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ON DECOUPLING CIVIL TIMEKEEPING FROM EARTH ROTATION

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Abstract. During the recent 15 years intense efforts have been done in order to cease introducing leap second corrections in the UTC scale. Before, probably the final, decision at the World Radiocommunication Conference in 2015, we discuss some aspects and consequences of such a UTC redefinition, to present our own viewpoint as well.

1. INTRODUCTION

Coordinated Universal Time (UTC) is the basis for civil timekeeping in almost all countries of the world because this is a precise atomic time scale publicly available and which with an acceptable tolerance follows the Earth rotation so that we have a close approximation to the traditional, astronomically defined, mean solar time on the Greenwich meridian. Till now the level of this tolerance has been changed several times, whereas the way of monitoring has been changed only twice.

Within the first decade of its existence, from the early sixties to late 1971, UTC was kept close to the Universal Time (UT2) in the way that either the carrier frequency was corrected or small time steps were introduced ($\leq$ 100 ms). Because of this, apart from the advantages, the UTC of that time also had two drawbacks: time-unit (UTC second) duration was variable and discontinuity.

In the beginning of the seventies the UTC scale was redefined following the recommendation of the International Radio Consultative Committee (CCIR) and from January 1, 1972 it has been established in a well-defined standard way. UTC has the same unit as the International Atomic Time (TAI) scale to which it is syntonized and from which it is allowed to differ by integral number of seconds only. The absolute deviation from the Universal Time within conventional limits (at first 0.7 s and afterwards, from the beginning of 1974, 0.9 s) has been solved through the "leap-second" mechanism, i. e. by adding or removing one second at standardized moments if it is clear that the difference $|\mathrm{UTC} - \mathrm{UT1}|$ will exceed the allowed value.

Through the dissemination of UTC the standardized high-accuracy frequency is available to everyone, which is very important for many applications in science and engineering, but the discontinuity of UTC is still present so that in the late nineties first ideas arose to abolish the leap second as a corrective mechanism. Over the previous 15 years ideas about a continuous UTC scale have grown into serious proposals and actions. However, in spite of a strong support from respected experts and institutions, the proposal on adoption of the new UTC, without leap seconds, has found a positive consensus at no relevant-body meeting. The main reason has been its historical significance to civil timekeeping and non-ignorable opponent positions. The scientific and professional public is very polarized as to this proposal, and some of them have even mentioned the lack of competence of the leading proponent (e.g. Quinn 2011). Therefore, it is still impossible to anticipate if the proposal will be adopted in the future.

The initiative and actions towards the abolishment of UTC leap second are backed by the United Nations agency for radio and communication technology issues named International Telecommunication Union (ITU), or more precisely, its part specified as: Working Party 7A (Broadcast and Frequency Services) of Study Group 7 (Science Services) of Radiocommunication Sector of ITU (WPA7A, SG7, ITU-R). A number of articles followed the proposal of this reputable organization and several scientific meetings were held, where many distinguished experts from various fields expressed their opinions . Two working groups of International Astronomical Union (IAU) also considered the initiative of ITU-R, out of which the first one was operative for six years (2000-2006) and the second one for two years (2012-2014).

In the reference list of the present paper a few characteristic articles are indicated, and among the meetings at which the topic was discussed, we distinguish the following ones:

- ITU-R SRG 7A Colloquium on the UTC timescale, May 28-29, 2003, Torino;
- Colloquium "Decoupling Civil Timekeeping from Earth Rotation", Oct 5-7, 2011, Analytical Graphics Inc, Exton, Pennsylvania;
- ITU Radiocommunication Assembly, Jan 20, 2012, Geneva (RA-12);
- ITU World Radiocommunication Conference, Feb 14,2012, Geneva (WRC-12);
- ITU/BIPM Workshop on the future of the international time scale, Sep 19-20, 2013, Geneva

Many of well known authors advocate the leap second abolishment (e.g. Arias, Beard, Guinot, Klepczinsky, McCarthy, Nelson, ...), but there are many distinguished opponents also (e.g. Allen, Gambis, Finkleman, Seago, Seaman, Seidelmann, ...).

