3.5 Product Centres
3.5.1 Earth Orientation Centre

This section presents activities and main results concerning the Earth Orientation Centre located at Paris Observatory over 2006. The main activities of the IERS Earth Orientation Parameters (EOP), operational activities and long analyses are presented at the web site <http://hpiers.obspm.fr/eop-pc>. According to the IERS Terms of Reference, the Earth Orientation Centre is responsible for monitoring Earth Orientation Parameters including long term consistency, publications for time dissemination and leap second announcements. The Earth Orientation Centre is making available different products to a broad community of users: long-term and operational series of Polar motion, Universal Time (UT1), Length of Day (LOD) and Celestial pole offsets.

Determination of EOP is in the form of combined solutions derived by the analysis centers of the different techniques. Various solutions are computed: long-term solution (IERS C01), normal values at five-day intervals (IERS C02) and the operational smoothed solution Bulletin B at one-day intervals published monthly and providing EOP with a delay of 30 days with respect to the date of publication. Bulletin B is updated in the operational C04. So far Earth Orientation Parameters and the terrestrial frame were separately computed. This leads to increasing inconsistencies between both of them. On January 2005, these inconsistencies were at the level of 300 microarcseconds for polar motion. In order to improve consistency between both systems, the Bulletin B and C04 were recomputed and aligned to the EOP solution associated to the ITRF2005 (Altamimi et al., 2007). By the way, the procedure leading to the combined solutions was upgraded.

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

It has been necessary to re-align the solution to improve its consistency with respect to the new realization of the ITRF, i.e. ITRF2005 (Altamimi et al., 2007).

Due to the separate determination of both celestial and terrestrial reference frames and EOP, there has been a slow degradation of the overall consistency and discrepancies at the level of 300 micoarseconds were present at 2004.0 between the current IERS C04 and the ITRF realization (Gambis, 2004). We have taken this opportunity to upgrade the numerical combination procedure; the improvements concern in particular routines, table dimensions and the generalization of double precisions. Using the combined polar motion solution associated with the newly released International Terrestrial Reference Frame 2005 (ITRF 2005), we produce a better solution mainly based on the time series derived by technique centers, i.e. IGS, IVS and ILRS. In addition formal errors associ-

Table 1: Estimated accuracies of individual solutions compared to the combined solutions Bulletin and 05 C04 over 2006–2007.

Individual solutions		Estimated uncertainties				
		Time	Terrestrial Pole in 0.001"	UT1 in 0.0001s	LOD	Celestial Pole in 0.001"
VLBI – 24 h						
EOP (AUS)	1 R 1	3–4d	0.176	0.066		0.081
EOP (BKG)	3 R 4	1–4d	0.160	0.066		0.088
EOP (GSFC)	4 R 2	1–4d	0.152	0.059		0.076
EOP (IAA)	5 R 2	1–4d	0.177	0.066		0.083
EOP (MAO)	3 R 1	1–4d	0.166	0.081		0.108
EOP (SPBU)	3 R 3	3–4d	0.320	0.098		0.092
EOP (USNO)	6 R 1	1–4d	0.161	0.063		0.063
VLBI – Intensive						
EOP (BKG)	3 R 2	1–3 d		0.263		
EOP (GSFC)	4 R 1	1–3 d		0.257		
EOP (IAA)	5 R 1	1–3 d		0.266		
EOP (SPBU)	2 R 1	1–3 d		0.130		
EOP (USNO)	5 R 1	1–3 d		0.300		
SLR						
EOP (ASI)	3 L 2	1d	0.272		0.60	
EOP (IAA)	2 L 1	1d	0.219		0.40	
EOP (MCC)	97 L 1	1d	0.291			
EOP (OCA)	5 L 1	1d	0.236			
GPS						
EOP (CODE)	98 P 1	1d	0.060		0.34	
EOP (EMR)	96 P 3	1d	0.198		0.31	
EOP (ESOC)	96 P 1	1d	0.078		0.48	
EOP (GFZ)	96 P 2	1d	0.059		0.38	
EOP (SIO)	96 P 1	1d	0.164		0.30	
EOP (JPL)	96 P 3	1d	0.091		0.33	
EOP (NOAA)	96 P 1	1d	0.140		0.31	

** The satellite techniques provide information on the rate of change of Universal Time contaminated by effects due to non modelled orbit node motion.*

ated to EOPs are available. EOP series have been reprocessed since 1984. Pole coordinates are now fully consistent with ITRF2005. The nutation offsets and UT1 are made consistent with the International Celestial Reference Frame (ICRF) through the IVS combined solution. Tables 1 to 4 give statistics concerning the analyses of Bulletin B and EOP series 05C04. A detailed description of the new solution can be found in the Technical Note available at <http://hpiers.obspm.fr/iers/eop/eopc04_05/C04_05.guide.pdf>.

