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FUTURE OPTIONS FOR CIVIL TIMEKEEPING: UTC AND THE ALTERNATIVES

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The 2012 Radiocommunication Assembly and World Radiocommunication Conference of the International Telecommunication Union recommended further studies concerning the future of UTC. Issues regarding UTC definition are not restricted to telecommunication, but have broad impacts scientifically, publicly, and legally. In response, various requirements, options, and issues are summarized, with one approach appearing to meet requirements and having consistency with current practices. This approach would officially sanction an atomic time scale with a constant offset from TAI, without leap seconds, for the users who require such a time scale, leaving the current definition of UTC unaltered. The additional scale might be realized by transmissions or services distinct from UTC, but it would be best realized as an encoded correction to UTC as currently defined. This latter approach is already recommended by ITU-R Recommendation TF.460-6.

INTRODUCTION

Mean solar time is the form of astronomical time that keeps pace with solar time-of-day over the very long term. Conceptually, its rate equals the rotation rate of the Earth (one cycle per sidereal day) minus the mean motion of the Sun (once cycle per year), where cycles are measured from the vernal-equinox direction.[1] Because both angular rates are nearly constant, mean solar time maintains nearly uniform hours and days, which is ideally suited to the regularity of timekeeping mechanisms. Thus, time "o'clock" and "mean time" have become synonymous.

By the late 19th century, mean solar time on the meridian of Greenwich, also known as *Greenwich mean time* (GMT), was recommended internationally for many scientific and navigational purposes.[2] Although "GMT" still enjoys civic and navigational usage to this day, this term has been largely supplanted with *Universal Time* (UT) in astronomical circles. Starting in 1928, the recently formed International Astronomical Union (IAU) strongly endorsed the term Universal Time to describe GMT "since midnight" for astronomical purposes, because GMT had been historically used in astronomy to describe mean time since noon.[3]

By the mid-20th century, an observed variability in Earth rotation prompted an arcane technical distinction between the original concept underlying mean solar time, and the realization which became Universal Time.[4] UT was the observed sidereal rotation multiplied by a scale fac-

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tor, whereas mean solar time is a concept expressing sidereal rotation with respect to a fictitious *mean sun*. These two conventions yield slightly different results when the rotation rate of Earth is not absolutely constant. A recent study[1] affirmed that varying Earth rotation causes UT1 to separate from Newcomb's *c*.1895 conventional expression for the mean sun by $^{1}/_{365¼}\,\Delta T$, or about 0.2 s since 1900.[*] The supposed ephemeris error in Newcomb's mean sun is also small relative to this difference; if a more modern determination of the Earth's orbital mean motion, such as that due to Simon *et al*. (1994),[5] was used to re-define the mean sun, the difference would appear to be almost negligible (Figure 1).

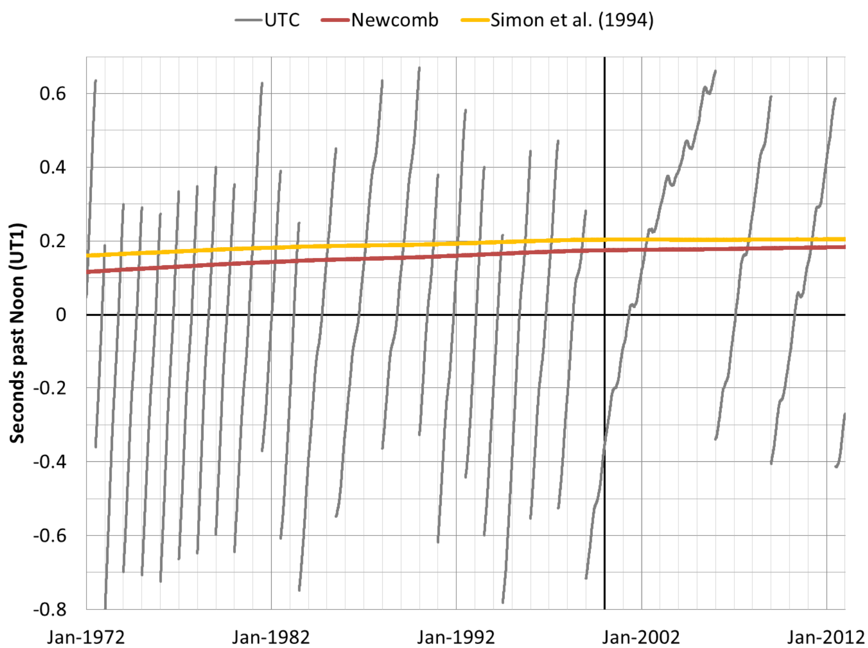

Figure 1. Differences between three mean solar time expressions with respect to noon UT1.

