BUREAU INTERNATIONAL DES POIDS ET MESURES

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Contents

Practical information about the BIPM Time Department

The BIPM Time Department issues four periodic publications. These are: UTCr (weekly), *Circular T* (monthly), TT(BIPM) (yearly) and the *BIPM Annual Report on Time Activities*.

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Time Department services webpage: https://www.bipm.org/en/bipm/tai/

Staff of the Time Department as of January 2019 :

Dr Patrizia TAVELLA,	Director
Dr Gérard PETIT,	Principal Research Physicist
Dr Zhiheng JIANG,	Principal Physicist (retired in July 2018)
Dr Gianna PANFILO,	Principal Physicist
Dr Lennart ROBERTSSON,	Principal Physicist (retired in March 2018)
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Ms Johanna GONCALVES,	Assistant
Ms Aurélie HARMEGNIES,	Assistant
Mr Laurent TISSERAND,	Principal Technician

For individual contact details, please refer to the BIPM staff directory

More information on the scientific work of the BIPM on time activities is available in https://www.bipm.org/en/publications/directors-report/. All the documentation mentionned in this document is available under request from the BIPM.

WARNING : HTML links on the BIPM website are likely to change over the coming months. For complete and up-to date information please refer to the BIPM Time Department's FTP server and Database.

Access to electronic files on the FTP server and the data base of the BIPM Time Department.

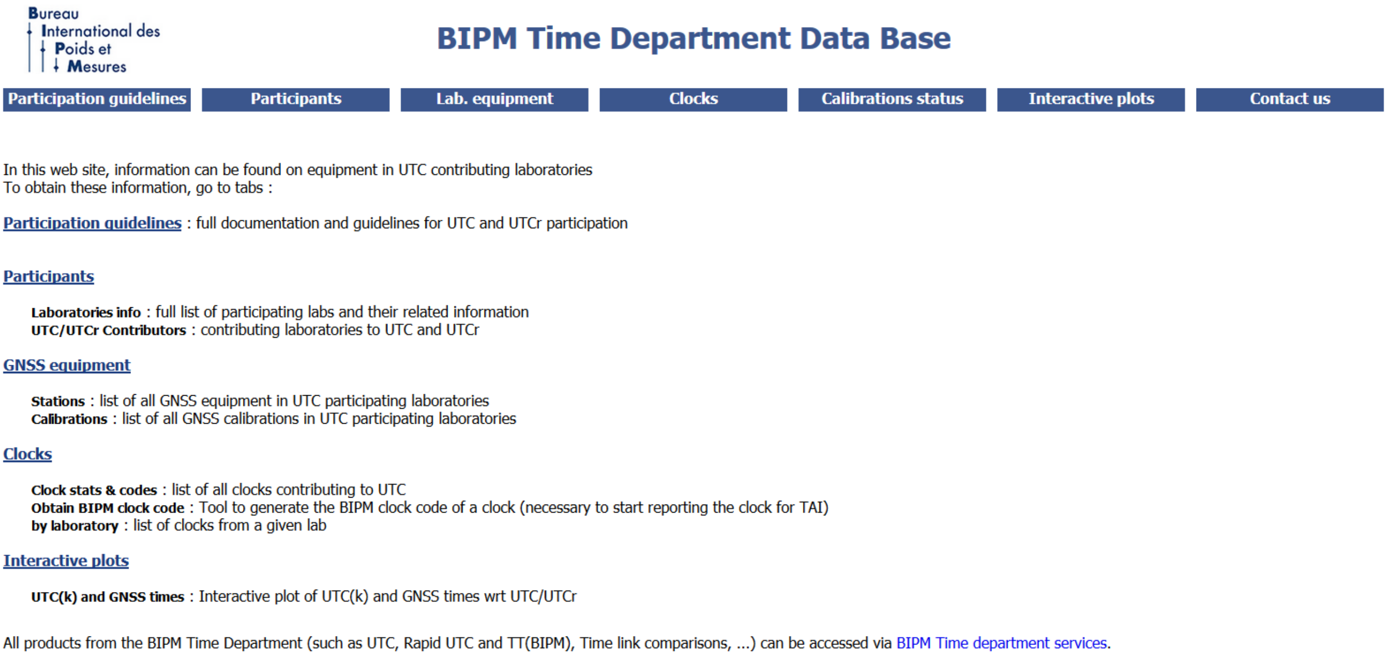
The files and information related to BIPM Time Activities are available from the website: https://www.bipm.org/en/bipm/tai/ .