Table 2: Uncertainty of the current solution of Bulletin B and the estimated accuracies of the predictions for horizons of 5 days to 1 year for 2006–2007.

Solutions		Terrestrial Pole mas	UT1 ms	Celestial Pole mas
Analysis daily	1-d	.004	.006	0.10
Prediction	1-d	.50	.18	0.10
	5-d	2	.60	0.10
	10d	4	1.40	0.10
	30d	12	5.	0.10
	90d	50	30.	0.10
	180d	60	70.	0.10
	1-yr	76	140.	0.10

Table 3: Mean and standard deviation in microarcsecond of the differences between various combined techniques solutions and IERS 05C04 over 2006–2007.

EOP	IGS Comb – IERS 05C04		ILRS Comb – IERS 05C04		IVS Comb – IERS 05C04	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
X (μas)	3	21	–133	166	–39	91
Y (μas)	–60	19	–118	156	8	114
UT1 (μs)	9	28			4	6.6
LOD (μs)	0	11	22	54		
Dψsinε (μas)					5	50
Dε (μas)					–4	51

Table 4: Mean and standard deviation for Pole components and UT1 of the differences between various solutions and Bulletin B over 2007.

EOP	Unit	Bull A – Bull B		Comb JPL – Bull B	
		Mean	Standard deviation	Mean	Standard deviation
X	μas	–30	32	–109	37
Y	μas	–20	30	–38	15
UT1	μs	3	8	4	10

Long-term series: C 01 (1846–2006)

EOP(IERS) C 01 is a series of the Earth Orientation Parameters given at 0.1 year intervals from 1846 to 1889 (polar motion only) and 0.05 year intervals 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 2003. It is a composite series based on following temporal solutions:

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

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

1962–2006: 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 performing the transformation between both terrestrial and celestial frames via the Earth Orientation Parameters. Gravity field models include the tesseral coefficients C21 and S21. These terms describe the position of the Earth's figure axis with respect to the Terrestrial Reference Frame. This axis should coincide with the observed position of the rotation pole averaged over the same time period.

The mean polar motion is affected by a long-term drift westward (direction 70.7 deg West, rate: 4.2 mas/yr). The mean rotation axis with respect to the IERS Terrestrial Reference Frame can be considered as the long-term trend obtained after filtering out the Chandler and seasonal terms, every year from 1900 to 2006 (Shiskin *et al.*, 1965). Figure 1 represents the polar motion over 2001–2006 and the path of the mean pole since 1900. The table is available in IERS Conventions 2003 (McCarthy and Petit, 2004) and at <http://hpiers.obspm.fr/eop-pc/>.

Normal Point Solutions: C 02 (1962–2006)

Other series, based on normal points solutions given at various time intervals, are also proposed to users, i.e. C 02 (5-day intervals, polar motion, UT1–UTC, $d\psi$, $d\varepsilon$), C 03 (one-day intervals, polar motion, UT1–UTC) (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

