frame.

In conclusion, it appears that there is a slight inconsistency in the IERS C04 y-pole solution of about 100 – 150 µas with respect to ICRF-Ext.1 and ITRF2000. However its values are of the same order as the discrepancy between VLBI and GPS solutions (150 µas).

5 IERS alignment campaign

The idea of the campaign was to compute EOP series with highest possible consistency with ITRF2000 / ICRF and investigate what the ultimate achievement of the overall accuracy. The main objectives were to study systematic discrepancies within techniques due to softwares difference, between techniques due to sub-network effects and understand their origin. The analyses we performed concerned more specifically long-term consistency, trends and biases, between techniques and the reference IERS C04. We have limited our analyses to long-term EOP series derived by analysis centers in which both references frames were fixed to ICRF and ITRF2000 in the course of the calculations (i.e. 5 VLBI, 3 SLR one GPS, one DORIS series). In fact for GPS and DORIS, the terrestrial reference frame is materialized by a realization of the ITRF2000. Tables 3 and 4 present systematic errors, respectively biases and drifts, between individual solutions obtained within same techniques, identical or different softwares, and IERS C04 for all parameters. The initial date for which biases and rates are computed is MJD=50448.0. Table 5 gives the overall weighted rms of these solutions compared to the C04 over the whole data span of each series. For polar motion, the rms agreement ranges from about 100 µas (GPS) to 2 mas (DORIS). For UT1, the mean rms is about 15 µs.

Table 3 Bias between individual solutions and IERS C04 for all EOP parameters. CSR solution, computed in a different reference frame than ITRF2000 was transformed using the correction given for the 1997 correction (IERS Gazette 8).

	Institute	Software	Data span	X µas	sX µas	Y µas	sY µas	UT1 µs	sUT1 µs	dPsi µas	sdPsi µas	dEps µas	sEps µas
VLBI	BKG	CALC	1984–2002	–114	6	143	5	–1	1	–27	8	6	4
	GSFC	CALC	1979–2001	–103	5	148	4	–1	1	–63	7	5	4
	SHA	CALC	1979–2002	–201	10	194	8	14	1	–15	8	8	4
	DGFI	OCCAM	1984–2002	–135	5	134	5	1	1				
	GAUS	OCCAM	1983–2002	–200	10	133	6	1	1				
	IAA	OCCAM	1980–2002	–138	6	116	5	–3	1	–39	9	27	4
SLR	ASI	GEODYN	1984–2002	–235	15	110	14						
	IAA	GROSS	1983–2002	–59	3	58	3						
	CSR	UTOPIA	1976–2002	–366	8	50	8						
GPS	CODE	BERNESE	1995–2002	44	4	–35	4						
DORIS	IGN/JPL	GIPSY	1992–2001	1042	57	377	33						

Table 4 Drift between individual solutions and IERS C04 for all EOP parameters. CSR solution, computed in a different reference frame than ITRF2000 was transformed using the correction given for the 1997 correction (IERS Gazette 8).

	Institute	Software	$\dot{X}$ µas/yr	s $\dot{X}$ µas/yr	$\dot{Y}$ µas/yr	s $\dot{Y}$ µas/yr	$\frac{dUT1}{dt}$ µs/yr	s $\frac{dUT1}{dt}$ µs/yr	d $\dot{\psi}$ µas/yr	sd $\dot{\psi}$ µas/yr	d $\dot{\varepsilon}$ µas/yr	s d $\dot{\varepsilon}$ µas/yr
VLBI	BKG	CALC	20	2	37	2	2	.1	–5	2	–1	1
	GSFC	CALC	16	1	31	1	2	.1	–14	2	–3	1
	SHA	CALC	–5	3	56	2	6	.2	0	3	–2	1
	DGFI	OCCAM	12	2	41	2	2	.2				
	GAUS	OCCAM	37	3	36	2	2	.1				
	IAA	OCCAM	3	2	38	2	3	.1	–10	2	–1	1
SLR	ASI	GEODYN	3	3	8	3						
	IAA	GROSS	11	1	–3	1						
	CSR	UTOPIA	–103	2	33	1						
GPS	CODE	BERNESE	–17	1	49	1						
DORIS	IGN/JPL	GIPSY	–203	23	–53	13						

