

3.5 Product Centres

3.5.1 Earth Orientation Centre

This section presents activities and main results concerning the Earth Orientation Centre located in Paris Observatory over 2002. General presentation of the IERS Earth Orientation Parameters (EOP), operational activities and yearly analyses are presented at the web site (<http://hpiers.obspm.fr/eop-pc>). According to the IERS Terms of Reference, the Earth Orientation Centre is responsible for monitoring Earth orientation parameters including long term consistency, publications for time dissemination and leap second announcements. It is making available to users different products: long-term and operational series of Polar motion, Universal Time (UT1), Length of Day (LOD) and Celestial pole offsets.

Determination of EOP is in the form of combined solutions derived by the analysis centres of the different techniques. Various solutions are computed: long-term solution (IERS C01), normal values at five and one-day intervals (IERS C02 and C03) and the operational smoothed solution Bulletin B at one-day intervals published monthly and providing EOP with a delay of 30 days with respect to the date of publication. Bulletin B is updated in an operational mode in the IERS C04 which is computed twice weekly.

Combined daily series: Bulletin B and EOP(IERS) C 04

Description of Bulletin B is available in the IERS Explanatory Supplement for Bulletin A and Bulletin B (Gambis and Ray, 2002). Since formal uncertainties reported by the contributors are often underestimated, they are calibrated by statistical assessment using the Allan variance analysis in order to reflect the real quality of the data (Gray and Allan, 1974; Gambis, 2002). This procedure leads to an optimal weighting of the individual series entering the combinations. Table 1 gives the estimated accuracy with respect to IERS C04 of these series over 2002-2003 after removal of systematic variations, mainly a bias.

Predictions

Different methods are used for prediction of the Earth rotation parameters.

Polar Motion

The formalism uses at first a floating period fit (Bevington, 1969) for both the Chandler and annual components estimation over a past time interval of several years. An autoregressive filter is then applied on the short-term residuals series and used for the prediction. The predictions of the celestial pole offsets $\Delta\psi$ and $\Delta\epsilon$ are based on an empirical model (McCarthy, 1996).

Universal Time

The present formalism used is based on the assumption that the long-term fluctuations (annual and semi-annual) of the preceding

Table 1: Estimated accuracies of individual solutions entering the combined solutions in 2002-2003.

Individual solutions			Estimated uncertainties				
			Time	Terrestrial Pole 0.001"	UT1 0.0001s	LOD	Celestial Pole 0.001"
VLBI - 24 h							
EOP (GAUS)	01 R 01	7d	0.28	0.12		0.09	
EOP (BKG)	01 R 03	7d	0.25	0.12		0.09	
EOP (GSFC)	02 R 04	7d	0.13	0.09		0.08	
EOP (IAA)	02 R 01	7d	0.19	0.09		0.07	
EOP (SPBU)	01 R 02	7d	0.70	0.15		0.12	
VLBI - Intensive							
EOP (BKG)	01 R 02	1-3 d		0.14			
EOP (GSFC)	02 R 03	1-3 d		0.13			
EOP (IAA)	02 R 02	1-3 d		0.12			
EOP (SPBU)	02 R 01	1-3 d		0.10			
Satellite Laser Trackin							
EOP (CGS)	97 L 02	3d	0.54	1.40 *			
EOP (CSR)	95 L 01	3d	0.40	0.90 *			
EOP (DUT)	98 L 01	3d	0.60	0.09 *			
EOP (IAA)	98 L 02	1d	0.20	0.19 *	0.03		
EOP (MCC)	97 L 01	3d	0.17		0.47		
GPS							
EOP (CODE)	98 P 01	1d	0.07		0.25		
EOP (EMR)	96 P 03	1d	0.08		0.29		
EOP (ESOC)	96 P 01	1d	0.11		0.62		
EOP (GFZ)	96 P 02	1d	0.09		0.29		
EOP (JPL)	96 P 03	1d	0.07		0.46		
EOP (NOAA)	96 P 01	1d	0.20		0.65		
EOP (SIO)	96 P 01	1d	0.08		0.32		

* The satellite techniques provide information on the rate of change of Universal Time contaminated by effects due to unmodelled orbit node motion. VLBI-based results have been used to minimize drifts in UT estimates

Table 2: Uncertainty of the current solution and the estimated accuracies of the predictions for horizons of 5 days to 1 year for 2002.

