3.5 Product Centres
3.5.1 Earth Orientation Centre

This section presents activities and main results concerning the Earth Orientation Centre located in Paris Observatory over 2001. General presentation of the IERS Earth Orientation Parameters (EOP), operational activities and yearly analyses are presented in the web site <http://hpiers.obspm.fr/eop-pc>. According to the IERS terms of reference, the Earth Orientation Centre is responsible for monitoring Earth Orientation Parameters including long term consistency, publications for time dissemination and leap second announcements. It is making available to users different products: long-term series of Polar Motion, Universal Time (UT1) and Length of Day (LOD), and operational solutions including real-time estimates and predictions.

Determination of EOP is in the form of combined solutions derived from the individual series. Various solutions are computed: long-term solution (IERS C01), normal values at five and one-day intervals (IERS C02 and C03) and the operational smoothed solutions at one-day intervals in Bulletin B published with a delay of thirty days between the date of publication and the last date of the standard solution. Bulletin B is updated in the IERS C04 computed twice weekly.

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

Description of Bulletin B is available in the IERS Explanatory Supplement for Bulletin A and Bulletin B (Gambis and Ray, 2001). Table 1 gives the estimated uncertainties of the individual solutions entering the combination for 2001 after removal of systematic variations. Formal uncertainties reported by the contributors are often under-estimated. They are calibrated by statistical assessment using the Allan variance analysis in order to reflect the real quality of the data (Gray and Allan, 1974; Gambis, 2002). This procedure leads to an optimal weighting.

Predictions

Different approaches are used for prediction of the Earth Rotation Parameters.

Polar Motion

The formalism uses at first a floating period fit (Bevington, 1969) for both the Chandler and annual components estimation over a past time interval of several years. An autoregressive filter is then applied on the short-term residuals series and used for the prediction. The predictions of the 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. Table 2 shows the current accuracy of the EOP solutions and also the skills of the predictions. New procedures for prediction are under investigation, they are based on Singular Spectrum Analysis SSA and Neuronal networks.

Table 1: Estimated accuracies of the different solutions entering the combined solutions.

Individual solutions		Estimated uncertainties				
		Time	Terrestrial Pole 0.001"	UT1 0.0001s	LOD 0.0001s	Celestial Pole 0.001"
VLBI – 24 h						
EOP (AUS)	01 R 01	7d	0.14	0.04		0.09
EOP (BKG)	00 R 02	7d	0.14	0.06		0.10
EOP (GSFC)	01 R 04	7d	0.15	0.05		0.12
EOP (IAA)	02 R 01	7d	0.11	0.03		0.09
EOP (SPBU)	00 R 03	7d	0.11	0.04		0.09
VLBI – Intensive						
EOP (BKG)	00 R 01	1–3 d		0.13		
EOP (GSFC)	01 R 03	1–3 d		0.14		
EOP (IAA)	02 R 02	1–3 d		0.11		
EOP (SPBU)	99 R 01	1–3 d		0.14		
Satellite Laser Tracking						
EOP (CGS)	97 L 02	3d	0.26	0.30 *		
EOP (CSR)	95 L 01	3d	0.44	0.27 *		
EOP (DUT)	98 L 01	3d	0.15	0.09 *		
EOP (IAA)	98 L 02	1d	0.08	0.03 *	0.03	
EOP (MCC)	97 L 01	3d	0.07		0.10	
GPS						
EOP (CODE)	98 P 01	1d	0.02	0.01 *	0.30	
EOP (EMR)	96 P 03	1d	0.07	0.23 *	0.08	
EOP (ESOC)	96 P 01	1d	0.03	0.03 *	0.03	
EOP (GFZ)	96 P 02	1d	0.02	0.02 *	0.02	
EOP (JPL)	96 P 03	1d	0.05	0.16 *	0.16	
EOP (NOAA)	96 P 01	1d	0.04	0.10 *	0.19	
EOP (SIO)	96 P 01	1d	0.11	0.55 *	0.20	

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

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

Table 2: Uncertainty of the current solution for 2001 and the estimated accuracies of the predictions for horizons of 5 days to 2 years.