When atomic frequency standards became available in the 1950's, slight variations in the rotation rate of Earth were precisely measured. During the 1960's, a system known as *Coordinated Universal Time* (UTC) was developed which permitted civil time to be regulated by atomic frequency standards, yet still allowed clocks to continue indicating mean time via Universal Time.[6] Variable broadcast frequency and fractional step adjustments were practiced globally until 1972, after which a simpler system was implemented that maintained constant frequency and used larger steps called *leap seconds*.[†] Over the next four decades this system was expansively adopted and employed, and endorsed by the *Conférence Générale des Poids et Mesures* (CGPM) as a basis for civil time after "considering that […] UTC is […] an approximation to Universal Time, (or, if one prefers, mean solar time)."[7] Thus, UTC has become the basis of civil time for most of the world as the atomic realization of Greenwich mean solar time.

[*] ΔT is the observed difference between UT1 and Terrestrial Time (TT), a theoretically uniform dynamical time scale having a rate of progression that is close to TAI.
[†] The intercalary adjustment is analogous to the introduction of February 29th into the calendar year, hence the name.

Because the wireless transmission of time signals facilitated early international coordination, responsibility for the definition of UTC fell to the Radiocommunication Sector of the International Telecommunication Union (ITU-R). Around 1999, a cause arose within ITU-R Study Group 7—the study group initially responsible for defining UTC with leap seconds—to recommend decoupling UTC from Earth rotation by ceasing future leap seconds.[8] This led to a formal ITU-R Study Question and the appointment of Special Rapporteur to address that Question.[9, 10] After a dozen years, ITU-R Study Question 236/7 still remains "open" (in force), with no consensus having been reached after exhaustive debate at study-group levels.

WRC-12 RESOLUTION 653

Study efforts up to 2011 are summarized in various other papers.[11, 12, 13] Since 2011, a Recommendation to suppress leap seconds advanced out of Study Group 7 without unanimity and onto the agenda of the 2012 ITU Radiocommunication Assembly (RA-12). The Assembly, representing about 190 nations, debated the matter before it deferred further consideration until 2015.[*] An ITU-R press release explained that this decision had "been reached to ensure that all the technical options have been fully addressed in further studies related to the issue," acknowledging that "suppression of the leap second […] may have social and legal consequences."[†]

Calls for Additional Study

The 2012 World Radiocommunication Conference (WRC-12) subsequently adopted Resolution 653, which drafted Agenda Item 1.14 for 2015.[14] This Resolution recognized "that a change in the reference time scale may have operational and therefore economic consequences," and invited WRC-15 to "consider the feasibility of achieving a continuous reference time-scale, whether by the modification of UTC or some other method, and take appropriate action, taking into account ITU-R studies."[15] The Agenda Item further invited the ITU-R "to conduct the necessary studies on the feasibility of achieving a continuous reference time scale for dissemination by radiocommunication systems" and "to study issues related to the possible implementation of a continuous reference time scale (including technical and operational factors)."

To fulfill the obligations of Agenda Item 1.14, ten international organizations were to be notified (a list which did not include any stakeholder organizations devoted to software development or the transmission of atomic time by means other than radio). Subsequently, the Russian Federation drafted a study outline requesting, among other things, that Study Group 7 consider and provide relevant information on the societal implications of keeping or removing the leap second, the organizational issues resulting from the introduction of a continuous reference time scale, the possibility and implications of using other technical options (such as a leap-minute adjustment), and the time table required for bringing a new reference time-scale into use.[16]

A 'Continuous' Reference Time-Scale

Resolution 653 specifically calls for study on achieving or implementing a "continuous" reference time scale. Unfortunately, use of the descriptor "continuous" within the context of Resolution 653 is imprecise, other than to suggest something different than UTC as currently defined. Outside of Resolution 653, the adjective *continuous* has been used to imply "without leap seconds" in literature as far back as 1999.[8, 17] Notably, Nelson *et al*. (2001)[18] use "continuous" to suggest both an uninterrupted scale (*e.g.*, "…once continuous atomic time became estab-

[*] http://www.youtube.com/watch?v=C-2UqYW9SEs
[†] http://www.itu.int/net/pressoffice/press_releases/2012/03.aspx

lished…", and "…disruptions to continuous service…"), and a scale without intercalary adjustments (*e.g*., "continuous, atomic time scale without steps"). Lately, this latter use has been declared to imply *mathematical continuity*;[19] however, such continuity cannot apply to a representation of time of day which rolls over at midnight—just as the conventional representation of angle is not continuous when it exceeds 2π by ε and returns to ε instead of $2\pi + \varepsilon$.

Guinot (2011) uses "discontinuous" to refer to the duplication of time stamps:[20]

> …we mention one fact (not a judgment): UTC is not a time scale on account of its discontinuities. In particular, […] two different events separated by one second receive the same date when a positive leap second occurs.

However, UTC as defined by ITU-R TF.460 does not employ or advocate duplicate time stamping, and it does not have "steps" *per se*, so the application of the word "discontinuous" in these senses seemingly applies only to non-standard realizations which are, arguably, not UTC. Furthermore, because UTC as defined via TF.460 is a continuous progression of seconds of equal length, the primary dictionary definition of the word *continuous* (*e.g*., "parts in immediate connection; uninterrupted") seems appropriate.

Hence, the terms "discontinuous" and "continuous" invite confusion by failing to adequately describe the problem space and the requirements to be addressed by a reference time-scale from which constant frequency is desired. From the context of historical use and recent use within WRC-12 Resolution 653, the terms "discontinuous" and "continuous" are better replaced by the terms "intercalated" and "unintercalated", respectively.