Solutions		Terrestrial Pole 0.001"	UT1 0.0001s	Celestial Pole 0.001"
Analysis	1-d	0.15	0.20	0.10
Prediction	5-d	3.	15.	0.10
	10d	6.	21.	0.10
	30d	12.	35.	0.10
	90d	40.	45.	0.10
	180d	60.	75.	0.10
	1-yr	50.	120.	0.10

3.5.1 Earth Orientation Centre

year are valid over the next few months. For short-term variations prediction, an autoregressive process is used. Table 2 shows the accuracy of the current EOP solutions and also the skills of the predictions. New procedures for prediction are under investigation, they are based on Singular Spectrum Analysis SSA and Neuronal networks.

Table 3 gives the agreement and consistencies of the IERS C04 solution with two combined solutions obtained by the IERS Rapid Service/Prediction Centre at USNO (Bulletin A) and the JPL. These values reflect the mean precision reached i.e. about 0.05 mas for polar motion and 10 microseconds for UT1. The overall accuracy taking into account the consistency between the terrestrial and celestial frames is in the range of 0.1 mas and 20 microseconds, respectively for Polar motion and UT1.

Table 3: Mean and standard deviation of the differences between various IERS solutions for 2002.

EOP	Unit	Comb JPL - IERS C04		BullA - IERS C04	
		Mean	Standard deviation	Mean	Standard deviation
X	mas	-0.19	0.07	-0.03	0.05
Y	mas	0.03	0.04	0.05	0.05
UT1	0.1 ms	-0.07	0.16	-0.05	0.20

Long-term series: C 01 (1846-2002)

EOP(IERS) C 01 is a series of the Earth Orientation Parameters given at 0.1 year interval from 1846 to 1889 (polar motion only) and 0.05 year interval from 1890 until now (polar motion, celestial pole offsets; UT1-UTC since 1962). For many decades, the observations were made using mostly visual and photographic zenith telescopes. Since the advent of the space era in the 1960s, new geodetic techniques were used for geodynamics. Now, the global observing activity involves Very Long Baseline Radio Interferometry (VLBI), Lunar (LLR) and Satellite Laser Ranging (SLR), Global Positioning System (GPS) and more recently DORIS.

The C 01 series was recomputed in the course of 2002. It is a composite series based on following temporal solutions:

1846-1899: Fedorov *et al.* (1972) polar motion solution derived from three series of absolute declination programs (Pulkovo, Greenwich, Washington).

1900-1961: Vondrak *et al.* (1995) solution derived from optical astrometry analyses based on the Hipparcos reference frame. The series gives polar motion, celestial pole offsets and Universal Time (since 1956).

1962-2003: BIH and IERS solutions (BIH and IERS Annual Reports).

Mean Pole with respect to the IERS reference origin

The analyses of the observations of space geodesy require to perform the transformation between both terrestrial and celestial frames via the Earth orientation parameters. Gravity fields models include the tesseral coefficients C21 and S21 coefficients. These terms describe the position of the Earth's figure axis with respect to the Terrestrial Reference Frame. This axis should coincide with the observed position of the rotation pole averaged over the same time period.

The mean polar motion is affected by a long-term drift westward (direction 70.7 deg West, rate: 4.2 mas/yr). The mean rotation axis with respect to the IERS Terrestrial Reference Frame, can be considered as the long-term trend obtained after filtering out the Chandler and seasonal terms, every year from 1900 to 2000 (Shiskin *et al.*, 1965). Figure 1 represents the polar motion over 2001-2002 and the path of the mean pole since 1900. The table is available in Conventions 2000 (McCarthy, 2003) and at the following address: <<http://hpiers.obspm.fr/eop-pc/>>.

