June 14, 2022

# CCTF preparation to the CGPM 2022
# Draft Resolution D – On the use and future development of UTC

## 1. Introduction

International and national timekeeping is critical in every country for the correct synchronization of information and communication systems. The resilience of time synchronization has been recognized as crucial to many pieces of critical national infrastructure, such as telecommunications, energy distribution, and the timing of financial transactions. It is also essential for position and timing applications based on the global navigation satellite systems (GNSS).

The international reference time scale is Coordinated Universal Time (UTC) which is computed by the BIPM using data from atomic clocks maintained in more than 80 institutions around the world. At its 26th meeting in 2018, the CGPM stated that

> "UTC is the only recommended time scale for international reference and is the basis of civil time in most countries".

By the same resolution, the CGPM also recommended that

> "all relevant unions and organizations work together to develop a common understanding on reference time scales, their realization and dissemination with a view to consider the present limitation on the maximum magnitude of UT1 – UTC, so as to meet the needs of the current and future user communities".

As part of its work to advance the common understanding on reference timescales, the Consultative Committee for Time and Frequency (CCTF) has carried out an on-line survey. The survey invited NMIs, UTC laboratories, liaisons, and stakeholders to evaluate the current realization of UTC, and to suggest actions to be taken to ensure its continued usefulness, acceptability, and universality. The survey was supported by presentations and videos[1] to introduce the topics.

More than 200 responses were received, most of which (around 80%) confirmed the need to take some action to allow a more useable and universal international system for time tagging giving accessibility to the SI second based on UTC.

In this note we explain how draft Resolution D (Appendix 1) has been prepared to address some of these concerns.

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[1] https://www.bipm.org/en/committees/cc/cctf/22-_1-2020 and https://www.youtube.com/playlist?list=PL-vj-3_a7wTBb7CKy-ckmZM8L6K3hipR5

## 2. Current situation and needs

### *2. 1. Atomic time and astronomical time*

The basis of atomic time is the “caesium second” which is defined with respect to the frequency of a hyperfine transition in the ground state of caesium 133. When Coordinated Universal Time (UTC) was introduced, it was decided to maintain a close agreement between the atomic time obtained by the accumulation of atomic seconds and the astronomical time scale (UT1), which is based on the rate of rotation of the Earth around its axis. However, over the last three decades the rate of rotation of the Earth has been increasing at an average rate of less than 1 second/year, but at a rate that is variable, hence, the difference between UTC and UT1 is impossible to predict with sufficient accuracy.

In 1972, when a code for the transmission of UTC was decided by the International Telecommunication Union Radiocommunication Sector (ITU-R), it was also decided to maintain the atomic and astronomical time scales within 1 second, by the insertion of an extra second to UTC whenever the UTC time scale is predicted to exceed UT1 by 0.9 s. Such a “positive leap second” is added at the end of a UTC day –chosen to be the last day of either June or December. The label for this leap second is 23:59:60, so that the last minute of the day has 61 seconds when a leap second is added.

The decision to maintain the agreement between UTC and UT1 at the level of one second allowed celestial navigation methods to use UTC as a proxy for UT1 with an accuracy corresponding to about 15” of latitude. In addition, the ITU-R defined a transmission code for the offset UT1-UTC, named DUT1, with a resolution of a tenth of a second.

Nowadays, the observed and predicted values of the difference UT1-UTC are estimated by the International Earth Rotation and Reference Systems Service (IERS), which publishes daily updates with microsecond accuracy. Other services are available to disseminate this information from the internet and from satellite systems.

In recent years, the practice of correcting UTC by inserting leap seconds has been questioned by users in several sectors. For example, most clocks, and especially digital clocks that keep time as the number of seconds elapsed since some epoch, cannot represent the time 23:59:60. In addition, the discontinuity in the time interval measured across a leap second is not consistent with assigning time tags to a real-time process. These and other difficulties have led some communities to devise “ad hoc procedures” which are not coherent with the agreed implementation of the leap second.

### *2. 2. GNSS timescales*

The issue of discontinuities in UTC was encountered first by GNSS designers who decided, in most cases, to develop systems that would ignore leap seconds after their initial synchronization in order to avoid any risk of failure in the system due to their insertion. Hence the GNSS time scales differ among themselves by an integral number of seconds as shown in Table 1 and Figure 1.