Solutions		Terrestrial Pole 0.001"	UT1 0.0001s	Celestial Pole 0.001"
Analysis				
	1–d	0.1	0.2	0.3
Prediction				
	5–d	1.6	6.0	0.3
	10d	3.0	16.	0.3
	30d	10.	40.	0.3
	90d	30.	30.	0.3
	180d	60.	55.	0.3
	1-yr	30.	100.	0.3

Table 3: Mean and standard deviation of the differences between various IERS solutions for 2001

EOP	Unit	SPACE 2001 – IERS C04		NEOS final – IERS C04	
		Mean	Standard deviation	Mean	Standard deviation
X	mas	–0.08	0.04	0.04	0.05
Y	mas	–0.02	0.04	0.07	0.05
UT1	0.1 ms	0.05	0.10	0.02	0.20
dψ.sinε	mas	–	–	–0.15	0.48
dψ	mas	–	–	–0.04	0.31

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

The C 01 series was recomputed in the course of 2001 to take into account, from 1900 to 1961, the series recomputed by J. Vondrak (1995) based on the processing of optical data using Hipparcos catalogue as the celestial frame. The C01 series is a composite series 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).

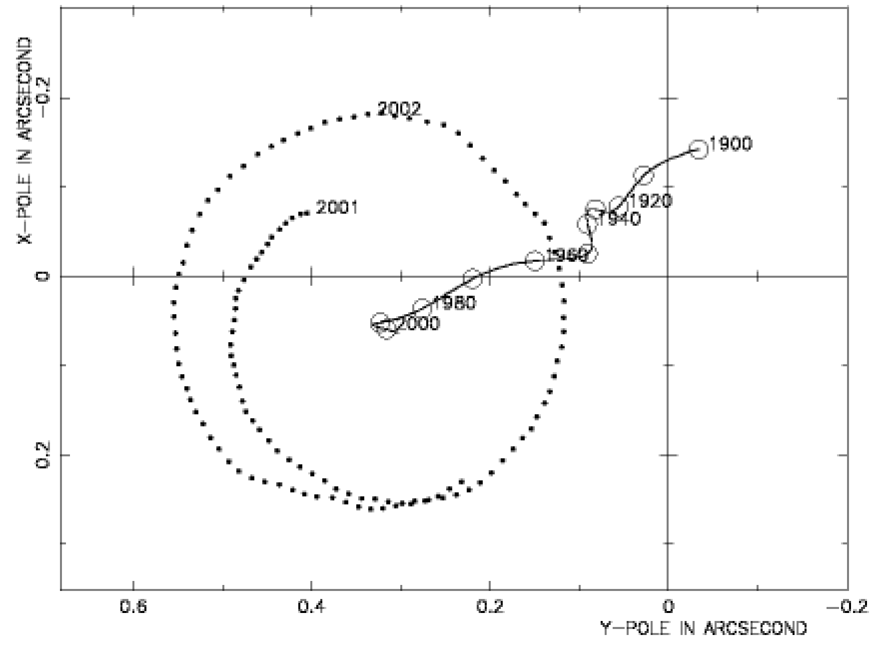
1962–2001: BIH and IERS solutions (BIH and IERS Annual Reports).

Mean Pole with respect to the IERS reference origin

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

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

Figure 1: Mean polar motion (1900–2001) and IERS C04 polhody over 2000–2001.



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, polar motion, UT1–UTC, dψ, dε), C 03 (one-day intervals, polar motion, UT1–UTC) (Gambis, 1996; Eisop and Gambis, 1997). These series are respectively consistent one to another. They use the full correlation matrix when available. Recently there were new developments in the normal point series C 02 and C 03 in which the estimation of the solution given at the central dates of the n-day interval is made using a least-square fit for all EOP components. Although the L2 estimation has been extensively used for data analysis, it has some drawbacks linked to problems of ill-conditioning and in the non-detection of outliers. Alternative methods based on robust estimators like M-Huber can be used. These estimators are a generalization of both the L1 and L2 class. They have been implemented in our analyses and are now currently used (Bougeard *et al.*, 2000; Gambis *et al.*, 2002). Table 4 gives the evolution of the mean uncertainties of C02 solution since 1962.

