RESULTS OF RADIO METEOR COMPARISON OF SCALES OF THE RUSSIAN UTC (SU) AND UKRAINIAN UTC (UA) TIME STANDARDS

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Abstract

The analysis of outcomes of radio meteoric comparisons of the State time measurement standards of the Russia and Ukraine scales is carried out in the paper. A check of statistical hypotheses about a normality of allocation of sampling, their homogeneity, and equal precision is realized. On sampling measurement outcomes for a session by classical and robust of procedures, we discovered ratings of a distribution central value and dispersion of samplings, determined their stability to contamination, and worked out the guidelines on application of these ratings. Linear regression analysis of a mutual course of the time standards scales by the first- and second-order models is carried out.

INTRODUCTION

The results of application of the radio meteor comparison method (RMCM) and the way of perfecting it are considered in this work. This method does not concede to a transported quantum clock or satellite radio navigation systems GPS and GLONASS on accuracy of comparison, having efficiency and autonomy. The advantages of RMCM determine the significance of scientific works on its improvement **[1]**.

Data obtained from of regular radio meteor comparison of scales of the Russian UTC (SU) and Ukrainian UTC (UA) time standards during 2000 on special meteoric equipment complexes "METKA – 6," developed at Kharkov Technical University of Radio Electronics, was used in the present work. Systems of spatial-temporal provision in Ukraine and Russia are equipped with such complexes. The UTC (SU) standard was located in Moscow, and UTC (UA) standard was located in Kharkov. The distance between them is equal to approximately 750 km. The relative instability of these standards is between 10^{-15} and 10^{-14}.

EQUIPMENT DESCRIPTION AND DATA ANALISIS

The equipment complex is intended for automatic precision measurement of a time scales discrepancy between the territorially remote time measurement standards. The equipment is placed in setups of a standard disposition. The transmitters radiate coded packs of 16 impulses 2 μsec in duration in both setups during a session of scale matching; the frequency of pack repetitions is 50 Hz; the power in each impulse is 20 kW; and the carrier frequency is 57.3 MHz. A passband is 1 MHz and quantization of the time interval gauges is 10 ns.

Fifty-three sessions were processed. The measurements were carried out averaging once per one week. The measurements started at the beginning of the day. The average duration of sessions was 1 hour. The total number of measurement results is 3,546. They were obtained from 256 "useful" meteoric traces. The main statistical indexes of a radio meteor comparison channel on a line Kharkov-Moscow for the year 2000 are reduced in Table 1. The sessions differ from each other in duration, the number of so-called "useful" meteors providing forward reflection, in the corresponding setup, the number of measurements obtained from these meteors, and the total number of measurements. Figure 1 gives a representation about allocation of measurement numbers for a session in days of the year 2000.

Table 1. The main statistical indexes of a radio meteor comparison channel on a line Kharkov-Moscow for the year 2000.

Index	Volume
Total number of the treated sessions	53
Maximum	17
Average of "useful" meteoric tracks in a session	4.83
Minimum	1
Total number of "useful" meteoric tracks	179
Maximum	1230
Average of outcomes of measurement in a session	66.9
Minimum	1
Total number of measurement outcomes	3546
Maximum	256
Average of outcomes from a "useful" meteoric track	13.8
Minimum	1
Total number of measurement outcomes after three times truncation by a three-sigma method	3461
Total number of the rejected outcomes	85
Average of measurement outcomes after truncation in a session	65.3
Average percent of sampling contamination for a session	2.4
Maximum number of the rejected outcomes for a session	27
Maximum percent of sampling contamination for a session	8.3

STATISTICAL PROPERTIES OF SAMPLINGS OF THE MEASUREMENT OUTCOMES

Obtained from a "useful" meteoric track, the measurement outcomes form a group. The number of such measurements in a group determines the size of a group. In Figure 2 is shown as the number of "useful" meteoric tracks in a session, and the number of sessions are connected.

The views of typical realizations of the measurement outcomes allow one to make a statistical conclusion that it is the essential nonstationary processes related to meteoric phenomena which is stipulated by effects of forming and corrupting a meteoric track, and also by modification of influx of meteoric substance within the day and within the year.

Figure 3 gives a representation about the character of modifications of the measurement outcomes in time for meteoric tracks existing a long time. There are typical realizations, namely magnification of dispersion by the extremity of a radio echo from a meteoric track and a modification of the average value in time in some cases. The probable reasons of such behavior are stipulated by singularities of physics of meteoric appearances: by a diffraction on a formed meteoric track, wind transition of the mirroring area, diffuse extension of a meteoric track, resonance in a meteoric track, multiradial distribution of radio waves, and other similar reasons.

