(Preprint)

Mean Solar Time, UT1, UTC, and Leap Seconds

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Historically, civil timekeeping has been based on mean solar time. With the discovery that the rotation of the Earth was not perfectly uniform, time scales based on Earth rotation were differentiated from more uniform scales, with astronomical time still serving as the basis of calendars and time of day. UT1 is now the observationally determined time of day based on the rotation of the Earth, whereas International Atomic Time (TAI) is a precise uniform time scale determined from atomic clocks. Coordinated Universal Time (UTC) was introduced in 1972 as an atomic time scale referenced to TAI, but with epoch adjustments via leap seconds to remain within one second of UT1 for the purposes of civil timekeeping. A family of dynamical times was further established to satisfy the theory of relativity and the requirements of solar system ephemerides.

A comparison is made between mean solar time, determined from Newcomb's expression and from a modern ephemeris, with UT1. The differences are less than 0.2 second. Also, various determinations of the long term trend in Delta T and the observed values are presented, illustrating the uncertainty of predicting when leap seconds will be necessary in the future.

After a decade of consideration, a proposal to redefine UTC without leap seconds was forwarded to the Radiocommunication Assembly of the International Telecommunication Union (ITU-R). The issue is not restricted to telecommunication, but has far-reaching impact scientifically, publicly, and legally. The 2012 Radiocommunication Assembly postponed any decision regarding the definition of UTC for at least another three years. The ITU-R postponement was offered to ensure that all other technical options were fully addressed. The World Radio Conference adopted a resolution supporting further studies.

If the definition of UTC is changed and future leap seconds are eliminated, the difference between UTC and UT1 will grow without limit, and the use of UTC, as giving UT1 within one second, would become invalid. Regular and accurate knowledge about the Earth rotation with respect to the celestial reference frame would be necessarily obtained from some source distinct from the time of day. For space surveillance, the pointing of telescopes could not rely on UTC as a close approximation to UT1.

Because changes to space surveillance software and hardware may be necessary, one option should consider keeping UTC as is, and add official recognition of an alternative time scale without leap seconds for technical applications that require such a time scale. This technical approach was advocated by the ITU-R and BIPM more than a decade ago, and is unofficially practiced today.

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INTRODUCTION

Mean solar time was used for uniform-time measurement for millennia and has been used as the basis for civil time for centuries. When variability in the rotation of the Earth was discovered in the 20th century, Ephemeris Time was established as a theoretically uniform scale (based on the independent variable of solar-system ephemerides), and Universal Time became a measure of Earth rotation which kept pace with the synodic day and which served as the global basis of civil timekeeping. At about the same time, precise time scales based on atomic clocks were developed. In the 1950s and 1960s the different timing centers, using various technologies as frequency sources, were seeking to coordinate their broadcast time scales with the rotation of the Earth by introducing small steps or changes in the length of the broadcast second.[1] The advent of space-flight initiated more global coordination, and as precision and techniques improved, it became apparent that slight variations in the length of the broadcast second, or equivalently in broadcast frequency, were becoming increasingly inconvenient and potentially troublesome.[2]

After the *Système International d'Unités* (*SI*) second was redefined in 1967 to be based on the radiation of the hyperfine transition of the cesium-133 isotope, a standard time scale called *International Atomic Time* (TAI) was developed based on the accumulation of SI seconds from ensembles of atomic frequency standards.[3] However, pure atomic frequency was considered unsuitable for civil timekeeping, because atomic frequency standards maintain a rate different than Universal Time of day. To eliminate the previous problems from varying the broadcast second, the epochs of the atomic scale were occasionally adjusted relative to TAI by inserting (positive) or neglecting (negative) leap seconds to remain within one second of UT1 for civil timekeeping. This system went into effect in 1972 and is called Coordinated Universal Time (UTC).[4]

In the 1970's, difficulties concerning the definition and determination of Ephemeris Time were becoming operationally apparent, and a group of dynamical time scales, based on the theory of relativity, were developed. These evolved to be Terrestrial Time (TT), Barycentric Coordinate Time (TCB), Geocentric Coordinate Time (TCG), and Barycentric Dynamical Time (TDB).[5, 6, 7, 8, 9] More recently, highly specialized background time scales have been developed related to TAI or UTC. The reasons for their existence vary, including system security or avoiding leap seconds. Examples include GPS time, which approximates TAI without leap seconds and with a fixed offset, and communications systems that maintain epoch offsets from other time scales for security purposes.[10]

Coordinated Universal Time (UTC) was recommended as a means of broadcasting time signals by the International Radio Consultative Committee (CCIR),[*] after official consultation with affected scientific organizations such as the International Astronomical Union (IAU). UTC provides the TAI frequency and time scale while serving as an atomic realization of UT1 within ±0.9 seconds. UTC is the basis for time broadcasts by national time services and is the basis for time re-distributed by other services. The predicted difference between UTC and UT1, known as DUT1, is made available to a precision of 0.1 seconds. The Bureau of Longitude (BIH) was responsible for the international standardization of UTC until 1988. The International Bureau of Weights and Measures (BIPM) took over responsibility for TAI, and the International Earth Rotation and Reference Systems Service (IERS) became responsible for UT1, DUT1, and leap-second announcements.[11, 12, 13]

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[*] The CCIR is the predecessor of the ITU-R.