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

YEARS −− Unit	σ(X) −− 0.001"	σ(Y) −− 0.001"	σ(UT1) −− 0.0001s	σ(dψ) −− 0.001"	σ (dε) −− 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	.4	.4	.2	.5	.3
1990–2000	.2	.2	.15	.3	.2
2001–2002	.1	.1	.10	.3	.2

Consistency of IERS EOP series with ITRF and ICRF

Individual EOP series determined from the analyses of the various techniques present mutually systematic errors, generally limited to biases and drifts which can be attributed to the adoption of different reference frames CRF and TRF. Monitoring of the consistency is currently performed at the Earth Orientation Centre in the IERS Annual Reports since 1991. Note that the mean consistency is regularly improving with years for the different techniques (Figures 2 to 4). This reflects both the improvement in the EOP accuracy and the better determination of reference frames ties. So far, the mean estimated values are about 0.1 mas for polar motion and 20 microseconds for UT1 (IERS Annual Reports).

Figure 2: Evolution of VLBI solutions since 1991

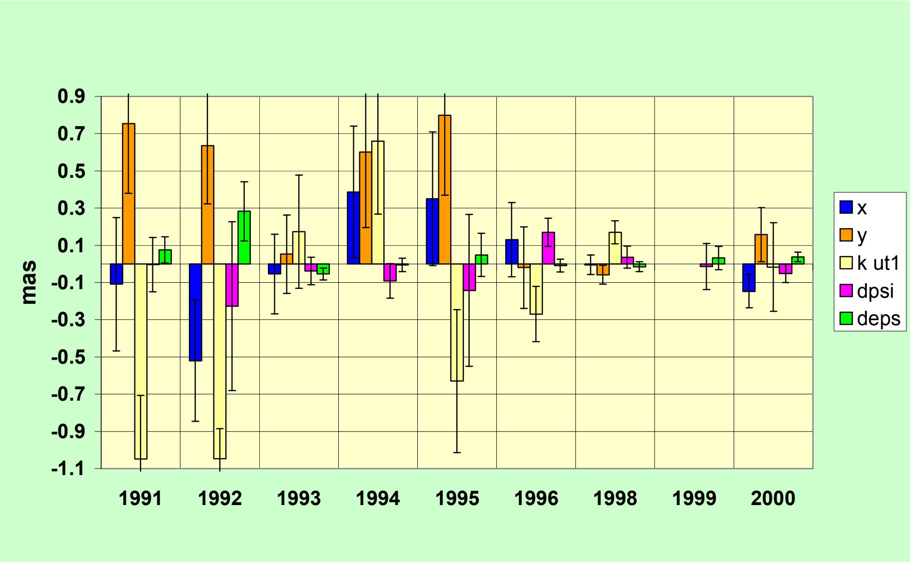
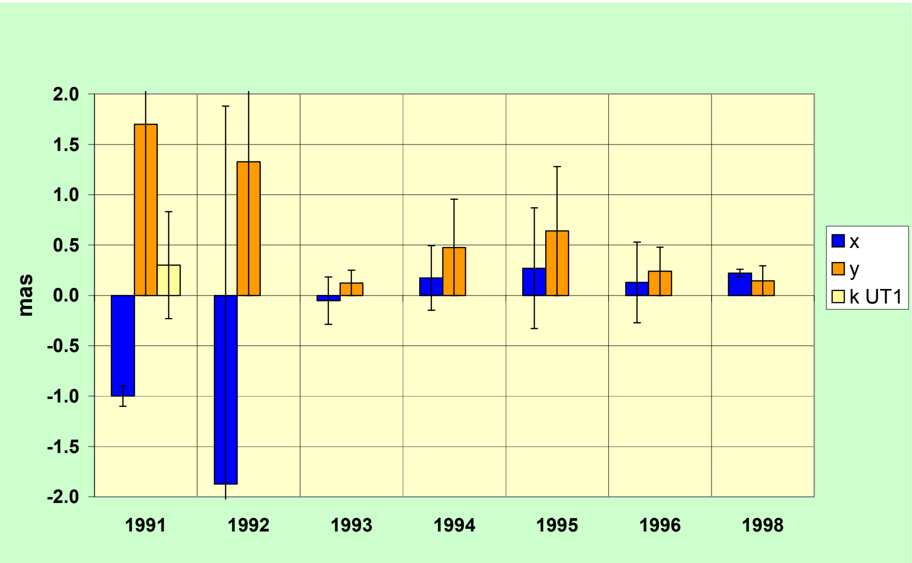