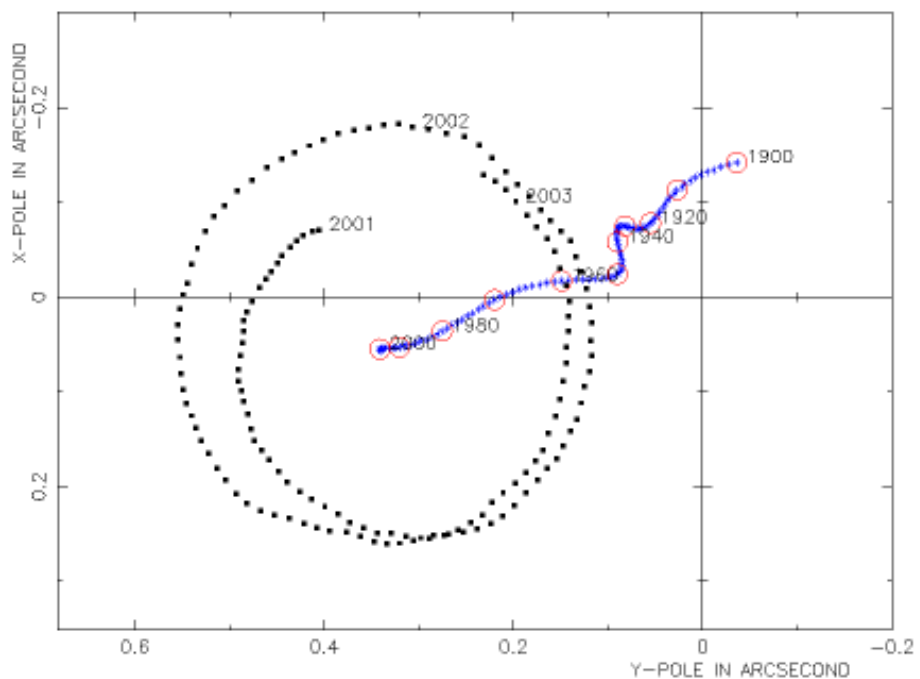


Figure 1 Mean polar motion (1900-2002) and IERS C04 polhody over 2001 - 2003.

Normal Point Solutions: C 02 (1962-2002), C 03 (1993-2002)

Other series, based on normal points solutions given at various time intervals, are also proposed to users, i.e. C 02 (5-day intervals, polar motion, UT1-UTC, $d\psi$, $d\epsilon$), C 03 (one-day intervals, polar motion, UT1-UTC) (Gambis, 1996; Eisop and Gambis, 1997). These

series are respectively consistent one to another. They use the full correlation matrix when available. Recently there were new developments in the normal point series C 02 and C 03 in which the estimation of the solution given at the central dates of the n-day interval is made using a least-square fit for all EOP components. Although the L2 estimation has been extensively used for data analysis, it has some drawbacks linked to problems of ill-conditioning and in the non-detection of outliers. Alternative methods based on robust estimators like M-Huber can be used. These estimators are a generalization of both the L1 and L2 class. They have been implemented in our analyses and are now currently used (Bougeard *et al.*, 2000). Table 4 reflects the evolution of the mean uncertainties of C02 solution since 1962.

Table 4: EOP(IERS) C 02 : Evolution of the mean uncertainty of the normal point solution given at five-day intervals

Years -- Unit	$\sigma(X)$ -- 0.001"	$\sigma(Y)$ -- 0.001"	$\sigma(UT1)$ -- 0.0001s	$\sigma(d\psi)$ -- 0.001"	$\sigma(d\varepsilon)$ -- 0.001"
1962-1967	30	30	20	-	-
1968-1971	25	25	17	-	-
1972-1979	11	11	10	-	
1980-1983	2	2	3	2	1
1984-1989	.40	.40	.20	.5	.2
1990-2000	.20	.20	.20	.3	.1
2001-2003	.15	.15	.1	.3	.1

Impact of IAU2000 Resolutions on EOP

Resolutions adopted at the 24th General Assembly of the International Astronomical Union recommend the implementation of new procedures concerning the transformation between the celestial and terrestrial reference systems: adoption of a new precession-nutation model (IAU 2000), of a new celestial pole (the Celestial Intermediate Pole) and of a new transformation between the terrestrial and celestial systems defining UT1 as directly proportional to the Earth Rotation Angle.

The IERS Workshop held in Paris in April 2002 had the objective to discuss the impact of these resolutions on the various IERS Products (Capitaine *et al.*, 2002). The description of all these changes for the IERS is presented in Rothacher (2002). Complete expressions and tables are described in Chapter 5 of the IERS Conventions 2000 (McCarthy, 2003).

To comply with these resolutions, effective on 1 January 2003, Bulletin B and IERS C04 are providing new products in addition to those already published. These products include the celestial pole offsets relatively to the new precession-nutation model IAU2000A and using the new formulation described in the following.

The changes in the EOP

New parameterisation of the Earth orientation

The most important changes are those introduced by IAU Resolutions B1.6 (IAU 2000 Precession-Nutation Model), B1.7 (Definition of Celestial Intermediate Pole) and B1.8 (Definition and Use of Celestial and Terrestrial Ephemeris Origins). Although it is not directly mentioned in the Resolutions, the new precession-nutation model is accompanied by a new formulation for the transformation between the celestial (*CRS*) and terrestrial (*TRS*) reference systems in the form recommended in the IERS Conventions 2000:

$$[CRS] = Q(t) \cdot R_3(-\theta) \cdot W(t) \cdot [TRS],$$

in which $Q(t)$, $R_3(-\theta)$ and $W(t)$ are time-dependent transformation matrices to account for the precession-nutation, proper rotation of the Earth about the axis corresponding to CIP and polar motion, respectively:

