Coordinated Universal Time (UTC) and the Status of the Leap Second
Report to the AAS Council

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ABSTRACT

Working Party-7A of the International Telecommunications Union Radiocommunications Section (ITU-R) recently discussed a draft recommendation to the ITU Working Party-7A to change the maximum time difference allowed between UT1 and Coordinated Universal Time (UTC) from 0.9 second to 1 hour, effectively eliminating the leap second. Comments regarding this proposal were submitted by a number of organizations before the ITU-R meeting in 2005 November. In particular, the AAS urged that no action be taken, to allow all affected parties time to evaluate the technical merit of the recommendation. ITU Working Party-7A decided to defer action in order to devote more time to building a consensus. The AAS may want to formulate a position on this issue in advance of the next ITU meeting in late 2006. This document: (1) gives a brief explanation and history of the leap second; (2) gives an explanation of the proposal made to the ITU-R; (3) provides a summary of arguments for and against the proposal; (4) suggests to AAS Council a preliminary list of institutions that should be consulted regarding the effect of the proposal on astronomy in the US and international institutions affiliated with the AAS; and (5) suggests the composition of a panel to undertake a survey of these institutions, should the Council take this course of action.

EXECUTIVE SUMMARY

Fundamental timekeeping involves a number of distinct time scales. The time scale known as UT1, for example, is derived from the actual observed rotation of the Earth. Coordinated Universal Time (UTC), on the other hand, uses the SI unit of the second, which is linked to the international atomic time standard (TAI). Each rotation of the Earth as measured by UT1 does not contain an integral number---or even the same number---of SI seconds, but varies with the change in the Earth's rate of rotation. The Earth's rotation is slowing due to a combination of predictable and unpredictable effects. It is therefore necessary to adjust UTC to keep it aligned with UT1.

Under the standard adopted in 1972, leap seconds are introduced as necessary so that the difference $|UT1 – UTC| < 0.9$ seconds. Since 1 January 1972, a total of 22 positive, and no negative, leap seconds have been introduced. The introduction of leap seconds is expected to become more frequent as the Earth's rotation slows over time.

The definition of UTC is governed by the International Telecommunications Union, Radiocommunications Sector (ITU-R), and within the ITU-R this work falls under the mission of Section 7, Working Party-7A (WP-7A).

In 2004, US Working Party 7A of the ITU-R proposed to ITU-R WP-7A that the current definition of UTC be amended to raise the tolerance for $|UT1 – UTC|$ from 0.9 seconds to 1 hour, effectively eliminating the leap second, and breaking the close tie between UT1 and UTC.

Some segments of the astronomical community submitted comments in advance of the 2005 November meeting of ITU-R WP-7A. The Royal Astronomical Society issued a statement opposing the change. The AAS has not formulated a position on the issue, but submitted a comment urging that no action be taken, to allow affected parties time to evaluate the technical merit and potential impact of the recommendation.

At the November 2005 meeting it was decided to attach the recommendation to the WP-7A chair's report for consideration at the next meeting of WP-7A, scheduled for late 2006. This delay permits interested communities to indicate their opinion whether to accept or decline the recommendation.

There is an IAU Division I Working Group on the Redefinition of UTC that is in the process of preparing a final report for the Prague General Assembly (2006). The Chair of this Working Group is Dennis McCarthy.

Arguments for the recommendation include:

> Need for uniform time. Advances in technology and interoperability of systems require a widely available scale of uniform time. UTC is currently not a uniform time scale because of leap seconds. Deleting the leap second could allow UTC to be this uniform time scale.

Safety issues. Aircraft using the DoD based Global Positioning System (GPS) to navigate may have a different time basis than those using GLONASS (the Russian based version of GPS). Air traffic controllers use UTC clocks, while navigation systems have a different time basis. This may lead to safety issues because of the non-standardization and non-uniformity of time scales.

Clocks. Precise clocks may have trouble inserting a leap second, leading to, among other things, problems with time stamping legal documents.

User survey. A survey of International Earth Rotation and Reference Systems Service (IERS)[1] users provided some opinions supporting the recommendation: (a) A discontinuous time scale is not convenient. (b) Leap seconds are cumbersome. (c) We may need to insert two leap-seconds per year in this century. (d) Eliminating leap seconds will cause no significant problems for civil purposes.

Arguments against the recommendation include:

History. Leap seconds have been an established part of timekeeping procedures for almost 35 years, and the use of a civil time scale based on the rotation of the Earth goes back to ancient times. Leap seconds provide for a close connection between UTC and a time scale related to the Earth's rotation.

Legal time. In some countries the legal basis of time is specified, as in the US, as mean solar time or the equivalent. For the US, the basis of time zones is specified in 15 US Code Section 261. Significant efforts might be required to bring about the necessary changes in legal codes that would be required to comply with a change in the definition of UTC.

