



INTERNATIONAL EARTH ROTATION AND REFERENCE SYSTEMS SERVICE (IERS)
SERVICE INTERNATIONAL DE LA ROTATION TERRESTRE ET DES SYSTEMES DE
REFERENCE

SERVICE DE LA ROTATION TERRESTRE
OBSERVATOIRE DE PARIS
61 Av. de l'Observatoire
75014 PARIS (France)
Tél. : 33 (0) 1 40 51 22 26
FAX : 33 (0) 1 40 51 22 91
Internet : services.iers@obspm.fr

May 2009

**EXPLANATORY SUPPLEMENT
TO IERS BULLETIN B**

IERS Bulletin B provides current values on the Earth's orientation in the IERS Reference System. This includes Universal Time, coordinates of the terrestrial pole, and celestial pole offsets. Bulletin A gives an advanced solution updated weekly as well as predictions. The standard solution is given weekly in Bulletin B. Its values are given over a time span of one month and extending until 30 days back with respect to now. They are maintained fixed. In the extended file, preliminary updated values are given. The Annual Report contains information on the data used, the models, the algorithms, and the reference frames. All solutions are continuous within their respective uncertainties. Bulletin A is issued by the IERS Rapid Service/Prediction Centre at the U.S. Naval Observatory, Washington, DC (<http://www.usno.navy.mil/USNO/earth-orientation>) and Bulletin B is issued by the IERS Earth Orientation Centre at the Paris Observatory. For scientific and long-term analyses of the Earth's orientation, users are advised to request the long-term continuous series EOP C01 maintained by the Earth Orientation Centre from 1846 (pole components), 1962 (UT), and 1981 (nutations) given at 0.05 year intervals. All solutions are available electronically.

THE IERS CONVENTIONS

The IERS uses the following conventions:

1. The International Celestial and Terrestrial Reference Systems

The International Celestial and Terrestrial Reference Systems (respectively ICRS, ITRS) are defined by their origins, directions of axes and, in the case of the ITRS, length unit. 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 micro-arcseconds. They are aligned with those of the FK5 within the consistency of the latter (± 80 milliarcseconds at epoch J1991.25 (van Leeuwen et al., 1997)). The ICRS is realized by estimates of the coordinates of a set of extragalactic sources: the International Celestial Reference Frame (ICRF) (Ma and Feissel, 1997; Ma et al., 1998). According to Resolution B2 of the International Astronomical Union (IAU) 23rd General Assembly (Kyoto, 1998), after 1 January 1998 the IAU celestial reference system is the International Celestial Reference System (ICRS) as defined by the International Earth Rotation Service (IERS) and the corresponding fundamental reference frame is the ICRF constructed by the IAU Working Group on Reference Frames. The IERS was asked to monitor the maintenance of the ICRS and its ties to the reference frames at other wavelengths. In the present IERS structure, two groups share this task: the International VLBI Service for Geodesy and Astrometry (IVS) and the IERS ICRS Centre, which is jointly operated by the Paris Observatory and the U.S. Naval Observatory.

The ITRS origin is at the center of mass of the entire Earth system, including the oceans and the atmosphere. Its length unit is the metre (SI), consistent with the TCG time coordinate for a geocentric local frame. The orientation of its axes is consistent with that of the BIH System at 1984.0 within ± 3 milli-arcseconds. The

International Reference Meridian (IRM) is implicitly defined through the adoption of the set of coordinates of stations realizing the ITRF.

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). For more details, see the IERS Conventions (McCarthy, 1996). A new ITRF realization (ITRF2005) is now available (Altamimi et al., 2007).

2. IERS constants and models

The IERS Conventions (McCarthy, 1996) are a set of constants and models used by the IERS Technique and Analysis Centres for Very Long Baseline Interferometry (VLBI), Global Positioning System (GPS), satellite radio positioning (DORIS), Satellite Laser Ranging (SLR), and by the IERS Product Centres in the combination of results.

The values of the constants are adopted from recent analyses. In some cases, they differ from the current IAU and International Association of Geodesy conventional ones. The models are, in general, the best estimates of the specialists in the field. The IERS Earth Orientation Parameters (EOP) describe the rotation of the ITRS relative to the ICRS, in conjunction with the conventional precession nutation model.