REDEFINITION OF UTC: 2000-2012

A proposal to redefine UTC by halting leap seconds after 2017 was advanced from Study Groups of the Radiocommunication Sector of the International Telecommunication Union (ITU-R) for consideration by the ITU-R Radiocommunication Assembly in January, 2012. The proposal originated within ITU-R Working Party 7A, which appointed a Special Rapporteur Group (SRG) on the future of UTC in October 2000 to address the following ITU-R Study Question:[14, 15]

1. What are the requirements for globally-accepted time scales for use both in navigation and telecommunications systems, and for civil timekeeping?
2. What are the present and future requirements for the tolerance limit between UTC and UT1?
3. Does the current leap-second procedure satisfy user needs, or should an alternative procedure be developed?

The Study Question further decided that the "studies should be completed by 2002 at the latest", but this completion date has been continually extended up to 2012, suggesting that consideration of the Study Question was never settled. This is curious because the Study Question also decided that "the results of the above studies should be included in (a) Recommendation(s)."

The proposal to halt leap seconds is now time worn.[16] By 2002 the SRG had already reportedly "converged to the opinion" to halt leap seconds, and called the ITU-R *Special Colloquium on the Future of UTC* in 2003 to present and discuss its judgment with interested and representative parties.[17] At the colloquium, which was advertised as "concluding" and for "drafting a recommendation to the ITU-R,"[18] the rapporteur group offered the substitution of leap seconds with less-frequent *leap hours* to "satisfy all civil requirements and concerns" regarding potential problems with the definition of national time scales tied to Universal Time. [19, 20] However, attendees countered that continuing use of the name "Coordinated Universal Time" and "UTC" was potentially harmful and technically confusing, because the label "Universal Time" was a technical term that has always been reserved for time "linked" to Earth rotation.[21] The consensus recommendation for a change of name was discounted by the SRG to potentially evade "great confusion and complications in the ITU-R process," and the purpose of the colloquium was re-characterized to suggest that the SRG never had a conclusive proposal under consideration.[22, 23] Meanwhile, ITU-R delegates from the USA and SRG proposed a revised Recommendation calling for the replacement of leap seconds with leap hours, but the specification of adding future leap hours was eventually dropped within Working Party 7A, and the result became a proposal to simply discontinue leap seconds.[24]

Answers to the Study Question would help resolve the uncertainty about the user requirements and an optimum means of satisfying the users' needs. User surveys have favored the *status quo*, in some cases overwhelmingly. There has been no consensus on the subject of UTC redefinition in either Working Party 7A or its parent, Study Group 7. On the basis that objections were not sufficiently technical, the proposal to redefine UTC was forwarded to the Radiocommunication Assembly of 2012.

STATUS OF PROPOSED REDEFINITION OF UTC

At the Radiocommunication Assembly in January 2012 (RA-12), about 190 countries considered the proposal to redefine UTC. Simultaneously, ISO Technical Committee 37 offered a technical opinion that the name of the time scale should be changed if redefined.[25] The Assembly's president suggested that nations were evenly divided among those in favor, those against, and those undecided. As a result, the Assembly agreed that changes to the definition of UTC required additional study on the broader implications and wider participation from administrations and external organizations. As a result, the World Radio Conference (WRC) adopted a resolution, and included the item in the 2015 agenda, calling for necessary studies on the feasibility of achieving a continuous reference time-scale, other options for a change, and the broader implications of the proposed change.

ITU-R Contribution from the Russian Federation

Following RA-12, the Russian Federation submitted a contribution to ITU-R Study Group 7 requesting that the following actions:[26]

- The WP 7A consider increasing the number of international meetings to two per year.
- External organizations should be kept informed of the progress being made in the studies.
- Administrations not participating in SG 7 studies should be kept informed.
- The WP 7A should inform the other ITU Study Groups on the current studies.

In addition to technical and regulatory issues, Study Group 7 is asked to study the societal implications of the modification of the civil time scale, organizational issues, the use of other technical options (like a leap minute), and the timing required for bringing into use a new time scale.

Further, the Russian Federation contribution recited the list of external organizations from WRC-12 that should be informed about the current status of the studies related to WRC resolution: International Maritime Organization (IMO), International Civil Aviation Organization (ICAO), General Conference of Weights and Measures (CGPM), Consultative Committee for Time and Frequency (CCTF), Bureau International des Poids et Mesures (BIPM), International Earth Rotation and Reference Systems Service (IERS), International Union of Geodesy and Geophysics (IUGG), International Union of Radio Sciences (URSI), International Organization for Standardization (ISO), World Meteorological Organization (WMO), and International Astronomical Union (IAU). It is notable that this list does not include any organizations dedicated to software or computing.