A slight but significant systematic error appears in Y-pole rate component of the IERS C04 (about 20 µas/yr), a few µs in UT1. However within VLBI technique, the comparisons show significant inconsistencies of solutions using same or different softwares (100 µas for pole biases and 30 µas/yr for pole rates). In addition, there are inconsistencies between the different techniques, DORIS excluded (300 µas for pole biases and 50 µas/yr for pole rates). In conclusion, within the inconsistencies level between different techniques, it appears that IERS C04 has a long-term consistency with the different solutions at the level of 100/300 µas in polar motion, and a few µs in UT1.

Table 5 Weighted RMS between individual solutions and the reference IERS C04

	Institute	Software	Data span	X µas	Y µas	UT1 µs	dPsi µas	dEps µas
VLBI	BKG	CALC	1984–2002	307	266	20	405	172
	GSFC	CALC	1979–2001	265	230	19	403	194
	SHA	CALC	1979–2002	532	453	47	420	188
	DGFI	OCCAM	1984–2002	212	199	16		
	GAUS	OCCAM	1983–2002	320	206	12		
	IAA	OCCAM	1980–2002	266	246	17	408	177
SLR	ASI	GEODYN	1984–2002	611	606			
	IAA	GROSS	1983–2002	249	239			
	CSR	UTOPIA	1976–2002	301	292			
GPS	CODE	BERNESE	1995–2002	125	116			
DORIS	IGN/JPL	GIPSY OASIS 2	1992–2001	3258	1860			

6 Conclusion

Individual EOP series determined from the analyses of the various techniques present mutually systematic errors, generally limited to biases and drifts which can be attributed to the adoption of different reference frames CRF and TRF. There are different approaches to estimate the consistency of the IERS EOP system with respect to both terrestrial and celestial reference frames. The current method performed at the IERS since 1991 consists in comparing the individual EOP solutions to the IERS C04 after estimation of the rotation angles between on one hand the individual CRF with respect to ICRF and on the other hand the individual TRF with respect to ITRF. It appears that the mean inconsistency for the various techniques has gradually improved from a couple of milliarcseconds for polar motion in 1991 to about 100 µas for polar motion and 20 microseconds for UT1 after 2000. Another approach to estimate the consistency is to directly inter-compare individual EOP solutions derived with fixed ITRF and ICRF (for VLBI) through an intermediate common solution, here the IERS C04. The analyses performed in the frame of the IVS Pilot Project and the IERS alignment campaign lead to the conclusions that small inconsistencies exist in the reference solution C04, however these inconsistencies are within the inconsistencies between the various technique solutions and in addition within the same technique VLBI, using identical or different software packages.

References

IERS Annual Reports for 1991 to 1999, Observatoire de Paris, Paris, France.

Bizouard C. and Gambis, D., 2002, Evolution of consistency between EOP series and the international reference, EGS Symp., Nice, March 2002

Gambis D., Bizouard C., Carlucci T., Jean-Alexis D., 2002, Comparative Study of the EOP Series Derived for the Second IVS Pilot Project, IVS 2002 General meeting proceedings, NASA/CP-2002-210002, (N. Vandenberg and K. D. Baver, eds.), pp. 330–334.

Nothnagel, A., 2001, Call for 2nd IVS Analysis Pilot Project, IVS mail message, 17 July 2001, (http://ivscc.gsfc.nasa.gov/mhonarc/ivsmail/msg00360.html)

Rothacher, M., 2001, IERS Analysis Campaign to align EOPs to ITRF2000 / ICRF, Call for Participation, IERS Message No. 19, December 20, 2001. (http://www.iers.org/iers/publications/messages/)

Zhu S.Y. and Mueller I.I., 1983: Effects of adopting new precession, nutation and equinox corrections on the terrestrial reference frames, *Bull. Géod.* **54,** 29.