THE EARTH ORIENTATION PARAMETERS, CURRENT DEFINITION

According resolution B1.7 Definition of Celestial Intermediate Pole adopted at the 24th general assembly (Manchester, August 2000)

1. The Celestial Intermediate Pole (CIP) is the pole of reference. Its motion is specified in the Geocentric Celestial Reference System (GCRS, see Resolution B1.3) by motion of the Tisserand mean axis of the Earth with periods greater than two days,
2. The direction of the CIP at J2000.0 is offset from the direction of the pole of the GCRS in a manner consistent with the IAU 2000A (see Resolution B1.6) precession-nutation model,
3. The motion of the CIP in the GCRS is realised by the IAU 2000 A model for precession and forced nutation for periods greater than two days plus additional time-dependent corrections provided by the International Earth Rotation Service (IERS) through appropriate astro-geodetic observations,
4. The motion of the CIP in the International Terrestrial Reference System (ITRS) is provided by the IERS through appropriate astro-geodetic observations and models including high-frequency variations,
5. For highest precision, corrections to the models for the motion of the CIP in the ITRS may be estimated using procedures specified by the IERS

Notes

The forced nutations with periods less than two days are included in the model for the motion of the CIP in the ITRS. The Tisserand mean axis of the Earth corresponds to the mean surface geographic axis, quoted B axis, in Seidelmann, 1982, Celest. Mech. 27, 79-106. As a consequence of this resolution, the Celestial Ephemeris Pole is no longer necessary.

The x-axis is in the direction of the IERS Reference Meridian (IRM), the y-axis is in the direction 90 degrees West longitude.

2. UT1 is the rotation angle about the pole. It 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 International Reference Meridian (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 calculated by the BIPM. Its unit interval is exactly one SI second at mean sea level. The origin of TAI is such that UT1–TAI was approximately 0 on 1 January 1958. The instability of TAI is about six orders of magnitude smaller than that of UT1.

UTC is defined by the International Radio Consultative Committee (CCIR) Recommendation 460-4 (CCIR, 1986). It differs from TAI by an integral number of seconds in such a way that UT1–UTC remains smaller than 0.9s in absolute value. The decision to introduce a leap second in UTC to meet this condition is the responsibility of the IERS; it is announced in Bulletin C. According to the CCIR Recommendation, first preference is given to opportunities at the end of June and December 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.

DUT1 is the difference UT1–UTC expressed with a precision of ± 0.1 s; it is broadcast with the time signals and announced in Bulletin D. The changes in DUT1 are decided by the IERS.

The difference between the astronomically determined duration of the mean solar day (D) and 86400s of TAI, is called the excess of the length of day (LOD). Its relationship with the angular velocity of the Earth, Omega, is at the first order:

$$\text{Omega} = 72\,921\,151.467064 - 0.843994803 D, \text{ where Omega is in picoradians/s and D in ms.}$$

UT1, hence D and Omega, are subject to variations due to zonal tides. The model, which is a part of the IERS Conventions, includes 62 periodic components with periods ranging from 5.6 days to 18.6 years. UT1R, DR, and OmegaR are the values of UT1, D, and Omega corrected for the short-term part of the model by Yoder et al. (1981), i.e., the 41 components with periods under 35 days. In absolute value UT1R–UT1 is smaller than 2.5 ms, LODR–LOD is smaller than 1 ms. As recommended in IERS Gazette #13 (McCarthy and Gambis, 1997), IERS Earth orientation data are produced at daily intervals and do not include the effects of semidiurnal and diurnal variations. These effects mainly result from ocean tides. The corresponding model adopted by the IERS used for interpolation is Ray's model (Ray et al., 1994). The corresponding numerical program is available from either Centre's ftp site; see McCarthy and Gambis (1997) for details.

