ВАК 2024 MODERN ASTRONOMY: FROM THE EARLY UNIVERSE TO EXOPLANETS AND BLACK HOLES
300 years Russian Academy of Sciences

On the issues of estimating the accuracy of Earth rotation parameters

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Abstract. Earth rotation parameters (ERP) are determined at the Institute of Applied Astronomy (IAA) by processing the following types of observations: Very Long Baseline Interferometry (VLBI), Global Navigation Satellite Systems (GNSS) and Satellite Laser Ranging (SLR). The IAA also carries out special sessions of VLBI observations on radio telescopes of the Quasar network for ERP determination in various modes. The accuracy of the obtained series is estimated by comparison with the combined results of the International Earth Rotation and Reference Systems Service (IERS) usually accepted as reference. The accuracy of various ERP series has been analyzed also using a method based on the assumption that there can be no abrupt changes in ERP and after removing the intra-day variations the series should be sufficiently smooth. In this method the evaluation is performed without calculating the differences of two independent series and is related only to the internal properties of the series. The article presents an overview of the results of the analysis and concludes that the proposed technique can be used to estimate the accuracy of the ERP series.

Keywords: Earth: rotation; methods: observational, statistical

DOI: 10.26119/VAK2024.142

1 Introduction

Earth rotation parameters consisting of Earth pole coordinates (Xp, Yp), celestial pole coordinates (Xc, Yc) and Universal time (UT1) are determined at present by methods of VLBI, GNSS and SLR. These methods determine parameters with different completeness, discreteness and frequency as shown in Table 1. The accuracy of the same parameters obtained by different methods may differ significantly. It is supposed that the combination of results obtained by various analysis centers based on different types of observations gives the highest accuracy.

Table 1. Time characteristics of ERP determination techniques (all values in days).

Parameters	VLBI method		GNSS method		SLR method	
	Sample interval	Observations duration	Sample interval	Observations duration	Sample interval	Observations duration
Xp, Yp	3	1	0.25	1	1	2–4
Xc, Yc	3	1				
UT1	1, 3	0.042, 1				

Support for the functioning of global navigation satellite systems imposes the highest requirements on the accuracy of ERP. Estimation of the real accuracy of the parameters remains an open problem for both the combined series and the individual ones produced by analysis centers.

2 Motivation

Within the framework of ERP service operating at the IAA since 1995 (Gayazov et al. 2016) ERP are determined from all types of observations performed at global network stations. Since 2012 IAA ERP service also conducts processing of special sessions of VLBI observations carried out on radio telescopes of the Quasar network for ERP determination (Ivanov et al. 2022). Since 2016 1^{h} sessions on RT-13 radio telescopes have been performed up to 6 times a day for UT1 determination. The accuracy of all series is usually estimated by comparison with the combined data of the IERS[1] accepted as reference. Comparison of UT1 series obtained from 1^{h} sessions of VLBI observations on Quasar network radio telescopes with the final series of IERS is shown in Fig. 1. Depending on time interval values of root-mean-square (RMS) of differences are within 50–60 μs for UT1 series from single baseline observations on radio telescopes RT-32 (Fig. 1a) and within 20–30 μs for series obtained from observations on three new generation radio telescopes RT-13 (Fig. 1b).

The necessity of an adequate assessment of the accuracy of UT1 series from Quasar network observations was the main motivation for this analysis.