Cost. The cost of revising software for data reduction, instrument control, and spacecraft operation is unknown, but initial estimates indicate that the cost could be prohibitive and could lead to unsafe conditions. This includes the hidden costs of numerous applications with low accuracy requirements, which tacitly assume UT1 = UTC.

Celestial navigation errors. A time error < 1 s corresponds to a celestial navigation error in longitude < 500 m, which is considered acceptable in current practice. However, if the tolerance were relaxed and a celestial navigator were to continue using UTC without modification, the error in longitude would quickly expand beyond tolerable limits.

All astronomical communities, facilities, and applications that do not account for the possibility of a difference between UT1 and UTC greater than one second are impacted by this decision. This includes low-precision users who may not be aware of the difference between UT1 and UTC.

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[1] The IERS maintains the International Celestial and Terrestrial Reference Frames and provides the Earth orientation parameters to transform between them.

AAS Council may consider it important for the AAS to frame a position on this issue. Establishing such a position may require surveying a broad array of constituencies within the astronomical community. The Council may choose to appoint an expert panel to conduct this survey and determine the effect of the ITU-R recommendation on astronomy in the US and other international institutions affiliated with the AAS.

1. WHAT THE LEAP SECOND IS[2]

Simon Newcomb (1882, p. 465) indicated that measurements of the transits of Mercury, the Moon, and Jupiter's satellites all showed similar variations, possibly related to the irregularities in the Earth's rotation. Since then, many studies have been undertaken to determine these variations over time. Evidence of the irregular variation of the Earth's rotation is commonly provided by the comparison of Universal Time determined from astronomical observations of the Earth's rotation (UT1) with a uniform time scale based either on the Earth's revolution about the Sun (Terrestrial Time, TT) or on atomic time (International Atomic Time TAI). McCarthy and Babcock (1986) found an empirical fit to the difference between UT1 and TAI of

$$(5.156 \pm 0.404) + (13.3 \pm 0.3)\,(t - 0.19 \pm 0.01)^2 \qquad (1)$$

where t is given in centuries since 1800.0. The important point of Eq. (1) is that the cumulative change in time between TAI and UT1 is quadratic. This is interpreted as a result of the roughly constant deceleration of the Earth's rotation, which is mainly due to the dynamical friction of the lunar tides on the Earth, modified by deglaciation, which also causes the semi-major axis of the lunar orbit to increase with time. This leads to a secular change in the length of the astronomical day and a resulting quadratic variation in the difference between the time scales. Stephenson & Morrison (1995) show that this quadratic accumulation of the difference between a uniform time and UT1 goes back to at least 700 BC. Thus, as more time passes, the mean difference between time as determined by an oscillator such as an atomic clock and time as determined from the rotation of the Earth will diverge at an increasing rate. This difference brings about one of the major conundrums of time scales. On the one hand, it is desirable to have a time scale that has a uniform time interval such as TAI. On the other hand, it is also desirable to have a time scale that is in concert with the natural rhythms of everyday life. Since Jan. 1, 1972, this latter time has been provided by Coordinated Universal Time (UTC). UTC is not a uniform time scale; it is discontinuous when a leap second is inserted.

In UTC, the basic unit is the second of the International System of Units (SI) as measured by an ensemble of atomic clocks on the Earth's geoid, corrected for relativistic effects. The same SI second is used as the basis of TAI.

However, to keep pace with the Earth's revolution, a one second adjustment to UTC, called a *leap second*, is made as necessary to keep the difference between UTC and the actual rotation of the Earth, UT1[3], under 0.9 seconds. According to the convention agreed upon when the current definition for UTC was set up, these leap seconds, either positive or negative, can be inserted[4] at the end of any month, but it is preferred that they be made either at the end June or December. If that is not possible, it is preferred that changes be made at the end of March or September. The difference TAI – UT is known as ΔT. The original specification of leap seconds also specified how events that occurred *during* the leap second should be time-tagged.

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[2] A more comprehensive version of this section can be found in Nelson, *et al.* (2001).

[3] Due to the complex rotation of the Earth there are three different versions of UT: UT1 is derived from observations of the Earth's true rotation angle; UT0 is UT1 modified to include the effect of the changing angular orientation of the Earth's rotational pole in the terrestrial reference system; UT2 is UT1 corrected for the seasonal changes in the Earth's rotation. UTC is specifically coordinated with respect to UT1.

[4] Although it is possible to insert a negative leap second, it is unlikely this will ever happen considering the mean rate of change of the Earth's rotation rate.

