THE EFFECTS OF THE REFERENCE FRAMES AND OF THEIR REALIZATION ON THE EARTH ROTATION PARAMETERS COMPUTED FROM DIFFERENT OBSERVATIONAL TECHNIQUES

Nicole Capitaine and Martine Feissel
Bureau International de l'Heure
Paris
FRANCE

ABSTRACT

The inaccuracies in the reference frames actually realized by the different techniques for measuring the Earth's rotation are theoretically investigated. The intercomparison of the available series of measurements provides numerical estimations of these defects. Using data corrected for reference frame effects high frequency fluctuations of UT1 are detected.

INTRODUCTION

The present methods for measuring the Earth rotation parameters are based on the determination of the Earth's orientation in space by terrestrial observation of the position of celestial objects. The geometric relations appearing in the reduction of these observations depend, indeed, on the orientation (given through precession, nutation, polar motion and UT1) of a terrestrial frame denoted (x,y,z), in which the observing stations lie, with respect to the non-rotating one, denoted (X,Y,Z), in which celestial objects are fixed or have well known motions. This is true for classical optical astrometry and satellite tracking (by Doppler or laser measurements), lunar laser ranging and interferometry on radio sources. All these kinds of measurements are now used to determine the Earth rotation parameters (BIH, 1980).

Each method, using one kind of measurement, has its particular problems in realizing these conventional reference frames. The differences in their realization can give rise to fictitious differences between the Earth rotation parameters computed by the different methods.

E. M. Gaposchkin and B. Kołaczek (eds.), Reference Coordinate Systems for Earth Dynamics, 135–144.

The aim of this paper is, in Part 1, to investigate all the defects in realization of the above reference frames by each method and, in Part 2, to perform a numerical estimation of these defects by a comparison between the available series of Earth rotation parameters.

1. EXPECTED DIFFERENCES DUE TO THE REALIZATION OF THE REFERENCE FRAMES

The theoretical ideal frames (x,y,z) and (X,Y,Z) used for computing Earth rotation parameters are both rectangular Cartesian frames centered at the Earth's center of mass G and such that the z and x axes are respectively close to the mean position of the Earth's rotation axis and towards the conventional origin of longitude. The Z and X axes are respectively the Earth's rotation axis and an arbitrary line of the true equatorial plane. Each type of measurement used in the computation leads to a non-ideal realization of these frames that will be analyzed now.

1.1 Optical Astrometry

The observations give the components of the local vertical in the celestial reference frame adopted as (X,Y,Z) system. The Earth rotation parameters are derived from the observations by a net of stations and the terrestrial reference frame is then realized by a set of conventionally adopted astronomical latitudes and longitudes of the observing stations.

Because of the non-coincident directions of the vertical and the normal to the geodetic ellipsoid, the center of this terrestrial frame cannot be the Earth's center of mass.

Because of plate motion, local deformations and tidal effects, the astronomical coordinates of the stations are not constant. In order to avoid rotation of the terrestrial frame, the number of observing stations must be sufficient and their adopted coordinates must be regularly updated for tectonic motions and corrected for tidal periodic variations.

The non-rotating reference frame is given by the conventional positions and proper motions of the observed stars in a stellar catalog (which, due to observational constraints, is not always the most precise and accurate one) and by a model for the precession-nutation rotations. The celestial reference frame so realized inevitably reflects the errors in the star coordinates and proper motions as well as in the representation of the precession-nutation. The minimization of these perturbations can be obtained by some applied corrections, which are described by Feissel (1979).

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1.2 Satellite Tracking

The observations give the distance or line of sight velocity of the satellite with respect to a set of terrestrial stations and are used to compute an Earth-based orbit and the Earth rotation parameters. The terrestrial reference frame is then realized by a set of geodetic station coordinates. The variation of these coordinates due to global or local Earth's crustal motions is not actually taken into account in the Doppler and laser reductions, except for the tidal effect (Anderle, et al., 1975, Smith, 1980) and that can be a source of deformation of the (x,y,z) frame.

The effect of inaccuracies of the station coordinates is minimized by a high density and an uniform distribution of the observing stations. This terrestrial frame is centered at G and is referred neither to CIO nor to the conventional longitude. The bias so obtained in the Earth rotation parameters derived by this method have been minimized in the case of the Doppler results by a fitting to the BIH data at an initial date (Anderle, et al., 1975).

