MONITORING EARTH ORIENTATION USING VARIOUS TECHNIQUES: CURRENT RESULTS AND FUTURE PROSPECTS

D. GAMBIS
IERS/CB, Observatoire de Paris
Paris, France

Abstract. Until 1972, astrometry based on a network of optical instruments was the only technique able to monitor the Earth orientation (polar motion, Universal Time and nutation). Since various techniques have shown their capability to give all or a part of these parameters: Doppler observations of navigation satellites, laser ranging to the Moon and to dedicated artificial satellites, Very Long Baseline Interferometry (VLBI) and more recently GPS and DORIS. The different Earth Orientation Parameters (EOP) series obtained by the individual techniques are inhomogeneous in time span, quality, time resolution – which supports the concept of combined solutions taking advantage of the various contributions.

The main task of IERS is the maintenance of both a conventional terrestrial reference system based on observing stations and a conventional celestial reference system based on extragalactic radio sources and also the matrix product allowing the transformation between these two systems which takes into account precession-nutation, polar motion and Earth rotation.

The objective of this paper is to present the evolution, the state of the art and future prospectives concerning the multi-technique EOP combined solution made at IERS/CB.

Abbreviations: EOP – Earth Orientation Parameters; IERS/CB – Central Bureau of the International Earth Rotation Service

1. Introduction

International programs of observation and analysis of the Earth rotation variations were initiated by astronomers and geodesists, at the end of the last century with the International Latitude Service (ILS, 1899) and at the

I. M. Wytrzyszczak, J. H. Lieske and R. A. Feldman (eds.),
Dynamics and Astrometry of Natural and Artificial Celestial Bodies, 475, 1997.

beginning of this century, with the Bureau International de l'Heure, (BIH, 1912). These scientific services continuously evolved and enlarged the scope of their activity, following the progress of observing techniques and the understanding of the phenomena involved. The International Earth Rotation Service (IERS) was created in 1988 by the International Union of Geodesy and Geophysics (IUGG) and the International Astronomical Union (IAU). It is in charge of providing basic references to the international scientific community. It plays a key role in the coordination of the observations and of their analyses, setting up and making available the indispensable basic references to the scientific community (Feissel and Gambis, 1993). It maintains a terrestrial reference frame and a celestial reference frame, and it monitors the Earth Orientation Parameters (EOP), which relate the two frames as a function of time. It also contributes to different scientific fields such as space astrometry, space navigation and geophysics. The contributions of the observing techniques and the evolution of the accuracies obtained since 1900 are summarized in Table 1. Now, the global observing activity involves Very Long Baseline radio Interferometry (VLBI), Lunar Laser Ranging (LLR), Global Positioning System (GPS) and Satellite Laser Ranging (SLR) and more recently DORIS. For more details on the work of IERS see the Annual IERS Report for 1995 and the IERS technical notes.

2. Combination of EOP Series

The maintenance of the reference systems and its long-term stability require long and homogeneous EOP series. The realization of combined solutions series must take advantage of the qualities of the independent series at the various time scales. For practical reasons also linked to statistical applications, these series are given at equidistant intervals (1 day). They are assumed to contain no jump and negligible systematic errors; at least 3 independant techniques are thus highly desirable for that purpose. The contribution of these 3 techniques to geodynamics is important for their complementarity but also for some aspects linked to redundancy in order to eliminate systematic effects.

2.1. GENERAL COMBINATION PROCEDURE

The first step in the general procedure for deriving the IERS/CB multi-technique combined solution is the evaluation for each solution of the correction of systematic errors, bias and drift in order to translate it into the IERS system. A known source of relative drifts in x, y and UT1−UTC is the variety of processes chosen by the analysis centres to control the time evolution of the adjusted terrestrial reference frames, complicated by the sampling of the tectonic plates and plate margins by the actual observing

TABLE 1. Evolution of the contribution of the various techniques to the Earth Orientation Parameters determination. The numbers of * roughly reflect the level of contribution (precision and density of measurements).
PM : polar motion (x, y)
CP : celestial pole coordinates ($d\psi \sin\epsilon$, $d\epsilon$)
UT : universal time UT1

Period		Opt.Astr.	LLR	Doppler	SLR	VLBI	GPS	resol.	Precision
1900-1961	PM	*						month	$0''.05$
1962-1971	PM	**						weeks	$0''.02$
	UT	**							$0^s.002$
1972-1979	PM	**		**				week	$0''.01$
	UT	**	**						$0^s.001$
1980-1983	PM				***			week	$0''.002$
	UT		*		*	**			$0^s.0004$
1984-1992	PM				**	**		days	$0''.0005$
	CP					****			$0''.0005$
	UT				*	***			$0^s.00005$
1992-1995	PM				***	***	***	day	$0''.0003$
	CP					****			$0''.0003$
	UT				*	***	*		$0^s.00003$

networks. The formal uncertainties estimated by the analysis centers being an internal consistency value, an external calibration has usually to be made in order to reflect the real uncertainty of the estimates. This is done using the Allan variance analysis (Gray and Allan, 1974) 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 can be considered to be 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, on which the weighting of the combined individual results is based. Consequently a scaling factor is given to the series. Weights of the series entering the combined solution are thus estimated. Table 2 gives the rough percentages of the contribution

https://doi.org/10.1017/S0252921100046972 Published online by Cambridge University Press

TABLE 2. Percentage of the contribution of the various techniques to the EOP combined solutions.