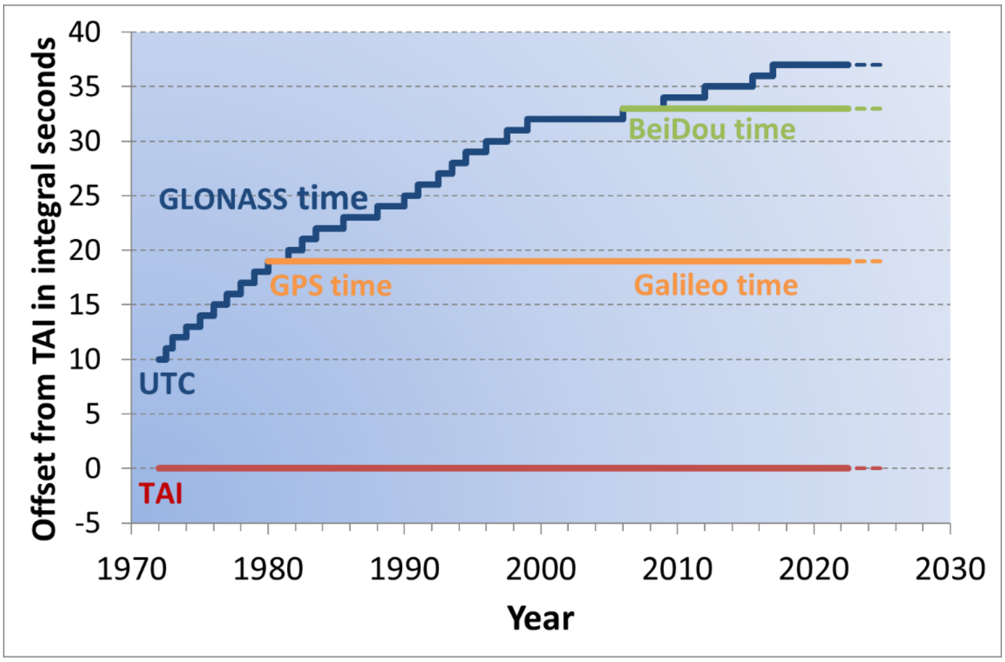


**Figure 1.** Offset between UTC, the GNSS internal time scales, and International Atomic Time TAI.

**Table 2.** Offsets in use by different GNSS internal time scales (2022).

| GNSS | Offset from UTC |
|---|---|
| GPS | + 18 s |
| GALILEO | + 18 s |
| BEIDOU | + 4 s |
| GLONASS | Zero offset – leap seconds are applied |

Although the GNSS time scales are only intended to be a parameter internal to the operation of their systems, they are often used as a reference time scale because they are easily accessible world-wide. This introduces confusion amongst users and creates a risk of potential synchronization errors. For example, a recent recommendation by ITU-T explains the need for a continuous reference time scale for the telecommunication networks and recommends GPS time as an alternative to UTC without leap seconds (G.8271/Y.1366 https://handle.itu.int/11.1002/1000/14209).

*2. 3. Synchronization of digital systems and ad hoc correction procedures*

The increasing importance of digital time systems and the possible disruption to national critical infrastructures caused by the insertion of leap seconds has led to the development of various *ad hoc* correction procedures as an alternative to the insertion of the leap second. For example, some systems repeat twice the second 23:59:59, or the second 00:00:00. Other examples are listed in Table 2. Each of these procedures make traceability to the SI second difficult to establish particularly *a posteriori*.

**Table 2.** Examples of ad hoc correction procedures used by major web service providers.

| Ad hoc correction procedure | User(s) |
|---|---|
| frequency adjustment for 24 h before the leap second | Google |
| frequency adjustment for 18 h after the leap second | Facebook |
| symmetrical "smear" from 12 h before to 12 h after the leap second | Alibaba |
| frequency reduced to one-half for the second before the leap second | Microsoft |

The use of such ad hoc corrections is increasing and is even being recommended by major web service providers as the basis for future international standards. These correction procedures are not compatible with UTC nor with each other. They create difficulties in determining the relationship between time data received from a particular reference source, with each other and with UTC. The use of these different ad hoc correction procedures now presents a risk of failure of crucial national services, and further threatens the choice of UTC for many contemporary applications, including those needed for the digital transformation of financial and telecommunication services. It should be noted that the time of application of a leap second coincides with the opening of the stock markets in most of the Asian countries.

### *2. 4. Future problems?*

It is important to note that recent observations of the Earth's rotation rate indicate an acceleration over the last 2 years, which could lead to the need for the first negative leap second – a phenomenon that has never been implemented previously (Fig 2).