The non-rotating reference frame is the one in which the satellite orbit is computed from the observations using a theoretical model of forces and would be the true equatorial system at the date of the beginning of the observations. It is practically obtained after a few iterations and is very dependent on the imperfections of the model of forces (errors in the representation of the Earth's potential, atmospheric drag, solar radiation forces, no consideration of the oceanic and atmospheric tidal forces) and to a lesser extent on the precession and nutation representation. This is responsible for linear and periodic errors and possible discontinuities in the Earth rotation parameters derived by this method which are specific to a given satellite, and of the used theoretical model of forces.

1.3 Lunar Laser Ranging

Each observation gives a time of aberration corresponding to the distance between the reflector on the Moon and the terrestrial observing station. A lunar ephemeris in the celestial reference frame and the corresponding observational residuals are then computed from such observations, using a theoretical model of forces and of lunar rotation, and nominal values for the Earth's orientation in space; these residuals can then be used for computing corrections to some parameters, such as the geocentric coordinates of the station in an Earth-fixed reference frame and UT1-UTC (Calame, 1980).

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When several stations are operating, the terrestrial reference frame is realized by a set of geodetic station coordinates of great accuracy. Prior to 1978, UT1 was derived from the observations of a single station (Calame, 1980), thus some local effects can perturb the results.

The non-rotating reference frame is the one in which the ephemeris of the lunar reflector is computed and would theoretically be the true equatorial system of the date of the observation. It is practically realized through the theoretical representation of the lunar orbital and rotational motions and thus reflects their errors. This is responsible for linear and periodic errors.

1.4 Radio Interferometry

The measurement consists of a phase difference between signals from a radio source when received by two terrestrial stations. These phase differences are temporal functions of the baseline and source parameters varying with the Earth's orientation in space. The Earth rotation parameters can be deduced from such measurements of one or several baselines of observing stations by two different observational techniques which are respectively connected element interferometry (McCarthy, et al., 1980) and very long base interferometry (Fanselow, et al., 1979).

The terrestrial reference frame is realized by the very accurate coordinates of radio interferometric stations as computed from these observations at an initial date and referred to the BIH origins of pole and longitude using the BIH Earth parameters at this date (BIH A.R. for 1979). The accuracy of this terrestrial frame can be perturbed by some local effects in the case of a single or too short baseline (as in the case of a single connected interferometer).

The non-rotating reference frame is realized by the coordinates of the observed radio sources in a catalogue which is very accurate in the case of a global determination but can be deteriorated by local effects in the case of one baseline determination.

2. OBSERVATIONAL EVIDENCE

The data analysed are those present in the BIH files, and published in the Annual Report of the BIH for 1979 (the pages are indicated in brackets), except for the results of IPMS, taken from Yumi (1980), p. 119-123.

Optical astrometry: Two computing centers, same observations.
- IPMS: x, y (smoothed values at 0.05 y interval), and UT1 (monthly means)
- BIH (AST): x, y, UT1 from astrometry only, at 5-day and 0.05 y intervals (pp. B-17, D-3).

Satellite Doppler tracking: Three computing centers, one common satellite, some common stations.

DMA: x, y at one-day interval (p. D-9)
MEDOC: x, y at 2-day interval (p. D-27)
NSWC: UT1 at one-day interval (p. D-11)

Lunar laser ranging: One computing center, two lunar ephemerides, same observations.

EROLD: UT1 at irregular interval, using the JPL ephemeris, DE 86, or the GERGA-Texas Ephemeris, ECT 18, (p. D-35)

Satellite laser ranging: Two computing centers, same observations.

GSFC: x, y, l.o.d. at 5-day interval (p. D-47)
IASOM: x, y, l.o.d. at 5-day interval (Fanselow, 1980)

Very long base interferometry (VLBI): One computing center, one network.

DSN: x, y, UT1 at irregular interval (p. D-75)

Connected interferometry (CERI): One computing center, one interferometer.

GBI: UT0, ϕ at irregular interval (p. D-67)

2.1 Long Term

The relative drifts are given in Table 1.