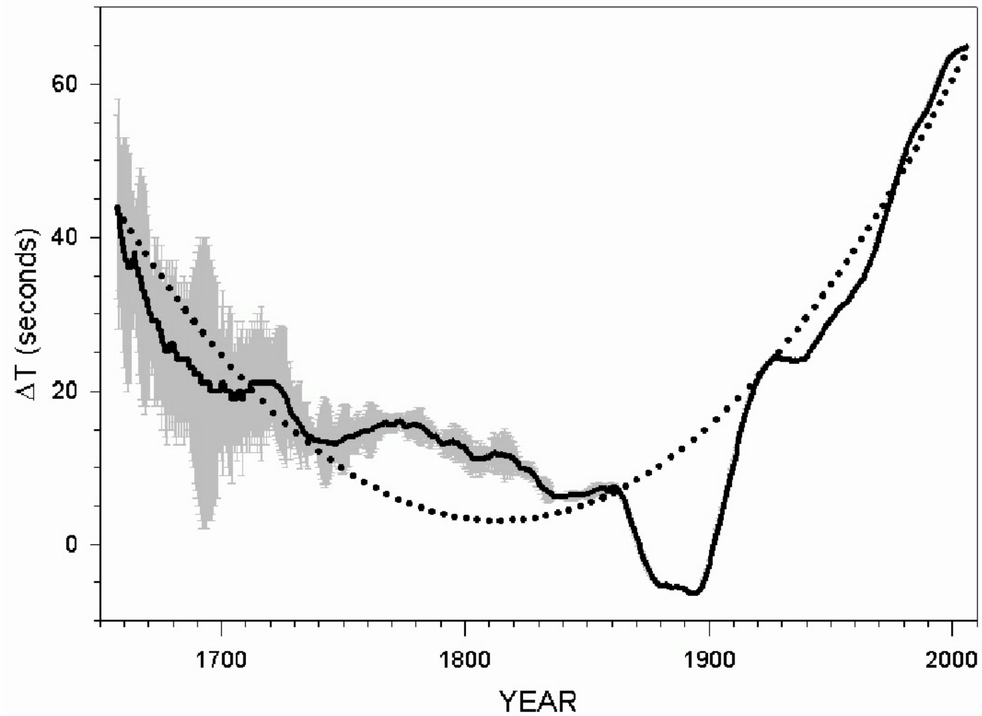

Figure 1. The calculated and observed values of ΔT from 1620 to 2005.

Predictions of UT1 a year or more in advance sometimes have errors of several tenths of a second; therefore, leap seconds are usually not scheduled more than about six months in advance. In Fig. 1, a subset of the data from McCarthy & Babcock (1986) shows that the difference between the observed values and values calculated from the quadratic expression of ΔT can be more than ten seconds.

Fig. 2, from Stephenson & Morrison (1995), shows the change in the length of day (lod) in milliseconds from -500 to 1995 CE. The change in lod is the first derivative of ΔT and should be linear if ΔT is purely quadratic. Instead, there is apparently a long term variation in the length of day of about 10 ms. The dotted line represents what the lod should be based on the observed tidal drag of the Moon alone. Thus, in addition to the short term departures of ΔT from its mean value shown in Fig. 1, there are long term periodic and secular changes in the Earth's rotation rate that are not completely understood.

The current history of UTC begins in 1960. It was agreed, when the US and UK nautical almanacs were combined (beginning with the 1960 edition), that they would also coordinate their time and frequency transmissions beginning on 1 January 1960. Gradually, other countries joined the system.

The coordination of the international contributions to UTC was entrusted to the Bureau International de l'Heure (BIH) in 1961. Details of the UTC system were formalized by the International Radio Consultative Committee (CCIR) in its Recommendation 374 (ITU 1963). The BIH decided to connect UTC to the A3 atomic time scale (which later became TAI) by a mathematical relationship in 1965. The name Coordinated Universal Time UTC was approved by a resolution of the International Astronomical Union (IAU) Commissions 4 and 31 at the 13th General Assembly in 1967 (IAU 1968).