In our opinion it is much better to preserve the actual definition of UTC scale with leap seconds than that proposed by ITU-R.

2. DIFFERENCES UT1-TAI, UT1-UTC AND UTC-TAI

Bureau International des poids et Mesures (BIPM) is the institution authorized for the establishment and maintenance of the TAI. The metrological scale TAI is not distributed, but appears as the basis on which other time scales of special use are formed, such as, for instance, Terrestrial Time (TT) or UTC.

The BIPM physical time scales TAI and UTC count the same portions of time, SI seconds, and have syntonized frequencies. They are derived by using special statistical procedures on the basis of regular time comparisons among several hundreds of atomic clocks distributed in more than 70 metrological laboratories and scientific institutes all over the world.

On the other hand, the mean solar time, the traditional basis of civil timekeeping, which is very close to the astronomical UT1 time, depends on the work of only one clock governed by the rotation of our planet. True, the properties of UT1 due to the irregularities in the Earth rotation are worse than those possessed by the atomic time scales TAI and UTC, but UT1 can be in no way ignored in the time metrology. It is important to anyone needing information on the Earth space orientation, and also the notion of day is still unsuitable to be defined through work of technical devices only, no matter how sophisticated they are.

By introducing new intermediate reference systems (terrestrial and celestial) in modern astrometry from 2003, UT1 has been in a simple way related to the Earth Rotation Angle (ERA), precisely determined from the VLBI observations of extragalactic objects. The linear relationship between UT1 and ERA in radians is given by

$$\mathrm{ERA}(T_u) = 2\pi(0.7790572732640 + 1.00273781191135448\, T_u)\ ,$$

where T_u = Julian UT1 date − 2451545.0 UT1. For final derivation of UT1, or more precisely, of the Earth-rotation parameter UT1-UTC the responsibility belongs to International Earth Rotation and Reference System Service (IERS). IERS also determines predictions of UT1-UTC and, based on them, announces the date of UTC leap second correction several months in advance.

Beginning from January 1, 1972, since when the present form of UTC with leap seconds adjustment exists, the relationship between the scales UTC, TAI and UT1 is defined by the differences:

$$\mathrm{UTC} - \mathrm{TAI} = \mathrm{N} \qquad \text{and} \qquad \mathrm{UTC} - \mathrm{UT1} = \mathrm{L}\ ,$$

so that N is an integral number of seconds and $|\mathrm{L}| < 0.7\,\mathrm{s}$ (before 1974), or $|\mathrm{L}| < 0.9\,\mathrm{s}$ (from 1974), as said in the previous section. All the values of the differences UT1-TAI and UTC-TAI realized up to now in accordance with this convention are plotted in Fig. 1, and in the case of the difference UT1-UTC in Fig. 2.

On the basis of a clearly expressed linear trend of increasing differences UT1-TAI during the last half century, in the era of atomic clocks, we can conclude that an approximately constant difference in the size of units of the time scales UT1 and TAI has existed and the astronomical second (UT1 second), very close to the mean solar day duration multiplied by 1/86400, lasted longer than the SI second. Figuratively speaking, the rate of UT1 clock was slower than that of TAI and UTC clocks of the same technical specifications. The only difference between the latter two clocks is that the TAI one worked all the time and the UTC clock from 1972 till now has been 25 times set back by one second, in order to be caught up by the UT1 clock, i. e. that the times shown by them are approximately equal within the limits of conventional tolerance[1] L (see Table 1).

[1] Before 1972 the UTC clock was several times set back by 100, 50 or 20 ms, and also a few times its rate was changed (elastic second era).

