A NEW METHOD OF UNIVERSAL TIME COMPUTATION USED IN THE STATE TIME AND FREQUENCY SERVICE OF THE USSR

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Processing of astronomical observational data of several time services and the publication of Universal Time of emission of time signals has been carried out in the USSR continuously for fifty years. Currently the Universal Time computations are made in the USSR State Time and Frequency Service using the observational data of eleven Soviet time services and ten time services of socialist countries that have volunteered to participate. The functioning of this system simultaneously with the BIH system that unites time services from all over the world has certain practical advantages. The Soviet Universal Time scale UT1(SU) may be influenced by some geophysical effects which are characteristic of the Eurasian continent, and consequently, it may be used advantageously for scientific and practical purposes in this region. The agreement between different time scales, produced by various methods and observational data, also makes it possible to evaluate the reliability of these scales.

Beginning in 1928, Universal Time computations have been made in the USSR by the "differential" method proposed by Prejpich (1933). This method is characterized by preliminary smoothing of the observational results of each contributing service. The BIH has used a similar method since 1931 when observational data from different time services were organized (Stoyko, 1946). The improvement of timekeeping methods and radio reception facilities made it possible to systematize astronomical observational data processing, to compare the data with one master clock, and to smoothe the combined data obtained by all time services. This method conceived in the USSR by N. N. Pavlov was put into practice by D. Yu. Belotserkovskij in 1951 (Belotserkovskij, 1967).

With the appearance of frequency standards and uniform atomic time scales, Universal Time remained in use only as a measure of the Earth's rotation (rotational time). Now there is no need for complete smoothing of astronomical observational data, but it is desirable that the information on the non-uniformity of the Earth's rotation be incorporated into the Universal Time scale. A new method of processing observational data has been utilized by the USSR State Time and Frequency Service

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since 1975 (Kaufman, 1976)

A probability-statistical approach is the main feature of this method which is analogous to the well-known method of smoothing proposed by Whittaker (Whittaker et al., 1960) and modified by Vondrak (1969). However, due to the necessity of processing a combination of statistically non-uniform data series obtained by different time services, different observers and instruments, the main condition for smoothing is enlarged by terms that take into account systematic observational errors, δ, and their variations with time. Thus we have the equation of condition,

$$\mu^2 \sum_j (\Delta''' u_j)^2 + \sum_i \lambda_i^2 (\delta_i - \delta_i')^2 + \sum_{i,j} P_{ij}(u_{ij}^* - \delta_i - u_j)^2 = \text{min.}, \quad (1)$$

where i refers to the "observer-instrument" combination; j the date of observation; u_j = (UT1 - UTC)$_j$ the value of the difference between the rotational time and the coordinated time at 12^h UT for the date, j; $\Delta''' u_j$ the third difference of successive u_j values; $u_{ij}^* = UT1_{ij}^* - UTC_j$ the observational results referred to the CIO; P_{ij} the weight of the observations characterizing their accuracy and depending on random errors; λ_i^2 coefficients characterizing the degree of systematic error (stability); and μ^2 the parameter characterizing the degree of smoothing for the series of u_j.

Universal Time computations are made weekly using a thirteen-day data interval from the preceeding Friday through the following Wednesday. This presumes that the systematic errors do not change during this thirteen-day interval and that the combination of the variations $\delta_i - \delta_i'$ between two neighboring intervals for all observers and instruments are random.

Thus the conditional equation (1) is a combination of three inter-related conditions for minimum sums of squares of three groups of random quantities: third differences $\Delta''' u_j$; differences of systematic errors, $\delta_i - \delta_i'$; and random errors, $u_{ij}^* - \delta_i - u_j$. The first of these conditions ensures a desirable degree of smoothness of the series of u_j; the second ensures the closeness of the systematic errors δ_i to their values δ_i' during the preceding interval (preservation of the system of the UT1 time scale); the third ensures the best agreement of the unknown quantities u_j and δ_i with the observations (suppression of random errors). The main feature of this method is the fact that no supposition is made beforehand as to the functional form of successive values for either the Universal Time or the systematic errors to be found. Only statistical limits are imposed on their limits.

The computation of the unknowns, u_j and δ_i, and their mean errors, m_{uj} and $m_{\delta i}$ is usually made by means of the method of least squares in which the system of linear equations resulting from the conditional equation (1) are solved. The number of such equations is equal to the number of "observer-instrument" combinations plus thirteen (the number of days to be processed). Calculated values of δ_i are used to replace the δ_i' in the processing of the next interval.

The weights, p_{ij} and the coefficients λ_i^2 are calculated by

$$p_{ij} = \frac{1}{m_i^2} (n_{ij})^{1/2}, \quad \text{and } \lambda_i^2 = \frac{1}{m_{\delta i}^2 + \sigma_i^2},$$

where n_{ij} is the number of individual time observations (groups of stars) for which a value of u_{ij}^* is determined during one evening, m_i the mean error for one observation of time, σ_i the mean square value of the variations $\delta_i - \delta_i'$ between neighboring intervals, and $m_{\delta i}$ the mean error of δ_i'. Values of m_i and σ_i are determined by analysis of the results for each "observer-instrument" combination of the preceding calendar year. The parameter μ^2 is calculated by

$$\mu^2 = \frac{1}{26} \sum_{i,j} p_{ij},$$

which ensures the stability of the frequency response characteristics of the observational smoothing for different intervals. This method is characterized by a frequency response which can distinguish periodic variations having periods greater than seven days (Figure 1). For comparison the frequency response characteristics of the Pavlov method and that of the BIH method (Annual Report, 1970) are also displayed in Figure 1.