EXPLORATION OF CIVIL TIMEKEEPING REQUIREMENTS

The term "requirement" has different meanings to different audiences,[21] but at the very least, a "requirement" is something *required*, *e.g*., it is a rudimentary characteristic that, once discovered, must be addressed.[22]

Historically, new time scales have been employed as new timekeeping requirements were discovered. For example, there is now a family of dynamical time scales (TCB, TCG, TT, and TDB) compatible with general relativity to meet the needs of precision ephemerides.[23] International Atomic Time (TAI) is an unintercalated scale estimated from the global output of atomic clocks to serve as a precise background reference. There are also time scales based on the rotation of the Earth: UT0, UT1, and UT2 have varying degrees of uniformity and correction which differ at the level of milliseconds, while UTC is based on TAI and adjusted as necessary to stay within ±0.9 s of UT1.

Availability of Constant Frequency and Time Interval

UTC with leap seconds was spawned from an apparent requirement to provide constant frequency and convenient access to the unit of duration of the *Système international* (SI). Communication systems with bandwidth restrictions and air-traffic collision avoidance systems of the 1970's needed an unwavering frequency spectrum.[24] Before this, variable ("rubber" or "elastic") broadcast seconds were convertible to a more uniform scale only through small frequency scale factors and step corrections, a process that was inconvenient and opaque.

Synchronization with Mean Solar Time

The duration of the second (SI) was closely calibrated against the mean solar second determined from astronomical observations of the 18th and 19th centuries;[25] thus, the second (SI) emulates the mean-solar second both in its name and in its duration. To a degree, this emulation masks a requirement for the synchronization of clock time with the solar day.

To prove that synchronization with mean solar time is a fundamental requirement of timekeeping, one only needs to imagine if the second (SI) was *not* accurately calibrated against the mean solar second.[22] If a mere 0.002% difference[*] existed in the specification of the second (SI), 86400 s (SI) would be about 1.7 s different from the mean solar day. To then keep clocks correlated with mean solar time, a leap minute would be needed about once per month, or a leap hour about every 5 ½ years. No responsible timekeeping professional would argue that such a rate difference from solar time is acceptable. Thus, clock synchronization with mean solar time is an unquestionable requirement; the debatable aspect is the level of tolerance between the two.

Technical applications deriving astronomical time from civil clocks have historically driven the designated tolerance between UTC and Universal Time, such that, if the current tolerance was to change, the extent of adverse operational impact is unclear, and it is also unclear where a new threshold should be established.[12] Restricting long-standing global access to Earth orientation via clock time would seemingly penalize applications that are already technologically disadvantaged, and no single organization is well positioned to gauge their current extent and scope—particularly the ITU-R.

Access to Earth Rotation

While the practice of celestial navigation has diminished substantially in recent years due to the general availability of Global Navigation Satellite Systems (GNSS), astronomical methods are still required as a backup to GNSS and other navigational aids. For example, U.S. Navy regulations require daily checking of directional gyrocompass errors by celestial means when navigating across open ocean.[†] Historically, systems have been able to maintain Universal Time by consulting time signals, or have otherwise assumed that data were tagged according to Universal Time from well-maintained clocks. Some systems have operational features designed around the long-standing UTC standard and the bounded nature of |UT1−UTC|, to accommodate situations where separate Earth-orientation parameters (EoPs) may not be available. This includes systems that may be network-isolated for security reasons.[26] Regardless of the fate of UTC and civil timekeeping, a requirement exists to globally distribute Universal Time as a measure of the rotation of the Earth for the purposes of celestial navigation, spacecraft tracking, and the astronomical pointing of telescopes, star-trackers, solar panels, antennae, *etc*.

Proposals regarding UTC redefinition have not clearly addressed passive UT1 accessibility, deferring that responsibility to the International Earth Rotation and Reference System Service (IERS). IERS methods for predicting UT1, and hence the timing of intercalary adjustments, are improving, such that leap seconds can be predicted a year or more in advance to a high level of probability.[27] However, while the IERS is responsible for estimating, publishing, and forecasting UT1 and leap seconds, the IERS is not a global telecommunication entity liable for the passive broadcast of timing corrections. If UTC no longer sufficed as an operational proxy for UT1, there may be greater demand for distribution of UT1 by means other than text files shared over computer networks, as is the common practice today.[28]

[*] Consider that Gregorian-calendar reform changed the mean length of the calendar year by 0.002%, from 365.25 days to 365.2425 days.

[†] U.S. Department of Defense, Navy (2010), "Surface Ship Navigation Department Organization and Regulations Manual." p. 3-16 (URL: https://www.netc.navy.mil/cen-ters/swos/_documents/NAVY+NAVDORM.pdf)

Software and Hardware Support for Existing and Future Systems

If ITU-R usage of the word "continuous" can be accurately interpreted as "unintercalated", then it clarifies that the ITU-R requires the distribution of an international reference time scale for which there are no intercalary adjustments. This specification is most likely justified by some lack of support or compatibility with existing hardware or software, such as an inability to represent and/or receive notice of an adjustment. The implicit requirement is that the time scale must be representable on pre-existing equipment.

