IV.4 EOP Section of the Central Bureau

This section presents the activities and results concerning the former EOP Section of the Central Bureau of the IERS in Paris. Starting from 1 January 2001, the Earth Orientation Parameters Product Center (EOP-PC) is replacing this section. The text was written under the responsibility of Daniel Gambis (Observatoire de Paris). Figures and Tables are available at the web site: <http://hpiers.obspm.fr/eop-pc>.

4.1 General Description

The IERS Conventions

Reference systems

The International Celestial and Terrestrial Reference Systems (resp. ICRS, ITRS) are defined by their origins, directions of axes and, in the case of the ITRS, length unit.

ICRS: The ICRS is described by Arias *et al.* (1995). Its origin is at the barycenter of the solar system. The directions of its axes are fixed with respect to the quasars to better than ± 20 microarcseconds; they are aligned with those of the FK5 within the uncertainty of the latter (± 80 milliarcseconds). The ICRS is realized by estimates of the coordinates of a set of quasars, the International Celestial Reference Frame, ICRF (Ma and Feissel, 1997). The maintenance of the ICRS/ICRF is under the responsibility of ICRS Product Center (<http://hpiers.obspm.fr/icrs-pc>).

ITRF: The ITRS origin is at the center of mass of the whole Earth, including the oceans and the atmosphere. Its length unit is the *meter* (SI), defined in a local Earth frame according to the relativistic theory of gravitation. The orientation of its axes is consistent with that of the BIH System at 1984.0 within ± 3 milliarcseconds. Its time evolution in orientation is such that it has no residual rotation relative to the Earth's crust. The ITRS is realized by estimates of the coordinates and velocities of a set of observing stations, the International Terrestrial Reference Frame, ITRF. A new ITRF realization (ITRF2000) is now available at the web site: <http://lareg.ensg.ign.fr/ITRF/>.

IERS constants and models

The values of the constants are adopted from recent analyses; in some cases they differ from the current IAU and IAG conventional ones. The models represent, in general, the state of the art in the field concerned. The IERS conventions used in this report are the IERS Conventions (1996), published as IERS Technical Note 21. New IERS Conventions 2000 will be published in the course of 2001. Two key aspects concern a new nutation model which will be adopted as of 1 January 2003 and the definition of Celestial Intermediate Pole (IAU Commission 19 web site: <http://danof.obspm.fr/iaucom19/>).

The Earth Orientation Parameters

The IERS Earth Orientation Parameters (EOP) describe the transformation between both the ITRS and the ICRS, including the conventional Precession-Nutation model.

Coordinates of the pole

The parameters x and y are the coordinates of the Celestial Ephemeris Pole (CEP) relative to the IERS Reference Pole (IRP). The CEP differs from the instantaneous rotation axis by quasi-diurnal terms with amplitudes under 0.01" (Seidelmann, 1982). The x-axis is in the direction of the IERS Reference Meridian (IRM); the y-axis is in the direction 90 degrees West longitude. The need for accurate definition of reference systems brought about by unprecedented observational precision requires the adoption of a new reference: the Celestial Intermediate Pole (CIP); see definition in IAU Resolution B1.7 at the web site: <http://danof.obspm.fr/iaucom19>. The implementation of the CIP will be on 1 January 2003.

Celestial pole offsets

VLBI and LLR observations have shown the existence of deficiencies in the IAU 1976 Precession and in the IAU 1980 Theory of Nutation; however, these models are kept as a part of the IERS standards, and the observed differences with respect to the conventional celestial pole position defined by the models are monitored and reported by the IERS. The celestial pole offsets, $d\psi$, $d\varepsilon$, are the offsets in longitude and in obliquity of the celestial pole with respect to its position defined by the conventional IAU precession/nutation models. A conventional correction model is available in the IERS Conventions (1996). It matches the observations within ± 0.001". The implementation of the new nutation model in January 2003 is assumed to lead to an agreement of 0.2 milliarcsecond (mas) with the VLBI observations.

Universal time and duration of the day

UT1 is related to the Greenwich mean sidereal time (GMST) by a conventional relationship (Aoki *et al*., 1982); it gives access to the direction of the IRM in the ICRS, reckoned around the CEP axis. It is expressed as the difference UT1–TAI or UT1–UTC.

TAI is the atomic time scale derived by the BIPM; its unit interval is exactly one SI second at sea level. The origin of TAI is such that UT1–TAI ≈ 0 on 1958 January 1. The instability of TAI is about 6 orders of magnitude smaller than that of UT1. The Terrestrial Time TT is realized in practice as TAI + 32.184s (McCarthy, 1996, chapter 11, p. 83). Observed values of UT1–TAI over 1962–2001 are given in *Table 1*.

UTC is defined by the CCIR (International Radio Consultative Committee) Recommendation 460-4 (1986), it differs from TAI by an integer number of seconds, in such a way that UT1–UTC remains smaller than 0.9 s in absolute value. The decision to introduce a leap second in UTC to meet this condition is the responsibility of IERS. According to the CCIR Recommendation, first preference is given to the opportunities at the end of December and June, and second preference to those at the end of March and September. Since the system was introduced in 1972 only dates in June and December have been used. The relationship of UTC with TAI is given in *Table 2*; the corresponding offsets and step adjustments of UTC are given in *Table 3*.

The “leap second” procedure is affecting the activities of modern communication and navigation systems. In order to envisage the possibility to redefine the Coordinated Universal Time (UTC), various working groups were created within the IAU and the ITU (International Telecommunication Union). During the ITU meetings discussions developed on the implication of changes on scientific, governmental, commercial and regulatory interests. Resolutions will be proposed at the CCTF (Comité Consultatif des Temps et Fréquences) in the course of 2003.

DUT1 is the difference UT1–UTC, expressed with a precision of 0.1 s, which is broadcasted with the time signals. The changes in DUT1 are decided by the EOP Product Center of the IERS. In the past, UT2 was used; it was derived from UT1 by adding the following conventional annual and semi annual terms:

$$\mathrm{UT2} - \mathrm{UT1} = 0.0220 \sin 2\pi t - 0.0120 \cos 2\pi t - 0.0060 \sin 4\pi t + 0.0070 \cos 4\pi t$$

the unit being the second and t being the date in Besselian years:

$$t = 2000.000 + (\mathrm{MJD} - 51544.03) / 365.2422.$$

The difference between the astronomically determined duration of the day and 86400s of TAI, is also called excess on the length of day and designed by D or LOD. Its relationship with the angular velocity of the Earth ω is:

$$\omega = \Omega\,(1 - D/T),$$

with T = 86 400 s and Ω the mean pole rate.

$$\omega = 72\,921\,151.467\,064 - 0.843\,994\,803\,D,$$

where ω is in picoradians/s and D in milliseconds.

It is useful to differentiate in some details the various forms of universal time series that can be derived from different observing systems. UT1 can be obtained only from inertial technique like VLBI. Other techniques (e.g. LLR) may estimate the Earth’s orientation relatively to a dynamical frame which is different of ICRS.

UT1, hence D and ω, are subject to variations under the effect of zonal tides. The model which is a part of IERS Conventions (1996) includes 62 periodic components, with periods ranging from 5.6 days to 18.6 years. UT1R, DR, and ωR are the values of UT1, D, and ω corrected for the short-term part of the model, i.e., the 41 components with periods under 35 days. The model is listed in *Table 4a* and *Table 4b*. A new model taking into account oceanic effects and recommended to users will be published in the IERS Conventions 2000.

Table 1. Observed values of UT1–TAI, 1962–2001

The uncertainty of UT1–TAI is smaller than 2 units of the last digit listed.
TT–UT1 can be obtained from this table using the expression: TT–UT1 = 32.184s – (UT1–TAI).

Date	UT1-TAI (s)	Date	UT1-TAI (s)	Date	UT1-TAI (s)	Date	UT1-TAI (s)
1962 JAN 1	-1.813	1972 JAN 1	-10.045	1982 JAN 1	-19.983	1992 JAN 1	-26.1252
APR 1	-1.936	APR 1	-10.347	APR 1	-20.184	APR 1	-26.3562
JUL 1	-2.058	JUL 1	-10.638	JUL 1	-20.391	JUL 1	-26.5569
OCT 1	-2.142	OCT 1	-10.888	OCT 1	-20.550	OCT 1	-26.7146
1963 JAN 1	-2.289	1973 JAN 1	-11.189	1983 JAN 1	-20.773	1993 JAN 1	-26.9378
APR 1	-2.407	APR 1	-11.489	APR 1	-21.036	APR 1	-27.1734
JUL 1	-2.551	JUL 1	-11.771	JUL 1	-21.250	JUL 1	-27.4010
OCT 1	-2.659	OCT 1	-12.016	OCT 1	-21.400	OCT 1	-27.5748
1964 JAN 1	-2.847	1974 JAN 1	-12.301	1984 JAN 1	-21.6042	1994 JAN 1	-27.8004
APR 1	-3.043	APR 1	-12.553	APR 1	-21.7603	APR 1	-28.0202
JUL 1	-3.217	JUL 1	-12.814	JUL 1	-21.9018	JUL 1	-28.2171
OCT 1	-3.350	OCT 1	-13.023	OCT 1	-22.0074	OCT 1	-28.3738
1965 JAN 1	-3.558	1975 JAN 1	-13.292	1985 JAN 1	-22.1587	1995 JAN 1	-28.6014
APR 1	-3.761	APR 1	-13.554	APR 1	-22.3058	APR 1	-28.8437
JUL 1	-3.964	JUL 1	-13.799	JUL 1	-22.4516	JUL 1	-29.0614
OCT 1	-4.139	OCT 1	-13.999	OCT 1	-22.5333	OCT 1	-29.2196
1966 JAN 1	-4.360	1976 JAN 1	-14.274	1986 JAN 1	-22.6872	1996 JAN 1	-29.4447
APR 1	-4.586	APR 1	-14.545	APR 1	-22.8157	APR 1	-29.6292
JUL 1	-4.817	JUL 1	-14.812	JUL 1	-22.9292	JUL 1	-29.8129
OCT 1	-5.006	OCT 1	-15.054	OCT 1	-23.0058	OCT 1	-29.9362
1967 JAN 1	-5.248	1977 JAN 1	-15.336	1987 JAN 1	-23.1382	1997 JAN 1	-30.1110
APR 1	-5.476	APR 1	-15.595	APR 1	-23.2788	APR 1	-30.2914
JUL 1	-5.700	JUL 1	-15.850	JUL 1	-23.3972	JUL 1	-30.4731
OCT 1	-5.871	OCT 1	-16.062	OCT 1	-23.4816	OCT 1	-30.6087
1968 JAN 1	-6.111	1978 JAN 1	-16.351	1988 JAN 1	-23.6356	1998 JAN 1	-30.7818
APR 1	-6.344	APR 1	-16.651	APR 1	-23.7823	APR 1	-30.9622
JUL 1	-6.573	JUL 1	-16.917	JUL 1	-23.9100	JUL 1	-31.1004
OCT 1	-6.775	OCT 1	-17.123	OCT 1	-23.9771	OCT 1	-31.1582
1969 JAN 1	-7.021	1979 JAN 1	-17.402	1989 JAN 1	-24.1159	1999 JAN 1	-31.2833
APR 1	-7.274	APR 1	-17.670	APR 1	-24.2443	APR 1	-31.3840
JUL 1	-7.521	JUL 1	-17.918	JUL 1	-24.3857	JUL 1	-31.4801
OCT 1	-7.734	OCT 1	-18.112	OCT 1	-24.4899	OCT 1	-31.5307
1970 JAN 1	-7.997	1980 JAN 1	-18.355	1990 JAN 1	-24.6713	2000 JAN 1	-31.6445
APR 1	-8.271	APR 1	-18.582	APR 1	-24.8631	APR 1	-31.7235
JUL 1	-8.526	JUL 1	-18.792	JUL 1	-25.0386	JUL 1	-31.7959
OCT 1	-8.722	OCT 1	-18.970	OCT 1	-25.1803	OCT 1	-31.8253
1971 JAN 1	-8.985	1981 JAN 1	-19.196	1991 JAN 1	-25.3813	2001 JAN 1	-31.9068
APR 1	-9.237	APR 1	-19.414	APR 1	-25.5871	APR 1	-31.9744
JUL 1	-9.503	JUL 1	-19.629	JUL 1	-25.7735		
OCT 1	-9.741	OCT 1	-19.777	OCT 1	-25.9204		

Table 2. Relationship between TAI and UTC

Limits of validity (at 0h UTC)	TAI − UTC
1961 Jan. 1 - 1961 Aug. 1	1.422 818 0s + (MJD - 37 300) x 0.001 296s
Aug. 1 - 1962 Jan. 1	1.372 818 0s + ""
1962 Jan. 1 - 1963 Nov. 1	1.845 858 0s + (MJD - 37 665) x 0.001 123 2s
1963 Nov. 1 - 1964 Jan. 1	1.945 858 0s + ""
1964 Jan. 1 - April 1	3.240 130 0s + (MJD - 38 761) x 0.001 296s
April 1 - Sept. 1	3.340 130 0s + ""
Sept. 1 - 1965 Jan. 1	3.440 130 0s + ""
1965 Jan. 1 - March 1	3.540 130 0s + ""
March 1 - Jul. 1	3.640 130 0s + ""
Jul. 1 - Sept. 1	3.740 130 0s + ""
Sept. 1 - 1966 Jan. 1	3.840 130 0s + ""
1966 Jan. 1 - 1968 Feb. 1	4.313 170 0s + (MJD - 39 126) x 0.002 592s
1968 Feb. 1 - 1972 Jan. 1	4.213 170 0s + ""
1972 Jan. 1 - Jul. 1	10s
Jul. 1 - 1973 Jan. 1	11s
1973 Jan. 1 - 1974 Jan. 1	12s
1974 Jan. 1 - 1975 Jan. 1	13s
1975 Jan. 1 - 1976 Jan. 1	14s
1976 Jan. 1 - 1977 Jan. 1	15s
1977 Jan. 1 - 1978 Jan. 1	16s
1978 Jan. 1 - 1979 Jan. 1	17s
1979 Jan. 1 - 1980 Jan. 1	18s
1980 Jan. 1 - 1981 Jul. 1	19s
1981 Jul. 1 - 1982 Jul. 1	20s
1982 Jul. 1 - 1983 Jul. 1	21s
1983 Jul. 1 - 1985 Jul. 1	22s
1985 Jul. 1 - 1988 Jan. 1	23s

Limits of validity (at 0h UTC)	
1988 Jan. 1 - 1990 Jan. 1	24s
1990 Jan. 1 - 1991 Jan. 1	25s
1991 Jan. 1 - 1992 Jul. 1	26s
1992 Jul. 1 - 1993 Jul 1	27s
1993 Jul. 1 - 1994 Jul. 1	28s
1994 Jul. 1 - 1996 Jan. 1	29s
1996 Jan. 1 - 1997 Jul. 1	30s
1997 Jul. 1 - 1999 Jan 1	31s
1999 Jan. 1 -	32s

Irregularities of the Earth's Rotation

Polar motion

The main components of polar motion are a free oscillation (Chandler wobble) with a period of 1.2 year and an oscillation which is forced by the seasonal mass redistribution in the atmosphere and oceans. The beating period of the two terms is approximately 6 years. A slow, irregular drift towards the west is superimposed to the cyclic variation.

Figures IV-4-1 and *IV-4-2* show a filtering of x and y coordinates of the pole since 1890 obtained by CENSUS X-11 (Shiskin *et al.,* 1965) modified to take into account two main periodic components. The series shown is EOP(IERS) C 01. The residual motion in the lower part of the figures includes irregularities with recurrence times ranging from days to years that are forced by the atmosphere, as shown on *Figure IV-4-3* for EOP(IERS) C 04.

Table 5 gives yearly coordinates of the mean rotation axis in the IERS Terrestrial Reference Frame, obtained by filtering the Chandler and seasonal terms. Their uncertainty is about 0.010".