UT1 AND MEAN SOLAR TIME

Mean solar time was the basis for all civil time keeping until the irregular rotation of the Earth was confirmed in the first half of the twentieth century. Then Universal Time was introduced based on measurements of the rotation of the Earth and UTC, based on atomic clocks stepped to stay within 0.9 second of UT1, became the basis of civil time keeping eventually world wide. The question has been raised at various times as to how close UT1 and UTC is to mean solar time.

A study to determine the answer to that question was undertaken, where an object moving around the Earth at the rate of Newcomb's fictitious mean sun was modeled in software and the transits of the Sun over the Greenwich meridian were calculated for the period 1972 to 2012. The results of that computation are shown in Figure 1. Theoretically the difference between UT1 and mean solar time should be $^{1}/_{365¼}\ \Delta T$. A plot of that value is also shown in Figure 1.

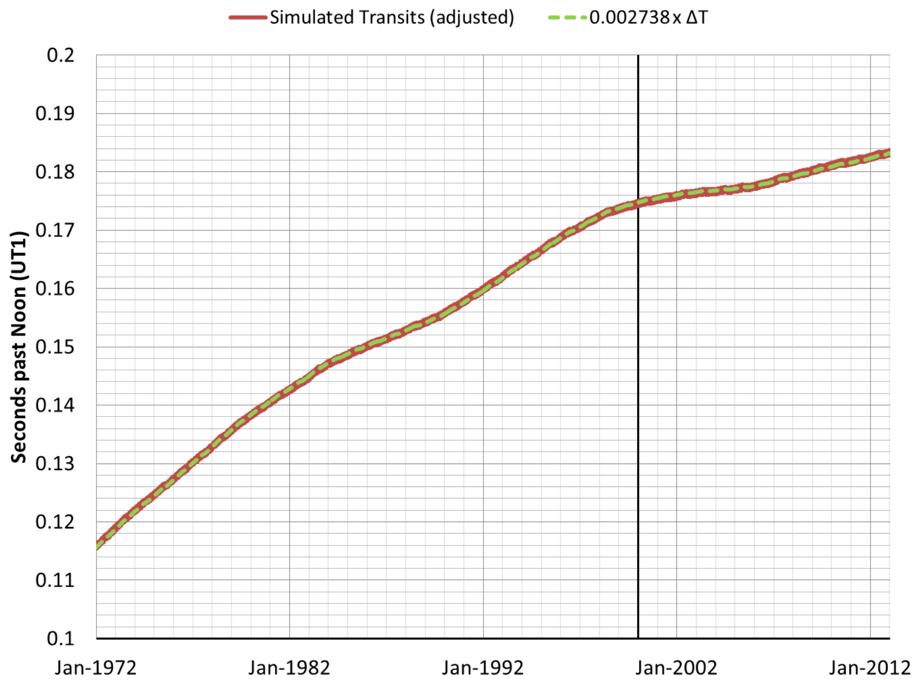

Figure 1 UT1 – mean solar time

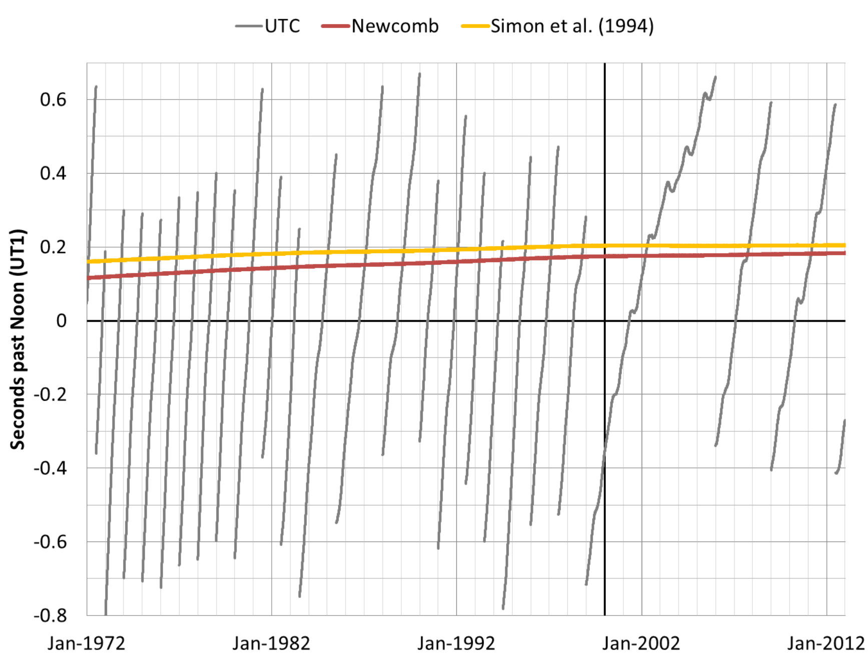

Figure 2 Differences between different mean solar time expressions and UTC and UT1