Three main items are accessible through this webpage :

1. TimeScales : information on various time scales
2. Database : BIPM Time Department Database
3. FTP server : all publications on the FTP

BIPM Time Department Database content :

The BIPM Time Department Database contains information on the UTC laboratory time scale, GNSS calibration and overall guidelines.



Bureau International des Poids et Mesures

BIPM Time Department Data Base

Participation guidelines | Participants | Lab. equipment | Clocks | Calibrations status | Interactive plots | Contact us

In this web site, information can be found on equipment in UTC contributing laboratories
To obtain these information, go to tabs :

Participation guidelines : full documentation and guidelines for UTC and UTCr participation

Participants

Laboratories info : full list of participating labs and their related information
UTC/UTCr Contributors : contributing laboratories to UTC and UTCr

GNSS equipment

Stations : list of all GNSS equipment in UTC participating laboratories
Calibrations : list of all GNSS calibrations in UTC participating laboratories

Clocks

Clock stats & codes : list of all clocks contributing to UTC
Obtain BIPM clock code : Tool to generate the BIPM clock code of a clock (necessary to start reporting the clock for TAI)
by laboratory : list of clocks from a given lab

Interactive plots

UTC(k) and GNSS times : Interactive plot of UTC(k) and GNSS times wrt UTC/UTCr

All products from the BIPM Time Department (such as UTC, Rapid UTC and TT(BIPM), Time link comparisons, ...) can be accessed via BIPM Time department services.

BIPM Time Department FTP server content :

The files can be found in the eight subdirectories: **Circular-T, Rapid-UTC, ttbipm, data, other-products, Links results, hardware delay characterization, and annual-reports.** They are all available by ftp (62.161.69.5 or ftp2.bipm.org, user anonymous, e-mail address as password, cd pub/tai).

Circular-T – All issues of BIPM *Circular T*.

Rapid-UTC – From February 2012 until June 2013 results of the Pilot Experiment on Rapid UTC (UTCr). Starting in July 2013 official results of Rapid UTC (UTCr).

ttbipm – The realizations of terrestrial time TT(BIPMXY).

data – All data used for the computation of TAI, including reports of evaluation of primary and secondary frequency standards and all clock and time transfer data files used for the computation of TAI, arranged in yearly directories. See readme for details.

other-products – Other products, including time differences and monthly values of clock weights and frequency drifts, etc.

Links results – Results of time links and time link comparisons processed with *Circular T*.

Hardware delay characterization – All characterized hardware delays of time transfer equipment, including reports.

annual reports – Archive of the BIPM Annual Reports on Time Activities and extracts from the BIH Annual Reports.

BIPM Time Department main products :

In the following directories XY represents the last two digits of the year number (19XY or 20XY); YYYY represents the year number; WW represents the week number in the year, ZT represents the month number in the year (01-12) except until 1997 when Z represents the two-month interval of TAI computation (Z =1 for Jan.-Feb., 2 for Mar.- Apr., etc…); XX, XXX are ordinal numbers.

products	**filename/link**
Acronyms of laboratories	Database
Circular T	cirt.XXX
Circular T HTML	cirt.XXX.html (starting 2016)
UTCr	UTCr_XYWW
Fractional frequency of EAL from primary and secondary frequency standards	etXY.ZT
Weights of clocks participating in the computation of TAI	wXY.ZT
Rates relative to TAI of clocks participating in the computation of TAI	rXY.ZT
Frequency drifts of clocks participating in the computation of TAI	dXY.ZT
Daily values of the differences between UTCr and its local representation by the given laboratory	UTCr - lab
Values of the differences between TAI and the local atomic scale of the given laboratory, including relevant notes	TAI - lab
Values of the differences between UTC and its local representation by the given laboratory including graphics and relevant notes	UTC - lab (+ plots)

Relations of UTC and TAI with GPS and GLONASS system times, and also with the predictions of UTC(*k*) disseminated by GNSS	UTC-GNSS (starting January 2011)
TT(BIPMXY) computation ending in 19XY or 20XY	TTBIPM.YYYY
Difference between the normalized frequencies of EAL and TAI	f(EAL)-f(TAI)
Difference between PSFS ensemble frequency and TAI frequency (d)	fpsfs-ftai
Difference between PSFS frequency and TAI frequency (d)	PFS-ftai
Measurements of the duration of the TAI scale interval	UTAIYYYY.pdf (starting 1995)
Mean fractional deviation of the TAI scale interval from that of TT duration of TAI scale interval	SITAIYYYY.pdf (starting 2000)