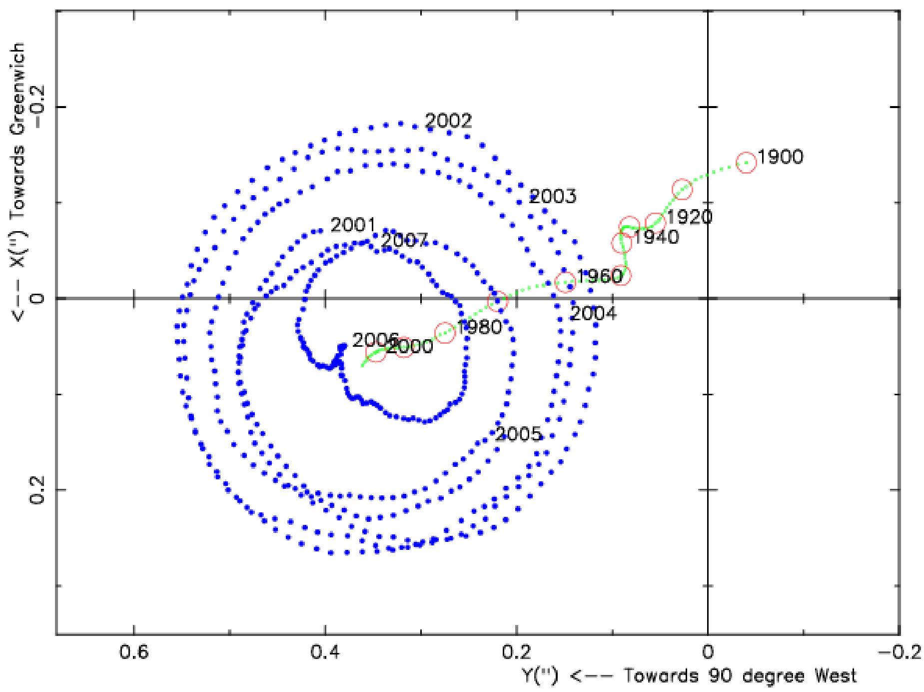

Fig. 1: Mean polar motion (1900–2010) and IERS C04 polhody over 2001–2007.

series C 02 and C 03 in which the estimation of the solution given at the central dates of the n-day interval is made using a least-square fit for all EOP components. Although the L2 estimation has been extensively used for data analysis, it has some drawbacks linked to problems of ill-conditioning and in the non-detection of outliers. Alternative methods based on robust estimators like M-Huber can be used. These estimators are a generalization of both the L1 and L2 class. They have been implemented in our analyses and are now currently used (Bougeard *et al*, 2000). Table 5 reflects the evolution of the mean uncertainties of C02 solution since 1962.

Evaluation of EOP derived from a simultaneous combination of TRF and EOPs

Although the current determination of reference frames and EOP temporal series are derived from the same software, rigorous approaches for simultaneously determining reference frames and EOP are not currently applied. This is however a more satisfactory approach to ensure a better consistency. Different approaches are currently being developed within the IERS (Altamimi et al. 2005). The first approach is based on combination at the observation-equation level. Anderson (1995) has developed a software package, called GEOSAT, for the combined analysis of VLBI, GPS, SLR and other types of satellite tracking data (e.g., GLONASS, DORIS, Precise Range And Range-rate Estimation (PRARE) and satellite radar altimetry). Here, the observations are combined at the observation-equation level with a consistent model and consistent analysis strat-

Table 5: EOP(IERS) C 02: Evolution of the mean 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(δψ) 0.001"	σ(δε) 0.001"
1962–1967	30	30	20	–	–
1968–1971	25	25	17	–	–
1972–1979	11	11	10	–	
1980–1983	2	2	3	2	1
1984–1989	.40	.40	.20	.5	.2
1990–2000	.20	.20	.20	.3	.1
2001–2006	.06	.06	.11	.09	.07

egies. In another project (Yaya, 2001; Biancale et al. 2002), the observations of the different techniques (VLBI, SLR, LLR, DORIS and GPS) are processed separately by the same single software package: GINS/DYNAMO, which has been developed at the GRGS (Groupe de Recherches de Géodésie Spatiale) since 1962. Here, the normal matrices are stacked to derive both the terrestrial frame and EOP. With this approach, it is essential that the results be optimal for the different techniques before a global solution be performed.

The project started in January 2005. Now the analyses are performed on an operational basis. For each individual technique, the processing of data is performed at different locations: GPS at CLS, Toulouse (S. Loyer), Doris at CLS, Toulouse (L. Soudarin), SLR at Cerga, Grasse (P. Bério), LLR at CNES, Toulouse (R. Biancale) and at the Observatoire de Paris (G. Francou), VLBI at CNES, Toulouse (R. Biancale) and at the Observatoire de Bordeaux (G. Bourda, P. Charlot). The final combinaison as well as the validation and various analyses are performed at the Observatoire de Paris (Gambis et al., 2006).