	VLBI	SLR	GPS
pole components	20	40	40
universal time	80	5	15
nutation offsets	100	0	0

TABLE 3. RMS agreement with the combined IERS/CB solution.

Series	x pole [mas]	y pole [mas]
GPS (IERS)	0.17	0.12
VLBI (USNO)	0.17	0.13
VLBI (IAA)	0.18	0.16
SLR (CSR)	0.18	0.18

of the various techniques to the combined solution for the different EOP parameters.

2.2. POLE COMPONENTS

The 3 main techniques (VLBI, SLR and GPS) have about the same contribution in the polar motion series, whereas for UT and celestial pole offsets the quasi-unique contributor is VLBI. Table 3 represents the RMS agreement of these series with the IERS/CB combined solution for both pole components. Note that these estimates are all smaller than 0.20 mas.

2.3. UNIVERSAL TIME

For Universal Time determination the situation is different since only VLBI techniques and in a smaller extent LLR, which has never achieved a routine data production, are inertial and able to give accurately long-term orientation of the Earth. Up to now, the IERS operational Universal Time solution is mainly based on VLBI series.

Due to the difficulty of determining the long-term behaviour of the non-rotating system realized through the orbit orientation, Universal Time

TABLE 4. RMS errors (in ms) of the Universal Time solution based on GPS and compared to prediction.

unit : 1 ms	1 week	2 weeks	3 weeks
usual prediction	1.15	4.05	7.20
GPS estimates	0.15	0.25	0.30

cannot be accurately derived from satellite techniques (SLR and GPS). Still, on time scales limited to a couple of months, errors are limited so that the high-frequency signal contained in the GPS UT determination can be used for densifying the series obtained by the VLBI technique (Gambis *et al.*, 1993) and also for UT extension from the last available current VLBI estimate (Gambis, 1996). In order to estimate the accuracy of the solution using this GPS UT estimates, series of simulation have been performed; results are shown on Table 4. The mean statistical error obtained, when GPS estimates are obtained are compared to prediction skill based on auto-regressive processes currently performed at IERS for routine predictions. As the table shows, a significant improvement is obtained.

3. Conclusion

Independent techniques are highly desirable to monitor the Earth rotation for their complementarity aspects but also partly for their redundancy allowing firstly to maintain permanently a reliable link between the primary reference frames, terrestrial and celestial and secondly to separate true geophysical signals from systematic fluctuations. This can be for instance illustrated by the 40–50 day oscillation which was only detected when other techniques than astrometry (Doppler tracking and Lunar laser ranging) began to contribute (Feissel and Gambis, 1980).

GPS is now the technique of choice for monitoring polar motion and high-frequency variations of UT1. For long-term variations of UT1 and nutation, VLBI techniques are still essential. Homogeneous polar motion SLR series, available since the launch of Lageos in 1976, bring also a significant contribution to the long-term stability of the IERS system. Although the internal UT1 series derived from GPS determinations are not directly usable for Earth Orientation monitoring, its high-frequency information can be used together with VLBI to derive a mixed solution which may be used both for scientific (densification) and for near real time applications from the last currently available VLBI estimate. In that case, the improvement of the solution is a factor 8 for 1 week and respectively 16 and 24 for 2 and 3 weeks compared to usual predictions based on VLBI data.

The evolution in the respective contribution of the observing techniques and the increasing temporal resolution and accuracies obtained by the techniques make it necessary to maintain and constantly improve the combination procedures. Mixing the temporal series in an optimal way is a permanent challenge.

In conclusion, understanding the multiple variations entangled in the Earth Orientation series requires continuous efforts in observation, theory and numerical modeling of astronomical, geodetic and of other atmospheric and oceanic processes.

References

Feissel, M. and Gambis, D.: 1980, "La mise en evidence de variations rapides de la durée du jour", *C. R. Acad. Sci. Paris, Serie B* **291**.

Feissel, M. and Gambis, D.: 1993, "The International Earth Rotation Service, current results for research on Earth rotation and reference frames", *Adv. Space Res.* **13**, 11, 143–150.

Gambis, D., Essaifi, N., Eisop, E., and Feissel, M.: 1993, "Universal Time derived from VLBI, SLR and GPS", *IERS Technical Note 16* (Dickey, M. Feissel, eds) **IV** 15–20.

Gambis, D.: 1996, "Multi-technique Earth orientation parameter combination", *IGS Annual Report for 1995*.

IERS 1996, *Annual Report for 1995*, Obs. de Paris.

Gray, J.E. and Allan, D.W.: 1974 "A method for estimating the frequency stability of an individual oscillator", *Proc. 8th Ann. Symp. on Frequency Control* **2439**, 277–287.