Discussion of Meaning and Definition of UT

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Abstract

The new definition of UT1 adopted by the IAU is useful but for many reasons not quite satisfactory. It depends e. g., 1) on the approximate values of some astronomical constants, and is therefore subject to revision in the future. 2) Since it is used for the FK5-based astronomical reference system, its eventual usefulness for space techniques is questioned. 3) Although the new and old UT1 merge continuously at a chosen epoch, they do not form a homogeneous series of data, in other words, the old and the new UT1 are systematically different from each other. 4) Neither the new definition, nor the way to convert the old to the new one is based on simple concepts and these are thus likely to be misunderstood by the nonspecialist user. A conceptual definition of UT1 is suggested, in order to correct this situation and a formula to realize this conceptual definition is presented, which can be used unchanged for every technique and is easily understood by the nonspecialist community.

1. Introduction

The basic need for a new definition of UT was raised by the introduction of a new system of astronomical constants. The corrections to the constant of precession and the motion of the equinox would have caused inconsistencies and systematic variations in UT1 had the old definition based on Newcomb's theories not been revised. After some spirited debating within the relevant scientific community, a new definition of UT1 was adopted at the General Assembly of the IAU in Patras. The newly adopted definition, (later called definition A for short) while useful is somehow for many reasons still not quite satisfactory. As pointed out by Aoki et al. (1982), it is "to be used with the FK5-based astronomical reference system", while Williams and Melbourne (1982), and Zhu and Mueller (1983) questioned its adequacy for the new space techniques such as VLBI and LLR, especially in view of the well known fact that the these techniques play an ever increasing important role in the determintion of UT1. Besides, as mentioned by Lieske in his letter to Aoki and other members of the Organizing Committees of IAU Commissions 4, 19, and 31, (1982), this new definition will have to be modified whenever the precession constant is modified. This prospect of a never ending sequence of definition changes worries him, a worry shared by many

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others. In this paper, we give in more detail reasons why it is worthwhile to reconsider the definition of UT1. Finally, we make a suggestion for redefining UT1.

2. Some problems with the newly adopted definition of UT1

a. At the Grenoble General Assemby of the IAU, it was resolved that the "relationship between mean sidereal time and UT1 be modified so that there is no change in either value or rate of UT1". In the paper by Aoki et al. (1982), this requirement was changed to "maintain the continuity of UT1, as determined from observations, both in value and rate **at the epoch of change**". These requirements are slightly different. The first one is somewhat ambiguous and might mean that continuity should exists not only at some chosen epoch but at any time later, so that the old UT1 and the new one would form a homogeneous series (neglect the trivial random difference caused by the individual corrections of star positions etc.). The second requirement only specifies continuity at a certain epoch. The third condition posed by Aoki et al. (1982), (i.e., to "represent a fiducial point with uniform sidereal motion in the new system") conflicts with the first requirement above. A change of 0.0002 T_u^2 and the addition of a T_u^3 term make the new UT1 inconsistent with the old TU1, although they are continous at a chosen epoch, which means that the old UT1 and the adopted new one belong to different systems. Their values differ at any epoch other than the chosen epoch. They increase at different rates. Besides, even at the chosen epoch, the observed rate of the Earth's rotation is still discontinuous, no matter how UT is defined. In any research which requires a long and homogeneous series of UT1 or the Earth's rotation rate, one still has to reprocess the old data by using the new constants.

b. Newcomb's definition of UT1 has been used for more than half a century. But, using the terminology of Eichhorn (1983), this is a "conventional" definition, or a specification. In this specification, some adopted parameter estimates are used which are subject to replacement by more accurate ones, which would cause the conventional definition to be revised.

Another example is this. The numerical values in the definition A, as are any estimates, are "accurate to some order, or degree" The coefficient of T_u^3 originally recommended by Aoki et al. (1982) is $6^s.210 \times 10^{-6}$. It holds when 1950.0 is chosen as the fundamental epoch. If 1984.0 is the fundamental epoch, the coeffiecient changes to $6^s.196 \times 10^{-6}$, and 2000.0, to $6^s.168 \times 10^{-6}$ (This shows that the number in equation (13) of Aoki et al. is incorrect.). Besides, there is more than one way to calculate mdt. Aoki and Kinoshita (1983) use

$$\zeta_A+Z_A - 2\int \sin^2(\tfrac{1}{2}\theta_A)\,d\zeta_A$$

Anther way would be to use $\int_0^T \frac{d(\zeta_A+Z_A)_{T,t}}{dt}\,dT \,\Big|_{t=o}$

where ζ_A and z_A are expressed in the form (cf. Lieske 1979)

$$(A_{00} + A_{01}\,T + A_{02}\,T^2)t + (B_{00} + B_{01}\,T)t^2 + C_{00}t^3$$

This second way leads to the same results for the coefficients of T and T^2, but a slightly different T^3 term. The coefficient of T^3 is $6^s.178 \quad 10^{-6}$ at epoch

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2000.0. Both ways are correct, the reason for the discrepancy is that the precession quantities are given only up to third order terms in time; if fourth order terms were included, the two approaches would have given identical results. Although the adopted value for the coefficient is $6^{s}.2 \times 10^{-6}$, the calculation above shows that definition A still involves some approximation process.

c. The exact concept of the fiducial point in definition A is not clear. According to Aoki et al. (1982), the sidereal and thus inertial motion of the fiducial point should be exactly a linear function of ET. UT1 does not progress uniformly. This implies that the time arguments in definition A are ambiguous.