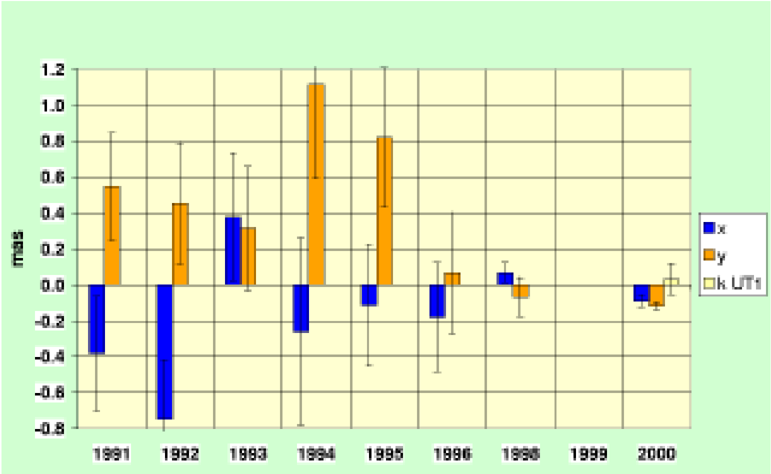
Figure 3: Evolution of GPS solutions since 1991



There are different approaches to estimate the consistency of the IERS EOP system with respect to both terrestrial and celestial reference frames.

The usual method performed at the IERS consists in comparing the individual EOP solutions to the IERS C04 after estimation of the rotation angles between on one hand the individual CRF with respect to ICRF and on the other hand the individual TRF with respect to ITRF. The basic formalism is described in Zhu and Mueller (1983) and in the IERS Annual Reports. Figures 2 to 4

Figure 4: Evolution of SLR solutions since 1991



represent, since 1991, the evolution of the unconsistency for the different techniques VLBI, GPS and SLR (Bizouard and Gambis, 2002). Note that the mean unconsistency is for the various techniques at the level of 0.1 mas for polar motion and 20 microseconds for UT1. This approach is so far not straightforward since due to constraints introduced in the determination of the terrestrial and celestial frames, angles between the individual TRF and the ITRF cannot be easily computed.

A more satisfying method to monitor the consistency, so far not realized within the IERS is based on a rigorous computation of both frames, CRF, TFR and EOP parameters.

An intermediate approach consists in assessing the systematic corrections between individual EOP solutions obtained through the analyses of the data of the various techniques, mostly VLBI and GPS in which both reference frames were constrained to ICRF-Ext1 and ITRF2000 (Altamimi et al., 2002). We have performed such comparisons with respect to the combined IERS C04 solution using the results obtained by the VLBI analysis centres for the IVS Pilot Project in 2001. We have also used comparisons of GPS solutions which are since December 2001 computed in the ITRF2000 frame which does not present any significant rotation with ITRF97 (Gambis et al., 2002). IVS Pilot 2001 EOP solutions are compared to the IERS C04 used as the reference: Significant systematic differences appearing between these individual series of both techniques and C04. Eleven analysis centres submitted EOP series for the second IVS pilot project. These series were derived from all available NEOS-A 24hr VLBI sessions over 1999 and 2000. In these solutions, the celestial and the terrestrial reference were held fixed respectively to ICRF-Ext1 and to ITRF2000 with the associated velocity field.

Estimated parameters include the pole components X-Pole, Y-Pole, UT1–UTC and the nutation offsets dPsi, dEps with respect to IAU 1980 model. The individual VLBI series are compared to IERS C04 together with the operational GPS series also referred to ITRF2000. Tables 5 and 6 give the statistics concerning the systematic biases and the mean values. For X-Pole the unconsistency is negligible, whereas for Y-Pole it is 0.326 mas (VLBI) and 0.188m (GPS).