Based on Pearson, Bartlett, Student, and Fisher statistics [2], statistical hypotheses about the hypothetical normal distribution, homogeneity, and equal accuracy of the samplings were tested on samplings of measurement results for all sessions by appropriate goodness-of-fit tests.

Use of probability logic of hypothesis acceptance or rejection allows one to make the following conclusions: it is impossible to consider the data to be groups of equal precision in 26% of cases; groups cannot be referred to the same distribution law in 6% of cases because the hypothesis about equal averages does not prove to be true; and in 8% of cases both the hypotheses about equality of averages and about equality of variances should be rejected.

The outcome of a statistical analysis consists of the following: the hypothesis about the normal distribution function of measurement outcomes for a session does not contradict the experimental data in 24.5 % of cases; the tests of such hypothesis cannot be carried out because sizes of samplings were small in 35.8% of cases; and the observed sample values will not be correspond to the hypothetical distribution in 39.7% of cases. Tests of the statistical hypotheses have shown that the measurement outcomes represented by 53 sessions for the year 2000 cannot be considered as normally distributed in approximately 40% of cases of homogeneous and equally precise samplings. These statistical properties of the sample data, obtained by a radio meteor comparison of scales of the time standards, justify the necessity of searching for noise-resistant procedures for their processing.

COMPARATIVE ANALYSIS OF THE DEFINITION PROCEDURES FOR THE CENTER OF A DISTRIBUTION

For a solution of this task, the following research was carried out: the various methods of stratification of sampling and their cleaning from a contamination were applied; estimation of a central value of the distribution was found by classical and robust procedures (a sampling mean, a weighed mean, a middle of scope, a trimmed mean, a winsorized mean, a quintile rating, a median, and the Huber, Hampel, Andrews, and Tukey M-estimations were calculated); and using classical and robust estimates the sampling dispersion was determined [3].

The elementary quantitative performance of a stability of ratings is the point of failure δ^*, which is determined as a part of the input data, which can be changed arbitrarily and, thus, do not suffer from uncontrollable errors of estimation.

Statistical research of measurement outcomes in a location condition (at a known zero shift of scales) allows one to make the following outputs. The sample average will increase directly proportionally with magnification of a contamination level ε, so its instability to contamination ($\delta^* = 0$) is exhibited. The middle of a range is rather sensitive to contamination; this rating is recommended for application only for a rectangular distribution of the data and lack of contamination. While the contamination level ε does not exceed a truncation level α for sampling, estimations depending from α (truncated average, winsorized average, and quintile estimation) have a small offset ($\delta^* = \alpha$). The sample median is a rather steady, reliable, and simple rating having a point of failure d* = 0.5; therefore, it is recommended to be used as the first approximation in more complicated and exact algorithms. It is recommended to use a sample median as the elementary steady estimation of scale shift for processing in real time, for example, for an interchanging of the measurement information about time of radio wave propagation between setups in the counter measurement method. The contamination causes the least offset in robust Andrews and Tukey M-estimations. These estimations of distribution center allow one to sustain a high percent of contamination without essential magnification of offset and standard deviation.

DETERMINATION OF THE MUTUAL COURSE OF THE TIME STANDARD SCALES BY THE REGRESION ANALYSIS

The measurement outcomes of the shift of time scales obtained for a time interval of 8000 hours have allowed us to estimate a mutual course of time scales of the compared measurement standards. The regression analysis of measurement outcomes of scale shift was carried out with this purpose. Statistical dependence of the course of the time scales of the measurement standards from time was revealed. The model was checked. In matrix notation it looks like

$$Y = X \cdot \beta + \varepsilon, \tag{1}$$

where Y = vector of the measurement outcomes of a scale shift , X = matrix of explanatory variables, every ith string looks like $(1,\ X_i)$ for the first order model and $(1,\ X_i,\ X_i^2)$ for the second-order model, β = vector of the estimated parameters, and $\beta' = [\beta_0 \quad \beta_1]$ and $\beta' = [\beta_0 \quad \beta_1 \quad \beta_2]$ for models of the first and second orders respectively, and ε = vector of errors. In this model X_i is expressed in hours. The beginning of the year 2000 has been chosen to be the time origin. It has been checked to be linear in the parameter model. Besides, it was considered that the appropriate scale shift measurement would be carried out at the moment of new date approach. The estimation of a vector was determined by the least-squares method [4]. The results of calculations for data obtained during the year 2000 are shown in Table 2. The outcomes of the regression analysis for models of the first and second orders are shown in Figures 5 and 6 respectively.

