PART I

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COMBINATION OF EARTH ROTATION PARAMETERS OBTAINED IN 1980 BY VARIOUS TECHNIQUES

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ABSTRACT

In 1980, Earth rotation parameters have been measured by classical astrometry, Doppler and laser satellite techniques, Lunar Laser Ranging and radio-interferometry. The precision of the series and their systematic differences are investigated ; a combination algorithm is applied to the series available throughout the year.

INTRODUCTION

In 1980, all the techniques, modern and classical, which can provide information on the Earth's rotation have been regularly operated by at least one group per technique. Some of them still need further study to be brought to their full expected accuracy, but all reached a stage where a regular consistent series of results could be established. A combination of these data is necessary for obtaining the best possible geophysical information.

This rises questions with respect to how the reference systems are defined and realized in each of the techniques and also of the numerical models that are used. We have presented elsewhere (Capitaine and Feissel 1981) a preliminary approach of this problem. It is expected that project MERIT will allow more detailed answers. The present study is directed mainly towards short term stability (for time intervals under one month). For the longer term, the BIH System is taken as the reference. The accuracy of the BIH system for the long term is established on classical astrometry, confirmed by comparisons with VLBI ; for the medium-term (one month to one year) it is based on Doppler tracking of satellites and Lunar Laser Ranging.

The second problem that has to be solved is the realistic estimation of the precision of the different determinations of the Earth rotation parameters. This question is of course closely related to the previous one. In an ideal world where all sources of systematic errors would be

O. Calame (ed.), High-Precision Earth Rotation and Earth-Moon Dynamics, 3–10.

accounted for in every technique, only the measurement errors would have an influence on the uncertainty of the results. The actual situation is not so. We have therefore made an attempt to characterize the precision of the different series by statistical analyses of their differences.

Finally we had to make a choice of which of the series could be used in the combination. We adopted for this choice the criteria that the series be dense enough throughout the year 1980 and that, to our knowledge, they had been obtained in a homogeneous way. The series that could be used are those of Table 1. The corresponding data or a reference to them can be found in the Annual Report of the BIH for 1980, part D.

Table 1 - Combined series

Name of the series	Technique	Computing Centre	Remarks
AST	Classical astrometry	BIH	94 stations
DOP	Sat.Doppler tracking	DMA	Satellites 1967-481 (48), 1967-921 (92), 1970-671 (67)
SLR	Sat. Laser Ranging	IASOM	Satellite LAGEOS system LPM 80-11
CERI	Connected Elements Radio Interferometry	USNO	Green Bank interferometer

A more complete discussion of the existing series is made in another study (Feissel 1981).

ANALYSIS OF THE INDIVIDUAL SERIES

1. The systematic differences between the series were investigated.

Pole coordinates (AST, DOP, SLR). DOP was averaged at 5-day interval, separately for each satellite. All the possible differences between two of the series were formed. The result of the analysis of these series of differences is as follows.

- There is no significant periodic signal in the range of Fourier frequencies from 0.03 to 1 cycle/year.
- Although for both DOP and SLR the stations coordinates were adjusted at one epoch in order that the derived pole coordinates match the BIH solution, a constant bias of the order of 0".01 is observed in all the series of differences.

Earth orientation parameters derived from the Green Bank interferometer (CERI). The residuals to an external solution (e.g. the BIH global solution) show a clear seasonal signature, which seems to be due to the inaccuracy of the atmospheric models available for the reduction of the observations. The total amplitude of this effect is of the order of 0".05.

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Length of day (SLR). The SLR length of day estimates are subject to spurious variations due to errors in the modeling of the motion of the orbit node. Since the end of 1979, when the tracking network was substantially improved, the error on the length of day determinations is mainly a constant bias of the order of 0.1 ms.

2. The noise level of the various series was estimated in several different ways.

For the pole coordinates, we took advantage of the availability of three independent series to estimate their individual stability. We used a method based on the Allan variance. This method was devised for the characterization of the stability of oscillators (Gray and Allan 1974) ; it can be applied to other time series.