Staff

Gambis	Daniel,	Astronomer, Head
Bizouard	Christian,	Astronomer
Francou	Gérard,	Astronomer
Carlucci	Teddy,	Engineer
Richard	J. Yves,	Engineer (since November 2007)
Becker	Olivier,	Engineer (since November 2007)
Saïl	Morad,	Engineer (until December 2007)
Bougeard	Mireille,	Mathematician
Baudoin	Pascale,	Secretary

References

Altamimi Z., Boucher C., Gambis D., 2005: Long-term Stability of the Terrestrial Reference Frame, *Adv. Space Res.* 33(6): 342–349, DOI: 10.1016/j.asr.2005.03.068.

Altamimi, Z., Collilieux X., Legrand J., Garayt B., Boucher, C., 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.

Anderson P.H., 1995, *High-precision station positioning and satellite orbit determination*. Ph.D. Thesis, NDRE/publication-95/01094, FFI/ E, Box 25, N-2007, Kjeller, Norway.

Biancale, R., Lemoine, J.-M., Marty, J.-C., Capitaine, N., Gambis, D., Gontier, A.-M., Chapront, J., Francou, G., Exertier, P., Coulot, D., Soudarin, L., Yaya, Ph., Charlot, P., 2002: GRGS activities on space technique combinations for the adjustment of Earth Orientation Parameters, presented at IERS Workshop, November 2002, Munich, Germany.

Bougeard, M., Gambis, D., Ray, R., 2000: Algorithms for box constrained M-estimation: fitting large data sets with applications to Earth Orientation Parameters series, *Physics and Chemistry of the Earth* 25, 9–11, pp. 679–685.

Fedorov, E.P., Korsun, A.A., Mayor, S.P., Pantscheenko, N.I., Tarady, V.K., Yatskiv, YA. S., 1972: *Dvizhenie polyusa Zemli s 1890.0 po 1969.0.* Naukova dumka, Kiev (English translation of the text available).

Gambis, D., 1997: Monitoring Earth Rotation using various techniques: current results and future prospects, *Dynamics and astrometry of natural and artificial celestial bodies, proceedings of IAU Colloquium 165*, I.M. Wytrzyszczak, J.H. Lieske, R.A. Feldman (eds.), Kluwer, Dordrecht, p. 475.

Gambis, D., 2004: Monitoring Earth Orientation at the IERS using space-geodetic observations., *J. of Geodesy* 78, pp. 295–303.

Gambis, D., 2005: Earth Orientation Monitoring, State-of-the-art and prospects, *Artificial Satellites, Journal of Planetary Geodesy* 40, 1, part 3, Earth rotation, pp. 61–69.

Gambis, D., Wooden, W., 2006: *Explanatory Supplement for Bulletins A and B*, Observatoire de Paris, also available by electronic access (<http://hpiers.obspm.fr/eop-pc>).

Gambis, D., Biancale, R., Carlucci, T., Lemoine, J.M., Marty, J.C., Altamimi, Z., Bério, P., Bourda G., Charlot, P., Loyer, S., Soudarin, L., 2006: Global combination of a terrestrial frame and Earth Orientation Parameters at the observation level, EGU General Assembly, Vienne, Austria, 2–7 April 2006, *Geophys. Res. Abs.*, Vol. 8.

McCarthy, D.D., Petit, G. (eds.), 2004: *IERS Conventions (2003)*, BKG, Frankfurt am Main (*IERS Technical Note* No. 32; Website: <http://tai.bipm.org/iers/conv2003/conv2003.html>).

Rothacher, M., 2002: Future IERS products, Implementation of the IAU 2000 resolutions, in: *Proceedings of the IERS Workshop on the Implementation of the New IAU Resolutions*, Observatoire de Paris, Paris, France, 18–19 April 2002, N. Capitaine et al. (eds.), BKG, Frankfurt am Main (*IERS Technical Note* No. 29), pp. 77–84 (Online: < http://www.iers.org/MainDisp.csl?pid=46-25773>).

Shiskin, J., Young, A.H., Musgrave J.C., 1965: *The X-11 variant of the Census Method II seasonal adjustment program*, U.S. Dept. of Commerce, Bureau of the Census *(Technical Paper No 15).*

Vondrak J., Ron C., Pesek I., Cepek A., 1995: New global solution of Earth orientation parameters from optical astrometry in 1900–1990, *Astron. Astrophys*. 297, 899–906.

Yaya, P., 2001: PhD Thesis, Paris Observatory.

Daniel Gambis, Christian Bizouard,Gérard Francou,
Teddy Carlucci, Najat Essaïfi, Morad Saïl,
Mireille Bougeard, Pascale Baudouin