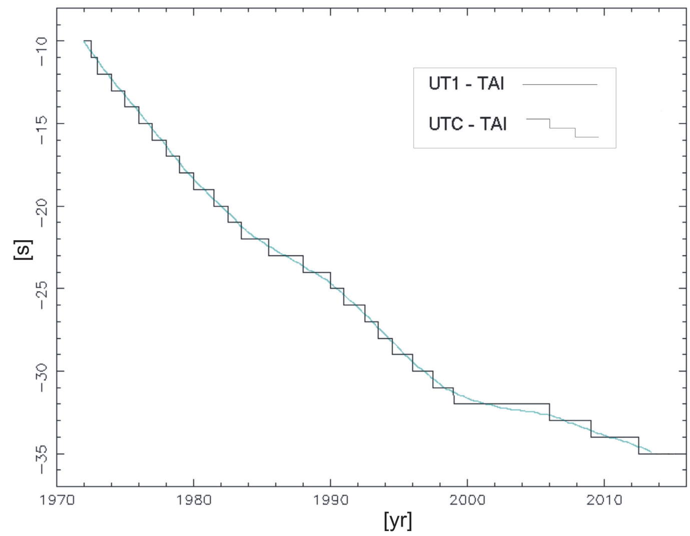

Figure 1: Differences UT1-TAI and UT1-UTC in the leap-second era (beginning from 1972).

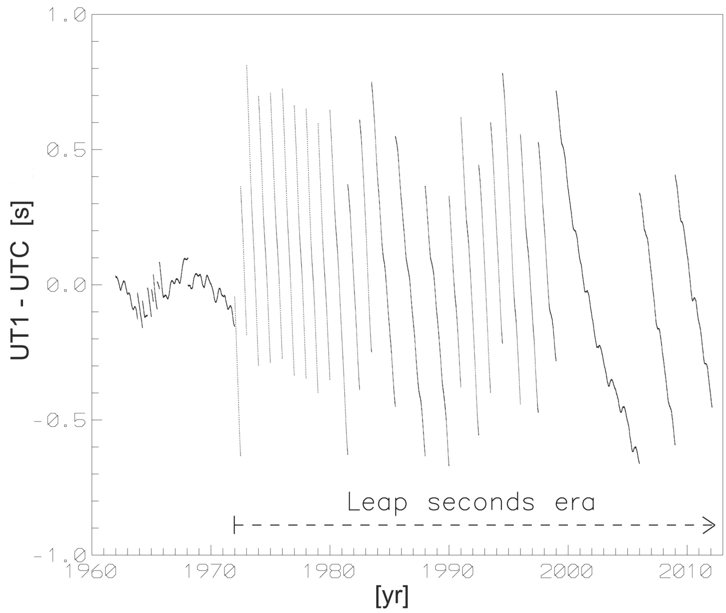

Figure 2: Discontinuities in the difference UT1-UTC.

Table 1: History of all UTC – TAI definitions

From	To	UTC – TAI [s]
1961.01.1	1961.08.1	–1.422818 – (MJD-37300)×0.001296
1961.08.1	1962.01.1	–1.372818 – (MJD-37300)×0.001296
1962.01.1	1963.11.1	–1.845858 – (MJD-37665)×0.0011232
1963.11.1	1964.01.1	–1.945858 – (MJD-37665)×0.0011232
1964.01.1	1964.04.1	–3.240130 – (MJD-38761)×0.001296
1964.04.1	1964.09.1	–3.340130 – (MJD-38761)×0.001296
1964.09.1	1965.01.1	–3.440130 – (MJD-38761)×0.001296
1965.01.1	1965.03.1	–3.540130 – (MJD-38761)×0.001296
1965.03.1	1965.07.1	–3.640130 – (MJD-38761)×0.001296
1965.07.1	1965.09.1	–3.740130 – (MJD-38761)×0.001296
1965.09.1	1966.01.1	–3.840130 – (MJD-38761)×0.001296
1966.01.1	1968.02.1	–4.313170 – (MJD-39126)×0.002592
1968.02.1	1972.01.1	–4.213170 – (MJD-39126)×0.002592
1972.01.1	1972.07.1	–10
1972.07.1	1973.01.1	–11
1973.01.1	1974.01.1	–12
1974.01.1	1975.01.1	–13
1975.01.1	1976.01.1	–14
1976.01.1	1977.01.1	–15
1977.01.1	1978.01.1	–16
1978.01.1	1979.01.1	–17
1979.01.1	1980.01.1	–18
1980.01.1	1981.07.1	–19
1981.07.1	1982.07.1	–20
1982.07.1	1983.07.1	–21
1983.07.1	1985.07.1	–22
1985.07.1	1988.01.1	–23
1988.01.1	1990.01.1	–24
1990.01.1	1991.01.1	–25
1991.01.1	1992.07.1	–26
1992.07.1	1993.07.1	–27
1993.07.1	1994.07.1	–28
1994.07.1	1996.01.1	–29
1996.01.1	1997.07.1	–30
1997.07.1	1999.01.1	–31
1999.01.1	2006.01.1	–32
2006.01.1	2009.01.1	–33
2009.01.1	2012.07.1	–34
2012.07.1	?	–35