In conclusion, it appears that there is a slight unconsistency in the IERS C04 y-pole solution of about 0.1 – 0.2 mas with respect to ICRF-Ext1 and ITRF2000. However its value is of the same order as the discrepancy between VLBI and GPS solutions (0.150 mas).

Table 5: Systematic biases of VLBI EOP series compared to IERS C04 used as the reference

VLBI	AUS	BKG	CAN	DGFI	GSFC	IAA	IGG	JPL	OSO	OSO2	SPBU	Mean*	rms
xpole(mas)	-.058	-.016	-.094	-.114	-.055	-.143	-.161	-.220	.062	.055	-.086	-.060	.076
ypole(mas)	.367	.330	-.403	.312	.328	.286	.319	.696	.330	.311	.347	.326	.024
UT1(µs)	6	8	7	8	8	6	10	13	14	16	7	9	3.4
deps(mas)	.028	-.090	.036	51.467	.009	-.015	51.372	.851	-.096	-.108	.031	-.012	.058
dpsi(mas)	049	.043	.000	5.519	.021	.086	5.512	-2.764	.096	.116	.038	.048	.034

* CAN and JPL are excluded for polar motion; DGFI, IGG and JPL for nutation

Table 6 : Systematic biases of GPS EOP series compared to IERS C04 used as the reference

GPS	CODE	JPL	GFZ	ESOC	NOAA	SIO	EMR	Mean	rms
xpole(mas)	-020	-.047	-.070	-.029	-.085	-.039	-.023	-.045	.024
ypole(mas)	.186	.180	.184	.257	.158	.207	.148	.188	.036
LOD (µs)	8	-7	-5	-33	-29	0	-19	-12	15

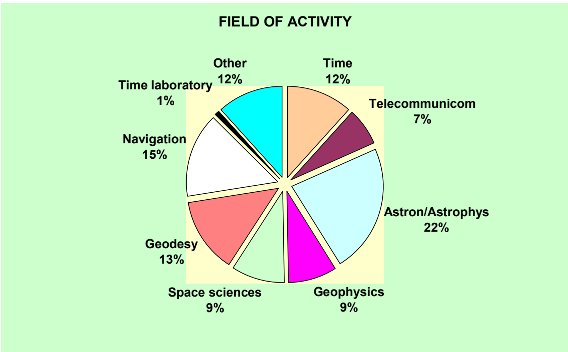
Survey for a possible UTC re-definition

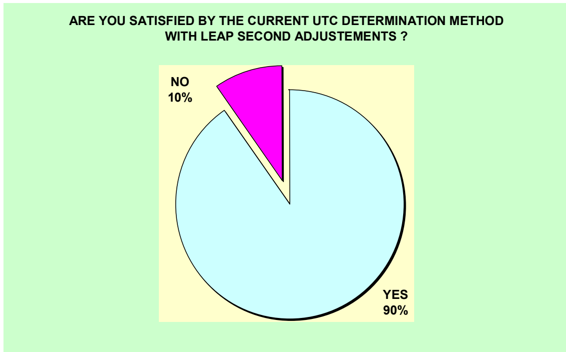
UTC (Coordinated Universal Time) is computed from TAI by the introduction of leap seconds such that UTC is maintained within 1 second of UT1. Since 1972, these leap seconds have been added on December 31 or June 30, at the rate of about one every 18 months. The relevant bulletins are:

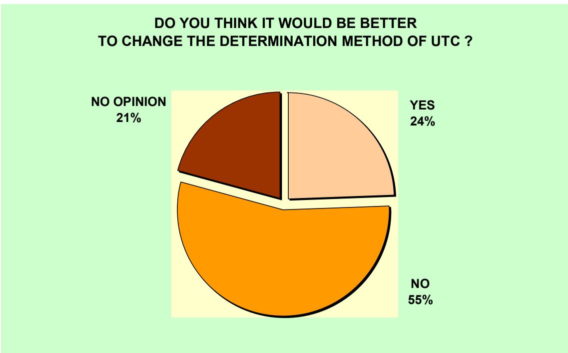
Bulletin C, Announcement of the leap seconds in UTC.