Recognizing that Newcomb's expression for mean solar time was based on observations prior to 1900, a more modern ephemeris of the Sun was also used. This is the theory of the solar system by Simon *et al*. which is basically fit to the JPL development ephemerides.[27] Figure 2 shows the difference between the two expressions for the mean sun and the values of UT1 and UTC. The differences between mean solar time and UT1 are less than 0.2 second at this time.[28]

Continuous Reference Time Scale

A potential area of technical confusion is the WRC-12 statement of record regarding the need "to consider the feasibility of achieving a continuous reference time-scale, whether by the modification of coordinated universal time (UTC) or some other method."[29] This unfortunate characterization promotes a technical misunderstanding that the present definition of UTC is not continuous, or worse, that "UTC is not a time scale on account of its discontinuities."[30] A dictionary defines *continuous* as "marked by uninterrupted extension in space, time, or sequence."[31] UTC is a record of the progression of atomic seconds that intend to be of equal duration. *Continuity* is less of a specification of the labeling of parts and more of a characterization of whether the sequence is interrupted. Therefore, by definition UTC is already continuous, and thus the precise requirements motivating a so-called "continuous reference time-scale" different than UTC are in need of clarification.

Options for Consideration

The WRC resolution calls for the consideration of the options. The following are options that should be considered:

1. Retain the *status-quo*, UTC as is.
2. Redefine UTC without leap second as was proposed, but not adopted.
3. Redefine UTC without leap seconds and rename it.
4. Retain UTC as is, but with supplementary means of accommodating leap-second adjustments (such as adjusting the rate of clocks during the period before the leap second).
5. Adjust UTC using a different duration, such as leap minutes.
6. Supplement UTC officially with an additional atomic time scale, for example TAI or GPS time.
7. Drop UTC and make an atomic time scale the civil time scale.

The following discussion explores some advantages and disadvantages of UTC with leap seconds versus a version of an atomic time scale independent of the rotation of the Earth or mean solar time.

ISSUES CONCERNING THE RECOMMENDATION TO REDEFINE UTC

There are a number of issues concerning the proposed redefinition of UTC that do not appear to have yet been satisfactorily considered and answered. There are differences of qualified opinions on the technical issues and, in most cases, supporting documentation is limited. A number of papers written, including those contained within a special issue of *Metrologia* on the subject, simply affirms that there are differences of opinion. The international colloquium on *Decoupling Civil Timekeeping from Earth Rotation* suggested that the discovery of potential issues has not been exhausted, and more work is needed to provide information about repercussions and suggested approaches toward reaching solutions.[32, 33] At best, we can only attempt to increase awareness of the different issues and provide commentary with the hope that these issues could be largely resolved before any final action is taken concerning the proposed redefinition of UTC.

Significance with Respect to Radiocommunication

The recommendation to redefine UTC without leap seconds was forwarded for consideration by the Radiocommunication Assembly on the grounds that opposition within the study groups could cite no technical issue related to radiocommunication. However, any radiocommunication issue at this time seems unremarkable compared to other technical, legal, and public issues. The issue supposedly relevant to radiocommunication is that "advances in telecommunications, navigation and related fields are moving towards the need for a single internationally recognized time scale to regulate and provide uniformity to these systems."[34] However, UTC is already a single internationally recognized time scale, and there is nothing inherent to recent advances in these fields that require calendar days to have equal atomic duration. The argument that leap seconds make UTC discontinuous is a confusing line of debate; our calendar has leap days (February 29th), but that does not make the calendar or its definition discontinuous. The existing UTC standard with leap seconds remains capable of time-tagging events unambiguously and with full atomic accuracy for centuries to come, while also satisfying long-standing requirements for civil clocks maintaining mean solar time.

Involvement of International Standards and Scientific Organizations

Currently there is a shortage of unified responses by stakeholder organizations. According to a summary by the former chairman of the SRG and Chairman of WP 7A:[35]

> Studies and information gathering on the potential future of the UTC time scale have been conducted over the past ten years by special groups from the ITU-R, the IAU, the IERS, URSI, the American Astronomical Society, and others. The issue of a continuous time scale for general usage has been pushed aside or generally ignored by the scientific societies at large. Consequently, special study groups have been faced with little interest from the parent bodies, which has resulted in an inability for some to make informed decisions.