Table 1. Drifts relative to BIH (AST). (Units: 0".001 for x,y; $0^s.001$ for UT1)

Series	Years	x	y	UT1
IPMS	67-78	-0.1 ± 0.2	+0.1 ± 0.3	-1.7 ± 0.4
DMA	72-79	-2.0 ± 0.4	+1.9 ± 0.5	
EROLD DE 86	71-78			-2.5 ± 0.7
EROLD ECT 18	71-79			-4.0 ± 0.7
DSN	71-78			+0.6 ± 0.7

The drift of IPMS is due to the implementation of different algorithms for the long term stability by the two services. The drift of LLR is partly due to the long term errors on the right ascension of the moon.

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2.2 Intermediate (6 c/y to 1 c/y)

The dominant features in optical astrometry and CERI are annual (and semi-annual) terms. Table 2 gives the amplitude of these terms for several series compared to BIH (AST). BIH (AST) is expressed in the 1979 BIH System, which annual terms have been calibrated by DMA for polar motion and EROLD (DE 86) for UT1.

Table 2. Annual and semi-annual terms relative to BIH (AST) (Units: 0."001 for x, y; 0.^{s}001 for UT1). The differences are expressed as b sin2πt + c cos2πt + d sin4πt + e cos4πt, t in years.

Series	Years	x				y				UT1			
		b	c	d	e	b	c	d	e	b	c	d	e
IPMS	67-78*	+5	0	0	-2	+13	+2	+1	-3	+1	+5	-5	+5
DSN	71-78									+12	-7	-12	+8
GBI	78-79	(Latitude:				+38	-80	0	+6)	+14	+67	+10	+10

*67-77 for UT1

UT1 (NSWC) is subject to large periodic errors in this domain due to the neglect of oceanic and atmospheric tides (Anderle, 1980). EROLD (ECT 18) shows no significant difference with EROLD (DE 86) at these frequencies. The analysis of GSFC and IASOM shows some signal in this frequency domain. This might be due to some imperfection in the modelling of non-gravitational forces in DMA, or it could be an effect of the changes in the effective network in SLR. The annual term of 2 ms amplitude in UT1 (DSN) is obtained from a small number of observations and needs further confirmation.

2.3 Short Term (periods under 60 days)

The data at 5-day and 2-day intervals have been analysed, after removing strong smoothing by the Vondrak's method (see Figure 1).

The spectral analysis of BIH (AST), GSFC, and IASOM show only noise in this domain. The Doppler method (DMA, MEDOC) shows periodic terms, due to inaccuracies in the resonance terms of the force field model, around 12d and 6d. The adjustment of the parameters of these terms is somewhat hazardous, as they are not high above the noise, and also they vary slightly with time. Figure 2 shows an example of the spectra obtained. Such terms are not present when using the Lageos satellite.

Universal time. Prior to the analyses, the series have been corrected for the variation of UT due to the zonal Earth tides

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with periods shorter than 32d. BIH (AST) has only noise in this domain. NSWC has a perturbing term at 13,6d due to the neglect of ocean tides. EROLD (ECT 18) and DE (86) have some perturbing terms due to the ephemerides used and to indirect effects of the interruption of observations at new moon. The amplitudes of these terms are 1 to 2 ms for both ephemerides.

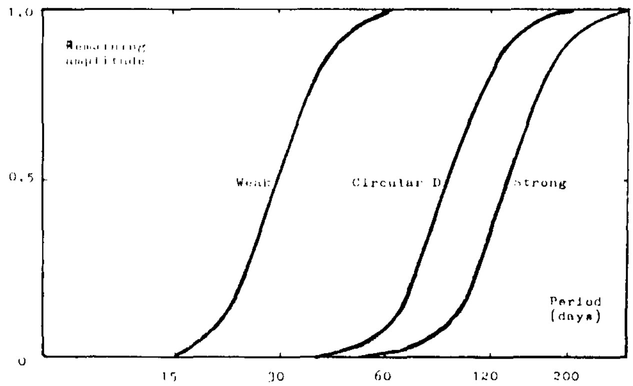

Figure 1. Filters corresponding to the smoothings used in the study.