However, any general requirement to operate on existing systems both supports, and argues against, the abandonment of an intercalated reference scale. Almost all applications which do not support intercalary adjustments came into existence after 1972; hence, these systems were developed out of ignorance of leap seconds, or by lacking a need to conform to ITU-R Recommendation TF.460. There also exists software and hardware that dutifully conform to TF.460, which might require reprogramming or replacement if UTC is redefined; such dependencies may not be apparent to users in some cases.

On the other hand, there is software and hardware that does not consider the existence of leap seconds, and special effort is sometimes required to introduce a leap second into the indicated time. For determining time of day (*hh*:*mm*:*ss*) from a continuous sequence of seconds (SI), the dates where leap seconds exist, both in the past and near future, must be known. The display of a leap second as "60" according to TF.460 is not traditional, yet some standards stipulate the use of UTC without allowing more than sixty seconds per minute (*e.g.*, POSIX).[29]

Regarding future hardware and software support, one must ask whether changes to the definition of an existing time scale is expected to simplify or complicate time-scale usage. Altering definitions now may simplify some applications, while complicating others now and in the future. Because past intercalary adjustments cannot be undone, they must be supported by software and hardware indefinitely regardless of when and how future adjustments happen.

Accessibility

Time signals must be accessible from national time services to sufficient accuracy, where sufficiency will be dictated by the application. Continuing developments in precise frequency standards will make much more accurate time scales possible, resulting in a more precise definition of the second (SI) and the potential need for new protocols to accurately distribute atomic time of the future. Thus, emerging requirements may force future reconsideration of transmission specifications such as Recommendation TF.460 regardless. Short-wave and long-wave radio broadcasts, regulated by TF.460-6, already lack sufficient accuracy for many critical endeavors. Higher accuracies may be obtained from GPS time servers, but GPS maintains its own internal system time and, thus, redefinition or supplementation of UTC offers few benefits to precision time received via GPS.

Terminological Integrity

The historical promotion of the term "UT" over "GMT" for astronomical purposes evidences the requirement for the terminological integrity of time scales. If Coordinated Universal Time was redefined to no longer track Universal Time, a new name would be required to avoid the confusion caused by having two fundamentally different time scales—one intercalated, and one unintercalated—sharing the same name.[30] Likewise, the term TAI should probably be reserved for the continuation of the historical background scale of the International Bureau of Weights and Measures (BIPM), although there is already some movement to retire the label "TAI" if the label "UTC" is retained for an unintercalated scale. Specifically, the Consultative Committee for Time and Frequency (CCTF), which advises the BIPM and CGPM, announced that it "would consider discussing the possibility of suppressing TAI," if UTC was redefined without leap seconds, "as it would remain parallel to the continuous [unintercalated] UTC."[31]

Conformity to Public Perceptions

A long-standing rationalization exists amongst specialists that an "everyday user" must have limited concern over the degree to which a clock should correspond with the orientation of the Earth and sky.[32] This is because static offsets caused by zone times and summer-time adjustments, and the *equation of time* (the cyclic difference between mean solar time and apparent solar time), already introduce noticeable deviations between 12:00 o'clock and apparent solar noon. Such rationalizations fail to acknowledge that time zones, daylight-saving time, *etc*., do not deviate secularly from solar time, and are employed because a single, global time is inadequate for local purposes. Locals seek to correlate local clock time with daylight hours, and otherwise resist methods of timekeeping which are perceived as "artificial" or foreign. China is sometimes exemplified of human tolerance and indifference to large deviations in the indicated time, because the mean solar time of China's isolated western border is three (3) hours earlier than Beijing Time (UTC + 8^h) nationally decreed for official use. Yet, "Ürümqi Time" (named for the largest city in western China), also known as "Xinjiang Time" (UTC + 6^h), is culturally maintained to within an hour of mean solar time by the Uighur inhabitants of western China.[33, 34]

If intercalary adjustments were eliminated from the reference scale, it has been suggested that local regions might instead alter their time-zone offsets as a summer-time adjustment "according to the wishes of citizens."[20] However, the Chinese example already demonstrates that distant seats of government can thwart the local exercise of timekeeping.* The method of implementation also appears problematic considering that a majority of people and nations do not practice daylight-saving time.[35] Furthermore, legislated zone re-definitions complicate maintenance of the International Dateline and would move what is now a common solar-standard for international timekeeping into far-flung decisions across different nations, states, and provinces. This would promote historical chaos as local time stamps become harder to accurately interpret over the long term.[36]

Thus, the decoupling of civil timekeeping and Earth rotation is not likely to go unnoticed by the "public sphere"—the sociological concept of "general public", where individuals freely discuss and identify societal problems. A 2011 BIPM press release acknowledged there "is also the feeling that a break in the present system of synchronization of UTC to the Earth rotation will decorrelate the human activities from solar time. […] Although this is a small difference increasing very slowly we recognize that it is an important matter of principle."[37] Satisfaction of public concerns over the synchronization of time-of-day and clock time is therefore a requirement in need of redress, even if this requirement for "astronomical conformity" is mainly symbolic.[38]