Given a time series (y_i) equally spaced, the sampling time being τ, the two-sample Allan variance of the series y is defined as

$$\sigma_y^2(2,\tau) = \frac{1}{2n} \sum_{i=1}^{n} (y_{i+1} - y_i)^2 \qquad (1)$$

Let a,b,c be three series of measurements of the same quantity at the same dates (equally spaced). The Allan variances of their differences σ^2_{a-b}, σ^2_{b-c}, σ^2_{c-a} can be computed by (1). If the three series are statistically independent their combination provides the individual stability estimators σ^2_a, σ^2_b, σ^2_c. The application of this technique to AST, DOP, and SLR over the period 1979 Sept. 8 to 1981 May 20 leads to the values of Table 2.

The individual series AST, DOP, and SLR have also been submitted to a Vondrak smoothing corresponding to filters of Figure 1. The rms residuals "observed-smoothed" are given in Table 2. The agreement of the two estimators is satisfactory.

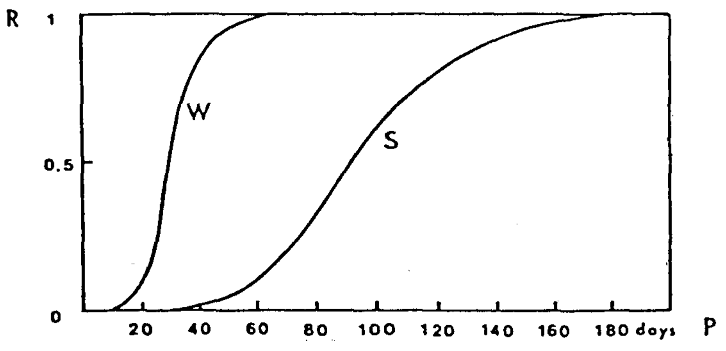

Figure 1. Characteristics of the two degrees of smoothing (Vondrak's method) used in this study. R is the remaining amplitude of a sine wave of period P and amplitude 1.

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For the other series, only the rms residual estimation could be performed. It provided the following precisions. For CERI, approximately at 3-day interval : 0".011 (latitude), 0.0011 s (time), with reference to smoothing S in Figure 1 ; for SLR length of day at 5-day interval, 0.16 ms with reference to smoothing W of Figure 1.

Table 2 - Stability of individual determinations of pole coordinates at 5-day intervals

Technique	Two-sample Allan variance x	Two-sample Allan variance y	rms residual to smoothing S x	rms residual to smoothing S y
AST	0".013	0".013	0".013	0".012
DOP(92)	0".022	0".015	0".018	0".011
DOP(67)	0".022	0".019	0".017	0".017
SLR	0".009	0".007	0".007	0".005

COMPUTATION OF THE COMBINED SOLUTION

The series of Table 1 were combined at 5-day interval , taking the data as they were made available to the BIH : individual determinations of time and latitude for AST and CERI, pole coordinates at two-day interval for DOP, pole coordinates and length of day at 5-day interval for SLR

The solution is referred to the 1979 BIH System, through the corrections of Table 3.

Table 3 - Systematic corrections to the individual series.

Series	x	y	UT	D
AST	0	0	0	0
DOP(sat.48)	-0".004	+0".011	-	-
DOP(sat.67)	+0".015	-0".006	-	-
DOP(sat.92)	+0".003	+0".005	-	-
SLR	-0".003	+0".014	-	+0.11ms
CERI	latitude :	+0".034	UTO : $-0^{s}.0035$	0
	-0".001sin2πt+0".034cos2πt		$-0^{s}.0020\sin 2\pi t-0^{s}.0039\cos 2\pi t$	
	-0".001sin4πt-0".012cos4πt		$+0^{s}.0006\sin 4\pi t-0^{s}.0009\cos 4\pi t$	

For weighting the different types of data, the standard errors provided by their authors were used. The reported uncertainties were first scaled separately for each series. A multiplying factor E was determined which equalizes the rms "observed-smoothed" to the rms reported uncertainties. The scaling factors used in the combination are given by Table 4.

Table 4 - Scaling factors for the reported standard errors
Reference smoothing (see Fig.1) : S for x,y;W for UT,D.