3. Precession-nutation is referred to CIP that exhibits, by definition, only long-periodic motions with periods of two days and longer in space. The IERS is now publishing the celestial pole offsets δX_{2000} and δY_{2000} referred to the new model IAU 2000 following the new formalism and the quantity s . Classical nutation angles, the celestial pole offsets in longitude and obliquity ($\delta \Delta \psi_{2000}$, $\delta \Delta \epsilon_{2000}$), respectively, referred to the new model can be easily derived from (δX_{2000} , δY_{2000}) using equations 23 in Chapter 5 of the IERS Conventions 2000 or the relative Fortran subroutine dXdY_dpsideps included in the package, uai2000.package (see next paragraph for its availability). These values δX and δY are now smaller than 1 mas, reflecting mostly the effect of the Free Core Nutation (FCN) that is not predictable and therefore not incorporated into the new model. The position of the CEO, given by s , is insensitive to any small change of the precession-nutation at the level of one mas, so only its model values are to be used (<http://maia.usno.navy.mil/ch5tables.html>). In parallel with these values, the values of the 'classical' celestial pole offsets $\delta \Delta \psi_{1980}$ and $\delta \Delta \epsilon_{1980}$ referred to the old IAU 1980 Nutation model and the IERS 1996 Precession/Nutation Theory are also being published for a limited period in Bulletin A, Bulletin B.,

Polar motion

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

$$s' = -47 \mu\text{as} (t - 51544.5) / 36525 \text{ where } t \text{ is expressed in modified Julian days (MJD).}$$

Universal Time

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

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

Availability of products and models

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

- Web:
http://hpiers.obspm.fr/eoppc/bul/bulb_new/
- anonymous ftp: hpiers.obspm.fr
files : / eoppc/bul/bulb_new/

Fortran subroutines

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

- Web page:
<http://hpiers.obspm.fr/eop-pc/models/models.html#software>
- Files:
 - <ftp://hpiers.obspm.fr/eop-pc/models/uai2000.package>
 - <ftp://hpiers.obspm.fr/eop-pc/models/uai2000.package.readme>
- anonymous ftp: hpiers.obspm.fr
files : /eop-pc/models/uai2000.package
/eop-pc/models/uai2000.package.readme

2) Interpolation of Polar Motion at hourly scale

- Web: <http://hpiers.obspm.fr/eop-pc/models/models.html#software>
- Files:
 - <ftp://hpiers.obspm.fr/eop-pc/models/interp.f>
 - <ftp://hpiers.obspm.fr/eop-pc/models/interp.readme>

THE DATA ANALYSIS

The data analysis that yields the values of the EOP published in Bulletins B includes several steps that are summarized below.

1. The individual Technique Centres are coordinating the observations made using the VLBI, SLR, GPS, and DORIS networks.
2. Analyses (operational and refined) by the Analysis Centres of the Technique Centres. The operational results are transmitted in parallel to the IERS Rapid Service/Prediction Centre to contribute to Bulletin A and to the IERS Earth Orientation Centre to contribute to Bulletin B. The operational results are also archived at each centre.

3. The IERS Rapid Service/Prediction Centre performs additional data processing on operational results. The IGS GPS satellite orbit data are used to estimate a GPS UT1-like quantity, and atmospheric angular momentum (AAM) analysis and forecast data from NOAA and from IERS global geophysical fluid center's special bureau of the atmosphere are used to estimate an AAM UT1-like quantity.

4. Determination of EOP by the IERS Earth Orientation Centre is in the form of combined solutions derived combined series issued as far as possible by technique centers. In the procedure systematic corrections and statistical weighting are applied. The results are published in Bulletin B with a sliding delay of thirty days between the date of publication and the last date of the solution.

CONTENTS OF BULLETIN B.

Section 1: Daily final values at 0:00 UT of pole components, UT1–UTC as well as *dX* and *dY* based on a combination of the series and their uncertainties. These series are very slightly smoothed in order to remove the high frequency noise. Values are held fixed. The time span extends from the past to one month back. The series is extended by preliminary values. Units are mas for pole components and nutation and ms for UT1–UTC.

Section 2: Daily values at 0:00 UT of celestial pole offsets $\delta\Delta\psi$ and $\delta\Delta\epsilon$ relatively to IAU 1980 and their uncertainties. Unit is the mas.

Section 3: Earth Angular velocity, daily estimates of LOD, OMEGA with their uncertainties

Section 4: Information on the time scales and announcement of occurring leap seconds.

Section 5: Average formal precision of the individual and combined series contributing or not to the combination and their agreement with the combination in term of WRMS over the time span given over Section 1.