Table 3. Offsets and step adjustments of UTC

Date (at 0h UTC)	Offsets	Steps
1961 Jan. 1	$- 150\times10^{-10}$	
Aug. 1	"	+ 0.050s
1962 Jan. 1	$- 130\times10^{-10}$	
1963 Nov. 1	"	- 0.100s
1964 Jan. 1	$- 150\times10^{-10}$	
Apr. 1	"	- 0.100s
Sept. 1	"	- 0.100s
1965 Jan. 1	"	- 0.100s
March 1	"	- 0.100s
Jul. 1	"	- 0.100s
Sept. 1	"	- 0.100s
1966 Jan. 1	$- 300\times10^{-10}$	
1968 Feb. 1	"	+ 0.100s
1972 Jan. 1	0	- 0.1077580s

Date (at 0h UTC)	Steps
1972 Jul. 1	- 1s
1973 Jan. 1	- 1s
1974 Jan. 1	- 1s
1975 Jan. 1	- 1s
1976 Jan. 1	- 1s
1977 Jan. 1	- 1s
1978 Jan. 1	- 1s
1979 Jan. 1	- 1s
1980 Jan. 1	- 1s
1981 Jul. 1	- 1s
1982 Jul. 1	- 1s
1983 Jul. 1	- 1s
1985 Jul. 1	- 1s
1988 Jan. 1	- 1s
1990 Jan. 1	- 1s
1991 Jan. 1	- 1s
1992 Jul. 1	- 1s

Date (at 0h UTC)	Steps
1993 Jul. 1	- 1s
1994 Jul. 1	- 1s
1996 Jan. 1	- 1s
1997 Jul. 1	- 1s
1999 Jan. 1	- 1s

Celestial motion of the pole

The variations in $d\psi$ and $d\varepsilon$ reflect the difference of the actual celestial motion of the pole with the one modeled by the conventional IAU precession and nutation models. *Figure IV-4-4* shows the observed variations of $d\psi$ and $d\varepsilon$. These variations reflect the errors in several terms of the IAU models: secular term, periodic terms (mainly 18.6 yr, 1.0 yr, 0.5 yr, 14 d). These terms are included in the IERS Conventions (1996) correction model. *Figure IV-4-5* shows the residual variations when the corrective model is applied. In order to refer to the ICRF pole, a bias both in longitude and obliquity should be added (see ICRS Section).

Universal time and excess of the duration of the day over 86400s

Universal time and the duration of the day are subject to variations mainly due to the zonal tides (*Tables 4a and 4b*), the atmospheric circulation, the internal effects and the transfer of angular momentum to the Moon orbital motion. *Figure IV-4-6* shows a decomposition of the variations in the duration of the day. The residual oscillation in the middle of the figure includes transient sub-seasonal oscillations that are forced by the atmosphere.

Table 4a. Earth rotation variations due to zonal tides with periods up to 35 days

UT1R, DR, ωR represent the corrected values of UT1, of the duration of the day D and of the angular velocity of the Earth ω, according to IERS Conventions (1996).
The units are 10^{-4} s for UT, 10^{-5} s for D, and 10^{-14} rad/s for ω.

N	ARGUMENTS					PERIODS	COEFFICIENTS		
	l	l′	F	D	Ω	DAYS	UT1-UT1R	D-DR	ω-ωR
							sin	cos	cos
1	1	0	2	2	2	5.64	-0.024	0.26	-0.22
2	2	0	2	0	1	6.85	-0.040	0.37	-0.31
3	2	0	2	0	2	6.86	-0.099	0.90	-0.76
4	0	0	2	2	1	7.09	-0.051	0.45	-0.38
5	0	0	2	2	2	7.10	-0.123	1.09	-0.92
6	1	0	2	0	0	9.11	-0.039	0.27	-0.22
7	1	0	2	0	1	9.12	-0.411	2.83	-2.39
8	1	0	2	0	2	9.13	-0.993	6.83	-5.76
9	3	0	0	0	0	9.18	-0.018	0.12	-0.10
10	-1	0	2	2	1	9.54	-0.082	0.54	-0.45
11	-1	0	2	2	2	9.56	-0.197	1.30	-1.10
12	1	0	0	2	0	9.61	-0.076	0.50	-0.42
13	2	0	2	-2	2	12.81	0.022	-0.11	0.09
14	0	1	2	0	2	13.17	0.025	-0.12	0.10
15	0	0	2	0	0	13.61	-0.299	1.38	-1.17
16	0	0	2	0	1	13.63	-3.208	14.79	-12.48
17	0	0	2	0	2	13.66	-7.757	35.68	-30.11
18	2	0	0	0	-1	13.75	0.022	-0.10	0.08
19	2	0	0	0	0	13.78	-0.338	1.54	-1.30
20	2	0	0	0	1	13.81	0.018	-0.08	0.07
21	0	-1	2	0	2	14.19	-0.024	0.11	-0.09
22	0	0	0	2	-1	14.73	0.047	-0.20	0.17
23	0	0	0	2	0	14.77	-0.734	3.12	-2.64
24	0	0	0	2	1	14.80	-0.053	0.22	-0.19
25	0	-1	0	2	0	15.39	-0.051	0.21	-0.17
26	1	0	2	-2	1	23.86	0.050	-0.13	0.11
27	1	0	2	-2	2	23.94	0.101	-0.26	0.22
28	1	1	0	0	0	25.62	0.039	-0.10	0.08
29	-1	0	2	0	0	26.88	0.047	-0.11	0.09
30	-1	0	2	0	1	26.98	0.177	-0.41	0.35
31	-1	0	2	0	2	27.09	0.435	-1.01	0.85
32	1	0	0	0	-1	27.44	0.534	-1.22	1.03
33	1	0	0	0	0	27.56	-8.261	18.84	-15.90
34	1	0	0	0	1	27.67	0.544	-1.24	1.04
35	0	0	0	1	0	29.53	0.047	-0.10	0.08
36	1	-1	0	0	0	29.80	-0.055	0.12	-0.10
37	-1	0	0	2	-1	31.66	0.118	-0.23	0.20
38	-1	0	0	2	0	31.81	-1.824	3.60	-3.04
39	-1	0	0	2	1	31.96	0.132	-0.26	0.22
40	1	0	-2	2	-1	32.61	0.018	-0.03	0.03
41	-1	-1	0	2	0	34.85	-0.086	0.15	-0.13

Table 4b. Earth rotation variations due to zonal tides with periods longer than 35 days

UT1R', DR', ωR' represent the corrected values of UT1, of the duration of the day D and of the angular velocity of the Earth ω, based on Yoder *et al.* (1981), with K/C = 0.94.
The units are 10^{-4} s for UT, 10^{-5} s for D, and 10^{-14} rad/s for ω.

N	ARGUMENTS					PERIODS	COEFFICIENTS		
	l	l′	F	D	Ω	DAYS	UT1-UT1R′	D-DR′	ω-ωR′
							sin	cos	cos
42	0	2	2	-2	2	91.31	-0.057	0.04	-0.03
43	0	1	2	-2	1	119.61	0.033	-0.02	0.01
44	0	1	2	-2	2	121.75	-1.885	0.97	-0.82
45	0	0	2	-2	0	173.31	0.251	-0.09	0.08
46	0	0	2	-2	1	177.84	1.170	-0.41	0.35
47	0	0	2	-2	2	182.62	-48.247	16.60	-14.01
48	0	2	0	0	0	182.63	-0.194	0.07	-0.06
49	2	0	0	-2	-1	199.84	0.049	-0.02	0.01
50	2	0	0	-2	0	205.89	-0.547	0.17	-0.14
51	2	0	0	-2	1	212.32	0.037	-0.01	0.01
52	0	-1	2	-2	1	346.60	-0.045	0.01	-0.01
53	0	1	0	0	-1	346.64	0.092	-0.02	0.01
54	0	-1	2	-2	2	365.22	0.828	-0.14	0.12
55	0	1	0	0	0	365.26	-15.359	2.64	-2.23
56	0	1	0	0	1	386.00	-0.138	0.02	-0.02
57	1	0	0	-1	0	411.78	0.035	-0.01	0.00
58	2	0	-2	0	0	1095.17	-0.137	-0.01	0.01
59	-2	0	2	0	1	1305.47	0.422	-0.02	0.02
60	-1	1	0	1	0	3232.85	0.040	0.00	0.00
61	0	0	0	0	2	3399.18	7.900	0.15	-0.12
62	0	0	0	0	1	6790.36	-1617.268	-14.95	12.62

Mean anomaly of the Moon $l = 134°.96 + 13°.064993(MJD-51544.5)$

Mean anomaly of the Sun $l' = 357°.53 + 0°.985600(MJD-51544.5)$

Mean longitude of the Moon from the node of the Moon $F = 93°.27 + 13°.229350(MJD-51544.5)$
$F = L - \Omega$
L : Mean longitude of the Moon

Mean elongation of the Moon from the Sun $D = 297°.85 + 12°.190749(MJD-51544.5)$

Mean longitude of the ascending node of the Moon $\Omega = 125°.04 - 0°.052954(MJD-51544.5)$

Fig. IV-4-1. X-coordinate of the pole (EOP(IERS) C 04)

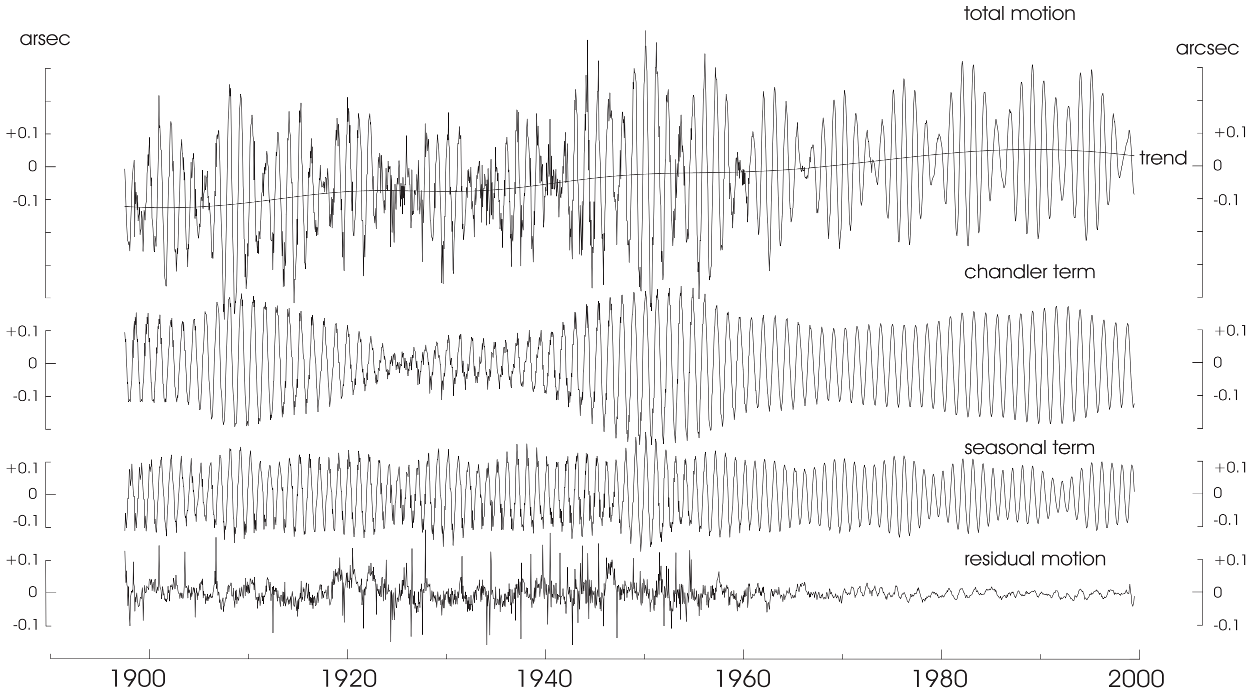

Fig. IV-4-2. Y-coordinate of the pole (EOP(IERS) C 04)

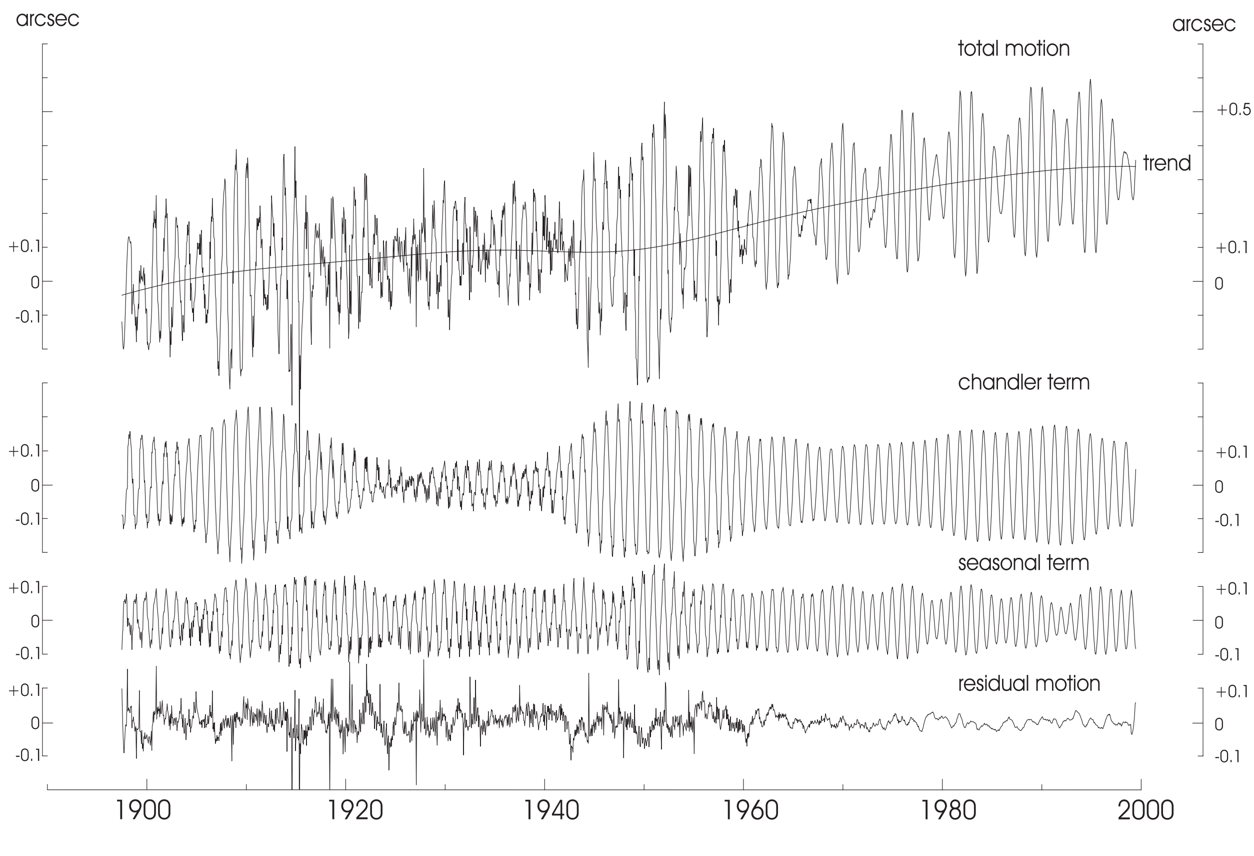

Fig. IV-4-3. Irregular variations in polar motion (EOP(IERS) C 04 filtered by CENSUS X-11)

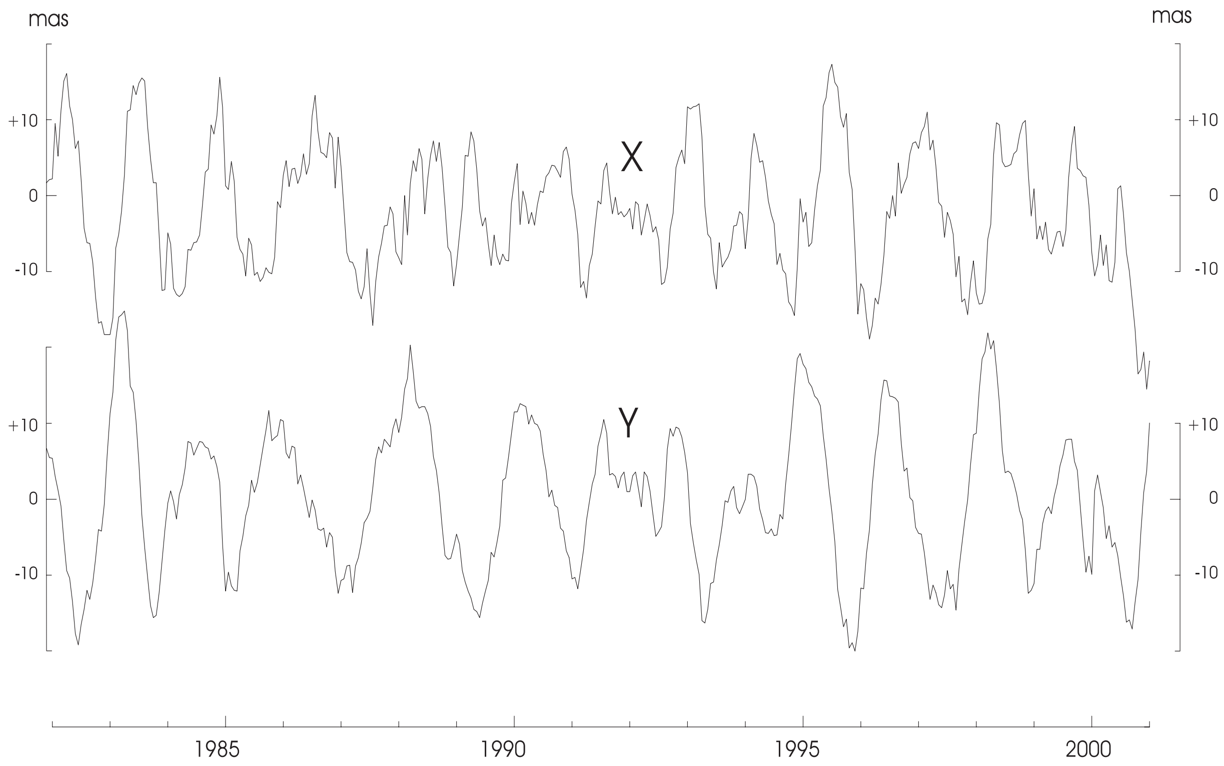

Table 6 gives mean annual values of the excess of the duration of the day D, which are available for the last four centuries. For the interval 1623–1955, the data are those provided by L.V. Morrison, Royal Greenwich Observatory, interpolated for the middle of the year. The mean solar time has been referred to the dynamical time scale derived from the time argument of the lunar ephemeris. The duration of the day has been obtained:

– from 1623 to 1860, by derivative of cubic splines fitted on individual values of the difference between mean solar time and dynamical time,
– from 1861 to 1955, by a 5-point quadratic convolute.