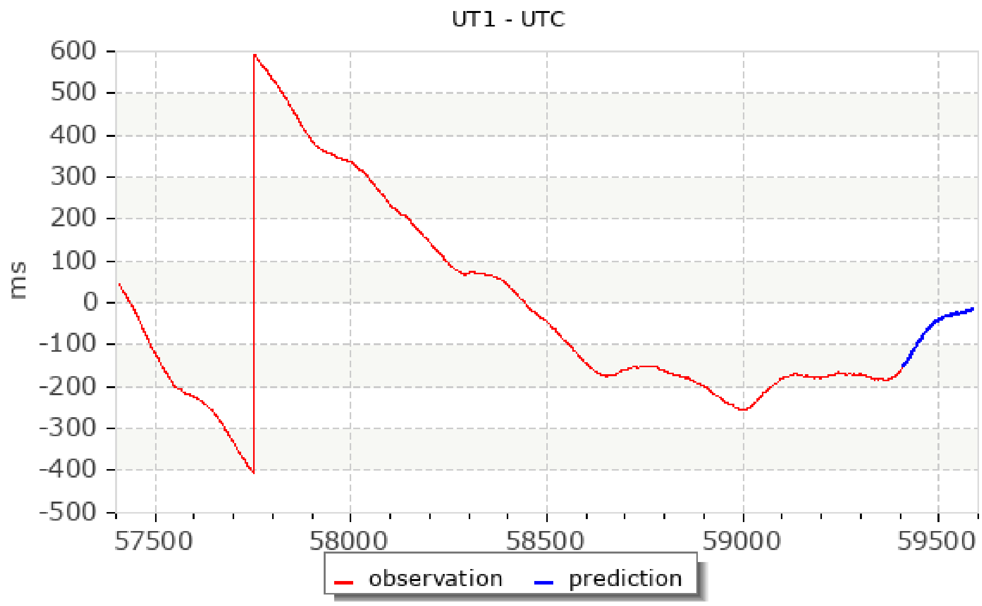


**Figure 3.** Observed and predicted value of UT1-UTC since the last insertion of a leap second in 2016. The abscissa shows the Modified Julian Date (MJD). (Figure extracted from [https://eoc.obspm.fr/index.php?index=realtime&lang=en](https://eoc.obspm.fr/index.php?index=realtime&lang=en))

### 2.5 Summary of the current situation and needs

In summary, it is not currently possible to predict the rate of rotation of the Earth with sufficient accuracy to calculate the corrections needed to adjust UTC into the future. However, the principle of astronomical conformity is historically linked to civil timekeeping for social reasons that go beyond immediate practical consideration[2]. Hence, the current method of implementing retrospective corrections is the only feasible way to adjust UTC to Earth rotation despite all of the associated confusions caused by the use of ad hoc correction methods.

In the following section we summarise the proposals from the CCTF to modernize this correction process.

## 3. Scenarios considered by the CCTF to modernize the method for the correction of UTC

The CCTF, has taken account of Resolution 2 of the 26th CGPM (2018) and has analysed the responses to its survey in order to examine the needs of users and the impact on modern applications of the discontinuities in UTC. Following this analysis, the CCTF has identified and discussed three scenarios for a possible way forward. These three scenarios are:

1. To “do nothing” and continue with the current method for the correction of UTC by the insertion of leap seconds.
2. To increase the tolerance for the correction of UTC by enlarging the tolerance on the offset UT1-UTC to an agreed fixed value that is reviewed in the future on an agreed cycle.
3. To suspend the process of correcting UTC by enlarging the offset tolerance on the UT1-UTC with no upper limit and review this decision in the future on an agreed cycle.

The details of the decisions needed to implement these scenarios are summarised in Table 3.

The first scenario proposes to maintain the current method for inserting leap seconds, but it incurs the risk of both the potential incidents that this can cause, and the diminishing role for UTC and the traceability network of NMIs and timing laboratories that participate in its definition and dissemination.

The other two scenarios propose an extension of the tolerance on the offset between UTC and UT1 to a new larger value that will delay the need for the insertion of future leap seconds and allow further discussions on whether this tolerance should be allowed to increase without limit.

A compilation of the main advantages and disadvantages of these scenarios is given in Annex 2.

[2] Gabor, P. (2017). The Leap Second Debate: Rational Arguments vs. Unspoken Unease. In: Arias, E., Combrinck, L., Gabor, P., Hohenkerk, C., Seidelmann, P. (eds) The Science of Time 2016. Astrophysics and Space Science Proceedings, vol 50. Springer, Cham. https://doi.org/10.1007/978-3-319-59909-0_31

The strong preference emerging from discussions at the CCTF is for the second scenario which allows for additional time to develop a plan to implement the new maximum tolerance value and the need to review this new value periodically and to revise it, if needed. It is possible, in fact, that new development or new discoveries will allow a better understanding and prediction of the Earth rotation that would allow a better solution for a civil time based on the regular ticking of the atomic clocks and also maintaining long-term agreement with the rotation of the Earth.