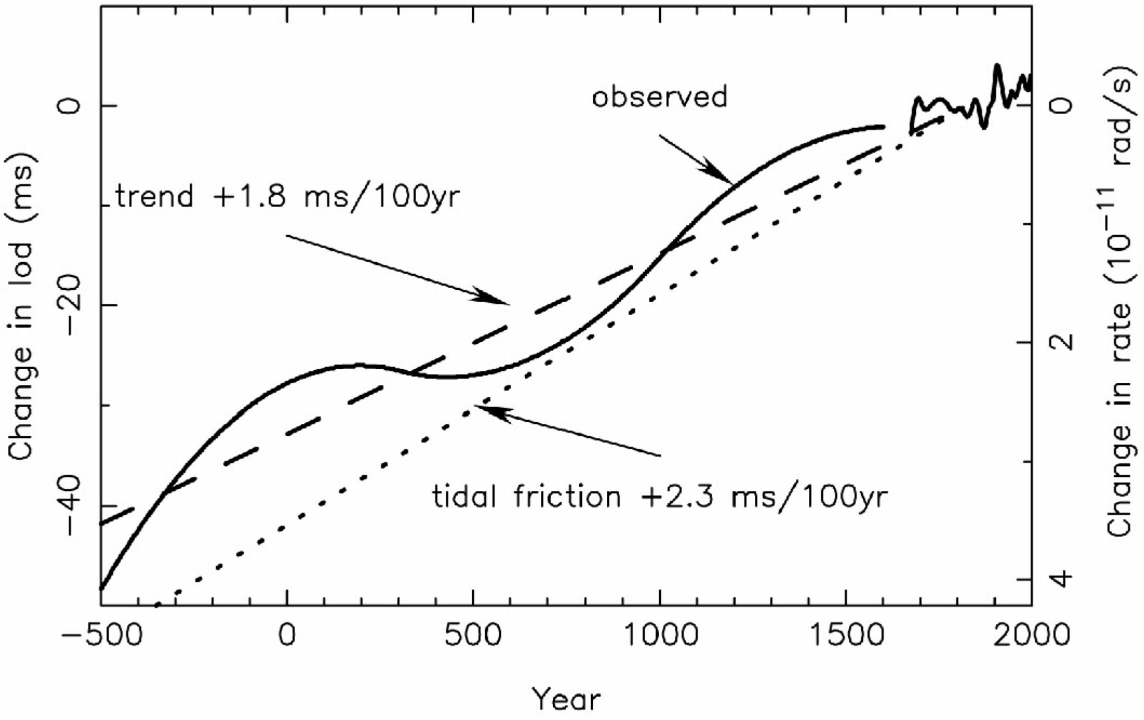

Figure 2. The observed change in the length of day from -500 CE to 1995 CE.

At that time, UTC was steered using both leap seconds and rate changes (*i.e*. the UTC second was *not* the same length as the TAI second) such that UTC stayed within 0.1 second of UT2. However, the use of a flexible length for the second was not considered satisfactory. Attempts to follow these fluctuations necessitated revisions in complex equipment on a frequent basis and risked temporary interruptions of service. In addition, it was pointed out that celestial navigation, the most important application at the time, requires the use of UT1 (the actual orientation of the Earth in space) rather than UT2 (the seasonally adjusted rotation). Thus, the CCIR (1972) redefined UTC such that: Beginning on 1 January 1972 the UTC second would be the same as the TAI second. On 1 January 1972 TAI UTC = 10 sec. The difference between UTC and TAI would remain an integral number of seconds. Leap seconds would be introduced, when necessary on the last second of a month, so that the value |UT1 – UTC| < 0.7 sec. And an announcement would be made six months before a leap second was introduced. In 1974, the CCIR increased the tolerance for |UT1 – UTC| from 0.7 sec. to 0.9 sec. (Nelson *et al*. 2001).

Since 1 January 1972 a total of 22 positive and no negative leap seconds have been introduced. All of these have been implemented either at 23:59:60 on 30 June or at 23:59:60 on 31 December. The last two leap second occurred on 31 December 1998 and 31 December 2005.

2. EXPLANATION OF THE RECOMMENATION MADE BY USWP-7A

The International Telecommunications Union, Radiocommunications Sector (ITU-R), the follow-on agency of the CCIR, governs the definition of UTC. Within the ITU-R this work falls under the mission of Section 7, Working Party 7A (WP-7A). In 2004, the US Working Party, USWP-7A, submitted a draft proposal, Preliminary Draft Revised Recommendation (PDRR) ITU-R TF.460-6 (Annex 4 to Document 7A/21-E dated 5 October 2004)[5], recommending that leap seconds be effectively eliminated from UTC by raising the UT1 – UTC tolerance from 0.9 seconds to 1 hour. The recommendation appears on page 8 of the revised annex to the PDRR.

At the November 2005 meeting of the ITU-R, there were contributions or statements submitted by the United Kingdom, France, Germany, and Italy concerning the recommendation. The UK objected to the changes to UTC as given in that document generally on the grounds that they saw no problems with the present status. France, Germany, and Italy did not object to deletion of leap seconds but suggested more time for making change. In addition, the Royal Astronomical Society issued a statement opposing the recommendation.[6] After considerable discussion, including strong support by the International Bureau of Weights and Measures (BIPM) for deletion of leap seconds, it was decided to once again attach the recommendation to the WP-7A chair's report for consideration at the next meeting of WP-7A scheduled for late 2006. That means no action is taken on the recommendation at this time. It will be considered for action at the 2006 meeting.

Should WP-7A accept the recommendation it will pass it along to Study Group 7, which then has its chance to look into the matter and possibly (likely) pass it on to the ITU-R. At that point the ITU-R would distribute the official recommendation to all of the participating nations and concerned international scientific unions for comment. In the US the response would come from the State Department, which would consult with appropriate scientific, commercial, and defense agencies in formulating that response. After the comments are incorporated the proposal voted on by country. At the moment, no Department of the US Government has gone on record supporting the recommendation.