More information on the computation of the duration of the day is available in Stephenson and Morrison (1984), with an estimation of the accuracy of these evaluations. From 1956 up to present, the duration of the day has been obtained from the BIH/IERS values of UT1–TAI; the table gives annual averages. At the level of precision of these values of the duration of the day, the unit of the dynamical time and the unit of TAI can be considered as having the same duration. Thus D is expressed in present SI units. The table gives also the values of the angular velocity of the Earth's rotation ω derived from the listed values of D.

Table 5. Coordinates of the mean rotation axis since 1900 (EOP(IERS) C 01)

Date (year)	x (")	y (")	Date (year)	x (")	y (")	Date (year)	x (")	y (")
1900.	-.122	-.033	1934.	-.074	.090	1968.	-.003	.208
1901.	-.124	-.026	1935.	-.072	.091	1969.	.000	.214
1902.	-.124	-.018	1936.	-.070	.091	1970.	.003	.220
1903.	-.125	-.011	1937.	-.068	.091	1971.	.006	.227
1904.	-.125	-.005	1938.	-.065	.091	1972.	.009	.233
1905.	-.124	.001	1939.	-.062	.091	1973.	.012	.239
1906.	-.123	.007	1940.	-.059	.090	1974.	.016	.244
1907.	-.121	.012	1941.	-.055	.089	1975.	.019	.250
1908.	-.119	.017	1942.	-.051	.088	1976.	.023	.256
1909.	-.117	.022	1943.	-.047	.087	1977.	.026	.261
1910.	-.114	.026	1944.	-.043	.086	1978.	.029	.266
1911.	-.111	.030	1945.	-.039	.086	1979.	.033	.272
1912.	-.107	.033	1946.	-.035	.085	1980.	.036	.277
1913.	-.104	.036	1947.	-.032	.086	1981.	.039	.282
1914.	-.100	.039	1948.	-.029	.087	1982.	.042	.286
1915.	-.096	.042	1949.	-.026	.088	1983.	.044	.291
1916.	-.092	.045	1950.	-.024	.091	1984.	.046	.296
1917.	-.088	.047	1951.	-.022	.094	1985.	.048	.300
1918.	-.085	.050	1952.	-.021	.098	1986.	.050	.304
1919.	-.081	.053	1953.	-.020	.102	1987.	.052	.309
1920.	-.079	.055	1954.	-.019	.108	1988.	.053	.313
1921.	-.076	.058	1955.	-.018	.114	1989.	.054	.316
1922.	-.074	.061	1956.	-.018	.120	1990.	.054	.320
1923.	-.073	.063	1957.	-.017	.127	1991.	.054	.323
1924.	-.072	.066	1958.	-.017	.134	1992.	.054	.326
1925.	-.072	.069	1959.	-.017	.142	1993.	.053	.329
1926.	-.072	.072	1960.	-.016	.149	1994.	.052	.332
1927.	-.073	.074	1961.	-.015	.157	1995.	.051	.334
1928.	-.073	.077	1962.	-.014	.165	1996.	.049	.336
1929.	-.074	.080	1963.	-.013	.172	1997.	.047	.337
1930.	-.074	.082	1964.	-.012	.180	1998.	.044	.338
1931.	-.075	.084	1965.	-.010	.187	1999.	.041	.339
1932.	-.075	.086	1966.	-.008	.194	2000.	.038	.339
1933.	-.074	.088	1967.	-.006	.201			

Fig. IV-4-4. Celestial pole offsets: motion of the celestial pole relative to the IAU 1980 Theory of Nutation and the IAU 1976 Precession (EOP(IERS C 04)

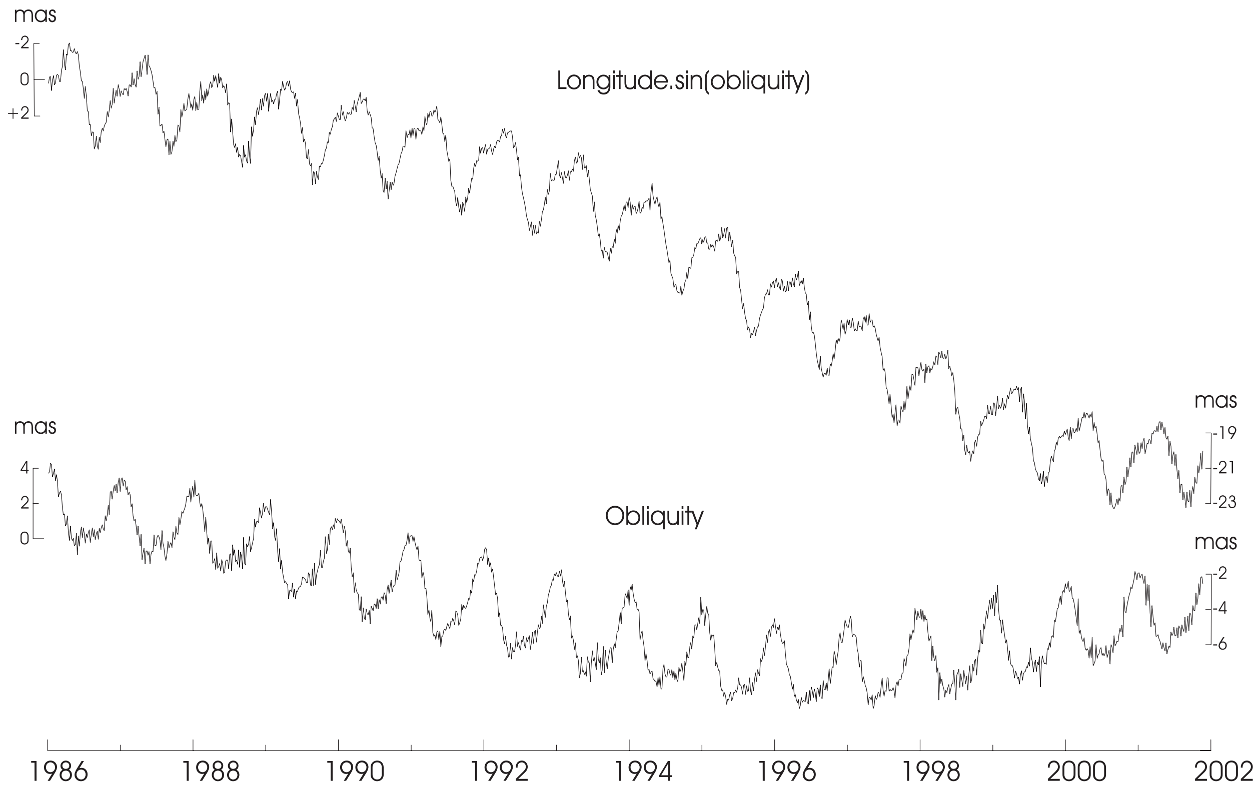

Fig. IV-4-5. Celestial pole offset corrected by the IERS Conventions (1996) precession-nutation corrective model (EOP(IERS C 04)

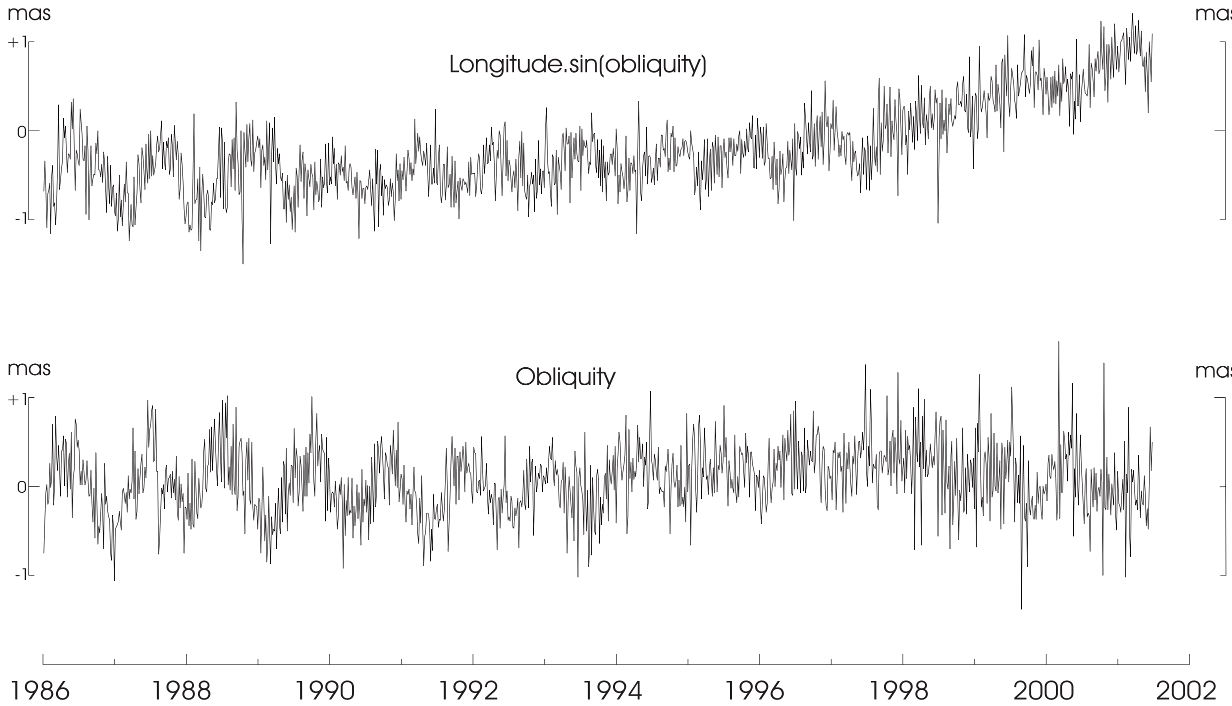

Fig. IV-4-6. Variation in the duration of the day (EOP(IERS C 04)

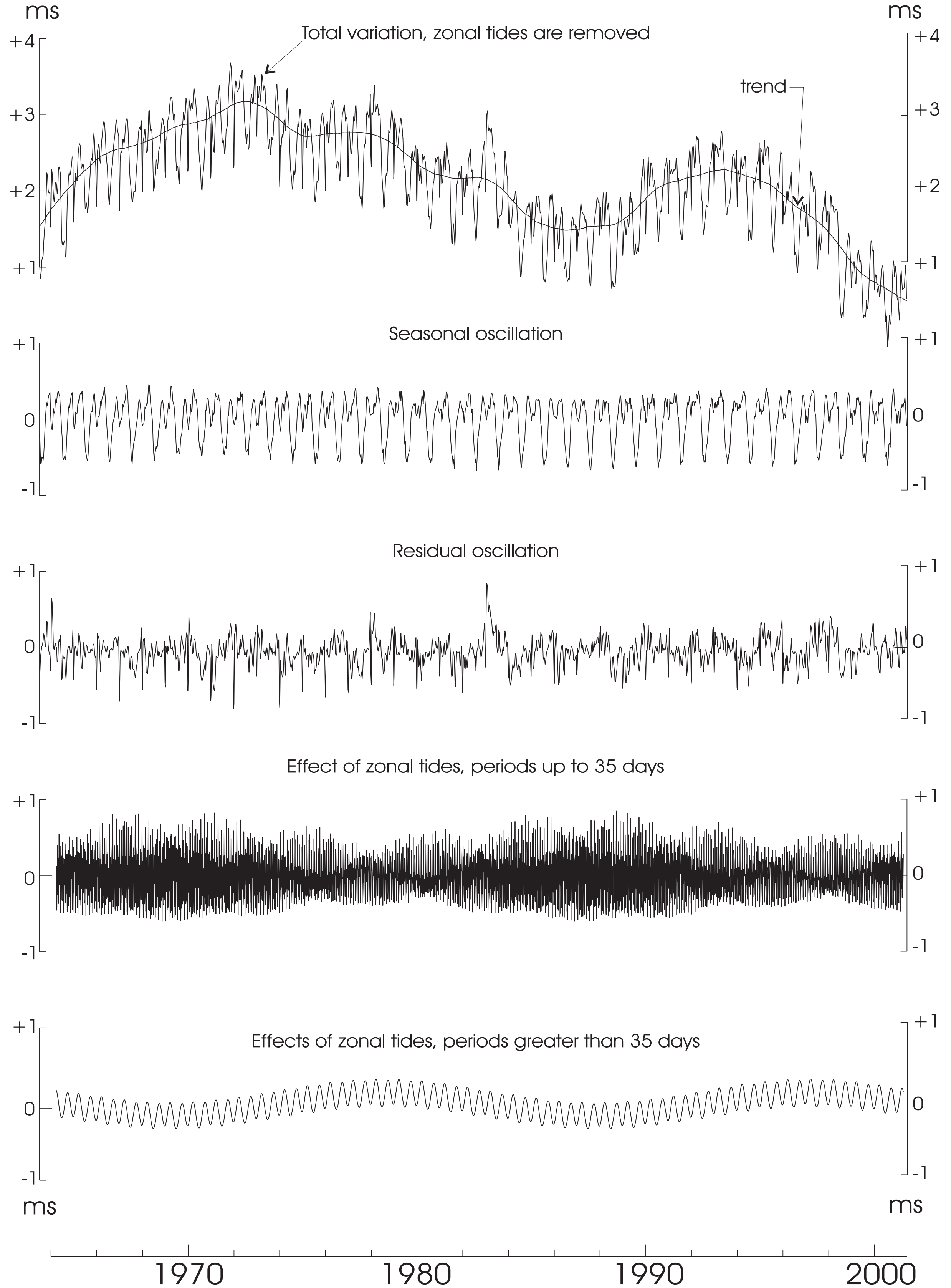

Table 6. Excess of the duration of the day to 86400s and Angular velocity of the Earth's rotation, since 1623

DATE (years)	D (ms)	ω (prad/s)	DATE (years)	D (ms)	ω (prad/s)	DATE (years)	D (ms)	ω (prad/s)
		72 921..			72 921..			72 921..
			1671.5	-3.	154.	1721.5	0.2	151.3
			1672.5	-3.	154.	1722.5	0.2	151.3
1623.5	-11.	161.	1673.5	-3.	154.	1723.5	0.1	151.4
1624.5	-11.	161.	1674.5	-3.	154.	1724.5	0.1	151.4
1625.5	-10.	160.	1675.5	-3.	154.	1725.5	0.1	151.4
1626.5	-10.	160.	1676.5	-3.	154.	1726.5	0.1	151.4
1627.5	-9.	159.	1677.5	-3.	154.	1727.5	0.1	151.4
1628.5	-9.	159.	1678.5	-3.	154.	1728.5	0.2	151.3
1629.5	-8.	158.	1679.5	-2.	153.	1729.5	0.2	151.3
1630.5	-8.	158.	1680.5	-2.	153.	1730.5	0.2	151.3
1631.5	-8.	158.	1681.5	-2.	153.	1731.5	0.2	151.3
1632.5	-7.	157.	1682.5	-2.	153.	1732.5	0.2	151.3
1633.5	-7.	157.	1683.5	-2.	153.	1733.5	0.2	151.3
1634.5	-7.	157.	1684.5	-2.	153.	1734.5	0.2	151.3
1635.5	-6.	157.	1685.5	-2.	153.	1735.5	0.2	151.3
1636.5	-6.	157.	1686.5	-1.	152.	1736.5	0.3	151.2
1637.5	-6.	157.	1687.5	-1.	152.	1737.5	0.3	151.2
1638.5	-5.	156.	1688.5	-1.	152.	1738.5	0.3	151.2
1639.5	-5.	156.	1689.5	-1.	152.	1739.5	0.3	151.2
1640.5	-5.	156.	1690.5	-1.	152.	1740.5	0.3	151.2
1641.5	-4.	155.	1691.5	-1.	152.	1741.5	0.3	151.2
1642.5	-4.	155.	1692.5	-1.	152.	1742.5	0.3	151.2
1643.5	-4.	155.	1693.5	0.	151.	1743.5	0.4	151.1
1644.5	-4.	155.	1694.5	0.	151.	1744.5	0.4	151.1
1645.5	-4.	155.	1695.5	0.	151.	1745.5	0.4	151.1
1646.5	-3.	154.	1696.5	0.	151.	1746.5	0.4	151.1
1647.5	-3.	154.	1697.5	0.	151.	1747.5	0.4	151.1
1648.5	-3.	154.	1698.5	0.	151.	1748.5	0.4	151.1
1649.5	-3.	154.	1699.5	0.	151.	1749.5	0.4	151.1
1650.5	-3.	154.	1700.5	0.1	151.4	1750.5	0.4	151.1
1651.5	-3.	154.	1701.5	0.2	151.3	1751.5	0.4	151.1
1652.5	-3.	154.	1702.5	0.2	151.3	1752.5	0.4	151.1
1653.5	-3.	154.	1703.5	0.3	151.2	1753.5	0.4	151.1
1654.5	-3.	154.	1704.5	0.3	151.2	1754.5	0.4	151.1
1655.5	-3.	154.	1705.5	0.3	151.2	1755.5	0.4	151.1
1656.5	-3.	154.	1706.5	0.3	151.2	1756.5	0.4	151.1
1657.5	-3.	154.	1707.5	0.3	151.2	1757.5	0.4	151.1
1658.5	-3.	154.	1708.5	0.4	151.1	1758.5	0.4	151.1
1659.5	-3.	154.	1709.5	0.3	151.2	1759.5	0.4	151.1
1660.5	-3.	154.	1710.5	0.3	151.2	1760.5	0.4	151.1
1661.5	-3.	154.	1711.5	0.3	151.2	1761.5	0.4	151.1
1662.5	-3.	154.	1712.5	0.3	151.2	1762.5	0.3	151.2
1663.5	-3.	154.	1713.5	0.3	151.2	1763.5	0.3	151.2
1664.5	-3.	154.	1714.5	0.3	151.2	1764.5	0.3	151.2
1665.5	-3.	154.	1715.5	0.2	151.3	1765.5	0.3	151.2
1666.5	-3.	154.	1716.5	0.2	151.3	1766.5	0.3	151.2
1667.5	-3.	154.	1717.5	0.2	151.3	1767.5	0.3	151.2
1668.5	-3.	154.	1718.5	0.2	151.3	1768.5	0.3	151.2
1669.5	-3.	154.	1719.5	0.2	151.3	1769.5	0.3	151.2
1670.5	-3.	154.	1720.5	0.2	151.3	1770.5	0.3	151.2

Table 6 (cont.).