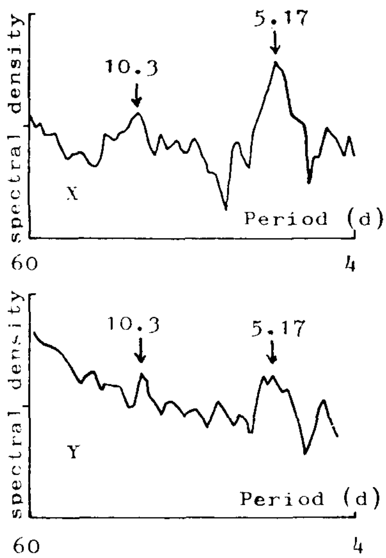

Figure 2. Doppler method for polar motion. Resonance terms.

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2.4 Comparison of corrected results. An example.

In order to show the improvement that can be obtained by correcting the original data with the systematic terms listed in this study, the short term variations of UT have been evaluated from May to December, 1979, from the independent sets of results available: BIH (AST), NSWC, EROLD (ECT 18), and GBI. The latter three are brought to the BIH System by means of the corrections determined above (long term, intermediate, and short term), all results are corrected for the effect of zonal Earth tides, and their residuals from a strong smoothing (see Figure 1) of BIH (AST) are computed. The NSWC residuals are averaged at 5-day intervals. The rms distances of these residuals to two different smoothings (Circular D and a weaker smoothing, see Figure 1) of BIH (AST) are then computed. The results are given in Figure 3 and Table 3. They show that the short term variations represented

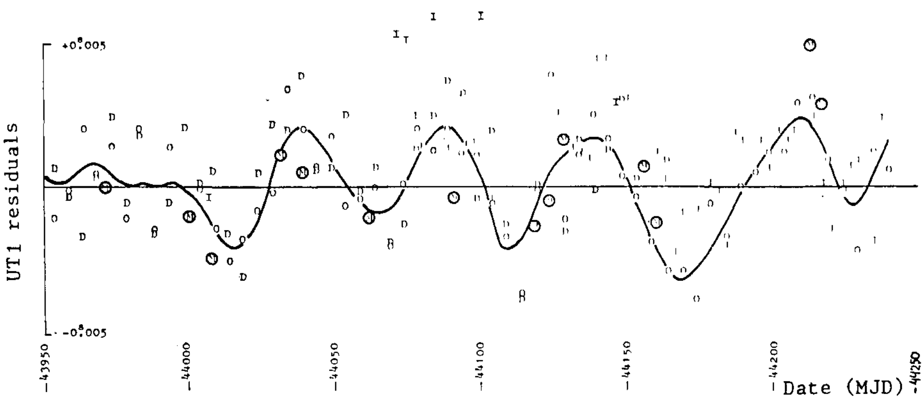

Figure 3: UT from May through December, 1979. Independent determinations (O: BIH (AST), D: NSWC, M: EROLD (ECT 18), I: GBI) and weak smoothing of BIH (AST) (solid line). The reference is a strong smoothing of BIH (AST).

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Table 3. Independent measurements of UT1, May-December, 1979: rms distances to two different smoothings (units: $0^s.0001$).

	rms distance to smoothings				Correlation coeficient of distances to smoothings	
	BIH (AST)	NSWC	EROLD (ECT 18)	GBI	BIH/NSWC	BIH/GBI
Circ. D	16	17	14	23	0.52	0.52
weak sm.	11	15	11	21	0.03	0.02
Nb of values	58	43	15	32	43	32
st. error	8	8	11	11		

by the weak smoothing are real. Such temporary perturbations in the Earth's rotation were already suspected, in connection with motions in the atmosphere, but as long as the optical astrometry was the only set of available data, no evidence of their reality was possible. The existence of such variations is probably responsible for the difficulties in determining the permanent short term variations (zonal Earth tides) and in detecting the abrupt changes in the length of day (Guinot, 1970). Another conclusion of Table 3 is that the standard error of BIH (AST), published yearly in the BIH Annual Report, Table 6B, is a good estimate of the precision of the series.

CONCLUSION

There is not actually <u>one</u> method able to provide at the same time an accurate geodetic network linked to the Earth, a perfect realization of the non-rotating celestial reference frame, and a continuous monitoring of the Earth's rotation. Each method has its own strengths and weaknesses. A calibration of the different methods by one another in order to express them in a common accurate system can be obtained by evaluating and correcting the effects of the perturbations present in each method.

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