There is an IAU Division I Working Group on the Redefinition of UTC that is in the process of preparing a final report for the Prague General Assembly (2006). The Chair of this Working Group is Dennis McCarthy (USNO).

3. ARGUMENTS FOR REVISING THE UT1 – UTC TOLERANCE

A uniform time scale is desirable because it minimizes time sensitive changes to the systems using the uniform time scale. UTC is not a uniform time scale (such as TAI) because of leap seconds. Nelson *et al* (2003) assert that the practice of inserting leap seconds into UTC has encouraged the use of alternative time scales which are uniform, and that this has made the Global Positioning System (GPS)[7] time scale a *de facto* standard. They then point out that advances in technology and interoperability of systems require a widely available scale of uniform time, and suggest that deleting the leap second would allow UTC to be this uniform time scale.

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[5] The document at http://www.cl.cam.ac.uk/~mgk25/time/leap/PropRevITU-RTF460-6.pdf is a 1 September 2004 version.

[6] See http://www.spacedaily.com/news/time-05g.html

[7] GPS is a Department of Defense (DoD) developed, worldwide, satellite-based radio navigation system that will be the DoDs primary radio navigation system well into the next century. The constellation consists of 24 operational satellites. GPS has been operational since April 27, 1995. For further information on GPS see http://tycho.usno.navy.mil/gpsinfo.html .

Do clocks exist to handle a 61 second minute in a friendly, robust way? McCarthy (2005) brings up concerns about what happens in clocks when a leap second occurs. Some timing systems may provide a minute with two seconds labeled *59* or possibly a second without any label. This is a particular concern in time stamping legal documents. On this issue, one can not simply say that the leap second is not a problem because it occurs in the middle of the night. The leap second is a global phenomenon occurring at 23:59:60 UTC. Depending on the local time zone, the leap second can occur at inopportune times in the business day.

McCarthy also states that eventually there will be multiple leap seconds required each year because of tidal deceleration. We may expect to insert two leap-seconds per year in this century. Since the institution of the current scheme for leap seconds, the number required has run well ahead of the number that would be estimated from Eq. 1. Klepczynski (2003) also points out that the number of future leap seconds will increase, and that they will not occur at uniformly spaced intervals.

Gambis *et al.* (2003) surveyed International Earth Rotation and Reference Systems Service (IERS) users[8] on their attitudes towards the discontinuation of the leap second. Opinions in support of discontinuation of the leap second were: (a) A discontinuous[9] time scale is not convenient. (b) Leap seconds are cumbersome. (c) Ignoring leap seconds will not be a significant problem for civil purposes.

Is human safety an issue? Klepczynski (2003) cites the specific case of the proposed aircraft radio navigation system known as Automatic Dependent Surveillance Broadcast (ADS-B). Klepczynski's concern is that time scale confusion during the insertion of a leap second could result in navigational problems in aircraft and resulting potential loss of life. An example of a system failure is GLONASS, the Russian equivalent of GPS, which was purportedly unusable for twenty hours after the occurrence of a leap second. Klepczynski further points out that not all of the automated systems use the same time basis. Specifically, he points out that international aircraft flights traveling eastward from the U.S. could have a different time basis[10] than those flights originating in the European Union traveling westward[11], and that air traffic controllers use clocks on UTC while navigation systems have a different time basis. Those who are designing ADS-B may not understand the differences in time scales.

Rebuttals to these arguments are:

The concern of Nelson et al. (2003) is that the failure to adopt a definition of UTC[12] suitable to the needs of modern electronic navigation and communications systems will result in a growing number of time scales that seek to solve the problem internally within their own proprietary system, resulting in a growing number of non-standard time scales. If the insertion of leap seconds were stopped would UTC then be adopted as the international uniform time scale?

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[8] The IERS is the service responsible for announcing the insertion of a leap second and for providing those in need of high accuracy time and Earth orientation values with the latest available values and predictions for UT1 – UTC.

[9] UTC is discontinuous whenever a leap second is introduced.

[10] Eastward travelers might use GPS time which has a constant offset from TAI. This offset is the value of TAI – UTC at the time the GPS time scale was initially constructed.

[11] European Union countries might mandate the use, when available, Galileo (see footnote 13) time. This time scale most likely will essentially be the same as TAI.

[12] TAI has been suggested as the uniform time scale for standard use in those cases where a discontinuous time scale is not acceptable. The problem with TAI is that it is not currently available except through UTC. That is, one gets TAI by knowing UTC and applying the variable integer second offset.

It has been suggested that if UTC were changed to be a uniform time scale, GPS and Galileo[13] may converge on this as the common time scale but there is no guarantee that this will actually occur.