DATE (years)	D (ms)	ω (prad/s)	DATE (years)	D (ms)	ω (prad/s)	DATE (years)	D (ms)	ω (prad/s)
		72 921..			72 921..			72 921..
1771.5	0.3	151.2	1821.5	-0.81	152.15	1871.5	-2.59	153.65
1772.5	0.2	151.3	1822.5	-0.99	152.30	1872.5	-2.55	153.62
1773.5	0.2	151.3	1823.5	-1.16	152.45	1873.5	-2.10	153.24
1774.5	0.2	151.3	1824.5	-1.32	152.58	1874.5	-2.03	153.18
1775.5	0.2	151.3	1825.5	-1.42	152.67	1875.5	-1.77	152.96
1776.5	0.2	151.3	1826.5	-1.49	152.72	1876.5	-1.37	152.62
1777.5	0.2	151.3	1827.5	-1.50	152.73	1877.5	-1.24	152.51
1778.5	0.2	151.3	1828.5	-1.48	152.72	1878.5	-0.90	152.23
1779.5	0.2	151.3	1829.5	-1.41	152.66	1879.5	-0.49	151.88
1780.5	0.2	151.3	1830.5	-1.30	152.56	1880.5	-0.23	151.66
1781.5	0.2	151.3	1831.5	-1.14	152.43	1881.5	-0.06	151.52
1782.5	0.1	151.4	1832.5	-0.94	152.26	1882.5	-0.15	151.59
1783.5	0.1	151.4	1833.5	-0.73	152.08	1883.5	-0.33	151.75
1784.5	0.1	151.4	1834.5	-0.52	151.91	1884.5	-0.24	151.67
1785.5	0.0	151.5	1835.5	-0.34	151.75	1885.5	-0.15	151.59
1786.5	0.0	151.5	1836.5	-0.18	151.62	1886.5	-0.05	151.51
1787.5	-0.1	151.6	1837.5	-0.04	151.50	1887.5	-0.04	151.50
1788.5	-0.2	151.6	1838.5	0.09	151.39	1888.5	-0.18	151.62
1789.5	-0.3	151.7	1839.5	0.19	151.31	1889.5	-0.25	151.68
1790.5	-0.5	151.9	1840.5	0.27	151.24	1890.5	-0.48	151.87
1791.5	-0.6	152.0	1841.5	0.33	151.19	1891.5	-0.58	151.96
1792.5	-0.7	152.1	1842.5	0.37	151.15	1892.5	-0.42	151.82
1793.5	-0.9	152.2	1843.5	0.39	151.14	1893.5	-0.13	151.58
1794.5	-0.9	152.2	1844.5	0.40	151.13	1894.5	0.33	151.19
1795.5	-1.0	152.3	1845.5	0.41	151.12	1895.5	0.86	150.74
1796.5	-1.0	152.3	1846.5	0.41	151.12	1896.5	1.53	150.18
1797.5	-1.0	152.3	1847.5	0.40	151.13	1897.5	2.16	149.64
1798.5	-1.0	152.3	1848.5	0.39	151.14	1898.5	2.64	149.24
1799.5	-1.0	152.3	1849.5	0.38	151.15	1899.5	3.00	148.94
1800.5	-0.87	152.20	1850.5	0.36	151.16	1900.5	3.31	148.67
1801.5	-0.75	152.10	1851.5	0.33	151.19	1901.5	3.60	148.43
1802.5	-0.61	151.98	1852.5	0.30	151.21	1902.5	3.70	148.34
1803.5	-0.46	151.86	1853.5	0.26	151.25	1903.5	3.69	148.35
1804.5	-0.34	151.75	1854.5	0.23	151.27	1904.5	3.55	148.47
1805.5	-0.23	151.66	1855.5	0.20	151.30	1905.5	3.40	148.60
1806.5	-0.14	151.59	1856.5	0.17	151.32	1906.5	3.48	148.53
1807.5	-0.06	151.52	1857.5	0.15	151.34	1907.5	3.57	148.45
1808.5	-0.01	151.48	1858.5	0.11	151.37	1908.5	3.65	148.39
1809.5	0.03	151.44	1859.5	-0.02	151.48	1909.5	3.71	148.34
1810.5	0.05	151.42	1860.5	-0.34	151.75	1910.5	3.77	148.29
1811.5	0.05	151.42	1861.5	-0.81	152.15	1911.5	3.86	148.21
1812.5	0.04	151.43	1862.5	-1.19	152.47	1912.5	3.89	148.18
1813.5	0.01	151.46	1863.5	-1.35	152.61	1913.5	3.62	148.41
1814.5	-0.04	151.50	1864.5	-1.61	152.83	1914.5	3.18	148.78
1815.5	-0.11	151.56	1865.5	-2.13	153.26	1915.5	2.92	149.00
1816.5	-0.18	151.62	1866.5	-2.76	153.80	1916.5	2.74	149.15
1817.5	-0.28	151.70	1867.5	-2.89	153.91	1917.5	2.35	149.48
1818.5	-0.39	151.80	1868.5	-2.60	153.66	1918.5	2.05	149.74
1819.5	-0.51	151.90	1869.5	-2.59	153.65	1919.5	1.76	149.98
1820.5	-0.65	152.02	1870.5	-2.51	153.59	1920.5	1.48	150.22

Table 6 (cont.).

DATE (years)	D (ms)	ω (prad/s)
		72 921..
1921.5	1.51	150.19
1922.5	1.28	150.39
1923.5	0.98	150.64
1924.5	0.93	150.68
1925.5	0.81	150.78
1926.5	0.56	150.99
1927.5	0.18	151.32
1928.5	-0.22	151.65
1929.5	-0.35	151.76
1930.5	-0.19	151.63
1931.5	-0.10	151.55
1932.5	-0.07	151.53
1933.5	-0.06	151.52
1934.5	-0.08	151.53
1935.5	0.00	151.47
1936.5	0.08	151.40
1937.5	0.22	151.28
1938.5	0.47	151.07
1939.5	0.78	150.81
1940.5	1.09	150.55
1941.5	1.25	150.41
1942.5	1.31	150.36
1943.5	1.35	150.33
1944.5	1.41	150.28
1945.5	1.41	150.28
1946.5	1.35	150.33
1947.5	1.30	150.37
1948.5	1.25	150.41
1949.5	1.20	150.45
1950.5	1.15	150.50
1951.5	1.10	150.54
1952.5	1.05	150.58
1953.5	0.99	150.63
1954.5	0.92	150.69
1955.5	0.86	150.74
1956.5	0.89	150.72
1957.5	1.34	150.34
1958.5	1.37	150.31
1959.5	1.31	150.36
1960.5	1.19	150.46
1961.5	1.09	150.55
1962.5	1.30	150.37
1963.5	1.54	150.17
1964.5	1.92	149.85
1965.5	2.21	149.60
1966.5	2.41	149.43
1967.5	2.37	149.47
1968.5	2.48	149.37
1969.5	2.67	149.21
1970.5	2.71	149.18

DATE (years)	D (ms)	ω (prad/s)
		72 921..
1971.5	2.90	149.02
1972.5	3.13	148.83
1973.5	3.05	148.89
1974.5	2.72	149.17
1975.5	2.69	149.20
1976.5	2.91	149.01
1977.5	2.77	149.13
1978.5	2.88	149.04
1979.5	2.61	149.26
1980.5	2.30	149.53
1981.5	2.16	149.64
1982.5	2.16	149.64
1983.5	2.28	149.54
1984.5	1.52	150.18
1985.5	1.45	150.24
1986.5	1.23	150.43
1987.5	1.36	150.32
1988.5	1.32	150.35
1989.5	1.53	150.18
1990.5	1.94	149.83
1991.5	2.04	149.75
1992.5	2.22	149.59
1993.5	2.37	149.47
1994.5	2.17	149.64
1995.5	2.31	149.52
1996.5	1.83	149.92
1997.5	1.84	149.91
1998.5	1.37	150.31
1999.5	0.99	150.63
2000.5	0.72	150.86

4.2 Operational Activity

Overview

One of the tasks of the Earth Orientation Parameters Product Center (EOP-PC) is to perform combined EOP series from the individual techniques, VLBI, SLR, GPS, LLR and DORIS. Various solutions, namely Bulletin B, EOP(IERS) C 01, C 02, C 03 and C 04 are thus published to fulfill the requirements of users, operational and scientific. They are available at the ftp/web site: hpiers.obspm.fr/eop-pc. The continuous improvement of the results derived from these geodetic techniques and the development of new methods of combination made possible the improvement of combined solutions; precisions of about 0.15 mas in polar motion and 15 microseconds for UT1 are currently obtained.

Combination of EOP Series

The maintenance of the reference systems consistency and its long-term stability require long and homogeneous EOP series. The realization of combined solutions must take advantage of the availability and the qualities of the independent series at the various time scales. They are assumed to contain no jump and negligible systematic errors.

General Combination Procedure

The first step in the general procedure for deriving the multi-technique combined solutions is the evaluation for each series of the systematic errors corrections, bias and drift, in order to translate it to the IERS system. A known source of relative drifts in x, y and UT1–UTC is the variety of processes chosen by the analysis centers to control the time evolution of the adjusted terrestrial reference frames, complicated by the sampling of the tectonic plates and plate margins. The formal uncertainties given by the analysis centers being an internal consistency estimate, usually an external calibration has to be made in order to reflect the real external uncertainty. This is done using the Allan variance analysis (Gray and Allan, 1974; Gambis, 2001) of the differences between series without any reference to a combined series. When three or more series of similar quality and time resolution can be differenced, the pair variance of the noise of each series can be evaluated, provided that their errors are considered statistically independent. The pair variance thus obtained is used as an estimate of the uncertainty of a single determination in a given series; its ratio with the rms formal uncertainty over the same period provides a scaling factor, from which the weighting of the combined individual results is based. Weighting of the series entering into the combined solution are thus estimated. The combined C 04 is now permanently updated on a near real-time basis.

Long-term Solution: C 01 (1846–2001)

EOP(IERS) C 01 is a series of the Earth Orientation Parameters given at 0.1 year interval from 1846 to 1889 and 0.05 year interval from1890 until now. 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 applied for geodynamics. Now, the global observing activity involves Very Long Baseline Radio Interferometry (VLBI), Lunar and Satellite Laser Ranging (LLR, SLR), Global Positioning System (GPS) and more recently DORIS.

The C 01 series is based on the following 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–now: BIH and IERS solutions (BIH and IERS annual reports).

Middle-term Solution: C 02 (1962–2001), C 03 (1993–2001)

Other series, based on normal points solutions given at various time intervals, are also proposed to users, i.e. C 02 (5-day intervals), C 03 (one-day intervals) (Gambis, 1996a and 1996b; 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 M.L., Gambis D. and R. Ray, 1999; Gambis *et al.*, 2000).

Operational Solution: EOP(IERS) C 04

Taking advantage of the recomputations of various individual series, EOP(IERS) C 04 is currently recomputed. In the course of the analyses the determination of the systematic corrections of individual series entering into the combination and the weighting procedure are re-examined. *Table 7* and *Table 8* give the characteristics of the smoothing adopted for each time interval. The variations with periods shorter than the value in the table are smoothed out, except the short term variations in UT1 due to zonal tides and the 14 d terms in celestial pole offsets which are first removed using a model then added back at the end of the series combination process. *Table 9* shows the uncertainty of one daily value of EOP for each period. *Table 10* shows the agreement and consistencies of the current solutions. The Bulletin B is issued on a monthly basis and is “frozen”, contrarily to NEOS Bulletin A and IERS C 04 which are permanently updated.

Predictions

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

- Polar Motion: The formalism uses at first a floating period fit 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 nutation offsets $d\psi$ and $d\varepsilon$ 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 year are valid over the next few months. For short-term variations prediction, an autoregressive process is used. The following *Table 11* shows the current accuracy of the EOP solutions and also the skills of the predictions.

Table 7. Frequency filtering characteristic of smoothing for polar motion and celestial pole offsets, [EOP(IERS) C 04]

Epsilon	PERIOD FOR REMAINING AMPLITUDE 5%	50%	95%	Years
$10^{-0.6}$	3.2d	10.0d	17.0d	1983-1985
$10^{+0.6}$	2.0d	6.3d	10.7d	1986-1989
$10^{+1.0}$	1.7d	5.4d	9.2d	1990-1991
$10^{+1.4}$	1.5d	4.5d	7.9d	1992
$10^{+1.6}$	1.4d	4.2d	7.3d	1993
$10^{+2.0}$	1.2d	3.7d	6.3d	1994-2000

Table 8. Frequency filtering characteristic of smoothing for Universal Time, [EOP(IERS) C 04]

Epsilon	PERIOD FOR REMAINING AMPLITUDE 5%	50%	95%	Years
$10^{-0.5}$	3.0d	9.6d	16.3d	1983-1987
$10^{+0.2}$	2.3d	7.4d	12.5d	1988-1989
$10^{+1.0}$	1.7d	5.4d	9.2d	1990-1991
$10^{+1.5}$	1.5d	4.5d	7.6d	1992-1993
$10^{+2.0}$	1.2d	3.7d	6.3d	1994-2000

Table 9. Uncertainty of one daily value, [EOP(IERS) C 04]

EOP	Unit	1962-67	1968-71	1972-79	1980-83	1984-95	1996-2000
X	mas	30	20	15	2	0.5	0.2
Y	mas	30	20	15	2	0.5	0.2
UT1-UTC	0.1ms	20	15	10	4	0.4	0.2
LOD	0.1ms	14	10	7	2	0.3	0.2
dPsi.sin(Eps)	mas	-	-	-	3	0.6	0.3
dEps	mas	-	-	-	2	0.6	0.3

Table 10. Mean and standard deviation of the differences between different solutions over 2000

EOP	Unit	SPACE 2000 - IERS C04		NEOS final - IERS C04	
		mean	std deviation	mean	std deviation
X	mas	-0.03	0.09	0.02	0.05
Y	mas	0.01	0.07	0.01	0.05
UT1-UTC	0.1ms	0.00	0.11	0.04	0.22
dPsi.sin(Eps)	mas	-	-	-0.15	0.48
dEps	mas	-	-	-0.04	0.31

Table 11. Assessment of the predictions precision over 2000

Solutions	Sample Time	Terrest. Pole 0.001"	UT 0.0001s	Celest. Pole 0.001"
Smoothed	1-d, 5-d	0.2	0.2	0.3
Raw	5-d	0.2	0.2	0.3
Prediction	10d	5.0	20.0	0.3
	30d	11.0	77.0	0.3

4.3 Analysis Centers Global Solutions

The data analyzed in the present Annual Report were provided by the various analysis centers together with their solutions. *Table 12* gives the earth orientation and reference frames results submitted in 2001.