**Table 3**. Details and implementation steps for the scenarios examined by the CCTF in March 2021 for the way forward with continuous UTC.

| Scenario 1 | Scenario 2 | Scenario 3 |
|---|---|---|
| We do nothing, the current implementation of leap seconds is maintained. | We agree to enlarge the tolerance in UT1 - UTC (in 2 steps).<br>The offset UT1 - UTC is accurately known and will continue to be disseminated widely. | We agree to enlarge the tolerance in UT1 - UTC (in 1 step) without fixing the limit.<br>The offset UT1 - UTC is accurately known and will continue to be widely disseminated |
| *At the CGPM in 2022*<br>Resolution to propose no further actions. | *At the CGPM in 2022*<br>Resolution to extend the tolerance in **2030** and to support precise determination and distribution of UT1-UTC | *At the CGPM in 2022*<br>Resolution to end the insertion of leap seconds in **2030** and to support precise determination and distribution of UT1-UTC |
| *ITU WRC in 2023*<br>▪ Rec 460 remains in force | *At the ITU WRC in 2023*<br>▪ Request endorsement of the CGPM resolution.<br>▪ DUT1 transmission code needs update (or interruption) | *At the ITU WRC in 2023*<br>▪ Request endorsement of the CGPM resolution.<br>▪ DUT1 transmission code needs update (or interruption) |
| | *At the CGPM in 2026*<br>▪ Agree new tolerance for implementation in 2030 | |

## 4. Summary and next steps

The CCTF has identified the main drivers for the improvement of the metrological quality, universality, usefulness, and world-wide recognition of UTC. It has developed a proposal that respects the historical association of astronomical conformity with civil timekeeping and also support new scientific and technological applications at the highest accuracy and reliability. It therefore proposes Draft Resolution D to the 27$^{th}$ meeting of the CGPM (2022), which is based on the second scenario described above. It will:

- address the risk of disruption to national critical infrastructures and digital networks,
- ensure the UTC is continued to be recognized as the unique reference time and limit the risk of incidents due to discontinuities or the use of multiple time scales,
- preserve the definition and realization of UTC under the authority of the CGPM, as established by the Metre Convention, which has been adopted by Member States,
- consolidate NMIs (and the BIPM) as the source of traceability and the main players in international timekeeping, with full recognition of all national real-time realisations of UTC, named UTC(*k*),
- ensure UTC remains an approximation of solar time UT1 for centuries, within the seasonal variations of solar time (15 minutes). The recognition of Greenwich as the reference for global longitude is not impacted. This means there will be no change for the wider public,
- ensure continuous UTC will support the correct functioning of high technology systems such as energy transmission, telecoms, and navigation, whose disruption would have a serious impact on our societies.

The CCTF and the members of the international timing and frequency community will work closely with:

- the International Astronomical Union (IAU) to inform users on the updated relationship between UTC and UT1, and consider the necessary updates to astronomical applications,
- the ITU-R and its working party 7A, to address the methods for broadcast formats of UT1-UTC and to continue the joint efforts to improve global access to UTC as recently agreed in the Memorandum of Understanding signed by ITU and BIPM in March 2020
- the IERS to support the evaluation and distribution of the relationship between UTC and UT1, and its timely and automatic publication,
- industrial and standardization bodies to define data fields for publication of UT1-UTC in the internet protocols such as NTP and PTP.

**Annex 1: Draft Resolution D –** (https://www.bipm.org/en/cgpm-2022, February 2022)

Draft Resolution D

## On the use and future development of UTC

The General Conference on Weights and Measures (CGPM), at its 27th meeting,

**recalling** that

- Coordinated Universal Time (UTC) is a time scale produced by the International Bureau of Weights and Measures (BIPM) with the same rate as International Atomic Time (TAI), but differing from TAI only by an integral number of seconds,
- the offset by an integral number of seconds is due to the agreement maintained between UTC and the time scale describing the angular rotation of the Earth (UT1),
- when the difference (UT1-UTC), as observed by the International Earth Rotation and Reference Systems Service (IERS), is predicted to approach 0.9 seconds, a leap second is applied according to the procedure described in Recommendation ITU-R TF.460-6 of the International Telecommunication Union Radiocommunication Sector (ITU-R),

**further recalling** that the CGPM at its 26th meeting (2018)

- stated that UTC is the only recommended time scale for international reference and the basis of civil time in most countries,
- recommended all relevant unions and organizations to work together to develop a common understanding on the realization and dissemination of reference time scales with a view to considering the present limitation on the maximum magnitude of UT1 - UTC to meet the needs of the current and future user communities,