Ordinarily, organizational abstentions would be regarded as contentment with the *status quo*, or else evidence of a lack of consensus amongst professional memberships; however, ITU-R study groups have interpreted this situation as one of organizational neutrality or as "having no concern" about the subject of UTC redefinition.[36] Still, the named organizations only represent a small fraction of the immense UTC user base, and ironically, the official positions of these named organizations are still largely indeterminate after a decade of consideration.

Other scientific and international standards organizations should be officially consulted and involved with the proposal to redefine UTC. Considering the wide impact of UTC redefinition and its technical and non-technical ramifications, the ITU-R may not be sufficiently positioned to broadly consider this issue. It has been suggested that responsibility for the definition of UTC should now be considered under the Meter Convention.[37]

Time Scale Nomenclature

When the conceptual definitions of time scales have changed, the names have also been changed to avoid confusion. The term *Universal Time* was introduced and encouraged to overcome a twelve-hour ambiguity with the earlier term for mean solar time at Greenwich, *Greenwich Mean Time* (GMT).[38] In 1925 astronomical and navigational almanacs in the USA and Great Britain switched from the "astronomical day", which began and ended at noon, to adopt the civil day, beginning and ending at midnight; however, the British *Nautical Almanac* continued to label this new convention as GMT. Although the IAU has recommended since 1928 that "astronomers are advised not to use the letters GMT in any sense for the present," the acronym still survives as a common navigational synonym for UT1, and in non-astronomical usage as a synonym for UTC.[39, 40] Multiple issues are, therefore, perceived with regard to the time-scale nomenclature.

A civil standard decoupled from Earth rotation would be fundamentally different from the existing and historical practice, and the name UTC has been statutorily adopted in many countries. The lack of name change alters the basis for civil timekeeping without the usual publicity required for such a conceptual and technical change. As was experienced with GMT, terminology does not fall out of use easily. It would be legally, technically, and historically confusing to have a time scale named "Coordinated Universal Time" close to, but decoupled from, Universal Time.

Applications dealing with historically UTC-tagged data cannot be spared from responsibly accounting for leap seconds, even if leap seconds are eventually abolished. It would be technically burdensome to have a historic version of UTC with leap seconds, and a newer version of UTC without leap seconds—both called UTC. Many systems use an internal or background time scale (in the sense of a system of labeling epochs), such as TAI or GPS time, to avoid leap seconds internally. These systems would not benefit much from a redefinition of UTC. Future systems would almost certainly be designed presuming that the UTC scale is historically uniform, only to discover that it is not when processing historic data. Also, scientists and analysts, both now and in the future, would be inhibited from converting archives of historical UTC data onto a new uniform civil time scale once and for all, if both the past and future scales were identically called UTC. [41] Ironically then, the lack of a change of name could encourage the retention and proliferation of so-called internal "pseudo time scales" in future systems that must process historical data.[42]

Alternative Time Scales

In the past, new time scales were introduced as technical requirements dictated. Today, there are a number of precise technical time scales available for use, most of which were invented within the last half-century.[43] With the exception of UT1, all modern scales are functionally related to, or approximate the rate of, TAI. Therefore, it seems reasonable to suggest that TAI be made available for use as a time scale without leap seconds, and for determining precision time interval, wherever necessary, rather than create another atomic time standard parallel to TAI. The suggested use of TAI[*] as an internal reference scale for operational systems has been explicitly recommended in the past by the Director of the BIPM, the Consultative Committee on Time and Frequency (CCTF), and the ITU-R via Recommendations TF.485-2, TF.536-2, and TF.1552.[44] The recommendation to broadcast DTAI = TAI – UTC for this purpose is still prescribed by Recommendation TF.460-6, yet the ITU-R study group responsible for this Recommendation has noted that "TAI is not an option for applications needing a continuous reference", partly because it has no means of dissemination![45]

Responsible study groups have also noted that "GPS time is not a reference time scale, but is instead an internal time for GPS system synchronization."[46] Nevertheless, many operational systems rely on high-precision GPS signals to establish internal reference time scales, such as CDMA cellular telephone networks.[47] Moreover, DTAI is easily deduced from external data and added to UTC to recover TAI, as UTC is basically TAI with leap-second adjustments. Therefore, if a time scale without leap seconds is required, a supplementary time scale comparable to GPS

[*] "TAI" actually refers to TAI(*k*) = UTC(*k*) + DTAI, with "UTC(*k*)" being a realization from a contributing timing center , *k* symbolizing an identifying acronym of a particular time service, and DTAI equaling TAI – UTC.

time or TAI could be introduced. For applications that only need precise time interval, differences between TAI or GPS time epochs suffice. For those who need only precise frequency without regard to epoch, *status-quo* UTC provides this already.