However, the effective resolution of this method is obtained at the expense of an increase in the mean error for daily values of Universal Time which is estimated to be 2 - 5 ms. Of course, if these values were averaged over five-day intervals it would be possible to diminish these estimates to 1 - 2 ms. In that case one would smoothe real, short-period fluctuations (in particular, fortnightly variations). This is confimed by spectral analysis of the data

In a plot of spectral density (Figure 2) for daily values of UT1 - UTC calculated by our method some peaks are distinguished. These peaks represent short-period, non-uniformities in the Earth's rotation and fluctuations of verticals. The heights of the tidal peaks are in good agreement with theoretical values (shown by circles). Also shown is a plot of spectral density of raw five-day BIH values of UT1 - UTC (Feissel, 1976) which shows that the M_f wave is noticeably decreased in comparison to the M_m wave.

The Universal Time data computed by the new method have been published since 1975 in weekly bulletins (Series A) and every three months in Series E bulletins. Series A bulletins present preliminary data calculated from current observations using preliminary polar coordinates from the BIH. Once a month Series A bulletins list the final UT1(SU) - UTC that have been computed using the polar coordinates given in BIH Circular D. Series E bulletins contain the Universal Time data for a

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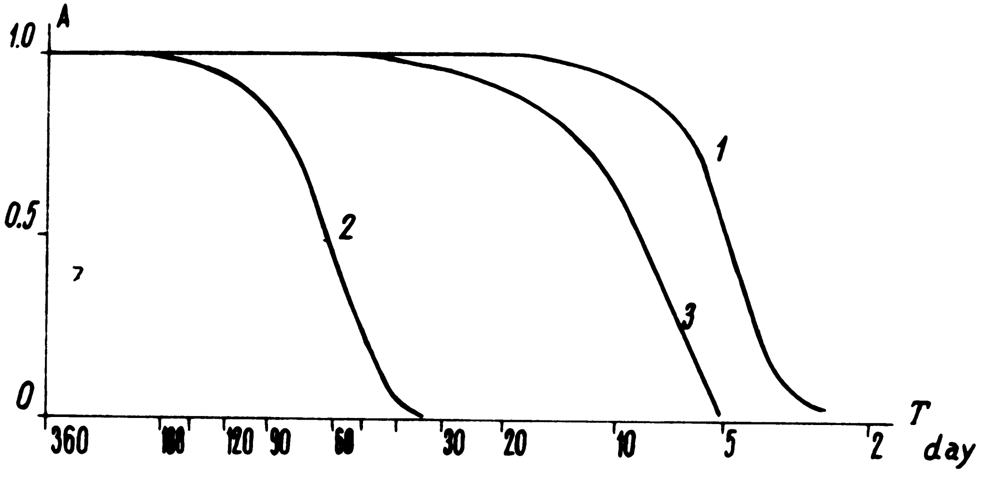

Figure 1. Frequency response of 1) this paper, 2) Pavlov's method, and 3) BIH method.

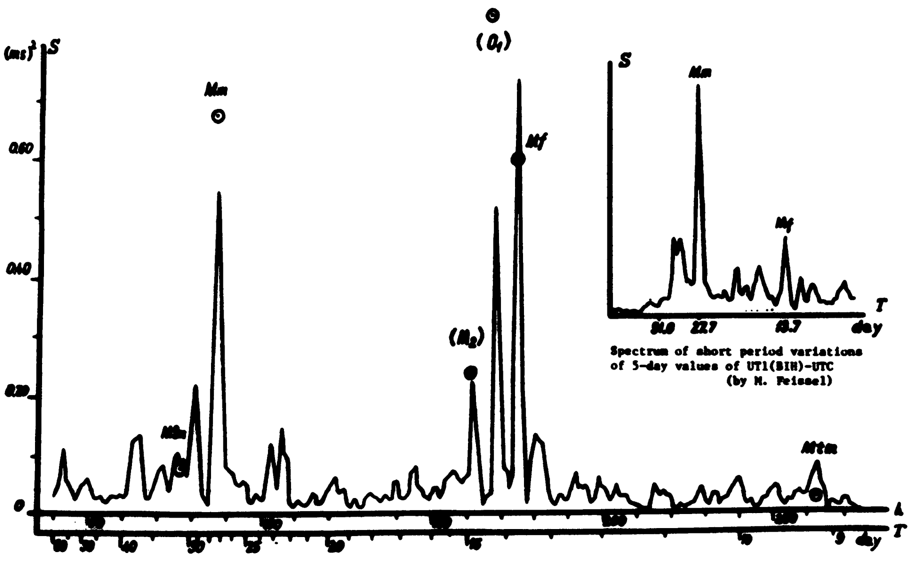

Figure 2. Spectrum of short period variations of daily values of UT1(SU) - UTC.

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three-month period and tables of observational astronomical data. We are convinced that the publication of these data should be the duty of any bureau engaged in the work of centralized processing of astronomical observations. Only in this way will it be possible for skilled persons to obtain additional information from the observational data.

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DISCUSSION

B. Guinot: The amplitude of the M_f wave in UT1 is reduced by a factor of between 0.6 and 0.7 in the BIH 5-day means, not by 0.1. The discrepancy between theoretical and observed M_f response seems to be due to an additional term, close in frequency but of unknown origin.

Ya. S. Yatskiv: I agree.