INDIVIDUAL SERIES CONTRIBUTING TO IERS BULLETIN B, JANUARY 2008

Table 1 gives the estimated accuracy with respect to IERS 05C04 of these series over 2007-2008 after removal of systematic variations, mainly a bias. The data sets are labeled as follows: EOP(AAAAA)XX T YY
 AAAAA= acronym of the institute producing the results (two to five letters)

XX= year–1900 when the data set was computed

T= the observing technique

R	:	Radio interferometry	D	:	Satellite Doppler tracking
A	:	Optical astrometry	C	:	Combination of techniques
P	:	Global Positioning System	M	:	Lunar laser ranging
L	:	Satellite laser ranging			

YY= serial number of the data set in the year XX, for the technique T and the institute AAAAA.

Table 1: Estimated accuracies of individual solutions entering and/or compared in the combined solutions in 2007-2008.

Individual solutions				Estimated uncertainties			
				Time	Terrestrial Pole μas	UT1 μs	LOD μs
VLBI - 24 h							
EOP (AUS)	01	R 01	3-4d	204	-	222	
EOP (BKG)	03	R 02	1-4d	105	7.0	129	
EOP (GSFC)	07	R 01	1-4d	135	5.7	86	
EOP (IAA)	05	R 02	1-4d	107	6.0	118	
EOP (MAO)	03	R 01	1-4d	99	7.0	152	
EOP (OPA)	07	R 01	1-4d	86	6.2	60	
EOP (SPBU)	05	R 01	1-4d	260	6.8	118	
EOP (USNO)	06	R 02	1-4d	95	5.8	86	
EOP(IVS)	02	R 01	1-4d	100	5.4	96	

VLBI - Intensive						
EOP (BKG)	03	R	02	1-3 d	12.4	
EOP (GSFC)	06	R	01	1-3 d	11.3	
EOP (IAA)	05	R	01	1-3 d	13.0	
EOP (SPBU)	05	R	01	1-3 d	14.3	
EOP (USNO)	05	R	01	1-3 d	13.1	
Satellite Laser Tracking						
EOP (ASI)	03	L	02	1d	220	54.1
EOP (IAA)	02	L	01	1d	169	31.4
EOP (MCC)	97	L	01	1d	147	-
EOP (OCA)	05	L	01	1d	133	-
EOP (ILRS)	05	L	01	1d	66	17
GPS						
EOP (CODE)	98	P	01	1d	35	14.1
EOP (EMR)	96	P	03	1d	55	17.8
EOP (ESOC)	96	P	01	1d	50	36.3
EOP (GFZ)	96	P	02	1d	40	16.3
EOP (IAA)	01	P	01	1d	190	30.1
EOP (JPL)	96	P	03	1d	76	116.3
EOP (NOAA)	96	P	01	1d	75	15.9
EOP (SIO)	96	P	01	1d	47	17.9
EOP (USNO)	03	P	01	1d	-	23.0
EOP (IGS)	07	P	01	1d	19	9.5
EOP (IGS)	96	P	02	1d	39	10.0

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

DISTRIBUTION OF THE PUBLICATIONS

IERS Earth Orientation Centre, at Paris Observatory:

- e-mail (contact: services.iers@obspm.fr)
- World Wide Web (<http://hpiers.obspm.fr/eop-pc/>)
- Anonymous ftp (hpiers.obspm.fr or 145.238.100.28)

BULLETIN B

ftp://hpiers.obspm.fr/iers/bul/bulb_new/bulletinb.dat

<http://hpiers.obspm.fr/eop-pc/>

Daniel Gambis and Christian Bizouard
IERS Earth Orientation Centre
daniel.gambis@obspm.fr
Christian.bizouard@obspm.fr