User Preferences

The wide-ranging opinions of users who will be affected by the proposed change should be sought via official means. There have not been broad studies of all the users of UTC or assessments of the impact of the change on the different types of users, including costs. This is not surprising, as there is a significant expense associated with accurate cost analyses, and organizations are likely unwilling to make such investments without knowing that they are necessary. Nevertheless, user surveys thus far have indicated that the majority of the respondents prefer retaining the *status quo*. ITU-R studies acknowledge that recently reported issues involving leap seconds are small in number and present "only minor anomalies," that users continue to express satisfaction with the *status quo*, and that contingency procedures already exist in situations where leap seconds might or might not be an issue:[48]

> The 2005 [leap second] event allowed the ITU-R to collect further documentation on leap second problems experienced in the areas of communication, navigation and other electronic systems. […] From the small number of responses collected from international bodies, timing laboratories, satellite agencies and network engineers, it appeared that only minor anomalies occurred, mostly on GPS driven equipment and on NTP time servers. At the same time, a few of the responses indicated their satisfaction with the present UTC system. It was noted by some that the early announcement of the leap second application by the IERS allowed them to avoid or fix any potential anomaly. In one case a computer network was shut down about an hour before the leap second occurred and brought back into operation an hour afterwards. The indications were that system operators using time information have learned to cope with the irregularities by one means or another, service disruption being one method.

Thus, a major concern is that there is no publicly available documentation that adequately or consistently justifies a proposed redefinition of UTC or expresses overwhelming user dissatisfaction with the *status quo*.

Software and Hardware Modifications

Global navigation satellite systems (GNSS) are often cited as applications benefiting from the elimination of leap seconds.[49] However, GPS as a navigation system is not particularly affected by leap seconds, and UTC redefinition will require changes to end-user software where the difference between UTC and UT1 is expected to be less than 1 second, including spacecraft and ground-based observing systems that equate UTC and UT. [50, 51, 52] Even systems requiring no changes from the UTC redefinition will still need to be thoroughly investigated and tested as a precaution.[53, 54, 55, 56] This would be an unnecessary cost incurred by systems already compliant with the existing standard.

Alternate implementations of timekeeping systems in software systems which preserve Universal Time may provide compromises that could simplify the solution of the problem.[57] Computer scientists and software developers could be a useful source of information about methods to handle the current UTC and what would be involved in any possible change to UTC, but there is little evidence that organizations and professionals with expertise on many types of software have been formally consulted. For example, a proposal to speed up computer clocks to "smear" over the leap second, called UTC-SLS, was successfully used by Google during the June 2012 leap second.[58, 59] The technique is also implemented as part of the Java programming language.[60] This technique is useful when the sequencing of date labels is more important than the accurate length of the second.

Timing signals are now widely distributed by telecommunications networks with varying accuracies.[61] Because computers are not very good timekeepers, many systems frequently and automatically check for time updates. The costs of changing software due to a change in the definition of UTC are not well established, whereas the distribution of UTC with leap seconds on computer networks is already being facilitated, and would continue to be facilitated, if no change were made.[62, 63] Many software development firms would be affected by this proposed change; if nothing else, documentation would need to be revised.

Distribution of UT1

The IERS will continue to estimate UT1. There remains a need to provide UT1 and UT1-UTC in an easily accessible manner. If UT1-UTC becomes non-negligible, there will be increasing numbers of subscribers for these data. Distribution of UTC, UT1, and UT1-UTC is fundamentally a telecommunication matter, but a presumption that every user of UT has a computer network by which information access is unlimited may be naïve, and it is unknown to what degree UT1 / UT1-UTC servers are robust to network denial-of-service attacks. The dissemination of UT1-UTC might be accomplished through the Virtual Observatory project.[64] But regardless of how UT1 is disseminated, there will be a need to make data concerning UT1 easily recognized and retrievable.[65]

Legal Considerations

In almost all countries the official (regulatory) time is realized as a fixed offset from some national frequency standard synchronized to UTC. In some nations the statutory specification for official time is related to mean solar time at Greenwich or Universal Time; in other countries it is explicitly designated as Coordinated Universal Time.[66] For nations where the statutory basis is Universal Time; redefinition of UTC could define a scale that increasingly deviates from the legal prescription, resulting in a *de facto* change in the legal time. There would at least be a need for statutory and regulatory changes to national legal systems for which astronomical time is the explicit standard. For countries where statute explicitly designates Coordinated Universal Time, there may be a question as to whether there is clear understanding of the consequences of decoupling civil time from Earth rotation by legislators or other representatives of the general public. Because the transmission of a time scale that cannot represent national legal time seems to be of little use, changes to standard international time should consider the official time of every nation.