3. SOME ESSENTIAL ISSUES REGARDING THE NEW UTC

The proposal for ceasing the further introduction of leap seconds in the UTC scale has caused many controversies because the acceptance of such a free atomic time scale for civil time keeping would *de facto* mean a complete end of its traditional link with the Earth rotation. Many questions concerning this can arise, from essential ones to quite formal, but we shall here consider only some of them and attempt answering them through brief discussions.

3. 1. IS THE UTC DISCONTINUITY A REAL NUISANCE?

Firstly, we can pose the question if UTC is discontinuous at all.

With regard to the interrupted lines representing the difference UT1-UTC in Fig. 2, the answer is certainly yes, but one should bear in mind that together with UTC a stable frequency of atomic time standard is continuously disseminated, so that the UTC scale is made of a continuous sequence of successive SI seconds. This means that every time interval between two moments t_1 and t_2, measured from the same initial epoch t_0 in seconds, is simply equal to the difference $t_2 - t_1$. Therefore, we can treat UTC as a continuous time scale when using the SI second, or any multiple of its, as unit.

Interruptions in the differences UT1-UTC are not due to interruptions in UTC, but to the conventional application of the change in duration of one UTC day at the moment of applying the leap-second mechanism. Then by shifting the marker for the beginning of a day in the UTC scale by one SI second, to either of the sides, we influence the shortening or lengthening of the preceding day[2]. For this reason the action for abolishing the leap second can be understood as a desire to equalize the UTC day duration and that it becomes a time unit always lasting exactly 86400 SI seconds.

Of course, we can ask the question, why it is important that a day has a fixed duration, when the months and years do not have such a property. The answer is simple: the number of days in any coming months and years can be always accurately determined, but not also their lengths, due to the variable Earth rotation and the existing limitation for the deviation |UT1-UTC|. However, this logically leads us to look for the answer to the following question.

3. 2. WHAT OR WHO NEEDS ABOLISHING THE UTC LEAP SECOND?

The only situation which we can imagine is programming of automatic activation of some technical device at a precisely defined moment of civil time, because with increasing the time distance of this moment the possible error in its location in the UTC scale also increases.

For instance, if we want this device to be automatically turned on in a fixed number of SI seconds, beginning from a defined moment, we cannot know precisely even the calendar date when this will occur in the future. Also the converse, if we wanted any activation of this device at an exact moment of the fixed calendar date, we would have to know precisely in how many SI seconds this will take place. In both cases, the actual UTC scale definition with leap seconds produces problems.

[2] In each of the 25 cases till now the leap second has been inserted in the UTC scale, i. e. the UTC day lasted 86401, instead of 86,400 SI seconds.

We do not want to speculate here what kind of devices they could be and for what circumstances their work has to be programmed in civil time (not in another existing continuous time scale, e.g. TT, TAI, or UTC(GPS), but in our opinion during the last 15 years the advocates of the UTC redefinition could have described in more detail "technical inconveniences" arising due to the UTC leap second. Especially, if borne in mind that there also exist users of modern computer, communication and satellite technologies to whom the leap second produces no technical problems.

At present it seems to us that the reasons for the proposed UTC redefinition are of administrative nature only.

3. 3. DO ANY SCIENTIFIC REASONS EXIST IN FAVOR OF THE UTC REDEFINITION?

The secular deceleration of the Earth rotation is one of them that is mentioned most frequently, but according to the results of the Earth rotation monitoring in the XX and XXI centuries it will be no serious argument for a long time in advance.