International Consensus and Commonality

The definition of UTC is also a legal issue as it relates to the standard time of nations. UTC is the *de facto* basis for zone times around the world,[39] even though many users do not understand or appreciate the details of UTC's basis and definition. ITU-R study groups recommended continuing with the term "UTC" for an unintercalated atomic scale, partly because UTC is a named legal standard for some nations. However, other countries specify legal time as being based on mean solar time, "world time", or Universal Time; because unintercalated UTC would no longer be related to those named legal standards, the legal impacts of a change in definition are uncertain.[35]

* China enjoyed five official time zones before a single national zone was imposed around 1950.

Widest Utility

Telecommunication and time metrology are not the only technical fields affected by a redefinition of UTC: also affected are astronomy, astrodynamics, geodesy, computer sciences, engineering, meteorology, space sciences, and others. When Louis Essen introduced the idea of a leap second, he wrote:[40]

> …time scales have always served the three quite distinct functions, of giving the time of day, the season of the year, and also a measure of time interval or duration. Any new scale must continue to serve these purposes, if it is to be of universal use and although an atomic clock can provide a very precise scale by simply counting and recording the number of seconds that have elapsed since some arbitrary zero, the time of day and the season of the year can be obtained only by astronomical measurements. It would of course be possible to use separate and independent scales of atomic and astronomical time but this possibility already seems to have been rejected, and rightly so in my view, since it would lead to confusion and duplication of effort.

Arguably, international civil time scales must then be useful over the widest possible conditions, having applicability to future users and present users of past data. Changes add penalizing complexity that must be technically supported indefinitely, because former definitions never disappear, once used.[41]

SOME NON-REQUIREMENTS

In addition to the requirements for civil timekeeping listed above, there are long lists of desirable criteria and characteristics for scientific, business, technical, legal, and other purposes which may or may not be absolutely required.[13] The following highlights some characteristics which have been purported to be time-scale requirements, yet do not meet a criterion of being unquestionably necessary.

Single Reference Time Scale

Although desirable, there is no true requirement for having only a single reference time scale. In practice, UTC already has many real-time national realizations and is not a single reference time scale. Indeed, definitive "TAI and UTC are not time-scales represented by clocks in real-time."[42] GNSS scales are specific examples of where experts chose to broadcast an unintercalated atomic reference scale different than UTC.

Study groups initially purported the modification of UTC alone because the ITU-R recommends UTC as the sole reference time scale for radio broadcasting. However, it has not been the historic position of the ITU-R that there must be only one reference time scale. ITU-R Recommendation TF.1552 specifically recommended "that in applications requiring a uniform time scale TAI be recovered from UTC," and TF.460-6 was amended in 2002 to include a recommendation to disseminate "DTAI" (TAI−UTC) via time signals. Only recently (2011) did ITU-R study groups suppress Recommendation TF.1552 to support a claim that "TAI is not an option for applications needing a continuous reference as it has no means of dissemination and is not physically represented by clocks."[43] Resolution 653 has reaffirmed the ITU-R's lack of a requirement for a single reference time scale by inviting consideration of "the modification of UTC or some other method," despite professional opinions that the availability of more than one scale promotes confusion or lack of standardization.

Uniform Duration of Non-SI Units

The second (SI) is the most accurate metrological unit and a basis of other standards.[44] However, it is not clear that non-SI units of duration used with the SI, such as the minute, hour, or day, must always have uniform duration when used for calendrical purposes. For example, NIST Special Publication 811 notes that such non-SI units might be necessary "when time relates to calendar cycles" (which are intrinsically astronomical), and also acknowledges the *year* as a useful unit of duration with a conventional length of 365.0×86400 seconds (SI).[45] However, the *tropical* (mean-solar) *year* as a natural unit is closer to 365.2424 days. Furthermore, the calendar year actually varies from 365 to 366 days. Thus, when time is specifically related to calendar cycles, there is precedent for non-SI units not maintaining fixed durations.

EXPLORATION OF OPTIONS

The call for additional studies by WRC-12 through Resolution 653 suggests that ITU-R study efforts may have prematurely discounted a number of practical approaches. Various options related to changes in civil timekeeping on Earth have been discussed since 1999; some of these have always appeared unviable but have been maintained in discussions for completeness.[17] Attention to the requirements, together with the WRC-12 Resolution 653, reveals several options that should receive revived consideration. Several of these options are now reviewed.