Non-Technical and Non-Scientific Applications

There may be a variety of societal practices that are linked to Universal Time, to which the impact of redefining UTC is presently unclear. A particular issue, which has been raised but not pursued within the precision time and time-interval community, is religious activities or religious preferences regarding time.[67] Sacred holidays which are astronomically determined, and calendars which have been refined through the ages to maintain concordance with the heavens in the long term, exemplify a philosophy, supported by religious texts, that time reckoning by astronomical means is divinely established.[68, 69] Local clocks and almanacs (or equivalent software) serve as intermediates for certain ritual customs that depend on actual sightings of the Sun or the Moon, whenever it is impractical for individuals to accomplish accurate astronomical sightings. For example, daily prayer times may be regulated by astronomical time of day and the apparent position of the Sun; such times are functions of Universal Time, luni-solar ephemerides, and the worshipper's location on Earth. If the definition of UTC is a consideration in the scheduling of worship activities, the degree to which religions might endorse the decoupling of clock time from Earth rotation is not well documented, and the consequences do not seem to have yet been thoroughly explored or dismissed by religious authorities.

Re-education

There is presumably a large amount of technical and educational literature reliant upon or citing the current definition of UTC, which would need to be revised if UTC is redefined.[70] Much literature and textbooks are dedicated to explaining the definition of UTC and its relationship with other time scales. Updated definitions and their dates of implementation will need to be clearly documented, perhaps taking decades for understanding to propagate through user communities. At the very least, documentation changes will affect technology domains that are otherwise unaffected by a redefinition of UTC; therefore, this aspect is presumed to be very far reaching and the identification of affected technical areas will be tricky.

Celestial Navigation and Almanacs

Celestial navigation is no longer used as a primary means of navigation, but it is still widely taught and critically relied upon as a backup to electronic navigation. There may be questions or confusion concerning the necessary corrections to a time scale not tied to the rotation of the Earth during a nautical emergency.[71] Similarly, Universal Time is used in national almanacs; a change in the definition of UTC might necessitate changes to almanacs and might present challenges on how to conveniently provide data and to educate almanac users of the change.[72, 73]

Rate of Rotation of the Earth

The long term trend in the rate of rotation of the Earth would indicate that the rate of leap seconds should increase. Currently the Earth-rotation rate is not following the long-term trend, so predicting the rate of leap seconds is difficult. In the past, there have been as many as two leap seconds per year without difficulty. Some hypothesize that the current rarity of leap seconds contributes to the difficulty of their proper handling today, while others speculate that an increasing frequency of the number of leap seconds will result in proportionately more problems. Of course these opinions about the future effects of changing Earth rotation are in direct opposition.

THE LONG TERM TREND IN EARTH ROTATION

The long term trend in the rate of Earth rotation is based on the tidal interaction between the Earth and the Moon and other variations as observed and with various fits to the observations is shown in figure 3. Figure 4 shows the projections into the future for the values of Delta T and the uncertainty in projecting the number of leap seconds in the future.

Long-Term Societal Effects

Because the issue of decoupling civil time and Earth rotation has not been seriously contemplated before now, the long-term philosophical and sociological concerns have yet to be carefully assayed. If mankind formally severs its timekeeping from the motion of the sky, it is unclear how the two might be reunited. The cessation of leap seconds now would remove future expectations that timekeeping and telecommunications equipment have built-in capability to maintain intercalary adjustments, creating technological barriers for realigning global timekeeping practices back to the heavens.[74] Long-term adjustment scenarios have been contemplated, such as so-called leap hours or adding a number of seconds or minutes to the end of each century, but these alternatives have all of the drawbacks of the current definition and none of the benefits. A “leap minute” also seems unacceptable based on similar grounds; it would likely take about a century to take effect, at which point technology would be unable to accommodate it.

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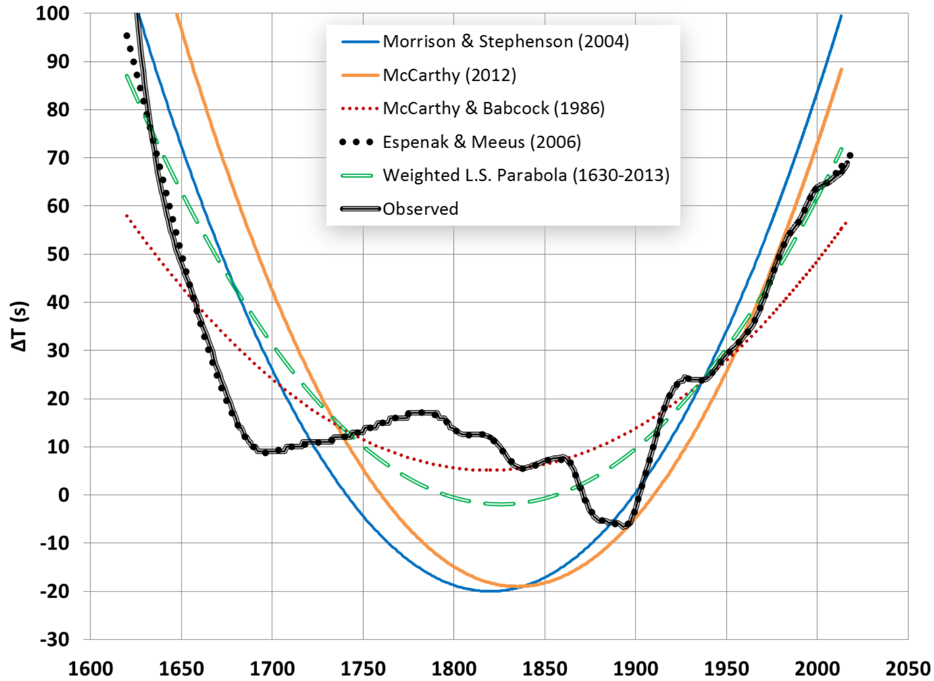