Astrometry

AICAS

This is an updated version of our previous solution of 1997, with slightly more observed data used and a different approach to observatories where more instruments were active. The observations of latitude and universal time variations made at 33 observatories all over the world with 47 instruments of different types are used to derive Earth Orientation Parameters (EOP) in the interval 1899.7–1992.0. To this end, all available results (latitude, universal time, star altitude) based on individual star or star pair observations (that were originally referred to local star catalogs) are re-reduced to the HIPPARCOS Catalogue and the present IAU standards. In cases when two or more instruments of the same type were active at an observatory (Mizusawa, Poltava, Pulkovo, Richmond, Shanghai and Washington), the observations were merged into a single series with the estimated steps removed.

The apparent places of the observed stars are calculated using relevant parts of the IERS Conventions (1996). About four thousand different Hipparcos stars were observed throughout the interval in question. Special care is devoted to double and/or multiple stars whose proper motions (and sometimes also positions) are corrected in order to be consistent with the other observations. These corrections are derived from the trends in the residuals of the respective star observations. They are applied only when sufficiently long series of ground-based observations are available and the corrections themselves are statistically significant; about twenty per cent of the observed Hipparcos stars are corrected. Additional corrections are also applied before the solution is made, such as the secular motions of the instruments (due to plate tectonics, using the geophysical model NNR NUVEL1), certain instrumental constants (plate scale, micrometer value), deformations of the apparent almucantar (due to anomalous refraction), oceanic tide-loading effects in the direction of the local verticals of the observatories. Short-periodic zonal tide variations in the speed of rotation of the Earth (due to deformations of the solid Earth) are removed from the observed values of universal time but they are added back to the values of UT1–TAI estimated from the solution.

From more than four million observations, almost thirty thousand unknown parameters are estimated in a single least-squares solution with constraints. Such a large system of linear equations is solved using a modified Cholesky decomposition of the sparse matrix of normal equations, taking into account their specific form. The estimated parameters comprise polar motion (i.e. motion of the spin axis in terrestrial reference frame) and celestial pole offsets (motion of the same axis in celestial reference frame), at five-day intervals in the whole time span. After 1956, when the International Atomic Time scale (TAI) became available, the differences between universal time UT1 and TAI are also determined, again at five-day intervals. In addition to these, combinations of Love numbers Lambda = 1 + k – l (governing the solid Earth tidal variations of the local verticals) are estimated, together with the small corrections of station coordinates and the seasonal effects in latitude/longitude (i.e. a constant, secular trend, semi-annual and annual terms) at each observatory. The latter are mutually tied by 18 constraints (these are meant to fix the terrestrial reference frame to the one defined by initially chosen station coordinates and to reduce the systematic deviations of individual instruments due to seasonal effects of refraction).

Very Long Baseline Radio Interferometry

BKG

Observing technique: VLBI, group delay observables. Data span: January 1984 – December 2000 (2376 sessions), worldwide set of VLBI observations, 24 hours sessions. Number of sites: 71. Number of radio sources: 730

Type of results: EOP, RSC, SSC/SSV; – Station coordinates and velocities; – Right ascension and declination of radio sources; – Earth orientation parameters (x,y,UT1–UTC,dpsi,deps) corrected for short periodic variations according to Gipson (1996); – Reference epochs for UT1–UTC and polar motion: midnight epochs; – Reference epochs for nutation offsets: beginning of each session.

Connection between systems: – The orientation of CRF is defined by no-net-rotation constraints for 209 ICRF defining sources; – Definition of initial translation and rotation of the TRF: condition that the sum of adjustments of 12 sites with respect to ITRF97 is zero; – The evolution of the TRF velocity field is defined by introducing the condition that the sum of adjustments of the velocities of five sites with respect to ITRF97 is zero.

GSFC

Solution *gsf2001b* estimates station position and velocity parameters to define TRF/CRF for computing EOP time series. Source positions are also estimated. The TRF is attached to ITRF2000 by imposing no-net-rotation and no-net translation conditions for the positions of a subset of stations and to NUVEL1-A NNR by similar conditions from velocities of a subset of stations. The CRF is attached to the ICRF by a no-net-rotation condition using the 212 ICRF defining sources. All available dual-band Mark-3/Mark-4 VLBI observations from 03-AUG-1979 through 03-APR-2001, 3051999 measurements of group delays were used in a combined solution.

Parameters are split onto three groups: 1) global parameters estimated over all sessions; 2) local parameters estimated for each 24-hour session individually; 3) segmented parameters estimated over 20–60 minutes time span.

Positions and velocities of all stations were estimated as global parameters. Positions of 552 sources were estimated as global parameters. Criteria for generating the list of these 552 sources: either 1) the source was observed during 2 or more sessions, in which it had 2 or more good observations, and the source had 40 or more good observations; or 2) the source was observed only during one session and had 25 or more good observations. Sources which were observed less than 2 times in any session were excluded. Positions of the other 138 sources were estimated for each session individually.

Two source catalogues are provided, *gsf2001b.crfg* – catalogue of 552 sources estimated as global parameters; *gsf2001b.crfl* – catalogue of 138 sources estimated as local parameters. Mean site gradients were computed from GSFC Data Assimilation Office

(DAO) model for met data from 1990–95. Atmospheric gradient delay is modeled as:

*tau = m_grad(el,az) * [GN*cos(az)+GE*sin(az)]*,

where el and az are the elevation and azimuth of the observation and the gradient mapping function is m_grad. The gradient vector has east and north components GE and GN.

IAA The solution was obtained from analysis of 2155 VLBI observation sessions since Sep-1980 till 13-Mar-2001 (among them 410 – NEOS-A, 589 – IRIS-A, 72 – IRIS-P, 142 – IRIS-S, 76 – CORE-A, 52 – CORE-B and the others). Model of reduction follows IERS Conventions (1996) except relativistic correction which was computed according to IERS Standards (1992). Celestial reference frame was fixed to ICRF-Ext.1. The solutions were obtained by using OCCAM software version 3.6. Wet tropospheric delays and clock offsets were modeled as random walk stochastic process and estimated using Kalman filter technique. Pole coordinates, UT1–UTC and nutation angles have been estimated. Terrestrial reference frame ITRF97 with the associated velocity field was used for station coordinates.

OPA The solution EOP(OPA) 01 R 02 consists in a series of estimated EOP (x, y, UT1–UTC, dPsi, dEpsilon) based on 24-hour observing sessions available in the IVS Data Centers for 1999 and 2000. The data analysis uses as adopted references the ITRF97 and its velocity field for the terrestrial frame and ICRF-Ext.1 for the celestial frame. The x, y, and UT1 results have no diurnal/semi diurnal variations (taken off by using the Ray 1995 model).

SHA The VLBI analysis center at the Shanghai Observatory of Chinese Academy of Sciences analyze in this year the MKIII VLBI group delay observations between Aug 1979 and Feb 2001. The solutions produce the full set of RSC, SSC, SSV and EOP. Using almost all geodetic and astrometric experiments from the NASA Crustal Dynamics Project, POLARIS/IRIS organized by NOAA, the Communications Research Laboratory (Japan), the Geographical Survey Institute (Japan), the University of Bonn Geodetic Institute, the National Astronomical Observatory (Japan), the Naval Research Laboratory Reference Frame Program, the USNO NAVNET/NAVEX, the NASA Space Geodesy Program-GSFC, the National Earth Orientation Service (USA), CORE project, and APSG VLBI observations, the data include 2928 sessions and 2,534,349 group delay observations. There are 113 sites and 675 sources in the analysis. The origin and orientation of the TRF are connected to ITRF97 at 1997.0 by applying no-net-horizontal-translation and no-net-rotation constraints to the position adjustments of 12 stations with uniform station weighting for both constraints. The evolution of the TRF is connected to NNR-NUVEL1A by applying no-net-horizontal-translation and no-net-rotation constraints to the velocity adjustments of five stations with uniform station weighting for both constraints. The right ascension origin and orientation of the CRF are connected to ICRF-Ext.1 by applying a no-net-rotation constraint to the position adjustments of the 212 ICRF95 defining sources with weighting proportional to the precision of the source positions. Three-dimensional velocities are adjusted for all sites with constraints for those sites with insufficient data. EOP values from 24-hr sessions are available at minimum weekly, and there are continuous periods up to two-weeks duration.

Lunar Laser Ranging

FSG

The solution is based on the LLR data acquired since the beginning of the observations (1970) until December 2000. The cartesian station coordinates of five sites and their velocities using weak constraints, are estimated. Differences between the three McDonald sites are constrained to local surveys. The model for calculating the station coordinates comprises of tidal displacements due to solid earth and polar tides, ocean loading, variations of latitude in agreement with IERS Conventions (1996). Diurnal and semidiurnal tidal variations in UT1 and relativistic contraction in the geocentric frame have been regarded as well. Corrections to precession and some nutation terms are applied or estimated. Input Earth rotation values are taken from a solution of R. Gross (JPL). This solution is called COMB2000 and is aligned with the IERS system. Daily corrections for UT0 and VOL are determined after the global fit. A total number of 1566 values have been computed. The ephemeris of the major solar system bodies are computed with the FSG ephemeris program, the lunar librations were integrated simultaneously. The initial values for the integration are essentially taken from the ephemeris DE200.

OPA

Paris Observatory Lunar Analysis Center presents two solutions for the orientation of the celestial dynamical ecliptic reference frame (OPA 01) M 01 & M 02 and two series for UT0–UTC and variation of latitude VOL (OPA 01) M 03 & M 04.

Solution OPA 01 M01 gives the position of inertial mean ecliptic of J2000.0 with respect to a celestial coordinate system tied to the mean CEP of J2000.0, and solution OPA 01 M02 gives it with respect to the IERS celestial reference system (ICRF). These solutions result from weighted fits of the Moon orbital motion theory ELP2000-96 and the improved Moons' theory of libration to 14754 LLR normal points provided by McDonald, Haleakala and Grasse observatories between January 1972 and March 2001. The fits used the values of parameters x, y, and UT1–UTC provided by the series EOP(IERS) C 04 and the LLR stations coordinates from ITRF94.

For OPA 01 M01 the fit involves an analytical representation of precession-nutation. For OPA 01 M 02 we used the IERS numerical corrections dPsi and dEpsilon.

Values of UT0–UTC and variation of latitude VOL have been determined by analyzing LLR observations from 1995 till 2000 for nights with four normal points at least. We used the results of the previous fit given by the solution OPA 01 M 01. Series OPA 01 M 03 contains 282 values of UT0–UTC and VOL from the observations provided by Grasse and series OPA 01 M 04 contains 178 values from McDonald.

UTXMO

The University of Texas McDonald Observatory (UTXMO) has submitted SSC and EOP results for the 2000 IERS Annual report. The analysis used the total set of lunar laser ranging data available. A total of 14803 normal points were acquired between September, 1969 and December, 2000 from the following stations: McDonald Observatory 2.7m telescope (which ceased operation in 1985), the McDonald Laser Ranging Station (saddle site and Mt. Fowlkes site) near Fort Davis, Texas, the Haleakala Observatory on Maui, Hawaii (which ceased operation in 1990), the Observatoire de Côte d'Azur station in Grasse, France were used in this solution. The node of the EMbary orbit was fixed to the MIT ITR-78 ephemeris to tie the longitude of the celestial reference frame. The orientation of the terrestrial reference frame was fixed to the EOP(CSR) 95 L 01 EOP series at 11 Jan 1985. There were sufficient data for 1514 station/reflector pair estimates of UT0–UTC including 99 UT0 estimates on 69 nights in 2000. The time interval between EOP values varied due to the phase of the Moon and to weather but the average interval was about 4 days.

Global Positioning System

CODE

The solution made available to the IERS by the CODE Analysis Center of the IGS for the 2000 submission was produced using as observations 7.5 years of GPS data of the global IGS network and fixing 50 stations to the corresponding ITRF2000 site coordinates and velocities. The UT1–UTC series was obtained by integration of the estimated LOD values (the first UT1–UTC value fixed to the corresponding C04 value). The time interval covered by the solution starts on day 200 of the year 1993 (July 19, 1993) and ends on day 135, 2001 (May 15, 2001). The spacing between subsequent EOP values is one day. The number of daily global IGS stations processed at CODE grew from about 35 (in 1993) to about 140 (in 2001). Regarding the satellite orbits the series is not homogeneous because the satellite orbit modeling was changed (improved) a few times. Concerning the EOP series we have to mention that subdaily EOP variations were modeled (Ray model) starting with January 1, 1995.

GFZ Earth Orientation Parameters (EOP(GFZ)01P01) have been estimated from the analysis of the global GPS data spanning 8 years from January 1993 to March 2001 using the GFZ analysis software package EPOS.P.V2. The daily EOP results (EOP(GFZ)01P01 with x, y, LODR, UT1R–TAI) are consistent with the global Set of Station Coordinates (SSC(GFZ) 00 P 01) computed for the year 2000 ITRF submission. The orientation of the system was defined by applying no-net-rotation constraints both for the site coordinates and the site velocities, as a reference the ITRF97_IGS_RS51.SNX reference frame including velocities was used.

Data: The initial data acquired at the GFZ IGS Analysis Center are the 30 sec RINEX data from the IGS Core stations collected at the global IGS data centers. For the analysis itself undifferenced ionospheric free phases were used. Starting with February 8, 1998 (GPS week 944) the elevation cut-off was changed from 20 to 15 degrees and the sample rate was changed from 6 minutes to 5 minutes. P-code data entered into the analysis to preset the ambiguities. The identified ambiguities were constrained to the expected P-code accuracy. We use 24 hour data segments in the analysis. Starting from the GPS week 971 (16 August 1998) we have introduced the so-called ambiguity fixing in our analysis.

Analysis: The solutions were obtained by using GFZ EPOS.P.V2 Software package, which is adapted to the IERS Standards. The adjusted parameter set results from a HELMERT blocking. For each parameter the time resolution can be chosen freely. The orbital elements are adjusted independently from day to day.

The Earth Rotation Parameters (pole coordinates and length of day) were adjusted as daily values independent from day to day. Since June 30, 1996 the daily and sub-daily polar motion and UT1 are modeled according to the IERS 1996 Standards. To get a stable reference for the pole parameter determination a set of core stations was fixed. Their number and nominal values vary from year to year. The whole series is homogenized to compensate for jumps originating from the changes in the reference frame and is aligned to our coordinate solution SSC(GFZ) 00 P 01. The orientation of the system was defined by applying loose no-net-rotation constraints both for the site coordinates and the site velocities, as a reference the ITRF97 (ITRF97_IGS_RS51.SNX) reference frame including velocities was used (the alignment is of the order of (0.2 mas).

JPL The most recent velocity and position solution from JPL is based on nearly ten years of data from 91jan22 through 00oct28. Position and velocity estimates were included for 168 sites with two or more years of data and official site log information. Sixty extra sites which lacked sufficient site log data were included in the stacov file but not in the sinex file. Daily estimation was carried out with JPL's

GIPSY software using strategies which generally adhered to IERS/IGS standards. Antenna height corrections were applied directly while uncalibrated offsets due to equipment changes or co-seismic motion were estimated as necessary. Each daily coordinate and EOP was aligned with ITRF97 by estimation and application of three rotations, three translations, and one scale. The translation and scale time series represent the daily offsets between the GPS implied origin and scale and those of ITRF97. Positions, velocities, and time series of latitude, longitude, height, polar motion, length of day, geocenter, and scale estimates are also available via the internet at <http://sideshow.jpl.nasa.gov /mbh/series.html>.

USNO 01

By about 17h each UTC day, the U.S. Naval Observatory (USNO) determines the UT1-like quantity UTGPS for UTC noon the previous day. This quantity is determined from the combined Rapid GPS satellite orbits produced by the International GPS Service (IGS). The IGS combined Rapid orbits for 12 to 16 GPS satellites are considered in producing each day's UTGPS. These combined Rapid orbits are, in turn, produced from the Rapid orbits submitted to the IGS by the Analysis Centers of the IGS, including USNO.

The software which determines UTGPS finds, for each satellite it considers, the relation between the satellite's Earth-referenced IGS orbit and a model of this satellite's orbit plane in inertial space. The software propagates each orbit-plane model using standard models of gravitational accelerations and an empirical model representing the radiation-pressure acceleration observed during several past years of in-flight experience. From the relation between the IGS and modeled orbits, the software finds a single-satellite estimate of Universal Time. Taking the median of these estimates gives UTGPS.

USNO 02

This submission is derived from solution EOP(USNO) 01 P 02. However the long-term variations which are not related to UT1 (due to orbit modeling errors and to nodal excitations induced by geophysical fluid motions) have been removed by applying a high-pass filter based on a comparison to less frequent VLBI determinations. The calibration process interpolates the GPS-based UT series to the epochs of all available VLBI determinations of UT1 (24-hour and Intensive sessions) using a cubic spline. These splined residuals are then high-passed smoothed using a Gaussian filter, fully transmitting variations with periods less than 10 days and attenuating by 50% those at about 26 days. The resulting low-pass curve is treated as a calibration trend and subtracted from the GPS UT. This creates a high-passed GPS UT1-like series that should not suffer from the long-term systematic effects seen in most GPS series based on integrated LOD. In this way, this submission is intended to provide quasi-independent estimates of high-frequency UT1 variations.