Retain the *Status-Quo*

This option would maintain ITU-R Recommendation TF.460-6 and its established timekeeping practices. Reasons for retaining the current definition of UTC with leap seconds include:

- A new time scale, fundamentally different than the current standard, will represent a historical discontinuity that will add operational complexity that cannot be undone, and risk confusion.
- There is an unknown amount of software and hardware based on |UTC−UT1| being less than one second. Alterations could prove difficult and expensive. For example, navigation systems operate within the current definition, and changing and testing configuration-controlled systems would be very expensive and without benefit.[46]
- Backup methods to GNSS will be impacted, which could result in confusion in an emergency.
- Documentation in textbooks and other literature would have to be extensively updated to recognize and explain both the old and new definitions.
- An unintercalated atomic time scale is already available via GPS.
- Public perceptions regarding the tie between civil timekeeping and celestial motions should not be ignored. The vast majority of nations, now or historically, base their national time scale on mean solar time, which UTC with leap seconds represents. If decoupled, changing back to a mean-solar-time standard would seem intolerable.
- Leap seconds gives the timekeeping community publicity it otherwise lacks.

An oft-repeated objection to the *status quo* is that the frequency of leap seconds might increase to nearly two per year in about a century; another is concern over emerging problems and thus growing dissatisfaction.[47] However, the established specification handles up to twelve leap seconds per year, and more frequent leap seconds would increase opportunities for testing and general awareness.[12]

Increased Tolerance between UTC and UT1

Two similar options fall within this category, both of which potentially increase the duration of intercalary adjustments.

Larger Leaps. This option would replace leap seconds with leap minutes occurring decades apart, or leap hours separated by centuries. The reported advantage of this approach is that "it would be relatively easy to adopt"[47] because "it pushes the problem so far into the future that no one is worried about it."[48] However, the details of how to promulgate an acceptable adjustment procedure into the distance future have never been clarified, and this ambiguity has already led to the apparent dismissal of leap hours by ITU-R study groups.[49] Leap minutes are also conjectured to be too infrequent to be employed successfully, addressing only aesthetics and raising more technical issues for the future than they solve now.[50]

Predictable Introduction of Leap Seconds. This option would introduce an intercalary adjustment (that is likely greater than one second) on a predictably recurring date such as February 29th. However, the possibility of introducing either zero or one second on the scheduled date still exists, just like the current practice of introducing leap seconds at the end of a month such as June and December. Thus, the primary distinction of this option from current procedures is that two or more leap seconds could be introduced and there is no existing infrastructure for this situation.

Cease Leaps

This option has received the most discussion and attention to date, having been recommended from Study Group 7 without acceptance by RA-12. Entire papers are devoted to its perceived advantages and disadvantages.[12] Some commonly recognized reasons for redefining UTC without leap seconds include:

- Many computer systems do not correctly account for the possibility of a leap second, with software and hardware assuming that there can only be sixty (60) seconds per minute.
- The leap second may not be properly disseminated, or may not be applied on time, causing differences in the readings of timekeeping devices and the time tagging of business transactions.
- Leap seconds are generally inconvenient, as they require resources to implement and test.
- Leap seconds encourage the introduction of unintercalated scales, possibly causing confusion.

However, if leap seconds are ceased, unofficial time scales with leap seconds might be potentially established by those who need a scale like the former system aligned with UT1 for their own purposes. These scales could introduce leap seconds according to some mutually established rules for inserting future leap seconds, or they might differ in how they track UT1.

Cease Leaps and Rename

This option would assign a new title to the time scale now known as UTC, and eliminate leap seconds, after a certain date, which is equivalent to retiring UTC and continuing with an unintercalated scale. This option carries the same justifications as the option to "Cease Leaps", except that the name of the scale is altered to maintain terminological integrity. A perceived disadvantage is that a change of name would require extensive documentation changes, but a fundamental change to civil timekeeping will demand changes regardless.