We therefore, suggest to reconsider the definition of UT1, by replacing the conventional definition by a conceptual definition based on some fundamental principle, which is not liable to revision. This is better than only to refine the specification by, e.g., adding more terms in the old conventional definition. The new UT should be defined by some basic concept, and at the same time a numerical formula is given to specifiy the realization of this conceptual principle. We would prefer the numbers involved in the specification formula not to change; cf. the suggestion given in the next section, but this is not an absolute necessity. The numbers could change, while the principal conceptual framework remains unchanged.

3. Suggestion of a new definition of UT1

Many of the original functions of UT1 have been assumed by UTC or TAL. At present, the basic aims of determining UT1 are: 1) To specifiy one of the parameters of the Earth's orientation in space and thus provides means to compute the orientation of some objects connected with the Earth; e.g. one must know UT1 to orient a radio telescope to a space vehicle. UT1 is needed for the to determination of longitudes and certain other parameters in geodesy and other fields; 2) To describe the rotation rate and its changes for astronomical and geodynamical studies. All this suggests that geometrical quantities, namely angle and rotation rate are more intrinsically connected with UT1 than physical "time". The new definition must reflect this.

There is no point in inventing new terminology or introducing strange ideas just to complicate matters. Rather, a definition should be made as simple and easily understood as possible. Here we only want to digest some ideas from relevant previously published papers, and try to compile them in a more reasonable way to arrive at a new definition of UT1 (definition B), which is as follows.

Guinot (1981) defines UT1 conceptually as follows: "UT1 is an angle which is proportional to the sidereal rotation of the Earth, the coefficient of proportionality is chosen so that 12h UT1, in long term, remain approximately in phase with Greenwhich Noon". The formula to realize the conceptual definition (cf. Xu et al. 1982) is

$$\theta_o = a + bT_u$$

or

$$UT1 = \kappa(\theta - \theta_o)$$

where a, b, (or κ) are defining constants, θ is Greenwich rotation angle, (or stellar angle), θ_o is θ of Oh UT1. T_u is the number of Julian centuries of 36525 days of UT which have elapsed since 2000 Jan.1, 12h UT1. (JD 2451545.0).

The "Greenwich rotation angle" is defined as the Greenwich hour angle reckoned from the true departure point. Using the equation given by Aoki and Kinoshita (1983, their Eq. A2-22), it is easy to compute the value of the angle θ from observed apparent sidereal time. $\theta = \omega$ is the rotation rate of the Earth, a, b, (or κ) are defining constants, which means that they are not revised when the astronomical constants change. Revised astronomical constants will change the value of θ as well as UT1. The proper way to get a homogeneous series of Earth rotation parameters is to use the new constants to reprocess the old data. If different groups wish to use different precession constants, they can have their own UT1 series, just as the polar motions given by BIH and IPSM are also different. The difference is caused only by the uncertainties in the estimates of the defining constants, all of which refer to the same basic concept.

Definition B is applicable to all tasks. Even the values of a, b, (or κ) can be the same for each technique. The precession error, however, does effect UT1 of different techniques differently. As pointed by Zhu et al. (1983), theoretically, the precession error is equivalent to an error of the position of the celestial pole, and the effect on UT1 will not depend on source position and observing location. But in practice, it is hardly possible to determine the whole set of ERP (polar motion and UT1) by some instantaneous observations. A variety of observations at various epochs is used to determine the average UT1 during the observing period. The effect of the error of precession on the position of the pole is modulated by the Earth's rotation and therefore produces an effect which is not constant but changes with time. Because of the averaging process, UT1 is in a very complicated way affected by the error of precession: Its effect depends not only on the position of the source, but also on observing epoch and the site location, even on the other parameters to be solved for. It is therfore natural to treat this difference as an error source. Using definition B, UT1 determined by different techniques is conceptually identical, though their numerical specifications suffer from different error sources.

4. Comparison of definition B with definition A

a. Similarity

1) With constants a and b (or κ) appropriately chosen, the two definitions will give essentially the same values for UT1 at the present time. 2) For both definitions, the computed values of UT1 depend on the precession parameters. It is, in fact, unnecessary and even impossible to avoid the influence of precession. If the reference system of the specific radio source approximates an inertial system with sufficient accuracy, the absolute orientation changes of the baseline in this inertial system could be detected by VLBI observations. But this orientation change is the combination of the effects of precession, nutation, and the Earth's rotation (polar motion and UT1). It is difficult to determine ERP without knowing precession and nutation.

3) Both use the (true) departure point as the starting point (one implicity, the other explicitly).

b. Differences

1) Definition B is a conceptual one, based upon fundamental principles, while Definition A is a conventional one and based on an approximation to the constant of precession which is subject to revision. 2) In definition B, $(GMST)_o$ is abandoned; instead, Greenwich rotation time θ_o is used. Accordingly, changes will have to be made in the astronomical ephemerides whenever certain constants are revised. 3) The principal concept in definition B is simple and easy to understand by by the nonastrometric community. The discouraging complexity of the specification of the Mean Sun is likewise abondoned. 4) Definition B establishes a clear relation between UT1 and the rate of the Earth's rotation.

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