Seidelmann & Seago (2005 private communication) have pointed out that at least three makers of high precision chronometers or time servers, Truetime (Truetime 2002), Spectracom (Spectracom 2005), and Kinemetrics, do produce devices capable of recording leap seconds. However, actual tests of timing equipment show that as of December 2005 there is no industry-wide compliance with the convention of an extra second being labeled *60*. Manufacturers of timing equipment are able to provide some equipment that complies with the convention of a second labeled *60*, but a substantial number of the suppliers do not have such equipment available. Clock manufacturers have had no economic reason to provide such a product previously.

The significance of the concern for human safety raised by Klepczynski is undocumented. Furthermore, the system failure of GLONASS referred to by Klepczynski is contradicted by an advisory to GLONASS users (NAGU 052-9706196) that states specifically that the unavailability of GLONASS was not a result of the leap second but a planned maintenance outage. In fact, the Russian statement to the International Colloquium on the UTC Timescale endorsed the status quo.

There does not now appear to be documentation that makes a strong enough case for making this change to UTC. Perhaps a strong case can be made, but more specific documentation should be required from the proponents of change, including endorsements from relevant organizations and professional societies.

4. ARGUMENTS AGAINST REVISING THE UT1 – UTC TOLERANCE

Leap seconds have been an established part of timekeeping procedures for almost 35 years, and the use of a time scale for civil purposes closely based on the rotation of the Earth goes back to ancient times. In some countries, the legal basis of time is specified, as in the US, as mean solar time or the equivalent. For the US, the basis of time zones is specified in 15 US Code Section 261. UTC is a viable realization of legal time in many places only because it stays within a second of UT1, which is the modern version of mean solar time. A change from the UTC status quo might therefore require an act of Congress to make UTC the official time scale of the United States. Parallel actions in other countries would probably also be required. For example, the United Kingdom uses Greenwich Mean Time (GMT). GMT is often assumed to be equivalent to UTC; however, the bill that would define GMT as UTC, the Coordinated Universal Time Bill, introduced into Parliament in 1997, apparently was never enacted.[14] Thus, GMT would also likley need to be redefined.

One result of deleting the leap second is that astronomical phenomena such as sunrise and sunset slowly get later and later by the clock (although noticeable changes are centuries away) thus breaking the historical tie to the seasonal variation of the year.

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[13] Galileo time is the European Union satellite navigation system, not yet operational. For further information see http://europa.eu.int/comm/dgs/energy_transport/galileo/index_en.htm . If Galileo adopts TAI as their time base, then TAI might be more readily available as a uniform time.

[14] See http://www.publications.parliament.uk/pa/ld199798/ldhansrd/vo970611/text/70611-10.htm

A potentially significant argument for keeping the current UT1 – UTC tolerance is the cost to upgrade systems in operation or in development. The most extensive survey of the estimated cost in making a change in the definition of UTC is the assessment by Seago & Storz (2003) of the satellite laser ranging (SLR) program carried out by a nine station network operated by the U.S. Air Force. They estimate, based on a preliminary effort, that it would cost at least $10,000 in labor to create just the conclusive impact assessment and cost estimate. However, a good-faith estimate suggests that, if UTC redefinition only required changes to the formats and read statements supporting Earth-orientation parameters for star calibration, the cost of upgrading nine SLR systems would likely require in excess of $100,000. More significant changes to the data-processing and tracking segments would likely result in a total cost closer to $500,000.

Seago & Storz could not make quantitative estimates for other space programs, but did survey both Naval Network and Space Operations Systems and HQ Air Force Space Command. They found that some key applications, used throughout the software in these commands, would be affected. Further, it would require years simply to determine the impact of eliminating leap seconds on each individual program's accuracy requirement. To the best of our knowledge no such survey has been made at NASA, but it is likely that a similar situation would exist there. Estimates of cost should include spacecraft operations and software costs for reprogramming solar panel controls for use of UT1 instead of UTC for solar pointing.

Other astronomy specific cost estimates are:

From S. Allen's (2003) survey the estimated cost per telescope to update the hardware and software are as follows: University of Texas, $20,000; Lick Observatory, $20,000; Keck Observatory, $50,000; Owens Valley Radio Observatory, $10,000; all telescopes at an unspecified optical/IR observatory, $500,000.

C. Corson, site engineer for the WIYN telescope (2005, private communication) estimates the cost of changes to be about $2,000,000.

P. Wallace (2005, private communication) estimates the costs to Gemini at about $10,000.

To the best of our knowledge, none of these estimates is the result of an in-depth examination of the code and hardware that would require modification or replacement. Thus, the actual costs may be quite different from these estimates.

It is, furthermore, unclear who would bear the cost burden of a change to UTC. For example, Bangert (2005, private communication) points out that while *The Nautical Almanac* requires UT as an argument, it does not distinguish between UT1 and UTC. Simply by stating that the time argument in *The Nautical Almanac* is UT1, it is possible to put the burden and cost of determining UT1 – UTC on the user of the publication rather than the producer. Thus, while cost may be a considerable factor, it is poorly quantified. It is not at all certain how many applications require a knowledge of the difference between UT1 and UTC, nor is there any real comprehensive idea of the costs or who would have to bear said costs.