Information on time dissemination by laboratories :

Time scales data	**filename/link**
Time Dissemination Services	TIMESERVICES.PDF
Time Signals	TIMESIGNALS.PDF

Leap seconds table is no more updated in the ftp site but it is available here:
https://hpiers.obspm.fr/eoppc/bul/bulc/Leap_Second.dat

Older files can be accessed directly from the ftp site (62.161.69.5 or ftp2.bipm.org).

Any comments or queries should be sent to: tai@bipm.org

Leap seconds

Since 1 January 1988, the maintenance of International Atomic Time, TAI, and of Coordinated Universal Time, UTC (with the exception of decisions and announcements concerning leap seconds of UTC) has been the responsibility of the International Bureau of Weights and Measures (BIPM) under the authority of the International Committee for Weights and Measures (CIPM). The dates of leap seconds of UTC are decided and announced by the International Earth Rotation and Reference Systems Service (IERS), which is responsible for the determination of Earth rotation parameters and the maintenance of the related celestial and terrestrial reference systems. The adjustments of UTC and the relationship between TAI and UTC are given in Tables 1 and 2 of this volume.

Further information about leap seconds can be obtained from the IERS:

IERS Earth Orientation Centre
Dr Christian Bizouard
Observatoire de Paris
61, avenue de l'Observatoire
75014 Paris, France

Telephone:	+ 33 1 40 51 23 35
Telefax:	+ 33 1 40 51 22 91
Email:	services.iers@obspm.fr
Website:	http://hpiers.obspm.fr/eop-pc
Anonymous:	ftp://hpiers.obspm.fr or ftp://145.238.203.2/

Establishment of International Atomic Time and Coordinated Universal Time

1. Data and computation

International Atomic Time (TAI) and Coordinated Universal Time (UTC) are obtained from a combination of data from about 500 atomic clocks operated by more than 80 timing centres which maintain a local UTC, UTC(*k*) (see http://webtai.bipm.org/database/showlab.html). The data are in the form of time differences [*UTC*(*k*) - *Clock*] taken at 5-day intervals for Modified Julian Dates (MJD) ending in 4 and 9, at 0 h UTC; these dates are referred to here as "standard dates". The equipment maintained by the timing centres is detailed in Table 4.

An iterative algorithm produces a free atomic time scale, EAL (Échelle Atomique Libre), defined as a weighted average of clock readings. The processing is carried out and, subsequently, treats one month batches of data. The weighting procedure and clock frequency prediction [1, 2] are chosen such that EAL is optimized for long-term stability. No attempt is made to ensure the conformity of the EAL scale interval with the second of the International System of Units (SI).

2. Accuracy

The duration of the scale interval of EAL is evaluated by comparison with the data of primary frequency caesium standards and secondary frequency standards recommended for secondary representations of the second, correcting their proper frequency as needed to account for known effects (e.g. general relativity, blackbody radiation). TAI is then derived from EAL by adding a linear function of time with an appropriate slope to ensure the accuracy of the TAI scale interval. The frequency offset between TAI and EAL is changed when necessary to maintain accuracy, the magnitude of the changes being of the same order as the frequency fluctuations resulting from the instability of EAL. This operation is referred to as the "steering of TAI" and file feal-ftai gives the normalized frequency offsets between EAL and TAI. Measurements of the duration of the TAI scale interval and estimates of its mean duration are reported in Table 6 and Table 7.

3. Availability

TAI and UTC are made available in the form of time differences with respect to the local time scales UTC(*k*), which approximate UTC, and TA(*k*), the independent local atomic time scales. These differences, [*TAI - TA(k)*] and [*UTC - UTC(k)*], are computed for the standard dates including uncertainties of [*UTC – UTC*(*k*)] [3].

The computation of TAI/UTC is carried out every month and the results are published monthly in *Circular T*.

The BIPM pilots the key comparison in time CCTF-K001.UTC. Institutes participating in the key comparison are National Metrology Institutes and Designated Institutes; they constitute a sub-set of the participants in *Circular T*.