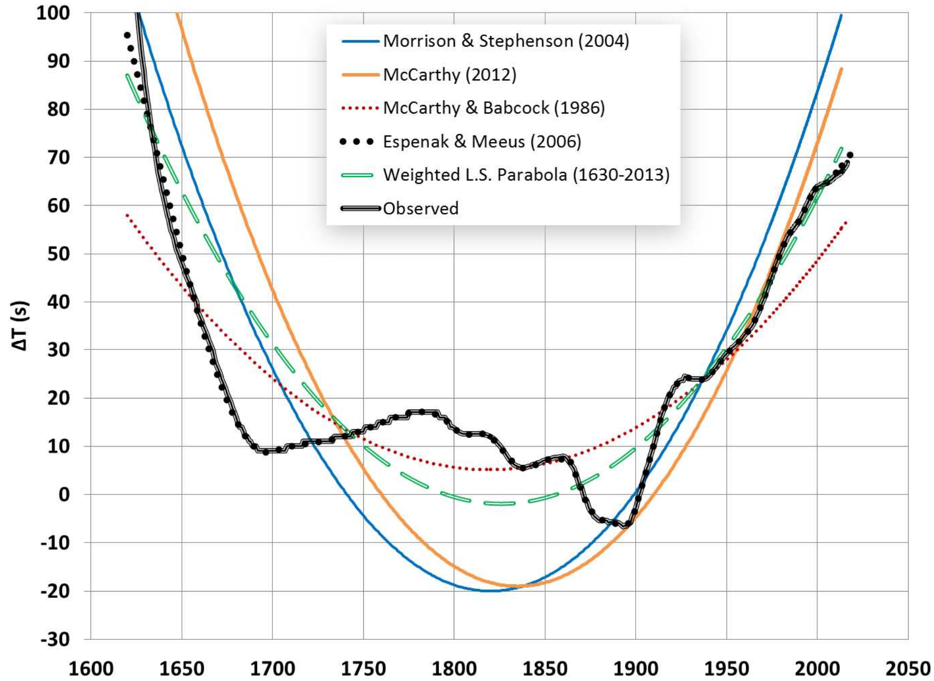

Figure 2. Past ΔT behavior and various fits to the observations

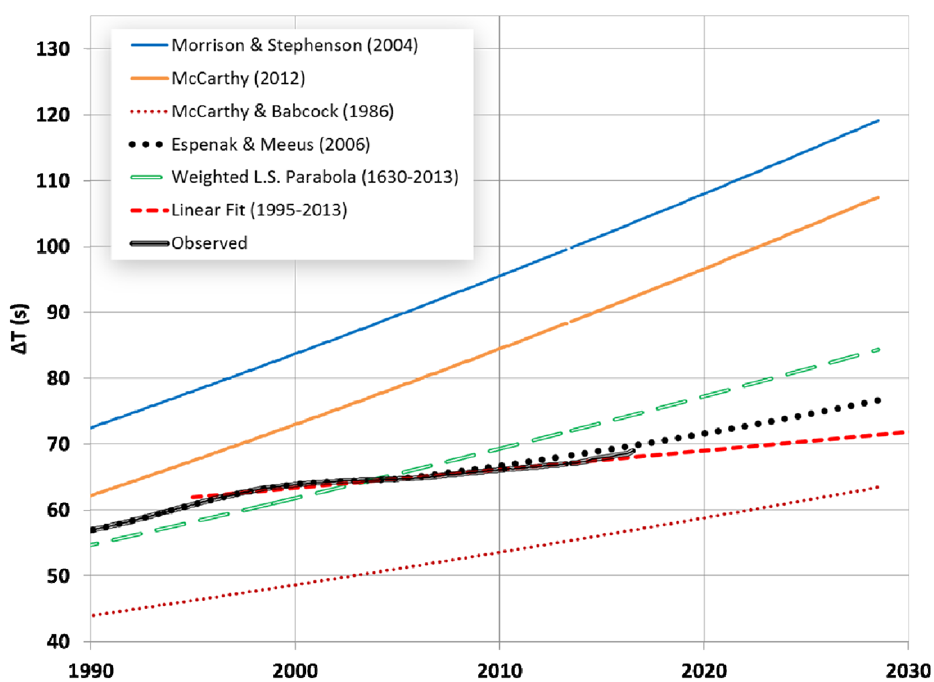

Figure 3. Projections of ΔT into the future.

Track Predicted Long-Term Trend

This proposal is relatively new; it would insert leap seconds into UTC according to an algorithm, rather than the observed rotation rate of Earth.[51] This option retains the title UTC, and employs leap seconds, to track an imaginary scale that separates parabolically from TT. However, there is some question as to what the "best" parabolic trend might be. Figure 2 recalls various fits[50] to historic ΔT; Figure 3 projects these estimates into the future, also adding a simple linear fit to ΔT from 1995 to 2013 to emphasize the most recent trend. The wide variation of these projections indicates the significant uncertainty in predicting the frequency of intercalary adjustments.

The uncertain long term trend in Earth's rotation rate is governed by tidal interactions between the Earth and the Moon. A trend for UT1−UTC that best fits the near term behavior should result in both large positive values and large negative values. A trend that accelerates faster has the operational advantage of keeping adjustments positive, but may result in a worse approximation of Universal Time. Perhaps of greatest technical concern is that this proposal masquerades at providing Universal Time by its name and continued use of leap seconds, but it does not represent Earth rotation at any technically useful level.

Add Unintercalated Atomic Scale

This option would retain UTC as it is currently defined, and would officially recognize and make available an unintercalated atomic time scale additionally. This approach was recommended by the ITU-R before the campaign to cease leap seconds. However, unlike ITU-R Recommendation TF.1552 suggesting that the unintercalated scale represent TAI, the unintercalated scale could carry a different name (such as *International Time*[52]) and be offset from TAI by zero, −19 s (the value of GNSS time[*]), or some other number that avoids confusion with UTC. Reasons for adding an unintercalated atomic time scale to UTC include:

- An intercalated scale, plus an unintercalated scale, together appears to satisfy all requirements.
- It visibly establishes a recommended scale without leap seconds.
- It formalizes practices already happening, and will continue, regardless of what the ITU-R decides. For applications that do not want leap seconds, GNSS or TAI-like time scales are currently being used.

A disadvantage with the broadcast of a supplementary scale is the appearance of duplicated effort and some mild risk of confusion. Thus, for operational acceptance, it seems prudent that the unintercalated scale be accessible via a broadcast parameter that is added to (or subtracted from) UTC and which increments at each leap second, not unlike DTAI as recommended in TF.460-6.