Series	E_x	E_y	E_{UT}	E_D
AST	1.2	1.2	1.0	1.6
DOP(sat.48)	2.7	2.9	-	-
DOP(sat.67)	4.7	3.8	-	-
DOP(sat.92)	3.2	3.1	-	-
SLR	1.6	1.3	-	1.7
CERI	latitude :	2.0	2.2	3.5

The combined solution was obtained by a least-square fit of x, y, UT1 among the individual determinations. The series were corrected according to Table 3 and the weights were inversely proportional to the squared standard errors scaled according to Table 4. The usual z term was considered for AST. The length of day D was derived in a second step, by combining the values obtained from the derivation of UT1-UTC with the raw values of SLR. The mean relative weights of the different techniques were as in Table 5. The raw results at 5-day interval are illustrated on Figures 2 and 3.

Table 5 - Mean relative weights of the series.

Series	x	y	UT	D
AST	0.22	0.16	0.84	0.52
DOP	0.28	0.25	-	-
SLR	0.47	0.55	-	0.39
CERI	0.03	0.04	0.16	0.09
TOTAL	1.00	1.00	1.00	1.00

Taking account of different measurements of their uncertainty - standard error of the least square fit, rms residual from a smoothing, Allan variance applied to the residuals from a smoothing - their precision can be evaluated to 0".005 (15 cm) on either pole coordinate. This is in agreement with what could be expected from the figures in Table 2. For UT, the precision is 0.0008 s (40 cm on the equator);for lod,0.1 ms.