According to the geophysical studies the secular deceleration of the terrestrial rotation is equal to about 5.5×10^{-22} rad s^{-2} (Lambeck 1980). Based on this, the accumulated values for the UT1-TAI difference and the corresponding number of leap seconds, which would have to be introduced, can be estimated. In Fig. 3 we can see a presentation of such an estimate over the interval of 1000 years and it is can be noted that this number is expected to increase in five centuries from the value of 0.6, which it has now, to 4, and in the end of the millennium to even more than 6 per year (Arias, Guinot 2004).

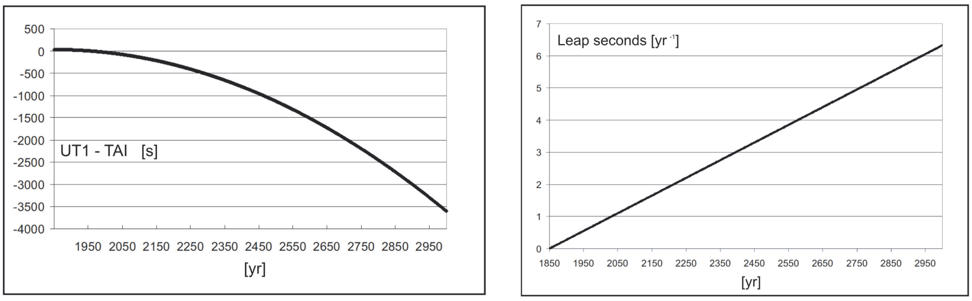

Figure 3: The projections of the UT1-TAI values(left) and increasing number of the leap-seconds per year (right) in the millennial time-span. (Arias, Guinot 2004).

However, the practical purpose for such crude and distant theoretical predictions is not clear since they do not suggest any urgency in solving the given problem. On the other hand, the observational data for the last hundred years do not indicate any deceleration in the Earth rotation, but quite the contrary.

In Figure 4 the length-of-day excess variations during the last four centuries (telescope era) and during the last five decades (atomic-clock era) are given in parallel. We can see that, though the theory and old observations indicate increasing in the day length, during the last 100 years, there exists a clear trend of its decreasing, i.e. of accelerating the Earth rotation.

Already now one can expect that in 2060, at the end of the first century of UTC existence, the real increase in day length, compared to that from the beginning of the 1960s, will be significantly different from $+1.7$ ms d^{-1} cy^{-1} (Stephenson, Morrison

1995), because from that time the average day length has already become shorter by about 2 ms (Figure 2, right), so that the increase rate is -4 ms d^{-1} cy^{-1} currently.

From Table 1 we can see that the number of leap seconds within the interval (1972-1993) is 17, whereas afterwards, during the next 20 years, only 8 leap seconds were introduced. This is a clear confirmation that the concern about increasing the number of leap seconds is unjustified, at least in the near future.