GLOSSARY

BIH	Bureau International de l'Heure
BIPM	Bureau International des Poids et Mesures
BKG	Bundesamt fuer kartographie und geodaesie
CEP	Celestial Ephemeris Pole
CCIR	International Radio Consultative Committee
CIO	Conventional International Origin
CODE	Center for Orbit Determination in Europe
CGS	Space Geodesy Center, Matera
CSR	Center for Space Research, University of Texas
DORIS	Doppler Orbit determination and Radiopositioning Integrate on Satellite
DUT	Delft University of Technology
EMR	See NRCan
EOP	Earth Orientation Parameters
ESOC	European Space Operations Center
GFZ	GeoForschungsZentrum
GMST	Greenwich Mean Sidereal Time
GPS	Global Positioning System
GSFC	Goddard Space Flight Center
IAA	Institute of Applied Astronomy
IAG	International Association of Geodesy
IAU	International Astronomical Union
IERS	International Earth Rotation Service
ICRF	IERS Celestial Reference Frame
ICRS	International Celestial Reference System
IDS	International DORIS Service
IGS	International GNSS Service
ILRS	International Laser Ranging Service
IRP	IERS Reference Pole
IRM	IERS Reference Meridian
ITRF	IERS Terrestrial Reference Frame
ITRS	International Terrestrial Reference System
IVS	International VLBI Service
JPL	Jet Propulsion Laboratory
LLR	Lunar Laser Ranging
LOD	Length of day
LODR	Length of day corrected from zonal tides effects
MCC	Russian Mission Control Center
MJD	Modified Julian Day
NEOS	National Earth Orientation Service
NOAA	National Oceanic and Atmospheric Administration
NRCan	Natural Resources Canada, formerly EMR
OPA	Observatoire de Paris
SPBU	St Petersburg University
SLR	Satellite Laser Ranging
SI	Système International
SIO	Scripps Institution of Oceanography
TAI	Temps Atomique International
TCG	Geocentric Coordinate Time
TT	Terrestrial Time
USNO	United States Naval Observatory
UT1	Universal time
UT1R	Universal time corrected for the effect of zonal tides
UTC	Coordinated Universal Time
VLBI	Very Long Baseline Interferometry

REFERENCES

- Aoki, S., Guinot, B., Kaplan, G.H., Kinoshita, H., McCarthy, D.D., Seidelmann, P.K., 1982: *Astron. Astrophys.*, 105, 1.
- Altamimi, Z., Collilieux X., Legrand J., Garayt B., and C. Boucher (2007). ITRF2005: A new release of the International Terrestrial Reference Frame based on time series of station positions and Earth Orientation Parameters, *J. Geophys. Res.*, 112, B09401, doi: 10.1029/2007JB004949
- Arias, F., Charlot, P., Feissel, M. and Lestrade, J.-F., 1995: *Astron. Astrophys.*, 303, 604.
- Bizouard C and D. Gambis, 2009, the combined solution C04 for Earth Orientation Parameters, recent improvements, Springer Verlag series, Series International Association of Geodesy Symposia , Vol. 134 Drewes, Hermann (Ed.), 330 p., ISBN: 978-3-642-00859-7
- CCIR, 1986: Recommendation and Reports of the CCIR, *16th Plenary Assembly (Dubrovnik), International Telecommunications Union, 12, 7*, Geneva.
- Lambert S. and Bizouard, C., 2002: Positioning the Terrestrial Ephemeris Origin in the International Terrestrial Reference Frame, *Astron. Astrophys.* 394, 317-321.
- Ma C., Arias, E.F., Eubanks, T.M., Fey, A.L., Gontier, A.M. , Jacobs, C.S., Sovers, O.J., Archinal, B.A., Charlot, P., 1998: The International Celestial Reference Frame as realized by Very Long Baseline Interferometry, *Astron. J.*, 116, 516.
- Ma, C. and Feissel, M., 1997: Definition and realization of the International Celestial Reference System by VLBI Astrometry of Extragalactic Objects, *IERS Technical Note No. 23*, Observatoire de Paris.
- McCarthy, D.D. (ed.), 2003: IERS Conventions (2000), *IERS Technical Note, in preparation*.
- McCarthy, D.D. and D. Gambis, 1997: Interpolating IERS Earth Orientation Data, *IERS Gazette No. 13*, at <http://maia.usno.navy.mil/iers-gaz13>.
- Ray, R.D., Steinberg, D.J., Chao, B.F. and Cartwright, D.E., 1994, Diurnal and Semidiurnal Variations in the Earth's Rotation Rate Induced by Oceanic Tides, *Science*, 264, 5160, p830.
- Seidelmann, P.K., 1982: *Celest. Mech.*, 27, 79.