[1] https://www.iers.org/

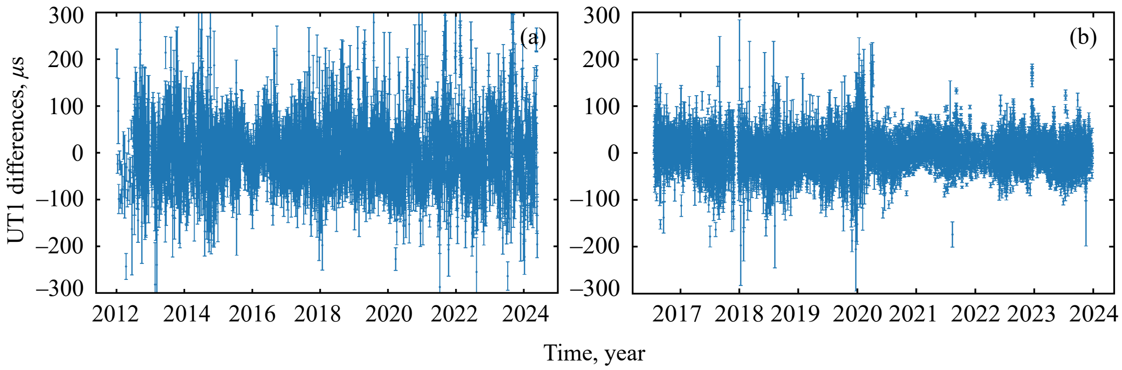

Fig. 1. UT1 series from Quasar network observations compared to IERS finals.

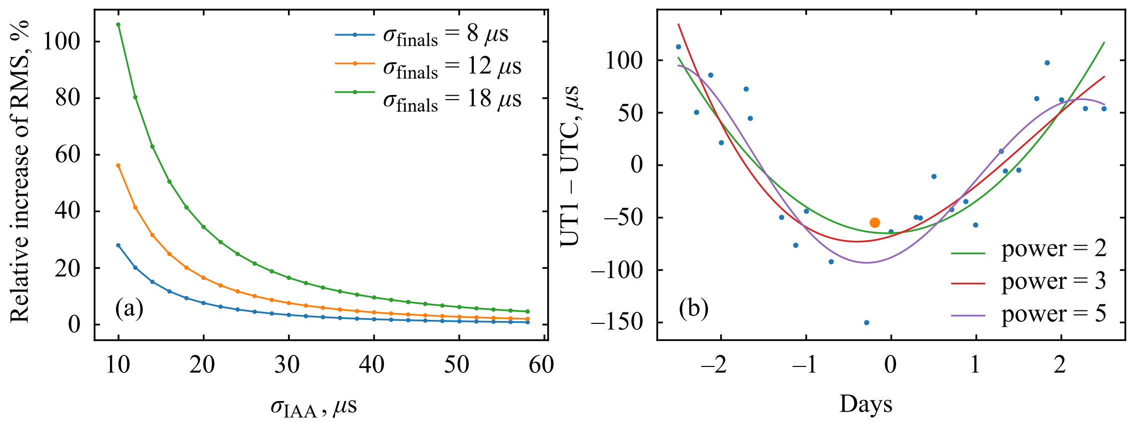

Fig. 2. RMS dependence on errors of IERS finals series (a) and errors from interpolation by various degree polynomials (b).

There are several types of ERP accuracy estimations used in practice:

1) formal estimates from the Least Square Method solution;
2) estimates obtained when combining results of analysis centers within one technique;
3) estimates obtained when combining results of analysis centers and of different techniques to form the IERS finals series;
4) estimates obtained by comparing with IERS finals.

Estimates can be obtained also from internal consistency analysis of series based on the smoothness criterion. This approach has been used in our analysis.

When we compare our series with series IERS finals the variances of both series contribute as $\text{RMS} = \sqrt{\sigma^2_{\text{IAA}} + \sigma^2_{\text{finals}}}$. This cannot be neglected in the case when the values of the variances are close. Fig. 2a demonstrates the essential dependence of RMS on the accuracy of the finals series in the area of 20 μs.

When comparing individual series with IERS combined data additional differences occur due to interpolation errors depending on degree of used polynomials (Fig. 2b).

The standard approach to estimating the accuracy of series consists of evaluating RMS by comparing with IERS finals. But a number of questions have been raised about the quality of IERS series of UT1 during the past few years. The combining procedure for obtaining the IERS series has not been described in detail for recent years (IERS annual reports have not been published since 2019). Weights of individual series of analysis centers are unknown. Monthly RMS values for UT1 results of different analysis centers taken from official IERS bulletins B are presented in Fig. 3 for 24^{h} sessions (a) and 1^{h} sessions (b). One can see increasing dispersion of results of analysis centers after 2020.