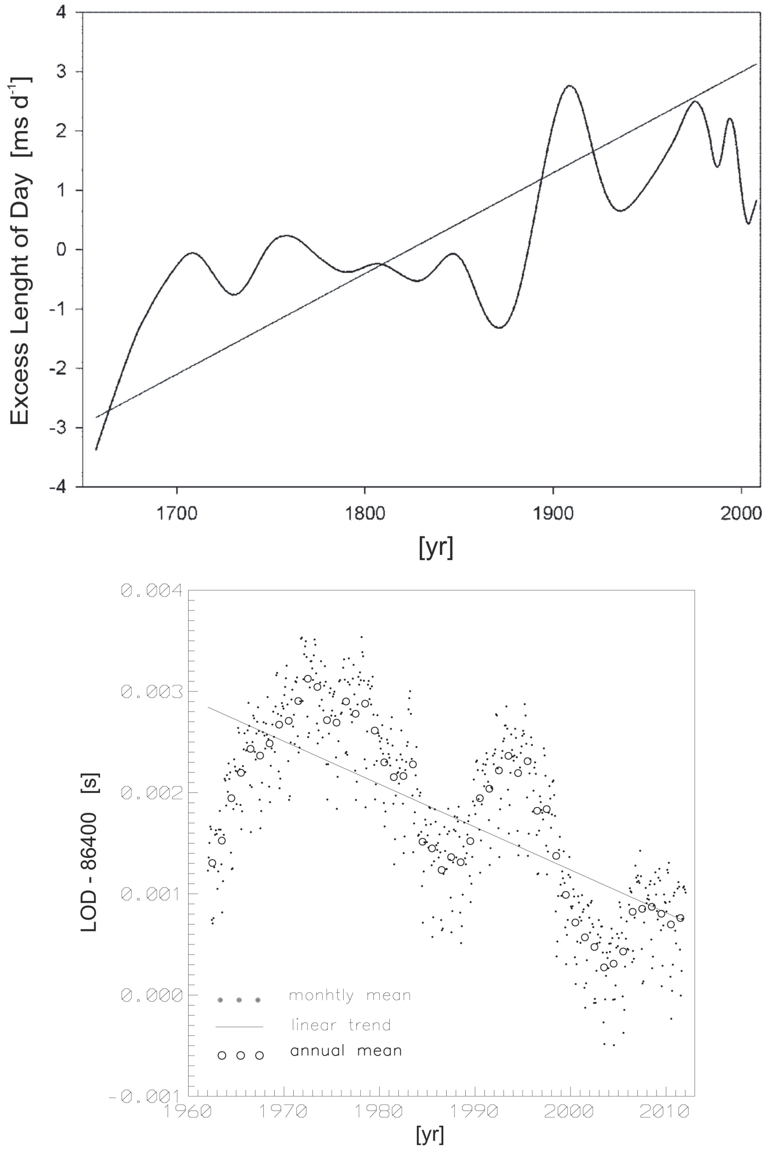

Figure 4: (Above:) Smoothed-out values of day-length excess and their linear (theoretical) trend in the telescope era (McCarthy, Seidelmann 2009) and (Below:) the mean monthly and mean annual values of the excess with linear trend in the atomic-clock era (according to the IERS data).

3. 4. CAN "THE DAY SAVING TIME" BE ARGUMENT IN THIS DISCUSSION?

Those advocating the new UTC, in order to diminish the importance of the increasing deviation of UTC from UT1, are inclined towards comparisons with seasonal legal-time shifting by ± 1 h and they suggest a leap hour as a good substitution for the leap second.

For example:
"We especially wished to show that the public accepts a departure of the legal time with respect to solar time by an amount reaching hours and, in many countries, time steps of one hour twice a year. Compared with this offset, the abandonment of leap seconds would introduce possible offset of 3 or 4 min by 2100, and half an hour between 2500 and 2600. It would be quite sufficient, for many centuries, to have a unique, continuous and uniform world time and to adjust legal times according to the wishes of citizens by steps of one hour, exactly as is already done twice a year." (Guinot 2011)

We do not think that the entire public are keen to accept "the day-saving time", nor that it is anywhere introduced following the will of the majority of citizens. Any time scale with overlaps and gaps of 60 min width can be characterized anyway, but not as good one. This is a splendid example demonstrating drastically what takes place when the time policy is regulated by someone authorized to make decisions, but who at the same time has not yet understood what the purpose of a time scale is.

According to our standpoint it would be much better if distinguished authorities for the field of time, such as, for instance, the author of the quotation given above, and international organizations, such as ITU and IAU, recommended to the governments worldwide to abolish the nuisance known as "day-saving time", than the tenacious advocating decade and half long for UTC redefinition, which should ensure a more precise link between the future activities of some undefined automated devices and the civil time. The history of formation of time scales is too complex (see e.g. McCarthy, Seidelmann 2009) to deserve frequent changes without any strong reason. This is especially true if there is no general agreement of the scientific and other public, as is the case here (see e.g. Gambis 2014).

3. 5. IS AN ALTERNATIVE UTC REDEFINITION POSSIBLE?

UTC without leap seconds following UT1 over sufficiently long time intervals, of a few decades, perhaps a whole century, can be realized by changing the length of the time-scale unit and by increasing the tolerance for the difference |UT1-UTC|.

For instance, if for UTC only, instead of the SI second, another unit were used, let it be named astronomical or civil second, which were always determined on the basis of all previous UT1-TAI values with initial epoch January 1, 1958, we would get a scale with a frequency related to the standard TAI scale through one multiplier only and then by means of TAI it is related to the other scales having the SI second as the unit. In this way we would derive standardized UTC scales, easily convertible into one another, whereas the interval between two neighboring versions could be fixed, in earlier versions, say, to 50 years, and in later ones to 100 years (e.g. UTC_{2050}, UTC_{2100}, UTC_{2200}, etc.), because any future correction of the civil second would be finer than the preceding ones.