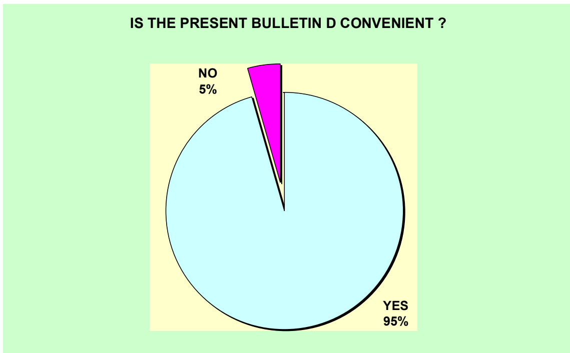
Bulletin D, Announcement of the value of DUT1 truncated at 0.1s for transmission with time signals.

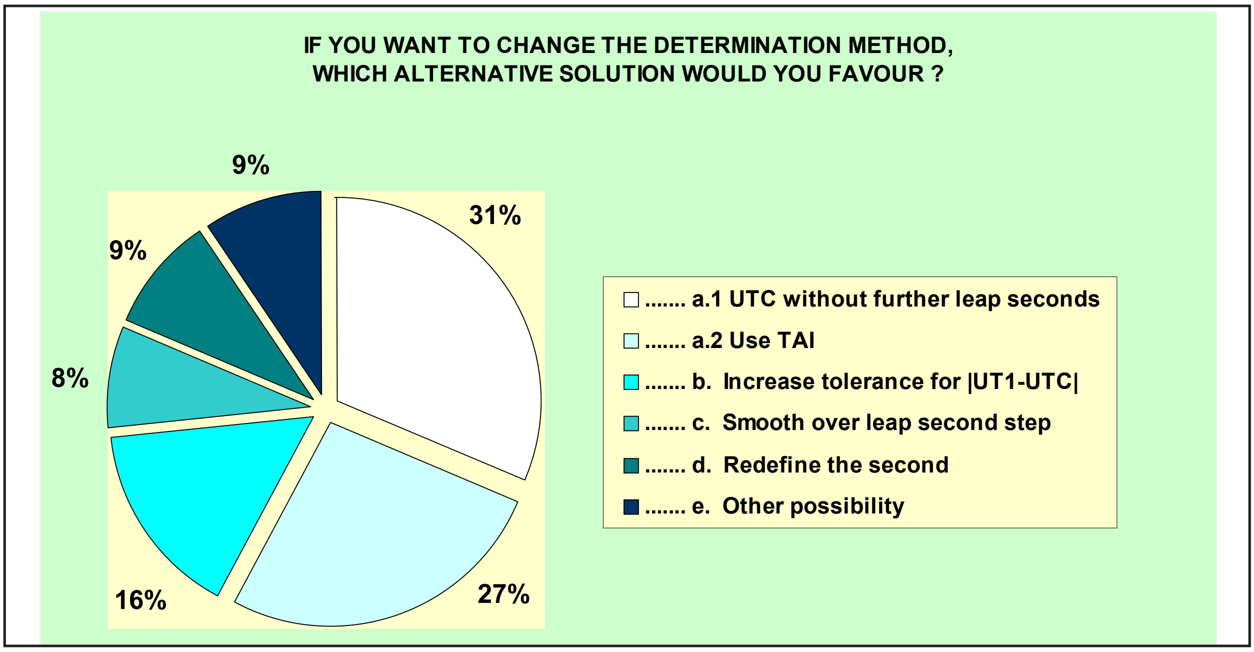
Recently, some communities linked to telecommunications and navigational systems have proposed a revision of the definition of UTC to avoid the discontinuities due to the intermittent leap seconds. The Earth Orientation Centre is responsible for prediction and announcement of the leap second (Bulletin C) and the announcement of the value of DUT1 truncated at 0.1s for transmission with time signals. It was thus of prime importance to question the users of Bulletins C and D to survey opinion concerning a possible redefinition of UTC. The questionnaire was sent via e-mail and also by usual airmail to about one thousand users altogether. 247 reponses were received and processed in Summer 2002. The main results and statistics are given in the following diagrams.











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