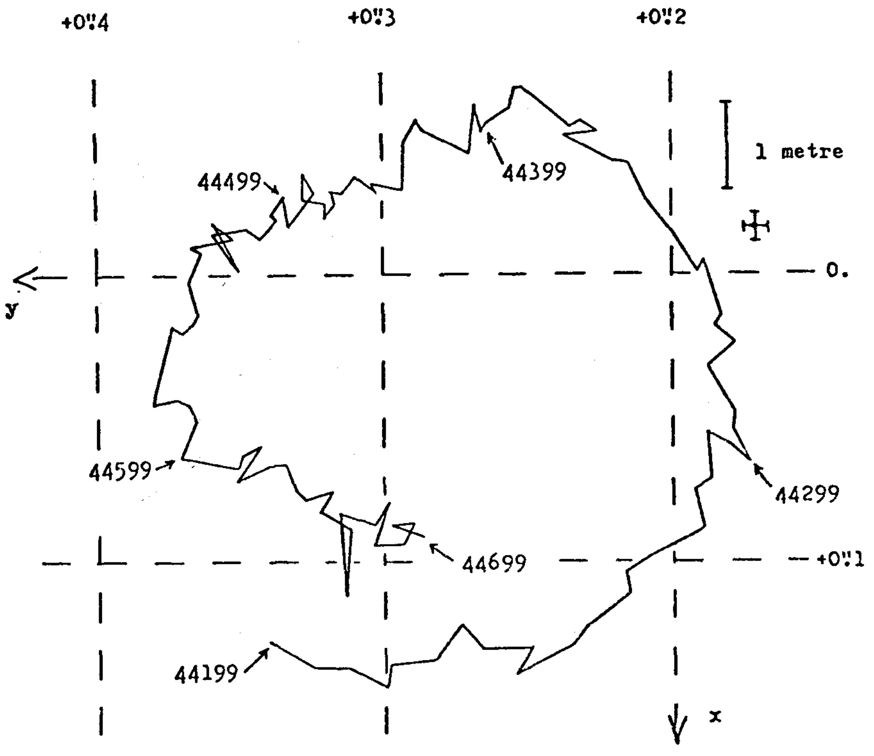

Figure 2 - Polhody 1979 Nov. 22 - 1981 Apr. 5

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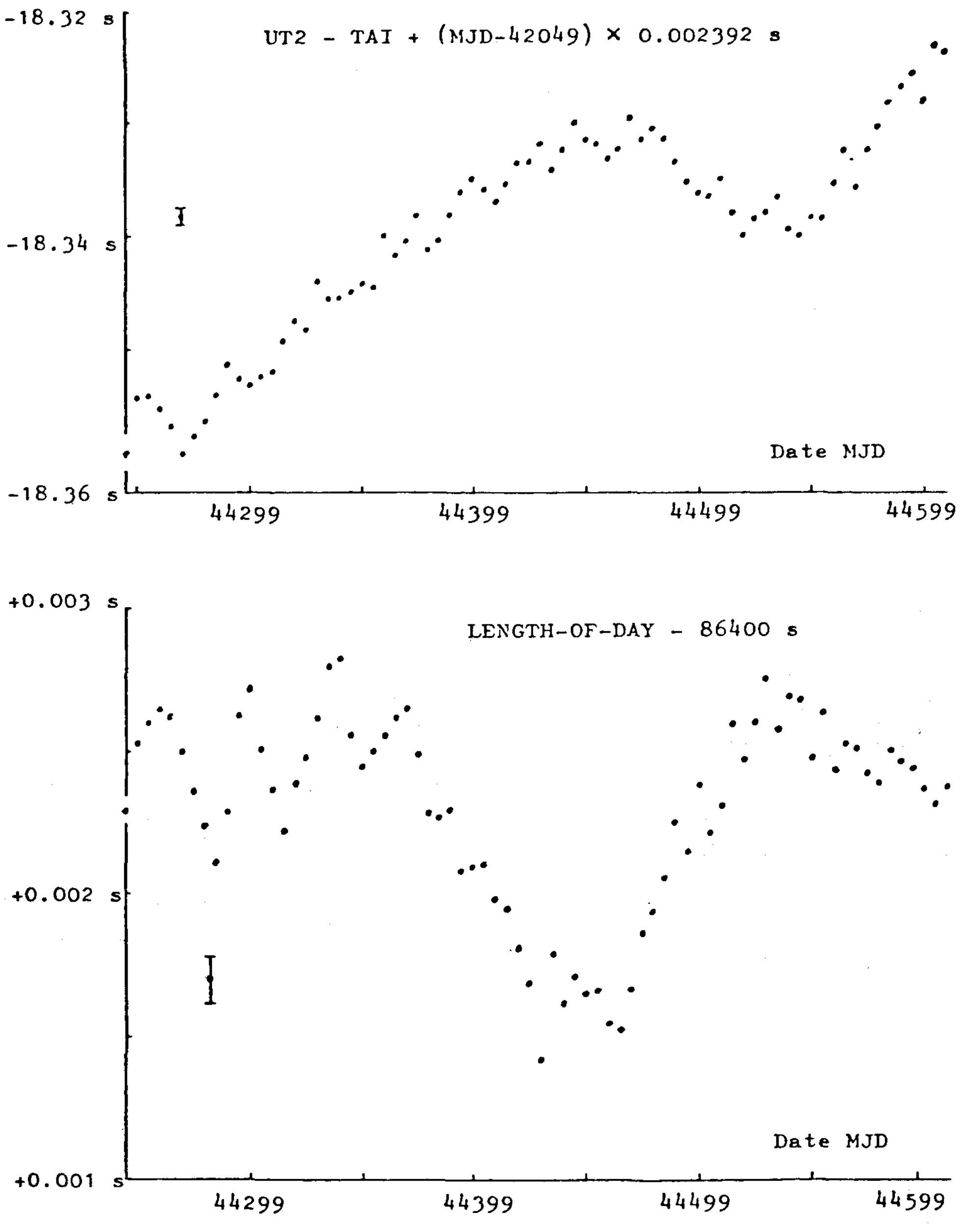

Figure 3 - Universal Time and length of day
1980 Jan. 1 - Dec. 31

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CONCLUSION

This work is a part of the studies made at the BIH in order to derive the best estimates of the Earth rotation parameters from all available data. The main differences with the algorithm previously used at the BIH are 1. the assumption that at the present level of precision the series of pole positions obtained by classical astrometry, Satellite Doppler tracking and Laser Ranging to Lageos have no systematic errors at the annual frequency (and harmonics) and 2. the weighting of data independently for every series of results, taking account of the scattering of residuals with respect to a smoothing.

The analysis of the results obtained shows that these algorithms and assumptions allow to obtain an increased short term stability. They will be used at the BIH starting with 1981 and their numerical results will be available in the BIH publications. In order to avoid duplications, they are given only as graphs in this paper.

Other parallel studies (Capitaine and Feissel 1981, Feissel 1981) are addressed to longer term stability, in which LLR and VLBI play an essential role.

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