$$Q(t) = \begin{pmatrix} 1 - aX^2 & -aXY & X \\ -aXY & 1 - aY^2 & Y \\ -X & -Y & 1 - a(X^2 + Y^2) \end{pmatrix} \cdot R_3(s),$$

$$a = \frac{1}{2} + \frac{1}{8}(X^2 + Y^2)$$

$$W(t) = R_3(-s') \cdot R_2(x) \cdot R_1(y)$$

The Earth Rotation Angle (ERA) between the CEO and TEO is given as function of UT1 by a simple linear relation:

$$\theta(T_u) = 2\pi(0.779\,057\,273\,264\,0 + 1.002\,737\,811\,911\,354\,48\,T_u)$$

where $T_u = \text{JD}(\text{UT1}) - 2\,451\,545.0$.

Here X , Y , s and x , y , s' describe the position of the Celestial Intermediate Pole (CIP) and the Celestial/Terrestrial Ephemeris Origins (CEO, TEO) in the Geocentric Celestial Reference System (GCRS) and International Terrestrial Reference System (ITRS), respectively (see <<http://maia.usno.navy.mil/ch5tables.html>>). The novelty are the quantities X , Y , s whose developments into Poisson series, based on the IAU 2000A precession-nutation model, are published by Capitaine *et al.* (2003). Expressions for the classical transformation based on the new IAU 2000 model have been developed to be equivalent in the new transformation (McCarthy, 2003).

Celestial pole offsets

Precession-nutation is referred to CIP that exhibits, by definition, only long-periodic motions with periods of two days and longer in space. The IERS is now publishing the celestial pole offsets δX_{2000} , δY_{2000} , referred to the new model IAU 2000 following the new formalism and the quantity s . Classical nutation angles, the celestial pole offsets in longitude and obliquity $\delta \Delta \psi_{2000}$, $\delta \Delta \epsilon_{2000}$, respectively, referred to the new model can be easily derived from $(\delta X_{2000}, \delta Y_{2000})$ using equations 23 of Chapter 5 of the IERS2000 Conventions or the relative Fortran subroutine dXdY_dpsideps included in the package uai2000.package (see next paragraph for its availability). These values δX , δY are now smaller than 1 mas, reflecting mostly the effect of the Free Core Nutation (FCN) that is not predictable and therefore not incorporated into the new model. The position of the CEO, given by s , is insensitive to any small change of the precession-nutation at the level of one mas, so only its model values are to be used (<http://maia.usno.navy.mil/ch5tables.html>). Parallel to these values, the values of 'classical' celestial pole offsets $\delta \Delta \psi_{1980}$, $\delta \Delta \epsilon_{1980}$, referred to the old IAU 1976 precession and 1980 nutation model, are also being published for a limited period in Bulletin B and in the operational combined series C04.

Polar motion

Polar motion is not affected by adopting the IAU 2000 resolutions. Polar motion contains (relatively small) diurnal and sub-diurnal terms, due to ocean tides and high-frequency nutation terms. These are *not* part of the polar motion values published by the IERS at daily intervals; they are represented by a model (IERS Conventions 2000, Chapters 5 and 8) and should be added after interpolation. The Earth Orientation Centre makes available a Fortran subroutine for such an interpolation (<ftp://hpiers.obspm.fr/eop-pc/models/interp.f>). The position of the TEO, given by s' , depends on the actual polar motion but the value of s' is so small that a simple linear approximation (Lambert and Bizouard, 2002) is sufficient:

$$s' = -47 \mu\text{as} (t - 51544.5) / 36525$$

where t is expressed in Modified Julian Days (MJD).

Universal Time

UT1-UTC is theoretically not affected by the resolutions. Although UT1 is now directly linked to the Earth rotation angle through the linear relation above, the positioning of CEO (represented by the quantity s) and IAU2000 expressions between sidereal time and universal time UT1 are such that continuity in UT1 is ensured at the epoch of change from the old system.

There are short-periodic (diurnal, semi-diurnal) variations in UT1 due to ocean tides that are treated similarly to polar motion (the IERS publishes the daily values from which these terms have been removed, and they are to be added back after the interpolation).

Availability of new products and models

Series of the EOC, in particular BULLETIN B and C04 are being duplicated since January 2003 to give δX and δY in the new formulation in addition to the current issue containing $(\delta\psi, \delta\epsilon\psi)_{1980}$.