A rapid solution, *UTCr* has been published without interruption since July 2013. Regular publication of the values [*UTCr - UTC(k)*] allows weekly access to a prediction of UTC [4] for about fifty laboratories which also contribute to the regular monthly publication. However, the final results published in BIPM *Circular T* remain the only official source of traceability to the SI second for participating laboratories.

The difference between UTC and UTCr (calculated as a weighted average over the laboratories participating to UTCr) is reported in Figure (1) from August 2012 until May 2019.

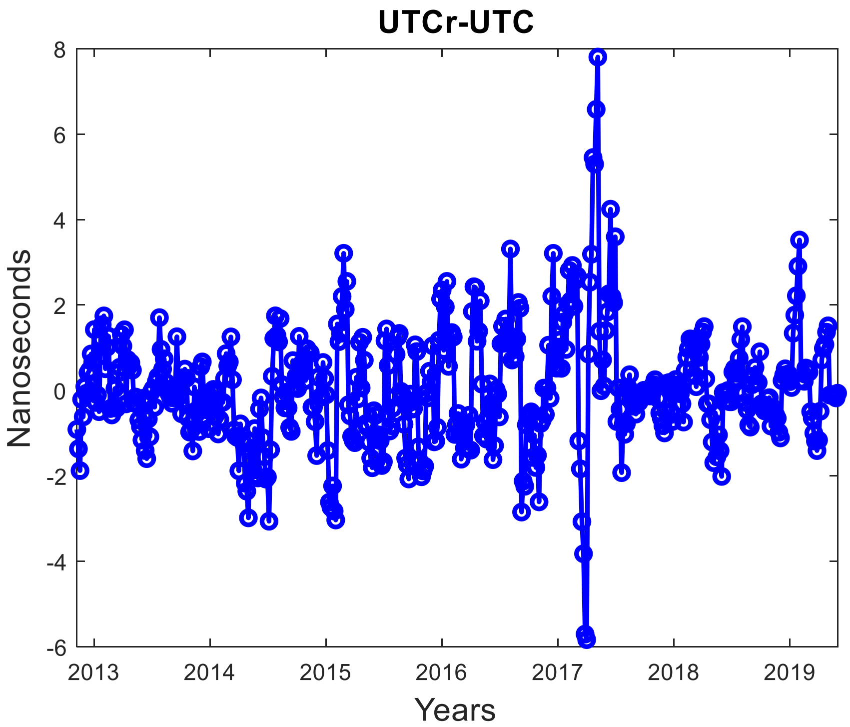


Figure 1. Difference between UTC and UTCr until May 2019.

4. Time links

The BIPM organizes the international network of time links to compare local realizations of UTC in contributing laboratories and uses them in the calculation of TAI. The network of time links used by the BIPM is non-redundant and relies on observation of GNSS satellites and on two-way satellite time and frequency transfer (TWSTFT).

Most time links are based on GPS satellite observations. Data from multi-channel dual-frequency GPS receivers are regularly used in the calculation of time links, in addition to that acquired by a few multi-channel single-frequency GPS time receivers. For those links realized using more than one technique, one of them is considered official for UTC and the others are calculated as back-ups. Single-frequency GPS data are corrected using the ionospheric maps produced by the Centre for Orbit Determination in Europe (CODE); all GPS data are corrected using precise satellite ephemerides and clocks produced by the International GNSS Service (IGS).

GPS links are computed using the method known as “GPS all in view” [5], with a network of time links that uses the PTB as a unique pivot laboratory for all the GPS links. Links between laboratories equipped with dual-frequency receivers providing Rinex format files are computed with the “Precise Point Positioning” method GPS PPP [6].

Clock comparisons using GLONASS C/A (L1C frequency) satellite observations with multi-channel receivers have been in use since October 2009 [7]. These links are computed using the “common-view” [8] method; data are corrected using the IAC ephemerides SP3 files and the CODE ionospheric maps.

A combination of individual TWSTFT and GPS PPP links and of individual GPS and GLONASS links are currently used in the calculation of TAI [9, 10].
The figure showing the time link techniques in the contributing laboratories can be downloaded from the BIPM website and is also reported below as “*Geographical distribution of the laboratories that contribute to TAI and time transfer equipment*”. For more detailed information on the equipment refer to [Table 4], and to BIPM *Circular T* for the techniques and methods of time transfer officially used and for the values of the uncertainty of [$UTC(k_1)$ - $UTC(k_2)$], obtained at the BIPM with these procedures.