INFERENCE

The basic conclusions consist of the following: measurement results for a session in approximately 40% of cases could not be considered as homogeneous and equally accurate and normally distributed sampling; we propose approximating the distribution of the measurement results of the shift of the scales by the ε–contaminated normal distribution with the normally distributed contamination; it is recommended to use the sampling median and the sampling median deviation as the elementary estimates for the parameters of a location and a scale, and the Tukey estimate as the basic estimate for a central value of the distribution in secondary processing of the measurement results; the mutual variation of the standard scales in 98.1% can be explained by the regression model of the first order and makes $4.4 \cdot 10^{-14}$ (3.8 ns per day); the model of the second order explains a mutual variation of the standard scales in 98.8% and gives the scale shift of 5.3 ns per day.

Table 2. Outcomes of the regression analysis of a course of the time standard scales.

Main Characteristics	For the first-order model	For the second-order model
The model equation in a general view	$Y_t = b_0 + b_1 \cdot X_t$	$Y_t = b_0 + b_1 \cdot X_t + b_2 \cdot (X_t)^2$
Coefficients of model	$b_0 = 0.292\,\mu s;$ $b_1 = -4.4 \cdot 10^{-14}$	$b_0 = 0.408\ \mu s;$ $b_1 = -6.18 \cdot 10^{-14};$ $b_2 = 0.53 \cdot 10^{-28}\ \mu s^{-1};$
The model equation, μs	$Y_t = 0.292 - 4.4 \cdot 10^{-14} X_t$	$Y_t = 0.408 - 6.2 \cdot 10^{-14} X_t +$ $+ 0.53 \cdot 10^{-28} \cdot X_t^2$
Course for one day, *ns*	-3.8	-5.3
Standard deviation, *ns*	47	37
Quadrate of correlation coefficient	98.1 %	98.8 %
Calculated value *F*	2053	1001
Tabulated value *F*	14.08	3.29

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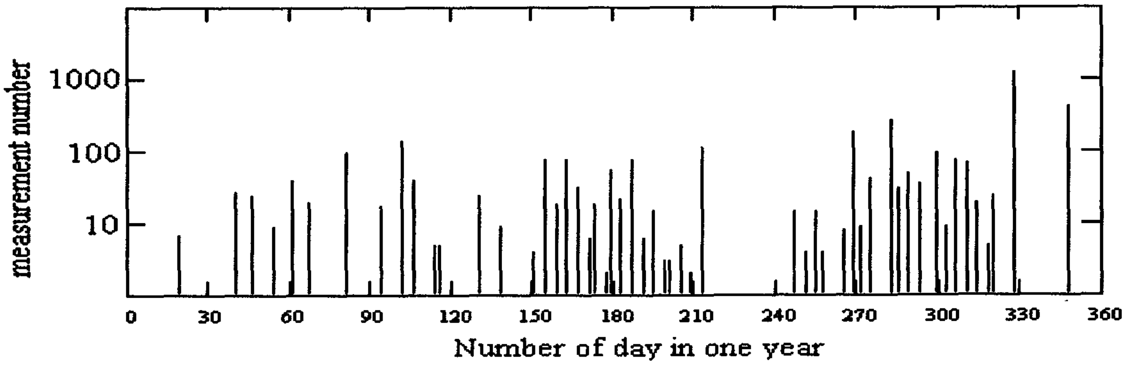

Figure 1. Allocation of measurement number for a session in days of the year 2000.