It is not clear how many applications exist that make the assumption that UT is a single concept, *i.e.*, assume that UT1 = UTC. The specific concern is that UT1 is an argument needed to compute sidereal time, which is then used to determine the hour angles of celestial objects. To fail to account for the difference between UTC and UT1 leads to errors in the topocentric positions of celestial objects or, equivalently, in the orientation of the topocentric coordinate system with respect to the celestial system. For example, an error of 1 second in UT1 results in an error in the hour angles of celestial objects of 1.003s, equivalent to 15.04" cos δ. Such an error is equivalent to up to 0.25 nautical mile (464 m) on the surface of the Earth. An error of 500 m is considered acceptable in current celestial navigation practice. For this reason, the current tolerance in |UT1 – UTC| was chosen to be 0.9 sec. However, if the tolerance were relaxed and a celestial navigator were to continue using UTC without modification, the error in longitude would quickly expand beyond tolerable limits. Thus a serious error in position can result if UTC is used in place of UT1, as is the common practice in celestial navigation. Predictions of UT1 – UTC are readily available at least a year in advance for use by celestial navigators. Most celestial navigators, however, are trained to do site reduction[15] by rote, so they would need to be retrained in this activity should UT1 – UTC become significantly greater than 1 sec. Thus, even low precision applications can quickly break down. Part of the cost in changing existing software is that some of that software has built-in code to raise error conditions should data be received indicating that |UT1 – UTC| > 0.9 sec.

Most (88%) of the respondents to the Gambis *et al.* (2003) survey of IERS users opposed the recommendation to abandon leap seconds. They cited the problem that any changes in these areas will likely cause substantial confusion. In particular, they cited the risk of confusion and problems if there is a large jump in the tolerance of UT1 – UTC. They also said that the current system works and no strong argument had been given to change.

Rebuttals to these arguments are:

TAI may be a uniform time scale but it is not easily accessible. TAI is currently available only by knowing UTC and then applying the relevant offset. Therefore, it is not a perfect choice for an international standard.

There is no quantification for the claim that there will be substantial confusion if there is a large change in the tolerance level for UT1 – UTC. Thus, while it may be valid it has not been demonstrated.

Concerns about human safety, if substantiated, should carry great weight, and would argue strongly for change.

Estimates of prohibitive cost are not based on comprehensive studies and may be significantly in error.

Updated values of UT1 – UTC are available daily along with their predictions for astronomical applications. The connection to the Earth's rotation is maintained through the use of this quantity. The concern about |UT1 – UTC| becoming greater than 1 second arises only because some applications have chosen to neglect UT1 – UTC.

5. OTHER ALTERNATIVES CONSIDERED

Various presentations at the *Colloquium on the UTC Timescale* considered at least six alternatives to the relaxation of the tolerance between UT1 and UTC to one hour. These alternatives are:

Redefine length of the second. This alternative is immediately considered a nonstarter. It would cause an unquantified amount of confusion. The second is the basis of many physical constants. Thus, redefining the second would have a ripple effect throughout science, engineering, and all other applications where time is used. Finally, it would be only a temporary fix. The leap second problem would reemerge as Earth's rotation rate continues to change.

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[15] Site reduction is the process of determining an observer's position from timed astronomical observations.

Adjust rate of UTC with respect to TAI. This option is also a nonstarter. As with redefining the second and adjusted rate would cause an unquantified amount confusion. This option was used without success from 1963 until the beginning of 1972. Such a system would also require that clocks showing UTC have an adjustable rate.

Put in leap seconds at predetermined times. This option is difficult to do and still maintain the tolerance limit because of the difficulty in predicting the Earth's rotation rate.

Increase tolerance for |UT1 – UTC|. More specifically, allow the tolerance to be a few seconds so that the stochastic nature of the change in the Earth's rotation rate is no longer a major factor in the uncertainty of when to insert leap seconds. What is unknown here is the value for which the difference in |UT1 – UTC| begins to cause breakdowns in low precision applications. For example, as described above, the accuracy of celestial navigation begins to break down when |UT1 – UTC| is significantly greater than 1 sec. and the navigator is either unaware that there is a difference between UT1 and UTC or has no source for the approximate current value of that difference.[16]

Smooth over leap seconds. That is, the leap second would be introduced in fractions of a second over the last minute or so. This option has technical considerations that have not been delineated.

Use already existing smooth time scale such as TAI. However, TAI itself is not directly accessible. It is only made available after-the-fact when the correlation of the components that go into determining TAI are correlated by the BIPM. The closest direct connection to TAI is through UTC, which, like GPS time, requires knowledge of ΔT, the offset between TAI and UTC.