Such a conception of UTC would enable the preservation of a link with the Earth rotation and the precise scheduling of events in the civil time much farther into the future would be realizable. All of the existing time scales, all physical and astronomical constants, as well as the existing software and hardware infrastructure, based on the SI second, would not be changed and could be operative in the future.

Figure 5 shows how a hypothetical change of the atomic-second length would affect the differences UT1-TAI from 1955 to 1999 (Jones 2000). The SI-second length, equal to 9 192 631 770 specific transitions in the atom Cs 133, has been adopted because of the prevailing desire in the astronomical community according to which it should be as close as possible to the second of ephemeris time (ET) and the results of experiments from the late 1950-ties (Markowitz et al 1958). However, if it had been chosen to be larger by 167, i.e. to correspond to the UT second on January 1, 1958, the deviations UT1-TAI would have been almost four times smaller and an optimal result would have been obtained for +227. We have obtained for the optimum +212, but for the interval [1962-2011].

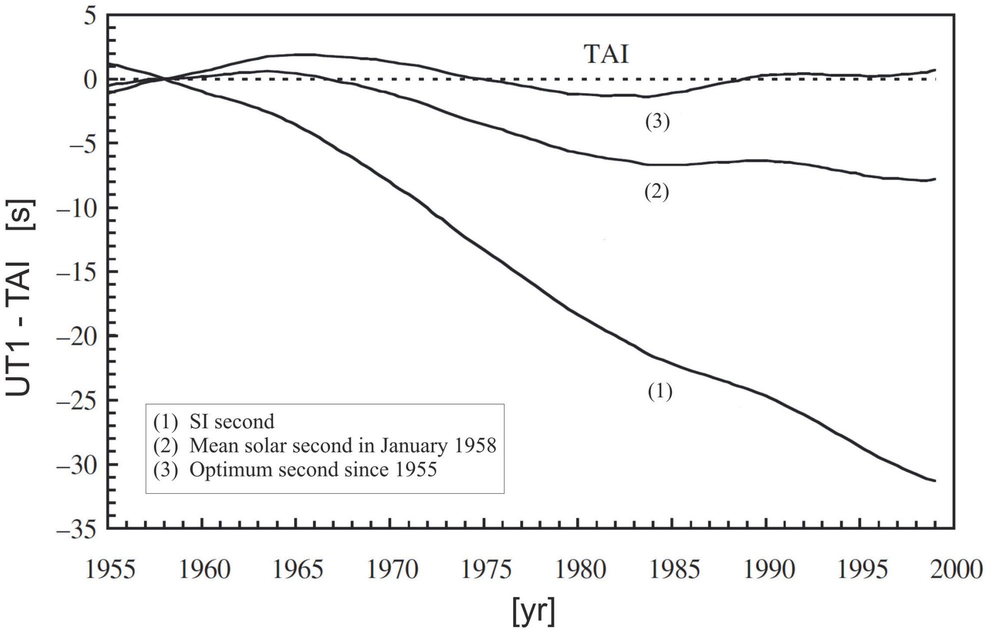

Figure 5: Dependence of deviations UT1-TAI on the size of TAI-scale unit. (Jones 2000).

4. CONCLUSION

In our opinion, the UTC scale should still maintain its present definition, since it successfully fulfills the purpose and meets the objectives of its establishment.

The adoption of the proposed UTC redefinition would have quantitative and qualitative impact on the present conception of civil timekeeping, based on not sufficiently persuasive arguments. As long as the progress in meeting the standpoints has not been made, the decision of such global importance should not be accepted by outvoting at any instance.

The options for another UTC definition can be found, however they have to be searched for in future carefully and in an unforced manner, simultaneously with analyzing all previous values of UT1-TAI deviations. Anyway, it is our opinion that civil timekeeping should preserve its astronomical basis with all the support that modern technology can provide, and not to abandon it for the sake of technological or some other comfort.

Acknowledgement

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