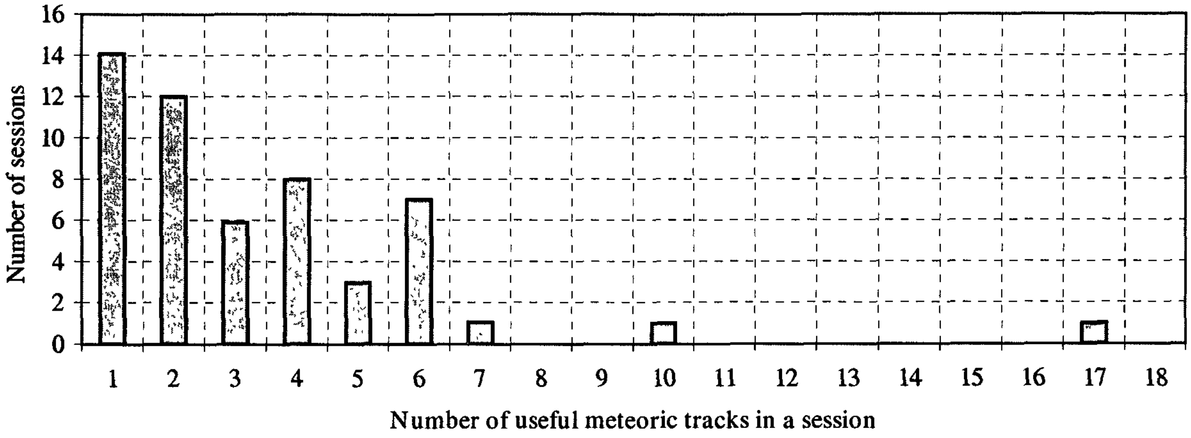

Figure 2. Structure of measurement.

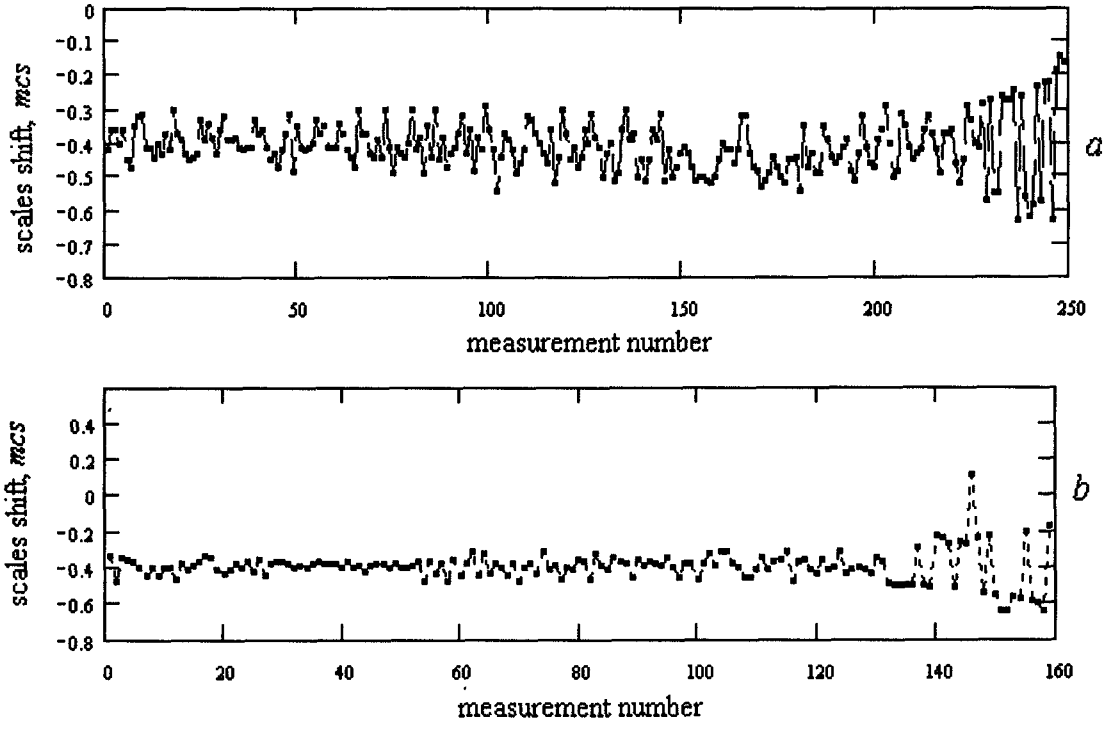

Figure 3. Examples of realizations from long meteoric tracks.