Satellite Laser Ranging

CGS

The SLR solution CGS 01 L 01 provides SSC/SSV at the reference epoch 970101 and 3-day EOP derived from Lageos I (Jan 1984 – Dec 2000) and Lageos II (Nov 1992 – Dec 2000) data.

The solution is obtained using the NASA/GSFC GeodynII/Solve software for the analysis of 30-day arcs and their combination to derive estimates of three dimensional site coordinates and 3-D velocities, 30-day C20 zonal coefficients and 3-day EOP (x,y,UT1–UTC) and with loose constraints on SSC/SSV.

The normal points collected from the worldwide network are analyzed using ITRF97 as a priori site coordinates and velocities, IERS Bulletin B for a priori EOP values, EGM96 geopotential (up to degree 70) and its own tides model. The secular drift and the influence of the dynamical pole on C21 and S21 coefficients, all the major planets perturbations as well as the relativistic effects have been applied. Residual unmodeled effects on the satellite orbit in the along-track direction are minimized by the estimation of fortnightly empirical accelerations.

CLG

The solution provided by the Central Laboratory for Geodesy SC/SSV/EOP 01 L 01 is based on the analysis of 1 389 906 Lageos-1 and Lageos-2 normal points covered the time span April 1984 – December 2000 and January 1993 – December 2000 respectively.

The analyses are made using the revised version 4.0 of the Satellite Laser Ranging Processor (SLRP) software developed at the CLG. Monthly arcs for the period are first analyzed and then combined to obtain the global solution. The gravity field model used is JGM3. The orientation of the terrestrial frame is defined by constraining three latitudes – Haleakala (7210), Greenbelt (7105) and Matera (7939) and two longitudes – Greenbelt and Matera to their ITRF97 values. The time evolution is constrained by adopting the 3-D ITRF97 velocities of Haleakala and Greenbelt. Estimates of 3-D site coordinates of 94 sites and 3-D velocities of 63 sites with good tracking history were derived using ITRF97 as a priori values. Earth orientation parameters (x, y, UT1) were estimated at 1 day interval keeping UT1R–UTC fixed at the IERS values at the end of each monthly arc and using IERS Bulletin B as a priori values. Length of the day (LOD) series were calculated by differencing the estimated UT1 series. A few more parameters were obtained in the global solution like geogravitational constant, selected sets of geopotential coefficients and ocean loading parameters, dynamic orbital parameters.

GAOUA

The GAOUA 01 L 01 solution is obtained by processing the SLR global network data of Lageos-1 acquired since September 1, 1983 through January 23, 2001 and Lageos-2 since October 24, 1992 through January 23, 2001. The data consists of 1.090.776 normal points for Lageos-1 and 515.485 normal points for Lageos-2 that have been processed using Kiev-Geodynamics-5.2 software. The solution include the ERP (x, y, UT–UTC) sets at three-day intervals since MJD 45583 till MJD 51952, coordinates of 100 stations at epoch January 1, 1997 (MJD 50449) and velocities of 70 stations located at 49 sites with good observing histories. The terrestrial reference frame is attached to ITRF96 by fixing the latitude of stations 7105 (Washington) and 7210 (Maui) and longitude of station 7105. The station velocities are linked to NNR-NUVEL1A by fixing the rates of these parameters to the values given by the NNR-NUVEL1A model. The velocities of 30 stations which velocities were not estimated were modeled using the NNR-NUVEL1A model. Transformation between the Celestial and Terrestrial Reference Frames is modeled using IAU (1976) precession model, IAU (1980) nutation model and a priori values of celestial pole offsets and ERP taken from the EOP(IERS) C 04 series.

IAA

The solution EOP(IAA) 01 L 01 is based on the SLR observations of Lageos since Jan 1983 till Feb 2001, the solution EOP(IAA) 01 L 02 is based on the SLR observations of Lageos and Lageos2 since Oct 1992 till Feb 2001. The model IERS Conventions 1996 with small exceptions was used for the reduction of observations. The length of arc was equal to five days (increasing of arc was applied when necessary). UT–UTC was estimated from free-running UT series computed summarizing of LOD and corrected for high-frequency variations obtained from comparison with EOP(IERS) C 04. To densify series overlapping arcs with one day shift was used. Station coordinates and velocities was not adjusted and was adopted from ITRF97. The analysis was done using the GROSS program package.

Combination

JPL01

A Kalman filter has been used to combine independent measurements of the Earth's orientation taken by the space-geodetic techniques of LLR, SLR, VLBI, and GPS. Prior to their combination, each series was adjusted to have the same bias and rate, the stated uncertainties of the measurements were adjusted, and data points considered to be outliers were deleted. The resulting combination, EOP(JPL) 01 C 01, also known as SPACE2000, spans September 28, 1976 to January 6, 2001 at 1-day intervals and has been aligned with the IERS combination EOP(IERS) C 04 during 1987–2000. Diurnal and semidiurnal tidal variations are not included in the reported polar motion (PMX, PMY) and UT1–UTC values since they have not been added back after having been removed (when necessary) from the measurements prior to their combination.

JPL02 & JPL03 A Kalman filter has been used to combine the space-geodetic Earth orientation series comprising SPACE2000 (EOP(JPL) 01 C 01; see description) with the BIH (Li, BIH Annual Report for 1984, pp. D31-D63) and ILS optical astrometric series. Prior to their combination with SPACE2000, the optical astrometric series were corrected to have the same bias, rate, and annual term as SPACE2000, the stated uncertainties of the optical astrometric series were adjusted to be consistent with the scatter of their residuals, and outlying data points were deleted. The adjusted optical astrometric series were then combined with SPACE2000 in two steps: (1) the BIH series was combined with SPACE2000 to form COMB2000 (EOP(JPL) 01 C 02), a combined series of smoothed, interpolated polar motion and UT1–UTC values spanning January 20, 1962 to January 5, 2001 at 5-day intervals, and (2) the ILS series was combined with COMB2000 to form POLE2000 (EOP(JPL) 01 C 03), a combined series of smoothed, interpolated polar motion values spanning January 20, 1900 to December 21, 2000 at 30.4375-day intervals. As with SPACE2000, both COMB2000 and POLE2000 have been aligned with the IERS combined EOP series EOP(IERS) C 04 during 1987–2000, and diurnal and semidiurnal tidal variations are not included in either the COMB2000 or POLE2000 reported polar motion (PMX, PMY) or UT1–UTC values.

USNO The description of the EOP (NEOS) 1 C01 is available in the Explanatory Supplement for Bulletins A and B or in the Sub-bureau report in the present Annual Report volume, section IV.5.

Notes to Table 12

Note (1): EOP headings.
Tp: coordinates of the pole,
T : universal time,
Cp: celestial pole offsets.

Note (2): Station velocities.
Es: estimated together with the SSC,
A : adopted from the same SSC,
I6: adopted from the ITRF96 velocity field,
I7: adopted from the ITRF97 velocity field,
N1: adopted from the Nuvel NNR-1 model,
NA: adopted from the Nuvel NNR-1A model,
A2: adopted from the AM0-2 model,
No: not considered.

Table 12. Earth orientation and reference frames results submitted in 2001

Centers & Data span	Earth orientation Nb of date (1)		Celestial frames Nb of sources	Terrestrial frames Nb of sites	Vel.(2)
VLBI					
BKG 1984-2000	EOP(BKG) 01 R 01 2280	Tp T Cp	RSC(BKG) 01 R 01 667	SSC(BKG) 01 R 01	Es
GSFC 1979-2000	EOP(GSFC) 01 R 01 2744	Tp T Cp	RSC(GSFC) 01 R 01 552	SSC(GSFC) 01 R 01	Es
GSFC 1980-2000	EOP(GSFC) 01 R 02 367	Tp T	RSC(GSFC) 01 R 02 137	SSC(GSFC) 01 R 02	Es
IAA 1980-2000	EOP(IAA) 01 R 01 2155	Tp T Cp	RSC(WGRF) 99 R 01 667	SSC(IERS) 97 C 01	I7
OPA 1999-2000	EOP(OPA) 01 R 02 106	Tp T Cp	RSC(WGRF) 99 R 01 667	SSC(IERS) 97 C 01	I7
SHA 1979-2000	EOP(SHA) 01 R 01 2928	Tp T Cp	RSC(SHA) 01 R 01 467	SSC(SHA) 01 R 01	Es
LLR					
FSG 1970-2000	EOP(FSG) 01 M 01 1566	.. T ..	- -	SSC(FSG) 01 M 01	Es
UTXMO 1970-2000	EOP(UTXMO)01 M 01 1514	.. T ..	- -	SSC(UTXMO)01 M 01	Es
OPA 1995-2000	EOP(OPA) 01 M 03 282	.. T ..	- -	EPH(OPA) 01 M 01	I6
OPA 1995-2000	EOP(OPA) 01 M 04 178	.. T ..	- -	EPH(OPA) 01 M 01	I6
GPS					
CODE 1993-2000	EOP(CODE) 01 P 01 2858	Tp . ..	- -	SSC(CODE) 01 P 01	Es
GFZ 1993-2000	EOP(GFZ) 00 P 01 2986	Tp . ..	- -	SSC(GFZ) 00 P 01	Es
JPL 1992-2000	EOP(JPL) 01 P 01 2854	Tp . ..	- -	SSC(JPL) 01 P 01	Es
SLR					
CGS 1984-2000	EOP(CGS) 01 L 01 2060	Tp . ..	- -	SSC(CGS) 01 L 01	I7
CLG 1984-2000	EOP(CLG) 01 L 01 6119	Tp . ..	- -	SSC(CLG) 01 L 01	Es
GAOUA 1983-2000	EOP(GAOUA)01 L 01 2115	Tp . ..	- -	SSC(GAOUA)01 L 01	Es
IAA 1983-2000	EOP(IAA) 01 L 01 6151	Tp . ..	- -	SSC(IERS) 97 C 01	I7
IAA 1992-2000	EOP(IAA) 01 L 02 3030	Tp . ..	- -	SSC(IERS) 97 C 01	I7
COMBINED					
JPL 1976-2000	EOP(JPL) 01 C 01 8867	Tp T ..	- -	- -	- -
JPL 1962-2000	EOP(JPL) 01 C 02 2847	Tp . ..	- -	- -	- -
JPL 1900-2000	EOP(JPL) 01 C 03 1212	Tp . ..	- -	- -	- -
USNO 1973-2000	EOP(USNO) 01 C 01 10226	Tp T Cp	- -	- -	- -

Table 13. Series of Orientation Parameters available for analysis

Analysis Centers by technique	Years	Number of measurements x,y	UT1	UT0	UT	LOD	Δψ Δε
ASTROMETRY							
EOP (AICAS) 01 A 01	1899 - 1991	6693	6693	-	-	-	6693
VLBI							
EOP (BKG) 00 R 01	1999 - 2001	-	602	-	-	-	-
EOP (BKG) 01 R 01	1984 - 2000	2280	2280	-	-	-	2280
EOP (GSFC) 00 R 01	1999 - 2001	-	596	-	-	-	-
EOP (GSFC) 01 R 01	1979 - 2001	2744	2744	-	-	-	2744
EOP (IAA) 01 R 03	1984 - 2001	-	3846	-	-	-	-
EOP (IAA) 01 R 04	1980 - 2001	2232	2232	-	-	-	2232
EOP (OPA) 01 R 02	1999 - 2000	106	106	-	-	-	106
EOP (SHA) 01 R 01	1979 - 2001	2928	2928	-	-	-	2928
EOP (SPBU) 99 R 01	1997 - 2001	-	866	-	-	-	-
EOP (SPBU) 00 R 03	1983 - 2001	1009	1009	-	-	-	1009
LLR							
EOP (FSG) 01 M 01	1970 - 2000	-	-	1566	-	-	-
EOP (OPA) 01 M 03	1995 - 2000	-	-	282	-	-	-
EOP (OPA) 01 M 04	1995 - 2000	-	-	178	-	-	-
EOP (UTXMO) 01 M 01	1970 - 2000	-	-	1514	-	-	-
GPS							
EOP (CODE) 01 P 01	1993 - 2001	2858	-	-	2858	2858	-
EOP (EMR) 96 P 03	1996 - 2001	1820	-	-	1820	1820	-
EOP (ESOC) 96 P 01	1996 - 2001	1824	-	-	1824	1824	-
EOP (GFZ) 00 P 01	1993 - 2001	2986	-	-	2986	-	-
EOP (JPL) 01 P 01	1992 - 2000	2854	-	-	-	2854	-
EOP (NOAA) 96 P 01	1996 - 2001	1821	-	-	1821	1821	-
EOP (SIO) 96 P 01	1996 - 2001	1756	-	-	1756	1756	-
EOP (USNO) 01 P 02	1995 - 2001	-	-	-	1953	-	-
EOP (USNO) 01 P 01	1995 - 2001	-	-	-	1946	-	-
SLR							
EOP (CGS) 01 L 01	1984 - 2000	2060	-	-	2060	-	-
EOP (CLG) 01 L 01	1984 - 2000	6119	-	-	6119	-	-
EOP (CSR) 95 L 01	1976 - 2001	2831	-	-	2831	-	-
EOP (DUT) 98 L 01	1993 - 2001	1034	-	-	1034	-	-
EOP (GAOUA) 01 L 01	1983 - 2001	2115	-	-	2115	-	-
EOP (IAA) 01 L 02	1992 - 2001	3030	-	-	3030	3030	-
EOP (IAA) 01 L 01	1983 - 2001	6151	-	-	6151	6151	-
COMBINED							
EOP (IERS) C 04	1962 - 2001	14877	14877	-	-	14877	14877
EOP (IERS) C 03	1998 - 1999	2556	2556	-	-	2556	-
EOP (IERS) C 02	1962 - 2001	2886	2886	-	-	2886	-
EOP (JPL) 01 C 01	1976 - 2001	8867	8867	-	-	-	-
EOP (JPL) 01 C 02	1962 - 2001	2847	-	-	-	-	-
EOP (JPL) 01 C 03	1900 - 2001	1212	-	-	-	-	-
EOP (USNO) 01 C 01	1973 - 2001	10300	10300	-	-	10300	-

4.4 Yearly Analyses

The Earth orientation series available for analysis are described in *Table 13*. They include the 38 series received from 27 Analysis Centers.

General Combination of Series

A known source of relative drifts in x, y and UT1–UTC is the variety of processes chosen by the analysis centers to control the time evolution of the adjusted terrestrial reference frames, complicated by the sampling of the tectonic plates and plate margins in the actual observing networks. The NNR-NUVEL1A model (DeMets *et al.*, 1990; DeMets *et al*., 1994) is recommended in the IERS Conventions (1996). The various ways in which the time evolution is globally constrained to follow a reference model reflect themselves in the EOP time series.

The calibration of the formal uncertainties associated with the EOP determinations which are combined is derived from the pair variance analysis of the differences between series, without considering any combined series in the process. The analysis follows the method of Gray and Allan (1974) extended to the case of correlated errors. When three or more series of similar quality and time resolution can be differenced, the pair variance of the noise of each series can be evaluated. In the case of series based on the same data set, the estimation model includes consideration of their possible correlation whenever permitted by the information available. The pair variance thus obtained is referred to as the estimated uncertainty of a single determination in a given series; its ratio with the *rms* formal uncertainty over the same period provides a scaling factor.

The weighting of the combined individual results is based on the quadratic sum of *estimated uncertainties,* obtained by multiplying the formal uncertainty of the original determination by the previously described scale factors of the series to which they belong, and of a term which reflects the uncertainty of the systematic correction applied. The effective weighting of the individual series obtained from the same data set (VLBI, GPS, SLR) is appropriately modified to take into account the resulting redundancy.

In the case of satellite techniques (SLR, GPS), the numbers in the columns labeled “UT-UTC” refer to the high frequency content of the results, i.e. for periods shorter than about 60 days.

Presentation of the Combined Solutions

Reference series of EOP at 0.05 year interval, EOP(IERS) C 01: Tables 14, 15, 16

EOP(IERS) C 01 is under the form of normal values at 0.05 year intervals since 1846 with associated formal uncertainties. It serves as a reference for the evaluation of systematic differences of the compared series. This solution is intended for long term studies. *Figure IV-4-7* represents the pole path over 1996 until 2001. The mean pole path since 1900 is represented in solid line. EOP (IERS) C 01 is based on the following data.

– 1980 – now: IERS solution of x, y, UT1–TAI, dψ, dε, based on VLBI, LLR, GPS (from 1992) and SLR.
– 1962 – 1979: IERS and BIH solutions, giving x, y, UT1–TAI. Space techniques are introduced starting with 1969 (LLR for UT) and 1972 (Doppler for polar motion).