New or improved time transfer system measures are evaluated and used as back up. These include the SDR (software defined radio receiver) [11], the preliminary use of the Galileo and Beidou GNSS [12, 13], IPPP (integer precise point positioning) [14].

The BIPM publishes in *Circular T* daily values of [*UTC – UTC(USNO)_GPS*] and [*UTC – UTC(SU)_GLONASS*] where *UTC(USNO)_GPS* and *UTC(SU)_GLONASS* are respectively, UTC(USNO) and UTC(SU) as predicted and broadcast by GPS and GLONASS. Evaluations of [*UTC - GPS time*] and [*UTC - GLONASS time*] are provided only through the ftp server of the Time Department. These tables are based on GPS data provided by the Paris Observatory (LNE-SYRTE), France, and on GLONASS data provided by the Astrogeodynamical Observatory (AOS), Poland.

5. Time scales established in retrospect

For the most demanding applications, such as millisecond pulsar timing, the BIPM retrospectively issues atomic time scales. These are designated TT(BIPMxx) where 19xx or 20xx is the year of computation [15, 16, 17]. The successive versions of TT(BIPMxx) are both updates and revisions; they may differ for common dates.

Starting with TT(BIPM09), until TT(BIPM12) extrapolation for the current year of the latest realization TT(BIPMxx) had been provided in the file TTBIPMxx.ext. It had been updated each month after the TAI computation. Starting with TT(BIPM13), a formula for extrapolation is provided in the file TTBIPM.yyyy where yyyy is the year number.

In Figure (2) the difference between the frequency of PFS/SFS and TTBIPM is reported.

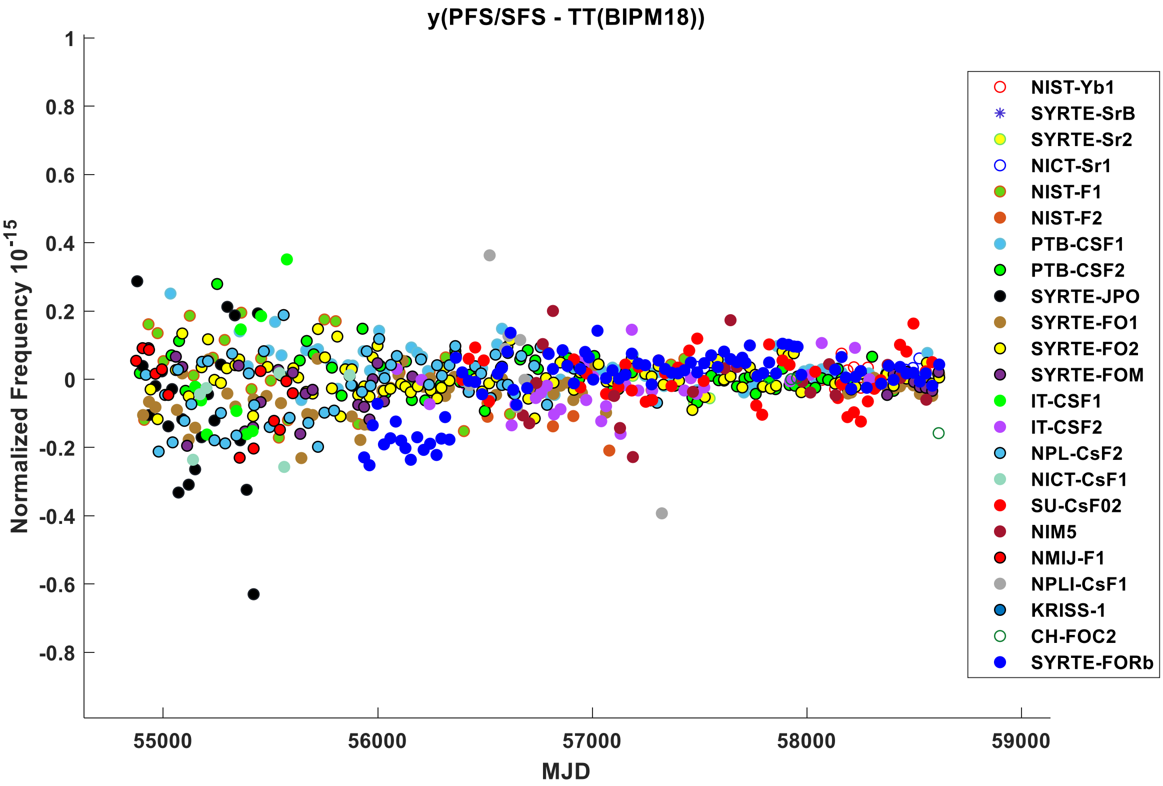


Figure 2. Difference between the frequency of PFS/SFS and TT(BIPM18).