Clock Slewing

As a supplementary method for accommodating leap seconds in UTC, some computer scientists have suggested the controlled slowing of oscillators to add a leap second gradually over last fraction of the day.[†] Because this approach has already been effectually implemented (*e.g.*, by

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[*] Like GPS time, the Galileo navigation system expects to maintain its time at approximately TAI−19 s, which could be referred to as the *GNSS time scale*. GPS time does not include leap seconds, but increments the difference between UTC and GPS time.

[†] "UTC with Smoothed Leap Seconds (UTC-SLS)." URL: http://www.cl.cam.ac.uk/~mgk25/time/utc-sls/

Google in 2012[*]) and meets the requirement of compatibility with existing hardware and software, it probably should not be objected to, especially in low-precision applications, where the sequence of date labeling is more important than the uniformity of the scale. However, this practice does not seem viable as an international reference time scale because it does not provide invariant frequency and time interval during the slewing interval. Nevertheless, the practice would benefit from the establishment of an industry-standard slewing interval, so networked applications that expect invariant frequency could exercise caution during this interval.

Variable Frequency

Variable frequency was used during the 1960's, where the rate relationship between civil time broadcasts and atomic frequency was fixed for extended periods. These slight frequency shifts could not guarantee long-term proximity to UT, such that small, fractional steps were also introduced. This approach was found to be too cumbersome for communication purposes, and is now considered obsolete.

Swap Scales

This option would cease UTC and substitute another atomic time scale as the reference time scale on some date.[47] Unlike the option to "Cease Leaps and Rename," this scale would not necessarily share UTC's epoch at the time of adoption. Synchronization with TAI has been proposed as a characteristic of the replacement candidate.[52] Nevertheless, this option is considered unviable, due to a number of practical operational disadvantages.

Redefine the SI Second

This option would alter the definition of the second (SI) by increasing its duration.[47] This approach is unworkable considering that other physical units are now based on the second (SI); also, a redefinition would only reduce the frequency and/or size of intercalary adjustments, but not eliminate them. Natural decadal variations in the rotation rate of Earth would still cause differences in the near term, and in the long term the Earth's rotation rate is still expected to decrease.

OPTIONS VERSUS REQUIREMENTS

Recognized requirements can be tabulated and compared to proposed options for time scales. Table 1 lists some of the requirements discussed, and which options appear to meet them. Of the requirements and options considered here, ceasing intercalary adjustments appears to be least satisfactory, while adding an unintercalated scale to *status-quo* UTC provides the most utility.

All potentially viable options are expected to provide general accessibility to invariant frequency. Although tracking a predicted "Long-Term Trend" promises some indication of mean solar time (less accurate than the current standard), it fails to reliably indicate Earth rotation to any technically useful level. It is also unclear to what degree the "Long-Term Trend" option will satisfy public perceptions regarding solar time or if it will meet with international consensus. Indeed, international consensus can be claimed for only two options: the *status quo*, and the *status quo* plus an unintercalated scale. This is because both options are reflected in ITU-R Recommendation TF.460-6, which is presently active. The cessation of intercalary adjustments ("Cease Leaps") is already known to lack international consensus, per national declarations within ITU-R study groups and RA-12.

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[*] "Time, technology and leaping seconds." URL: http://googleblog.blogspot.com/2011/09/time-technology-and-leaping-seconds.html

Table 1. Requirements v. Options.

	Status Quo	*Increase* |UT1−UTC|	*Cease Leaps*	*Cease Leaps & Rename*	*Long-term Trend*	*Add Unintercalated Scale*
Constant frequency & interval	✓	✓	✓	✓	✓	✓
Synchronized w/ Mean Solar Time	✓	inaccurate			inaccurate	✓
Earth-Rotation Access	✓	inaccurate				✓
Software & Hardware Support	varies		varies	varies	limited	✓
Accessibility	✓	✓	✓	✓	✓	✓
Terminological Integrity	✓			✓		✓
Public Perceptions	✓	varies			?	✓
Int'l Consensus	✓	?			?	✓
Widest Utility						✓

Despite WRC-12 Resolution 653, consideration of the requirements and relevant options raises some question over the urgency for action. ITU-R Recommendation TF.460-6 already advocates the broadcasting of *status-quo* UTC together with the parameter DTAI = TAI(k)−UTC(k) to allow users to realize an unintercalated TAI(k). That DTAI is not yet broadcast suggests that user demand for civil TAI-like time via radio may not be as great as Resolution 653 implies. Further evidence is the fact that the proposal for "UTC-without-leap-seconds" has languished in committee for more than a decade. In the meantime, GPS already distributes an unintercalated time scale well suited for many operational applications seeking such a scale.

CONCLUSIONS

Historically, new time scales have been developed as new requirements emerged. After exploring different requirements and reflecting on various options that meet those requirements, it seems logical to address WRC-12 Resolution 653 by officially recognizing a supplementary time scale without intercalary adjustments, rather than eliminating the current UTC with leap seconds. It would be appropriate for this supplementary scale to be distinctly offset from UTC to avoid confusion with UTC, just as current GNSS scales. To transmit such a scale, TF.460-6 already advocates the broadcast of a supplementary offset parameter to be added to UTC. It would also be appropriate to give this unintercalated time scale a unique name (such as *International Time*).

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