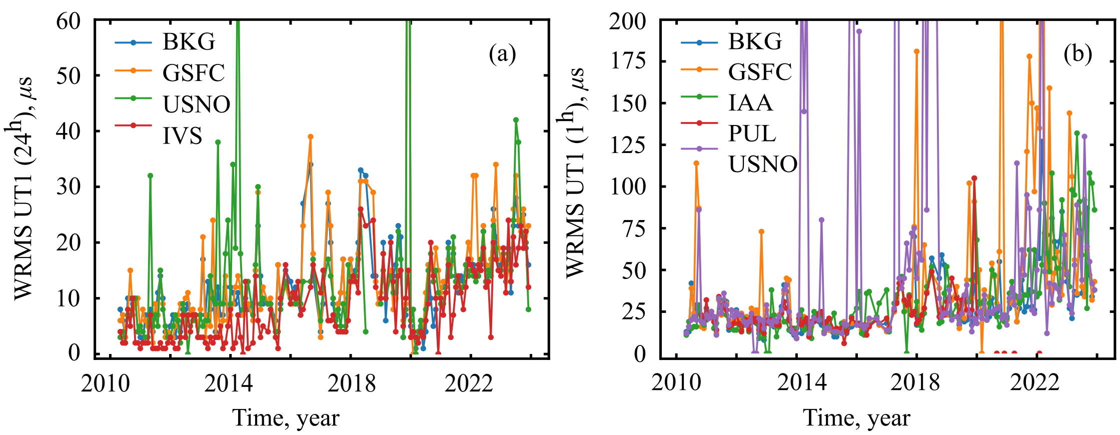

Fig. 3. Weighted RMS of monthly UT1 series of analysis centers from 24^{h} (a) and 1^{h} (b) VLBI sessions.

3 Analysis of smoothed series

We analyzed various ERP series using a method (Kurdubov & Skurikhina 2021) based on the assumption that changes in the Earth's rotation cannot occur too fast and after removal of intra-day variations the UT1 series should be smooth enough. A smoothed series is constructed by sliding interpolation of values by polynomials of various degree using $2N$ points of the series around the interpolated point excepting the point itself (N points forward and backward). RMS of differences of the original

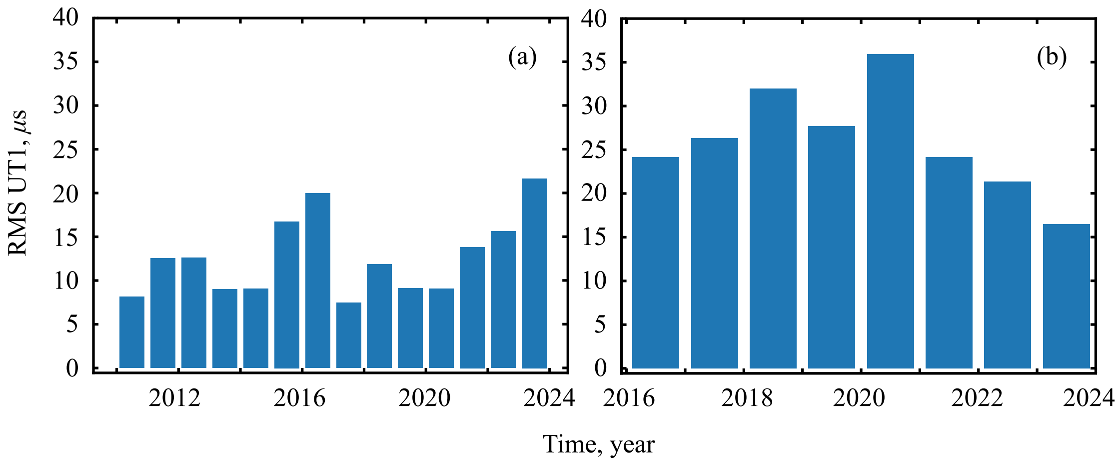

Fig. 4. Annually averaged accuracy estimations of UT1 series from IERS finals (a) and from Quasar RT-13 1^{h} sessions (b).

and interpolated series are used as an estimate of the internal accuracy of the series. From analysis of the UT1 series IERS finals in (Kurdubov & Skurikhina 2021) the optimal values for N and the polynomial degree (P) have been settled as $N = 3$ and $P = 5$.