Notes

Since January 2016 BIPM *Circular T* has been published in a new format with a different distribution of content in the sections. See ftp://ftp2.bipm.org/pub/tai/publication/notes/explanatory_supplement_v0.1.pdf.

Since September 2016, a Time Department Database has been made accessible via the website at http://webtai.bipm.org/database/. It contains all relevant information relating to contributions to UTC and UTCr.

A full list of time signals and time dissemination services is compiled by the BIPM from the information provided by the time laboratories.

A recent overview of UTC computation and realization can be found here [18]. A formal definition of TAI and UTC can be found in Resolution 2 of the 26th CGPM. https://www.bipm.org/utils/common/pdf/CGPM-2018/26th-CGPM-Resolutions.pdf .

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[17] Petit G., Atomic time scales TAI and TT(BIPM): present status and prospects, *Proc. 7th Symposium on frequency standards and metrology*, L. Maleki (Ed.), World Scientific, 2009, 475-482.

[18] G Panfilo and F Arias 2019 Metrologia 56 042001, The Coordinated Universal Time (UTC).

Geographical distribution of the laboratories that contribute to TAI and time transfer equipment (2018)

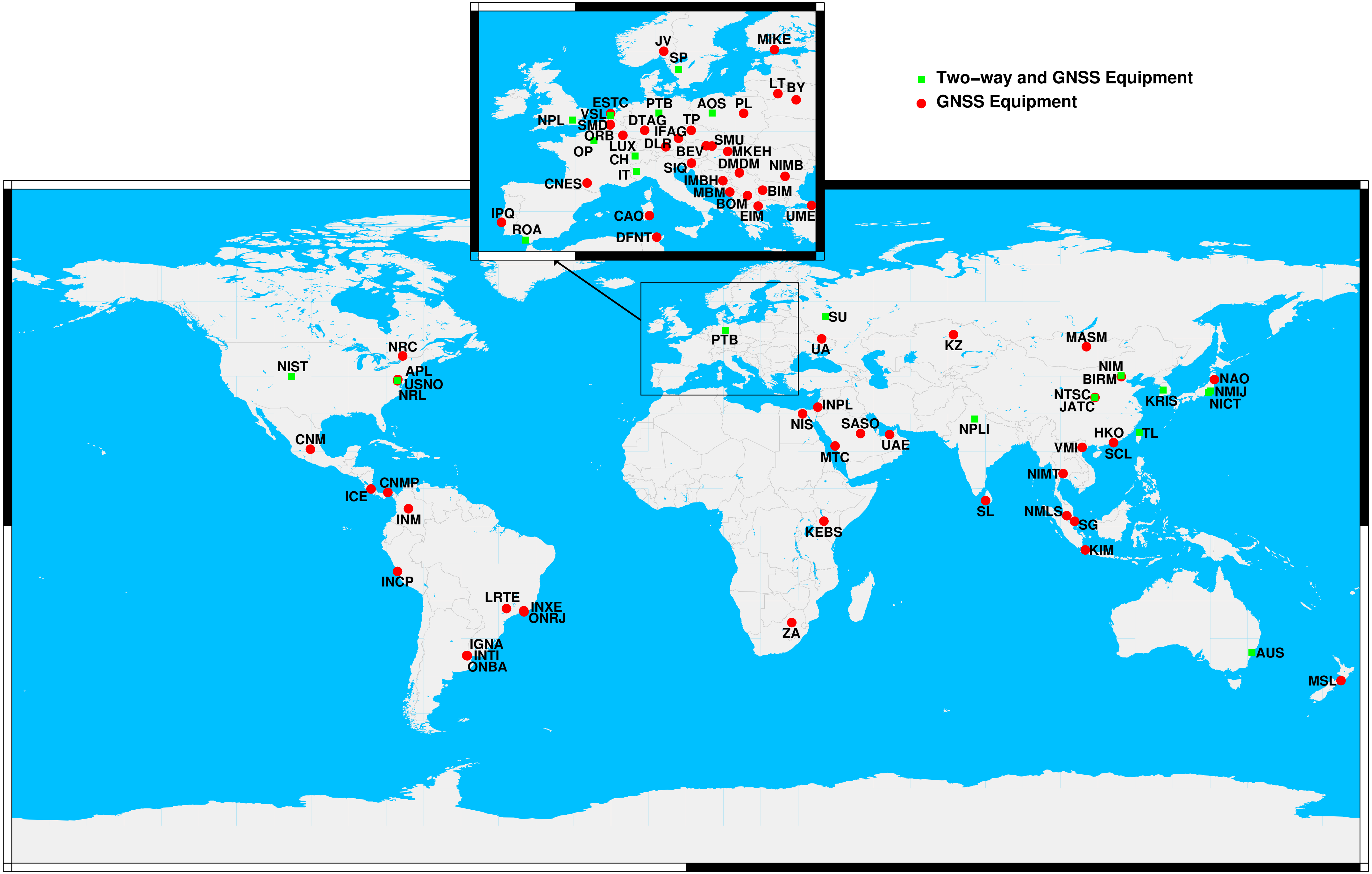

Table 1. Relative frequency offsets and step adjustments of UTC, up to 31 December 2019

Date (at 0 h UTC)	Offsets	Steps/s
1961 Jan. 1	-150×10^{-10}	
1961 Aug. 1	"	+0.050
1962 Jan. 1	-130×10^{-10}	
1963 Nov. 1	"	−0.100
1964 Jan. 1	-150×10^{-10}	
1964 Apr. 1	"	−0.100
1964 Sep. 1	"	−0.100
1965 Jan. 1	"	−0.100
1965 Mar. 1	"	−0.100
1965 Jul. 1	"	−0.100
1965 Sep. 1	"	−0.100
1966 Jan. 1	-300×10^{-10}	
1968 Feb. 1	"	+0.100
1972 Jan. 1	0	−0.107 7580
1972 Jul. 1	"	−1
1973 Jan. 1	"	−1
1974 Jan. 1	"	−1
1975 Jan. 1	"	−1
1976 Jan. 1	"	−1
1977 Jan. 1	"	−1
1978 Jan. 1	"	−1
1979 Jan. 1	"	−1
1980 Jan. 1	"	−1
1981 Jul. 1	"	−1
1982 Jul. 1	"	−1
1983 Jul. 1	"	−1
1985 Jul. 1	"	−1
1988 Jan. 1	"	−1
1990 Jan. 1	"	−1
1991 Jan. 1	"	−1
1992 Jul. 1	"	−1
1993 Jul. 1	"	−1
1994 Jul. 1	"	−1
1996 Jan. 1	"	−1
1997 Jul. 1	"	−1
1999 Jan. 1	"	−1
2006 Jan. 1	"	−1
2009 Jan. 1	"	−1
2012 Jul. 1	"	−1
2015 Jul. 1	"	−1
2017 Jan. 1	"	−1

This table is also available here: https://hpiers.obspm.fr/eoppc/bul/bulc/TimeSteps.history