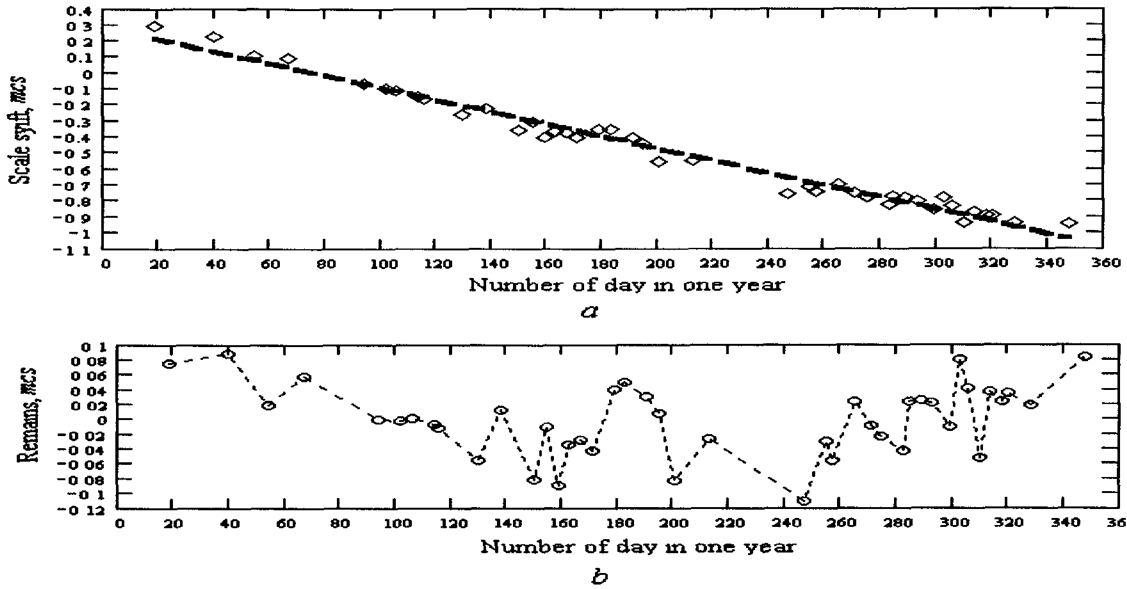

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Figure 4. Outcomes of the regression analysis for the first-order model.

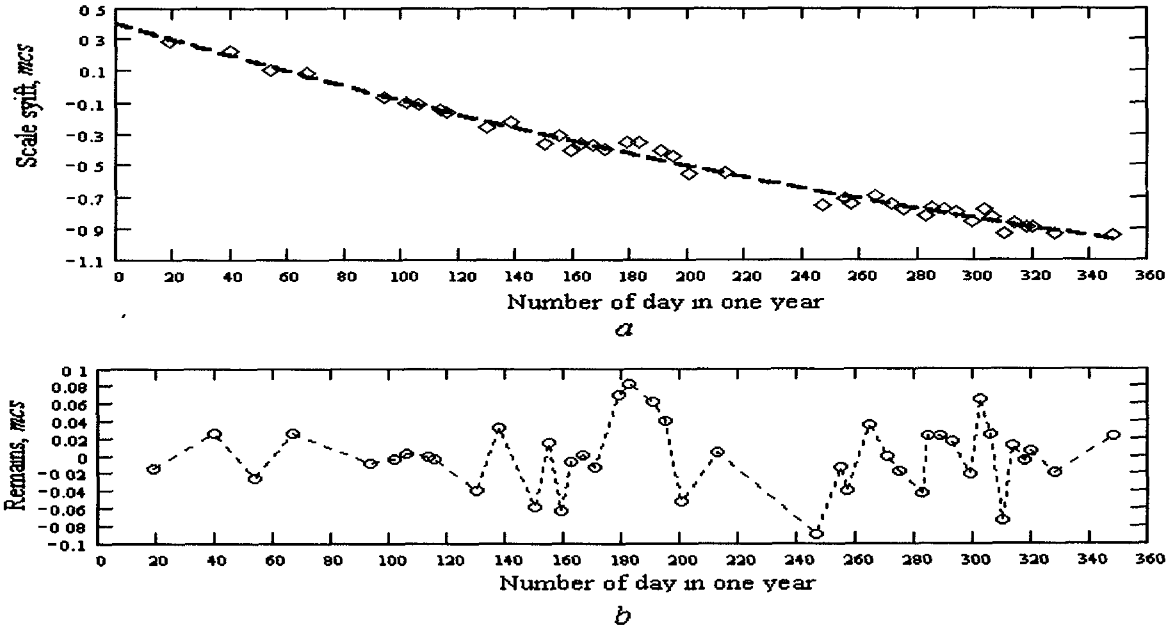

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Figure 5. Outcomes of the regression analysis for the second-order model.