The 1996–2000 interval of EOP(IERS) C 01 is re-computed with this year's analysis. It is obtained as the series of the weighted mean of the three intra-techniques solutions (VLBI, SLR and GPS) under the form of normal values at 0.05 year interval. The individual values are weighted by means of their formal uncertainties, scaled to match the pair variance of each series at 0.05 year interval, with added variance derived from the uncertainties in the estimation of the systematic corrections. The relative contribution of these solutions to the EOP(IERS) C 01 solution are listed in *Table 14*.

Fig. IV-4-7. Polar motion, 1996–2000 (EOP(IERS) C 04). Solid line: mean pole displacement, 1900–2000

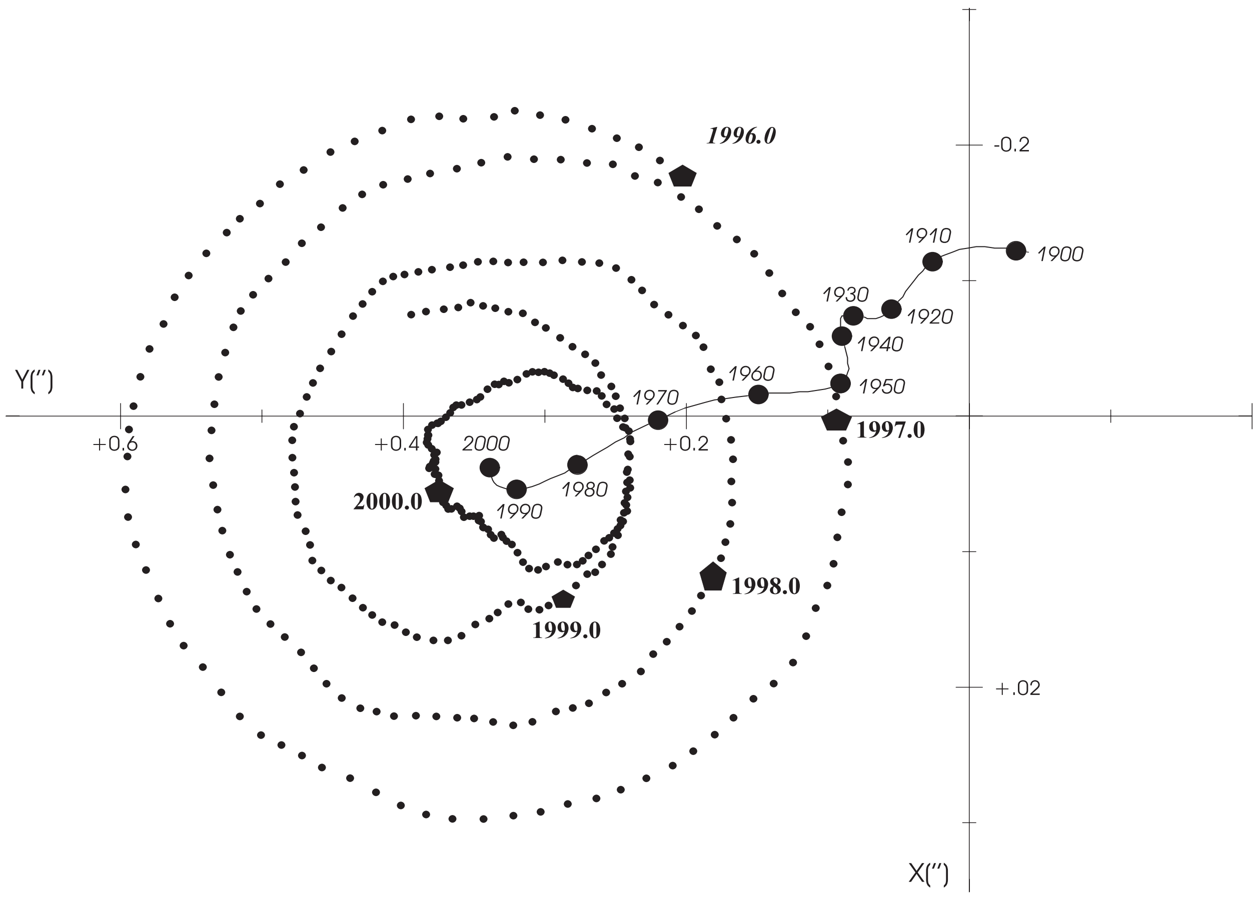

Table 14. EOP(IERS) C 01: Percentage of the contribution of various techniques in the final solution

TECHNIQUE	POLAR MOTION	UT1-UTC	LOD	NUTATION OFFSET
IERS VLBI	20	100	10	100
IERS SLR	10	-	-	-
IERS GPS	70	-	90	-

Table 15. EOP(IERS) C 01: Evolution of the mean uncertainties

YEARS	X		Y		UT1-UTC		dψ		dε	
	Nb /year	σ (mas)	Nb /year	σ (mas)	Nb /year	σ (0.1ms)	Nb /year	σ (mas)	Nb /year	σ (mas)
1846-1889	10	80.	10	90.	-	-	-	-	-	-
1890-1900	20	50.	20	70.	-	-	-	-	-	-
1900-1961	20	30.	20	40.	-	-	-	-	-	-
1962-1972	20	15.	20	15.	20	15.	-	-	-	-
1973-1979	20	10.	20	10.	20	5.	-	-	-	-
1980-1983	20	1.2	20	1.1	20	1.2	20	2.0	20	0.5
1984-1987	20	0.16	20	0.15	20	0.11	20	0.20	20	0.10
1988-1995	20	0.11	20	0.11	20	0.08	20	0.16	20	0.08
1995-2000	20	0.08	20	0.08	20	0.04	20	0.06	20	0.04

Table 16. EOP(IERS) C 01: Earth orientation parameters at 0.05 yr interval

Date	Normal values						Uncertainties					
Bessel. year	x "	y "	UT1-UTC s	LOD s	dψ 0.001"	dε 0.001"	x 0.001"	y 0.001"	UT1 0.0001s	LOD 0.0001s	dψ 0.001"	dε 0.001"
2000.00	.043240	.377693	.3554825	.0009023	-50.46	-2.44	.009	.012	.016	.002	.05	.02
2000.05	.052402	.375673	.3413541	.0008776	-51.51	-2.92	.008	.010	.011	.002	.04	.02
2000.10	.060578	.372437	.3250566	.0008094	-50.23	-3.48	.008	.010	.012	.002	.04	.02
2000.15	.068039	.365452	.3071142	.0009868	-49.81	-4.66	.010	.010	.016	.005	.06	.02
2000.20	.074497	.357951	.2899853	.0008020	-49.55	-5.15	.010	.011	.010	.003	.03	.01
2000.25	.075411	.345975	.2762529	.0008396	-47.65	-5.71	.010	.012	.020	.003	.06	.02
2000.30	.082297	.343177	.2552617	.0012363	-47.61	-6.21	.007	.010	.014	.005	.04	.02
2000.35	.088037	.331942	.2358645	.0008132	-47.54	-6.58	.008	.010	.018	.002	.05	.03
2000.40	.096328	.321422	.2198827	.0006230	-48.98	-7.18	.006	.008	.014	.002	.04	.02
2000.45	.113551	.304341	.2064849	.0004528	-51.74	-6.51	.009	.008	.020	.002	.06	.02
2000.50	.110095	.279075	.2040671	.0000078	-54.23	-6.58	.010	.007	.024	.002	.09	.03
2000.55	.096143	.261651	.2004162	-.0001027	-56.25	-6.15	.007	.008	.011	.002	.04	.02
2000.60	.083051	.248520	.1987965	.0000841	-58.40	-6.31	.011	.012	.017	.005	.08	.03
2000.65	.058367	.242754	.1949480	.0004127	-60.77	-6.56	.008	.011	.015	.004	.06	.02
2000.70	.025943	.239566	.1871300	.0002841	-59.88	-5.77	.007	.008	.012	.002	.06	.02
2000.75	-.005736	.246950	.1747323	.0008476	-60.10	-5.05	.007	.007	.020	.004	.08	.02
2000.80	-.035990	.262843	.1599588	.0008995	-57.11	-3.77	.007	.009	.014	.002	.04	.02
2000.85	-.059984	.292223	.1391539	.0010610	-54.98	-3.79	.007	.008	.012	.002	.06	.02
2000.90	-.076903	.325406	.1205417	.0009176	-55.13	-2.77	.009	.009	.019	.002	.09	.03
2000.95	-.082693	.357049	.1045876	.0006411	-53.18	-1.91	.010	.010	.017	.002	.06	.03

Combined series at 5-day intervals, EOP(IERS) C 02: Table 17

This series is available from 1962. For each date at 5-day intervals, individual determinations available within ±2.5 days are brought to the central date by a modeled time variation of each of the EOP. The combined normal values are obtained by a weighted least square adjustment taking into account the covariance matrices of the individual determinations. The *a priori* standard deviations are based on the formal uncertainties associated with the individual values of the EOP, scaled to match the pair variance of the series, with added variances. The GPS series were first combined prior to the compilation of EOP(IERS). The uncertainties given in *Table 17* represent the short-term instability of the normal values.

Combined series of EOP (normal points) at 1-day interval, EOP(IERS) C 03: Table 18

This series is available from 1993. It is only continuous for polar motion. For each date at one-day interval, all individual determinations of universal time available within ± 0.5 days are brought to the central date by a modeled time variation of UT and corrected for their difference with the IERS System. A weighted mean is then performed; the *a priori* standard deviations of the individual values are based on the formal uncertainties, scaled to match the pair variance of the series, with added variances.

Combined daily series, EOP(IERS) C 04: Table 19

This series continues the one available since 1962. After being homogenized and merged, the contributing series of each of the EOP are slightly smoothed by the Vondrak algorithm. The filter characteristics, given in *Table 23*, are selected so that the weighted *rms* residuals of the original EOP series in a given time interval match their estimated precision. The series are given at one-day intervals and can be interpolated linearly; the oscillations in UT and in duration of the days due to zonal tides for periods under 35 days, as well as the 14d terms in $d\psi$ and $d\varepsilon$ are present in the series.

EOP(IERS) C 04 series and its continuation until the current date is available at the web site: <http://hpiers.obspm.fr/eop-pc>.

Table 17. EOP(IERS) C 02: Average uncertainty of the normal point solution given at five-day intervals

YEARS	σ(X)	σ(Y)	σ(UT1)	σ(dψ)	σ(dε)
	0.001"		0.0001s	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	0.4	0.4	0.2	0.5	0.3
1990-2000	0.2	0.2	0.1	0.3	0.2

Table 18. EOP(IERS) C 03: Number of values and average uncertainty

YEAR	X (mas)		Y (mas)		UT1-UTC (0.1ms)		dψ (mas)		dε (mas)	
	Nb	σ	Nb	σ	Nb	σ	Nb	σ	Nb	σ
1993	365	0.41	365	0.38	236	0.26	70	0.23	70	0.11
1994	365	0.32	365	0.32	194	0.17	52	0.17	52	0.08
1995	365	0.28	365	0.26	216	0.14	52	0.17	52	0.08
1996	366	0.28	366	0.27	215	0.15	53	0.17	53	0.08
1997	365	0.28	365	0.27	257	0.15	53	0.17	53	0.08
1998	365	0.25	365	0.12	257	0.15	53	0.17	53	0.08
1999	365	0.10	365	0.10	259	0.08	88	0.17	88	0.08
2000	366	0.10	365	0.10	259	0.08	88	0.17	88	0.08

Table 19. EOP(IERS) C 04: Uncertainty of a daily value

EOP	Unit	1962-67	1968-71	1972-79	1980-83	1984-95	1996-2000
X	mas	30	20	15	2	0.7	0.2
Y	mas	30	20	15	2	0.7	0.2
UT1-UTC	0.1ms	20	15	10	4	0.4	0.2
LOD	0.1ms	14	10	7	1.5	0.3	0.2
dPsi.sin(Eps)	mas(1)	12	9	5	3	0.6	0.3
dEps	mas(1)	2	2	2	2	0.6	0.3

Note (1): Prior to 1984, dψ, dε are evaluated by an empirical model.

Comparison of Series with the EOP(IERS) C 04

The combination of series of EOP which is described in the above sections is based on two major hypotheses:

- the high frequency behaviors of the series combined are statistically independent,
- the applied corrections (bias and drift) appropriately model their systematic differences.

The high frequency correlation of the individual series has been investigated. Each series is first corrected for known effects (effects of zonal tides in UT, 14d term in $d\psi$ and $d\varepsilon$), and high pass filtered by a Vondrak smoothing (Bulletin B degree of smoothing, *Table 23*). The series of residuals are then correlated two by two, considering only dates less than 0.25 day apart. The correlations are lower than +0.3 across techniques and lower than +0.5 within the same technique.

Systematic differences: when estimating by weighted least squares the systematic differences between pairs of series under the form of a bias and a linear drift over common time intervals, the weighted *rms* postfit residuals found are consistent with the *a priori* uncertainties used in the computation of EOP(IERS) C 01.

Series used in the computation of EOP(IERS) solutions

The individual series used in the computation of EOP(IERS) C 01, C 02, C 03, C 04 are compared with EOP(IERS) C 04 over 1999–2000 in *Table 20*.

The *formal uncertainties* are the averages of those given by the analysis centers after removing the spurious values (values > 3 sigma). The *rms* is the root mean square residual obtained from the comparison to EOP(IERS) C 04.

Consistency of daily combined EOP series

Two daily combined EOP series obtained by JPL and NEOS are compared with EOP(IERS) C 04 and between themselves. The main features of the implementation of the three series are quite similar. They are based on a limited number of VLBI and SLR series, GPS being introduced mid-1992. The unification of the systems is obtained by correcting the individual series for a bias and a linear drift. The weighting of individual values is based on their original standard error, multiplied by a scaling factor specific to each series. They are low-pass filtered, with a frequency cutoff corresponding to a few days.

Table 21 gives the systematic long term differences between the three series. The standard deviations are consistent with the estimated quality of EOP(IERS) C 04.

Table 22 gives an estimation of the stability of the IERS, JPL and NEOS series, based on their intercomparison, for sampling times of 1 through 64 days. The three series have similar characteristics.

Table 20. Formal uncertainties and rms residuals of individual determinations of the EOP, 1999–2000

Individual Series	Errors	X 0.001"	Y 0.001"	UT1-UTC 0.0001s	dPsi 0.001"	dEps 0.001"	D 0.0001s	sample time
VLBI								
EOP (BKG)	formal:	0.17	0.13	0.09	0.25	0.10	-	1d
00 R 02	rms:	0.17	0.13	0.15	0.28	0.12	-	
EOP (BKG)	formal:	-	-	0.18	-	-	-	0.05d
00 R 01	rms:	-	-	0.19	-	-	-	
EOP (GSFC)	formal:	0.14	0.12	0.07	0.24	0.09	-	1d
00 R 01	rms:	0.14	0.10	0.14	0.40	0.15	-	
EOP (GSFC)	formal:	-	-	0.17	-	-	-	0.05d
01 R 01	rms:	-	-	0.15	-	-	-	
EOP (IAA)	formal:	0.12	0.10	0.06	0.21	0.08	-	1d
01 R 03	rms:	0.17	0.16	0.12	0.37	0.16	-	
EOP (IAA)	formal:	-	-	0.15	-	-	-	0.05d
01 R 04	rms:	-	-	0.15	-	-	-	
EOP (OPA)	formal:	0.09	0.07	0.04	0.06	0.06	-	1d
01 R 02	rms:	0.22	0.32	0.12	0.29	0.15	-	
EOP (SHA)	formal:	0.14	0.12	0.07	0.20	0.08	-	1d
01 R 01	rms:	0.16	0.11	0.14	0.29	0.13	-	
EOP (SPBU)	formal:	0.09	0.08	0.04	0.20	0.08	-	1d
00 R 03	rms:	0.14	0.13	0.09	0.30	0.14	-	
EOP (SPBU)	formal:	-	-	0.19	-	-	-	0.5d
99 R 01	rms:	-	-	0.16	-	-	-	
GPS								
EOP (CODE)	formal:	0.01	0.02	-	-	-	0.01	1d
01 P 01	rms:	0.09	0.08	-	-	-	0.24	
EOP (EMR)	formal:	0.06	0.06	-	-	-	0.10	1d
96 P 03	rms:	0.21	0.27	-	-	-	0.92	
EOP (ESOC)	formal:	0.03	0.03	0.04	-	-	0.03	1d
96 P 01	rms:	0.16	0.15	0.52	-	-	0.32	
EOP (GFZ)	formal:	0.01	0.01	-	-	-	0.01	1d
01 P 01	rms:	0.07	0.08	-	-	-	0.32	
EOP (JPL)	formal:	0.06	0.06	-	-	-	0.16	1d
01 P 01	rms:	0.11	0.11	-	-	-	0.32	
EOP (NOAA)	formal:	0.03	0.03	-	-	-	0.19	1d
96 P 01	rms:	0.27	0.27	-	-	-	0.80	
EOP (SIO)	formal:	0.06	0.07	-	-	-	0.16	1d
96 P 01	rms:	0.16	0.10	-	-	-	0.36	
EOP (USNO)	formal:	-	-	-	-	-	-	1d
01 P 01	rms:	-	-	0.30	-	-	-	
SLR								
EOP (CGS)	formal:	0.12	0.12	-	-	-	-	3d
00 L 01	rms:	0.58	0.55	-	-	-	-	
EOP (CSR)	formal:	0.35	0.35	0.29	-	-	-	3d
95 L 01	rms:	0.44	0.30	1.13	-	-	-	
EOP (CLG)	formal:	0.29	0.28	-	-	-	-	3d
01 L 01	rms:	1.51	1.45	-	-	-	-	
EOP (DUT)	formal:	0.11	0.11	-	-	-	-	3d
98 L 01	rms:	0.35	0.37	-	-	-	-	
EOP (GAOUA)	formal:	0.18	0.16	-	-	-	-	3d
01 L 01	rms:	0.30	0.28	-	-	-	-	
EOP (IAA)	formal:	0.07	0.07	0.04	-	-	0.04	5d
00 L 01	rms:	0.22	0.19	0.37	-	-	0.22	
EOP (IAA)	formal:	0.05	0.05	0.03	-	-	0.03	5d
00 L	rms:	0.19	0.16	0.29	-	-	0.18	
LLR								
EOP (FSG)	formal:	-	-	0.62	-	-	-	0.05d
01 M 01	rms:	-	-	1.46	-	-	-	
EOP (UTXMO)	formal:	-	-	3.32	-	-	-	0.05d
01 M 01	rms:	-	-	1.21	-	-	-	
EOP (OPA)	formal:	-	-	0.27	-	-	-	0.05d
01 M 03	rms:	-	-	0.56	-	-	-	
EOP (OPA)	formal:	-	-	0.44	-	-	-	0.05d
01 M 04	rms:	-	-	0.41	-	-	-	

Table 21. Differences between combined daily series of EOP over 1996–2000

The differences are expressed under the form: A + A'(t–1997.0), where t is the date in Besselian years. R is the rms residual after the adjustment of A and A'.