**welcoming** the signature of a Memorandum of Understanding between the BIPM and the International Telecommunication Union (ITU), which ensures that they continue their joint work to improve global access to UTC,

**noting** that

- the accepted maximum value of the difference (UT1-UTC) has been under discussion for many years because the consequent introduction of leap seconds creates discontinuities that risk causing serious malfunctions in critical digital infrastructure including the Global Navigation Satellite Systems (GNSSs), telecommunications, and energy transmission systems,
- operators of digital networks and GNSSs have developed and applied different methods to introduce the leap second, which do not follow any agreed standards,
- the implementation of these different uncoordinated methods threatens the resilience of the synchronization capabilities that underpin critical national infrastructures,
- the use of these different methods leads to confusion that puts at risk the recognition of UTC as the unique reference time scale and also the role of National Metrology Institutes (and Designated Institutes) as sources of traceability to national and international metrological standards,
- recent observations on the rotation rate of the Earth indicate the possible need for the first negative leap second whose insertion has never been foreseen or tested,
- the Consultative Committee for Time and Frequency (CCTF) has conducted an extensive survey amongst metrological, scientific and technology institutions, and other stakeholders, and the feedback has confirmed the understanding that actions should be taken to address the discontinuities in UTC,

**recognizing** that the use of UTC as the unique reference time scale for all applications, including advanced digital networks and satellite systems, calls for its clear and unambiguous specification as a continuous time scale, with a well-understood traceability chain,

**decides** that the maximum value for the difference (UT1-UTC) will be increased in, or before, 2035,

**requests** that the CIPM consult with the ITU, and other organizations that may be impacted by this decision in order to

- propose a new maximum value for the difference (UT1-UTC) that will ensure the continuity of UTC for at least a century,
- prepare a plan to implement by, or before, 2035 the proposed new maximum value for the difference (UT1-UTC),
- propose a time period for the review by the CGPM of the new maximum value following its implementation, so that it can maintain control on the applicability and acceptability of the value implemented,
- draft a resolution including these proposals for agreement at the 28th meeting of the CGPM (2026),

**encourages** the BIPM to work with relevant organizations to identify the need for updates in the different services that disseminate the value of the difference (UT1-UTC) and to ensure the correct understanding and use of the new maximum value.

**Annex 2**. Summary of the principal advantages and disadvantages of the scenarios examined by the CCTF
in March 2021 for the way forward with continuous UTC.

<table>
<tr><th>Scenario 1</th><th>Scenario 2</th><th>Scenario 3</th></tr>
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<tr><td>Advantages<br>- Stops time consuming discussion.<br>- No SW update is necessary for astronomers.<br>- Radio emitting stations will continue to use the DUT1 code.</td><td>Advantages<br>- UTC is accepted as the unique time standard.<br>- NMIs (and BIPM) remains the source of traceability and the main players in international timekeeping.<br>- NMIs (and BIPM) support digitalization and the needs of modern applications (from 2026).<br>- Limit the risk of incidents due to discontinuities or multiple time scales.</td><td>Advantages<br>- Stops time consuming discussion.<br>- UTC is accepted as unique time standard.<br>- NMIs (and BIPM) remain the source of traceability and main players in international timekeeping.<br>- NMIs (and BIPM) support digitalization and the needs of modern applications (from 2022).<br>- Limit the risk of incidents due to discontinuities or multiple time scales.<br>- Future generations will decide how and when to realign UTC on UT1.</td></tr>
<tr><td>Disadvantages<br>- UTC risks not being recognized as the unique reference time scale.<br>- NMIs (and BIPM) risk losing recognition as the source of traceability for global time scale users soon after 2022.<br>- Commercial IT giants will take the role of setting digital time standards for new modern applications.<br>- High risk of incidents in energy distribution, telecom, finance, GNSS, … using systems not applying leap second in a standard way.</td><td>Disadvantages<br>- SW update is necessary for astronomers.<br>- Radio emitting stations will have to update or stop DUT1 transmission code.<br>- Other sources disseminating UT1-UTC may need to update.<br>- Some countries may need to update the legal time (that is most probably already based on a UTC(k) time scale).<br>- Some additional years of discussion to build consensus.</td><td>Disadvantages<br>- SW update is necessary for astronomers.<br>- Radio emitting stations will update or stop DUT1 transmission code.<br>- Other sources disseminating UT1-UTC need update.<br>- Some countries may need to update the legal time (that is most probably already based on a UTC(k) time scale).</td></tr>
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