6. ASTRONOMICAL COMMUNITIES IMPACTED BY THE PROPOSED CHANGE

All astronomical communities that do not allow for the possibility of a difference between UT1 and UTC greater than one second are impacted. This includes low-precision users who may not be aware of the difference between UT1 and UTC[17]. Most high precision users can be expected to account already for the difference between UT1 and UTC in the software. A preliminary list of affected communities, with representative institutions, is as follows:

The space astronomy community, *e.g.,* STScI, CXC, IPAC, NASA/GSFC

The radio interferometry community, especially those very long baseline Interferometry, *e.g.,* NRAO, VLBA, FCRAO

The radar ranging community; *e.g.* NAIC, DSN (Deep Space Network)

The celestial navigation community, *e.g.* USNO

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[16] One concern here is whether or not celestial navigation is of any importance any more. On the one hand, electronic navigation aids such as GPS provide positions that are orders of magnitude more accurate than traditional celestial navigation. On the other hand, the electronic navigation aids are subject to problems such as breakdown and jamming. Thus, celestial navigation provides an essential low-accuracy backup. For this reason, the U.S. Navy still requires *The Nautical Almanac* be onboard every ship along with navigators trained in its use, and is currently pursuing an Automated Celestial Navigation project. There is also still a significant civilian market for *The Nautical Almanac*.

[17] Many observations in journals are published in UTC to the nearest minute or so.

The communities requiring precision pointing and control of terrestrial instruments; *e.g.* NOAO, NSO, Gemini, and other O/IR observatories
The millisecond pulsar observers, *e.g.* NRAO, NAIC
The lunar and satellite laser ranging community, *e.g.* JPL, McDonald
Those dealing with orbit determination problems, *e.g.* GSFC, JPL
The space surveillance community; *e.g.* NRL.

7. PLAN OF ACTION

The next ITU-R meeting to consider the elimination of the leap second will be held in late 2006. We suggest the following plan of action for the period of time before that next meeting:

AAS Council should consider whether the AAS, like the Royal Astronomical Society, should formulate a position concerning the proposed change in UTC. If so, this stance should be decided upon expeditiously, disseminated publicly, and forwarded to the International Astronomical Union (IAU). While it may be years before the proposed change in UTC is formally adopted, should the AAS decide to oppose the change, an earlier intervention would be more effective.

If Council does determine that the AAS should take a stand on the issue, institutions including, but not necessarily limited to, the above list should be contacted without delay and surveyed (see below) on the potential impacts of the change. It is hoped that this document will provide a starting point for such a survey. Council may want also to consider polling the membership of the AAS, and/or consulting with experts on UTC and the leap second before conducting any survey. We provide a list of experts at the end of this report.

7.1. Survey Questions

We urge that care be taken in formulating a survey of the affected constituencies. Survey design is problematic, and wording of the questions can affect the outcome. For example, Gambis *et al*. (2003) asked, “Are you satisfied by the current UTC determination method with leap second adjustments?” This question garnered a positive response of 88%, which we have interpreted as implying that 88% of respondents were opposed to dropping leap seconds. But the result might have been different had the question been, “Do you oppose the dropping of the use of leap seconds?”

It is also important that any survey reach the right people, and gather information from individuals who are in charge of critical software or real-time systems. An essential issue that must be addressed is the institutional cost of software upgrades required to accommodate a change. Some AAS members who have professional involvement in national security, electronic financial transactions, or safe passage of people and goods may have particularly valuable insights.

In the course of preparing this paper we have found three previous surveys on this topic. The questions in these surveys are available on request. AAS Council may be well advised to hire a survey expert to conduct the survey on its behalf.

7.2. Suggestions for Further Information

AAS Council may have questions concerning the UTC leap second not answered in this document. To provide answers, as well as a wide range of views on the topic, we suggest consulting the following experts (listed in alphabetical order), in addition to the Working Group itself:

John A. Bangert (USNO)
Bill Bollwerk (USNO)
Fred Espanak (NASA GSFC)
Henry Fliegel (Aerospace Corporation, retired)
James L. Hilton (USNO)
George H. Kaplan (USNO, retired)
Kerry A. Kingham (USNO)
Bill Klepczynski
Chopo Ma (NASA GSFC)
Dennis D. McCarthy (USNO, retired)
Steven J. Ostro (JPL)
Jim Ray (NOAA)
P. Kenneth Seidelmann (U Va.)
Peter Shelus (U Tex.)
Victor J. Slabinski (USNO)
E. Myles Standish (JPL)
Sean Urban (USNO)
James G. Williams (JPL)
William H. Wooden (USNO)

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[18] The proceedings of this colloquium can be found at: http://www.ien.it/luc/cesio/itu/ITU.shtml

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[19] The proceedings of this colloquium can be found at: http://syrte.obspm.fr/journees2004/PDF/Proceedings.html .