Units: x, y, $d\psi$, $d\varepsilon$: A and R in 0.001", A' in 0.001"/yr
UT1–UTC: A and R in 0.0001s, A' in 0.0001s/yr

SOLUTIONS		JPL – IERS	NEOS – IERS	NEOS – JPL
X	A	0.052 ± 0.004	-0.021 ± 0.004	-0.073 ± 0.002
	A′	-0.033 ± 0.002	-0.080 ± 0.002	0.028 ± 0.001
	R	0.109	0.091	0.063
Y	A	-0.033 ± 0.004	-0.037 ± 0.004	-0.016 ± 0.003
	A′	0.020 ± 0.002	0.004 ± 0.002	-0.010 ± 0.001
	R	0.102	0.091	0.060
UT1-UTC	A	0.019 ± 0.006	0.013 ± 0.008	0.002 ± 0.003
	A′	-0.012 ± 0.003	0.007 ± 0.004	0.010 ± 0.002
	R	0.191	0.240	0.093
dPsi	A	- -	-0.206 ± 0.019	- -
	R	- -	0.557	- -
dEps	A	- -	-0.011 ± 0.012	- -
	R	- -	0.339	- -

JPL: series 01 C 01
NEOS: series 01 C 01
IERS: series C 04

Table 22. Allan variance analysis of the combined series of EOP for sampling times of 1 through 64 days based on the 1996–2000 data

Combined EOP Series	Sampling time	X (0.001")	Y (0.001")	UT1-UTC (0.0001s)
IERS C 04	1 d	0.10	0.18	0.04
	8 d	0.03	0.07	0.07
	32 d	0.02	0.04	0.04
	64 d	0.01	0.03	0.03
JPL 01 C 01	1 d	0.09	0.18	0.03
	8 d	0.04	0.07	0.01
	32 d	0.02	0.04	0.01
	64 d	0.02	0.03	0.01
NEOS 01 C 01	1 d	0.09	0.18	0.09
	8 d	0.03	0.06	0.06
	32 d	0.02	0.03	0.02
	64 d	0.02	0.02	0.01

IERS Bulletin B

An advanced version of EOP(IERS) C 04 is distributed monthly in IERS Bulletin B. The time series of EOP issued in Bulletin B are based on the annual analysis described in the above sections, applied to the series provided weekly or monthly by the operational analysis centers. Each of the series available is referred to the IERS System considering a bias and a linear drift derived from previous analyses. The formal uncertainties are scaled to reflect the real uncertainty of the data. All series of determinations of the same parameters are then merged, and the five resulting series (x, y, UT1, $d\psi$, $d\varepsilon$) are smoothed with the adopted degree of smoothing. UT1 is treated under the form of UT1R (effect of zonal tides with periods under 35 d removed), and $d\psi$, $d\varepsilon$ are treated under the form of residuals to a modeled correction; these modeled corrections are added back at the end of the processing. The degrees of smoothing used in 2000 are given in *Table 23*. They are chosen as allowed by the precision of the input series. The *rms* differences between the Bulletin B series and EOP(IERS) C 04 in 2000 are 0.2 mas on x, y, 0.02 ms on UT1, and 0.0003" on $d\psi \sin\varepsilon$ and $d\varepsilon$.

Table 23. Bulletin B: Transfer functions of smoothings by Vondrak algorithm

Epsilon	Period for Remaining amplitude 5%	50%	95%	Parameters involved
10^{-2}	6d	15d	25d	$d\psi$, $d\varepsilon$ through B96 (Dec 1995)
$10^{-0.5}$	6d	8d	12d	x, y, UT1, LOD through B96 (Dec 1995)
10^{+2}	2d	3d	5d	all parameters starting with B97 (Jan 1996)

Two different approaches are used for prediction of the Earth rotation parameters.

- Universal Time: The formalism used is based on the assumption that the long-term fluctuations (annual and semi-annual) of the preceding year are valid over the next few months. For short-term variations prediction, an autoregressive process is used.

- Polar Motion: The formalism uses at first a floating period fit for both Chandler and annual components estimation. An autoregressive filter is then applied on the short-term variations.

Table 24. Bulletins A and B: Individual series contributing to IERS, January 2000

The formal uncertainties are those which are reported by the contributors. They are used in the combinations for Bulletins A and B after being calibrated by statistical assessment.

INDIVIDUAL SERIES CONTRIBUTING TO IERS BULLETINS A AND B		SAMPLING TIME	FORMAL UNCERTAINTIES BASED ON 1999-2000 DATA			
			Terrest.Pole 0.001"	UT 0.0001s	LOD 0.0001s	Celest.Pole 0.001"
VLBI						
EOP(GSFC)	00 R 01	7d	--	0.21	--	--
EOP(GSFC)	00 R 02	7d	0.64	0.29	--	0.15
EOP(BKG)	00 R 01	7d	--	0.22	--	--
EOP(BKG)	00 R 02	7d	0.16	0.09	--	0.08
EOP(IAA)	98 R 01	7d	0.10	0.04	--	0.10
EOP(IAA)	00 R 04	7d	--	0.18	--	--
EOP(USNO)+	99 R 01	7d	0.14	0.06	0.20	0.13
EOP(USNO)+	99 R 02	1-3 d	--	0.23	--	--
EOP(SPBU)	99 R 01	1-3 d	--	0.22	--	--
SLR						
EOP(CGS)	97 L 02	3d	0.28	0.25 *	--	--
EOP(CSR)	95 L 01	3d	0.39	0.31 *	--	--
EOP(DUT)	98 L 01	3d	0.11	0.10 *	--	--
EOP(IAA)	98 L 02	1d	0.05	0.04 *	0.04	--
EOP(MCC)	97 L 01	3d	0.05	--	0.10	--
GPS						
EOP(CODE)	98 P 01	1d	0.05	--	0.10	--
EOP(EMR)	96 P 03	1d	0.07	1.05 *	0.13	--
EOP(ESOC)	96 P 01	1d	0.02	0.03 *	0.03	--
EOP(GFZ)	96 P 02	1d	0.01	0.01 *	0.01	--
EOP(JPL)	96 P 03	1d	0.04	0.14 *	0.14	--
EOP(NOAA)	96 P 01	1d	0.03	0.10 *	0.19	--
EOP(SIO)	96 P 01	1d	0.07	0.45 *	0.16	--
EOP(IGS)	95 P 02	1d	0.05	0.17 *	0.08	--
EOP(IGS)	96 P 02	1d	0.08	0.29 *	0.14	--

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

The content of Bulletin B is as follows (7 sections):

1. Smoothed values of x, y, UT1R–UTC, UT1R–TAI, $d\psi$, $d\varepsilon$, sampled at five-day interval. Final Bulletin B values over one month and provisional extension over the next four months. The smoothings are based on the Vondrak (1977) algorithm, with degrees of smoothing indicated in the legend (see also Feissel and Lewandowski, 1984). However, the oscillations in UT and in duration of the day due to zonal tides with periods under 35

days, as well as the 14 days term in $d\psi$, $d\varepsilon$, are present in full size in the series.

2. Daily values of x, y, UT1–UTC, UT1–UT1R, D, $d\psi$, $d\varepsilon$, same series as in section 1.
3. Five-day normal values of x, y, UT1–UTC, $d\psi$, $d\varepsilon$, and their uncertainties based on a combination of the series of section 6.
4. Smoothed values of DR and ωR, with the same degree of smoothing than for UT1R–UTC.
5. Current values of UTC–TAI and DUT1, reproducing IERS Bulletins C and D.
6. Statistics on the data used.
7. Data of IERS analysis centers (available only in electronic distribution). In this section, the original results received from the IERS analysis centers and used for the solution listed in sections 1 to 3 are reproduced. These results are those which are available one to five weeks after the observation dates. Updated results received later are stored, but as a general rule, they are not printed in Bulletin B. The series used in January 2000 are listed in *Table 24*.

4.5 Consistency of IERS Results

Consistency of IERS EOP Series with ITRS and ICRS at a Reference Epoch

Let us consider two series of EOP (x, y, UT1, $d\psi$, $d\varepsilon$) and (x', y', UT1', $d\psi'$, $d\varepsilon'$) 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). 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:

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

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

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

If the EOP series were consistent, then the systematic differences in the pole coordinates, Δx and Δy, in the universal time, ΔUT1, and in the celestial pole offsets, $\Delta d\psi$ and $\Delta d\varepsilon$ would be only due to the rotation angles (A_1, A_2, A_3) between the two celestial frames and the rotation angles (R_1, R_2, R_3) between the two terrestrial frames, with:

$$\begin{aligned}
\Delta x &= x' - x \\
\Delta y &= y' - y \\
\Delta \mathrm{UT1} &= \mathrm{UT1}' - \mathrm{UT1} \\
\Delta d\psi &= d\psi' - d\psi \\
\Delta d\varepsilon &= d\varepsilon' - d\varepsilon
\end{aligned}$$

It can be shown that these systematic differences would satisfy the following relationships with an accuracy of a few microarcseconds:

$$
\begin{aligned}
\Delta x &= R_2 \\
\Delta y &= R_1 \\
\Delta \mathrm{UT1} &= (-R_3 + A_3)/\, f \qquad (1)\\
\Delta d\psi &= A_2/\sin\varepsilon \\
\Delta d\varepsilon &= -A_1
\end{aligned}
$$

where f is the conversion factor from Universal Time to sidereal time, and ε is the obliquity of the ecliptic.

It is worthwhile to know 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) characterizes the internal consistency of the set of IERS results, time series and reference frames. In this objective the quantities:

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

are computed.

Time evolution of the IERS EOP series relative to ITRF

We consider two terrestrial frames, each one having its own velocity field. The corresponding series of EOP, the relative drifts $\Delta\dot{x}, \Delta\dot{y}, \Delta\dot{U}T1$ between the series of EOP can be predicted by relationships (2), obtained as the time derivatives of the first three relationships (1):

$$\Delta\dot{x} = \dot{R}_2 \quad ; \; \Delta\dot{y} = \dot{R}_1 \quad ; \; \Delta\dot{U}T1 = -\dot{R}_3 \qquad (2)$$

where $\dot{R}_1$, $\dot{R}_2$, $\dot{R}_3$ 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) C 01 with their predicted values based on the definition of the corresponding terrestrial velocity field.

Results for the EOP Series (2000)

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) C 01. The second step is the comparison, given hereafter, between these biases and slopes, and those theoretically produced by the rotations between the reference frames, as already explained.

Consistency analysis extends over the period 1988–2001, except for the recent VLBI series produced by the Paris Observatory since 1999 (OPA). The data before 1988 were not involved, because they are considered to be of less quality. Bias and trend have been computed with respect to the epoch 1997.0 expressed in Julian year.

Actually since the year 1998, the angles between the individual TRF and the ITRF have not been computed by the ITRF Product Center of the IERS (located at the Institut Géographique National, France, formerly known as the ITRF Section of the Central Bureau) for some technical reason. In turn consistency analyses of the last long term series up to 2001.0, collected by the IERS EOP Product Center in the framework of the Annual Report 2000, cannot be made systematically for polar motion and UT1, because the angles R_1, R_2, R_3 are not available for computing the corresponding closure relations.

For this reason the analysis has been restricted to 7 series, 5 of them derived from VLBI processing, and 2 from SLR processing. *Table 25* gives the evaluations of the internal consistency for EOP series, involving SSC or RSC, of which the orientation is known. The celestial frames angles can be found in Celestial System Section.

Nutation offsets consistency

For VLBI series, the associated radio-source catalogue either corresponds to the ICRF (zero angles, case of IAA, OPA and SHA series) or to celestial frame departing from the ICRF at the level of 50 microarcseconds (case of BKG and GSFC series). In turn consistency of nutation offsets of these series can be fully investigated. Acceptable consistency, less than 100 microarcseconds, is obtained for celestial pole offset ($d\psi\sin\varepsilon$, $d\varepsilon$) of the BKG, GSFC, IAA and SHA series. Celestial pole offsets of OPA series present inconsistencies, which may be caused by the shortness of the time span (two years).

Polar motion and UT1 consistency

Polar motion and UT1 consistencies have been investigated in the case of two VLBI series (IAA, OPA), and two SLR series from LAGEOS observations (IAA L 01, IAA L 02). These 4 series are referred either to ITRF 2000 or to terrestrial frames, which do not present any net rotation with respect to ITRF 2000. Let us notice that for other VLBI series the rotation matrix with respect to ITRF 2000 remains unknown. Polar motion consistency smaller than 100 microarcseconds is reached only for SLR series IAA L 01. UT1 consistency is under this threshold for (IAA) VLBI series and the 2 (IAA) SLR series.

Table 25: Consistency of VLBI EOP series with celestial reference frames, based on the rotation angles relative to ICRF at the epoch 1997

SERIES		R2 Δx C(x)	R1 Δy C(y)	A3-R3 ΔUT1 C(UT1)	A2/sinε Δdψ C(dψ)	-A1 Δdε C(dε)
	1 2 3					
EOP(BKG)	1	-	-	-	0.000±0.040	-0.030±0.016
01 R 01	2	-0.090±0.009	0.055±0.008	-	-0.091±0.018	-0.008±0.013
1988-2000	3	-	-	-	-0.091±0.044	0.022±0.021
EOP(GSFC)	1	-	-	-	0.003±0.043	-0.008±0.017
01 R 01	2	-0.122±0.008	0.189±0.007	-	-0.047±0.021	0.000±0.013
1988-2000	3	-	-	-	-0.050±0.048	0.008±0.021
EOP(IAA)	1	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000
01 R 04	2	-0.148±0.009	0.157±0.008	-0.020±0.035	-0.054±0.022	0.089±0.014
1988-2000	3	-0.148±0.009	0.157±0.008	-0.020±0.035	-0.054±0.022	0.089±0.014
EOP(OPA)	1	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000
01 R 02	2	0.057±0.126	0.201±0.205	0.280±0.334	0.253±0.084	0.116±0.046
1999-2000	3	0.057±0.126	0.201±0.205	0.280±0.334	0.253±0.084	0.116±0.046
EOP(SHA)	1	-	-	-	0.000±0.000	0.000±0.000
01 R 01	2	-0.115±0.008	0.102±0.007	-	-0.059±0.020	0.002±0.013
1988-2000	3	-	-	-	-0.059±0.020	0.002±0.013
EOP(IAA)	1	0.000±0.000	0.000±0.000	0.000±0.000	-	-
01 L 01	2	-0.077±0.032	-0.102±0.018	0.057±0.084	-	-
1992-2000	3	-0.077±0.032	-0.102±0.018	0.057±0.084	-	-
EOP(IAA)	1	0.000±0.000	0.000±0.000	0.000±0.000	-	-
01 L 02	2	-0.102±0.032	-0.148±0.025	0.002±0.087	-	-
1992-2000	3	-0.102±0.032	-0.148±0.025	0.002±0.087	-	-

Unit: 0.001"

IERS Earth Orientation Centre

For the address of the IERS Earth Orientation Centre and for electronic access see Chapter V.4 and Appendix 2.

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