This technique has been used for the analysis of final UT1 series of IERS. Annual averages of obtained internal estimates for UT1 from IERS finals starting from 2010 are presented in Fig. 4a. Analogous results for UT1 series obtained from observations of the Quasar RT-13 stations network are shown in Fig. 4b.

It can be seen in Fig. 4a that internal estimates for IERS finals are close to dispersion of data in Fig. 3a and have shown an analogous degradation trend in recent years as seen in Fig. 3a, b. We suppose that the following factors can be responsible for this:

1) different analysis centers present a different set of products;
2) using observations of new VGOS stations with inaccurate coordinates;
3) unevenness of data distribution (series with unequal moments, different density);
4) undeclared changes in IERS combination scheme;
5) influence of interpolation schemes;
6) errors in intra-day variations model or its degradation with time.

As a good test for the technique used we consider its implementation for pole coordinates obtained from GNSS observations. Fig. 5a, b show the data from IERS Bulletins B and Fig. 5c, d show annual average values of RMS obtained using the proposed technique. It can be seen that the common level of our estimations is very close to dispersion of results of different analysis centers.

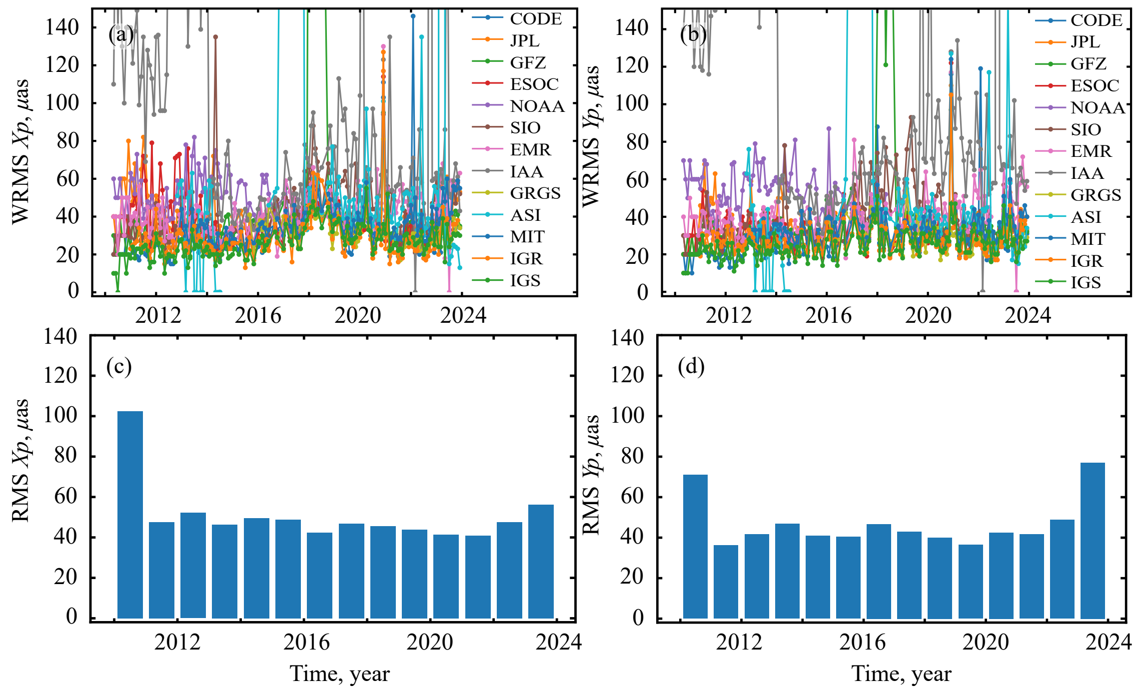

Fig. 5. Bulletine B data for pole coordinates from GNSS observations (a, b) and annual estimations obtained using proposed technique (c, d).

4 Summary

UT1 series IERS finals have shown noticeable degradation of accuracy in recent years due to a few negatively affecting factors. It is important to develop independent criteria for estimating the accuracy of our own ERP series. Adequate accuracy estimates can be obtained using the technique based on the smoothness criterion. Estimates of internal accuracy of UT1 series obtained from Quasar RT-13 network observations in recent years are at the same level as that of UT1 series from IERS finals.

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