The new files are available at the following Web/ftp sites:

– Web:

http://hpiers.obspm.fr/eoppc/eop/eopc04/eopc04_IAU2000.02

http://hpiers.obspm.fr/eoppc/eop/eopc04/eopc04_IAU2000.03

– anonymous ftp: [hpiers.obspm.fr](ftp://hpiers.obspm.fr)

files: [/eop-pc/eop/eopc04/eopc04_IAU2000.02](ftp://hpiers.obspm.fr/eop-pc/eop/eopc04/eopc04_IAU2000.02)

[/eop-pc/eop/eopc04/eopc04_IAU2000.03](ftp://hpiers.obspm.fr/eop-pc/eop/eopc04/eopc04_IAU2000.03)

Fortran subroutines

1) Transformation of $(\delta X, \delta Y)_{2000}$ to $(\delta\psi, \delta\epsilon\psi)_{1980}$ or $(\delta\psi, \delta\epsilon\psi)_{2000}$ and inversely are available in Fortran 77/90 at:

– Web:

<http://hpiers.obspm.fr/eop-pc/models/models.html#software>

files:

<ftp://hpiers.obspm.fr/eop-pc/models/uai2000.package>

<ftp://hpiers.obspm.fr/eop-pc/models/uai2000.package.readme>

– anonymous ftp: [hpiers.obspm.fr](ftp://hpiers.obspm.fr)

files: [/eop-pc/models/uai2000.package](ftp://hpiers.obspm.fr/eop-pc/models/uai2000.package)

[/eop-pc/models/uai2000.package.readme](ftp://hpiers.obspm.fr/eop-pc/models/uai2000.package.readme)

2) Interpolation of Polar Motion at hourly scale

– Web: <http://hpiers.obspm.fr/eop-pc/models/models.html#software>

files: <ftp://hpiers.obspm.fr/eop-pc/models/interp.f>

<ftp://hpiers.obspm.fr/eop-pc/models/interp.readme>

Consistency of IERS EOP series with ITRF and ICRF

Earth Orientation Parameters (EOP) provide the transformation between the International Celestial Reference Frame (ICRF) and International Terrestrial Reference Frame (ITRF) of which the last realization is the ITRF2000 (Altamimi *et al.*, 2002). The IERS reference series, labeled 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 thus 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 re 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 (Bizouard and Gambis,

2002, Gambis *et al.*, 2002) and the IERS alignment campaign in 2000 (Gambis and Bizouard, 2003).

IERS alignment campaign

The idea of the campaign (Rothacher, 2002) is to create EOP series with highest possible consistency with ITRF2000 / ICRF and investigate the ultimate achievement of the overall accuracy. The main objectives are to study and understand systematic discrepancies, long-term trends and biases, within techniques due to software differences and also between techniques due to sub-network effects and to investigate long-term consistency, trends and biases, between techniques and the reference IERS C04.

We limited our analyses to long-term EOP series derived by analysis centres in which both reference frames were fixed to ITRF2000 (Altamimi *et al.*, 2002) and ICRF in the course of the calculations (i.e. 5 VLBI, 3 SLR and one GPS series). Table 5 presents systematic errors between individual solutions obtained within same techniques, same or different software, and IERS C04 for all parameters.

Table 5: Systematic errors between individual solutions and IERS C04 for all EOP parameters. Units: μas for pole and nutation bias, μs for UT1, $\mu\text{as/yr}$ for pole drift and nutation drift, $\mu\text{s/yr}$ for UT1 drift. 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	X bias	X drift	Y bias	Y drift	UT1 bias	UT1 drift	D Ψ bias	D Ψ drift	D ϵ bias	D ϵ drift
VLBI	BKG	CALC	-114	20	143	37	-1	2	-27	-5	6	-1
	GSFC	CALC	-103	16	148	31	-1	2	-62	-14	5	-3
	DGFI	OCCAM	-135	12	134	41	1	2				
	GAUS	OCCAM	-200	37	133	36	1	2				
	IAA	OCCAM	-138	3	116	38	3	3	-39	-10	27	-1
SLR	CGS	GEODYN	-235	3	110	8						
	IAA	GROSS	-59	11	58	-3						
	CSR	UTOPIA	-360	-101	27	24						
GPS	CODE	BERNESE	44	-17	-35	49						

In conclusion, it appears that the C04 series is for pole components inconsistent with ITRF2000 at a level of 50–200 μas for biases and 40 $\mu\text{as/yr}$ for drifts. It is still premature to apply any correction to it since there are inconsistencies between the different techniques at the same level.

More investigations are needed to identify the reasons of the discrepancies within same techniques, same or different packages used and between the different techniques.

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3.5.1 Earth Orientation Centre

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