Figure 3 Observed values of Delta T and various fits to those values

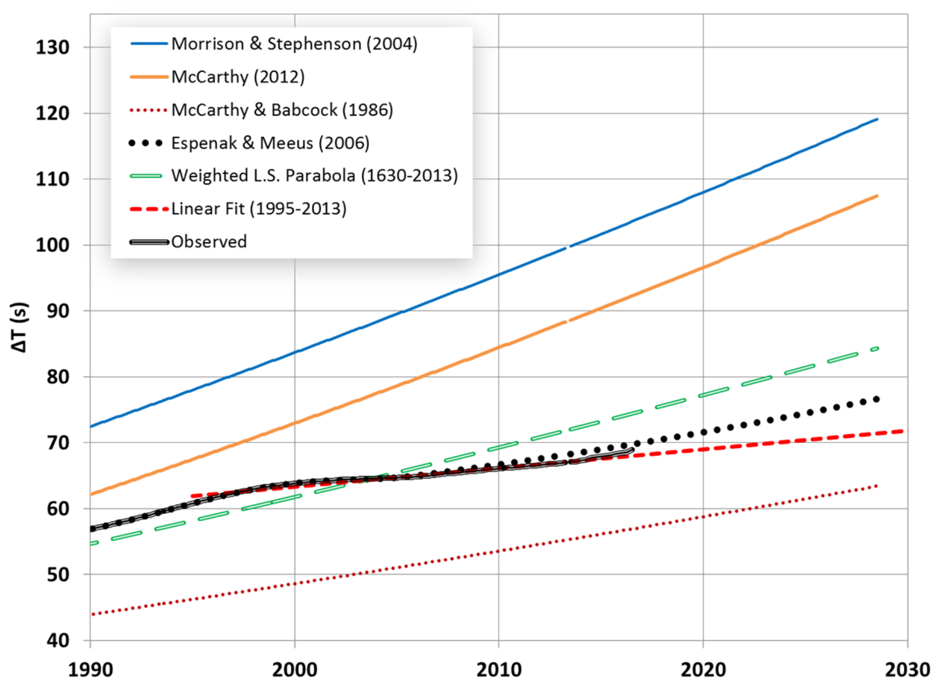

Figure 4 Future projections of Delta T based on the various fits to the observed values.

IMPACT ON SPACE SURVEILLANCE

There are a number of space activities where UTC might be conveniently used as a substitute for UT1, because the difference has been less than one second.[75] However, if a proposed change in the definition of UTC is adopted, that difference could grow without limit and software would have to be modified. A real-time source of UT1 would also be needed and introduced into software to know the orientation of the Earth to the accuracy required by the application. In particular, UT1 is needed to know the pointing for telescopes and antenna. Documentation would also be substantially affected.

PERSONAL RECOMMENDATION

Historically, new time scales have been introduced as requirements dictated. Mean solar time was recognized as a uniform time scale since Ptolemy and the single time scale since the 19th century. In the 20th century we introduced Universal Time scales based on the rotation of the Earth, Ephemeris Time based on the solar system motions, International Atomic Time (TAI) as an internal time scale of the precision timekeeping community, and the family of dynamical time scales, based on the relativistic theory required for different gravitational systems.

Recent evidence suggests a potential need for a strictly uniform atomic time scale for civil usage, and especially electronic devices. Such a scale could be directly related to TAI, GPS or Galileo time scales offset from TAI, or a time scale with a different offset from TAI. The offset between this uniform time scale and UTC could be made known on a continuing basis. The wider availability of a supplementary atomic time scale would avoid the problems of changing the existing definition of UTC, which now experiences widespread operational application.

A decision can be expected in 2015. The WRC invites additional study exploring the feasibility of a uniform time scale before then. A feasibility study should consider the user requirements, the available options, the pros and cons of the options, and the transition process, if a change is required. Individuals, organizations, and administrations should contribute to the study activities of ITU WP 7A. Individuals in the USA should be able to provide input via the Federal Communications Commission on this subject.

Because there is a need for widespread consideration of timekeeping issues and options, a colloquium on the "Requirements for UTC and Civil Timekeeping on Earth" will be held in May 2013 in Charlottesville, VA, USA. This is an opportunity for international discussion and documentation of requirements for civil timekeeping of the future.[76]

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