Table 2. Relationship between TAI and UTC, up to 31 December 2019

Limits of validity (at 0 h UTC)	[*TAI - UTC*] / s
1961 Jan. 1 - 1961 Aug. 1	1.422 8180 + (MJD - 37300) × 0.001 296
1961 Aug. 1 - 1962 Jan. 1	1.372 8180 + " "
1962 Jan. 1 - 1963 Nov. 1	1.845 8580 + (MJD - 37665) × 0.001 1232
1963 Nov. 1 - 1964 Jan. 1	1.945 8580 + " "
1964 Jan. 1 - 1964 Apr. 1	3.240 1300 + (MJD - 38761) × 0.001 296
1964 Apr. 1 - 1964 Sep. 1	3.340 1300 + " "
1964 Sep. 1 - 1965 Jan. 1	3.440 1300 + " "
1965 Jan. 1 - 1965 Mar. 1	3.540 1300 + " "
1965 Mar. 1 - 1965 Jul. 1	3.640 1300 + " "
1965 Jul. 1 - 1965 Sep. 1	3.740 1300 + " "
1965 Sep. 1 - 1966 Jan. 1	3.840 1300 + " "
1966 Jan. 1 - 1968 Feb. 1	4.313 1700 + (MJD - 39126) × 0.002 592
1968 Feb. 1 - 1972 Jan. 1	4.213 1700 + " "
1972 Jan. 1 - 1972 Jul. 1	10 (integral number of seconds)
1972 Jul. 1 - 1973 Jan. 1	11
1973 Jan. 1 - 1974 Jan. 1	12
1974 Jan. 1 - 1975 Jan. 1	13
1975 Jan. 1 - 1976 Jan. 1	14
1976 Jan. 1 - 1977 Jan. 1	15
1977 Jan. 1 - 1978 Jan. 1	16
1978 Jan. 1 - 1979 Jan. 1	17
1979 Jan. 1 - 1980 Jan. 1	18
1980 Jan. 1 - 1981 Jul. 1	19
1981 Jul. 1 - 1982 Jul. 1	20
1982 Jul. 1 - 1983 Jul. 1	21
1983 Jul. 1 - 1985 Jul. 1	22
1985 Jul. 1 - 1988 Jan. 1	23
1988 Jan. 1 - 1990 Jan. 1	24
1990 Jan. 1 - 1991 Jan. 1	25
1991 Jan. 1 - 1992 Jul. 1	26
1992 Jul. 1 - 1993 Jul. 1	27
1993 Jul. 1 - 1994 Jul. 1	28
1994 Jul. 1 - 1996 Jan. 1	29
1996 Jan. 1 - 1997 Jul. 1	30
1997 Jul. 1 - 1999 Jan. 1	31
1999 Jan. 1 - 2006 Jan. 1	32
2006 Jan. 1 - 2009 Jan. 1	33
2009 Jan. 1 - 2012 Jul. 1	34
2012 Jul. 1 - 2015 Jul. 1	35
2015 Jul. 1 - 2017 Jan. 1	36
2017 Jan. 1 -	37

This table is also available here: https://hpiers.obspm.fr/eoppc/bul/bulc/UTC-TAI.history

Table 3. Acronyms and locations of the timing centres which maintain a local approximation of UTC, UTC(*k*), and/or an independent local time scale, TA(*k*)

The up-to-date list and historical information of laboratories are available at http://webtai.bipm.org/database/showlab.html.

Table 4. Equipment and source of UTC(*k*) of the laboratories contributing to TAI in 2018

Equipment abbreviation used in this table

Atomic clocks

Ind. Cs: industrial caesium standard
Ind. Rb: industrial rubidium standard
Lab. Cs: laboratory caesium standard
Lab. Rb: laboratory rubidium standard
H-maser: hydrogen maser

Time transfer techniques

GNSS: Global Navigation Satellite System receiver (details can be found here)
TWSTFT: Two-Way Satellite Time and Frequency Transfer (details can be found here)

* means 'yes'

Lab *k*	Atomic clock	Source of UTC(*k*) (1)	TA(*k*)	UTCr	Time transfer technique	
					GNSS	TWSTFT
AOS	3 Ind. Cs 2 H-masers (15)	1 H-maser (2) + microphase-stepper	* (15)	*	*	*
APL	3 Ind. Cs 3 H-masers	1 H-maser + frequency synthesizer steered to UTC(APL)			*	
AUS	5 Ind. Cs	1 Cs		*	*	*
BEV	2 Ind. Cs 1 H-maser	1 Cs		*	*	
BIM	2 Ind. Cs	1 Cs			*	
BIRM	4 Ind. Cs 3 H-masers	1 H-maser + microphase-stepper		*	*	
BOM	2 Ind. Cs	1 Cs		*	*	
BY	7 H-masers	3-6 H-masers + microphase-stepper			*	
CAO (a)	2 Ind. Cs	1 Cs			*	
CH	2 Ind. Cs (3) 3 H-masers	1 H-maser (3) + frequency synthesizer steered to UTC(CH.P)	*	*	*	*

Table 4. Equipment and source of UTC(*k*) of the laboratories contributing to TAI in 2018 (Cont.)

Lab *k*	Atomic clock	Source of UTC(*k*) (1)	TA(*k*)	UTCr	Time transfer technique	
					GNSS	TWSTFT
CNES	8 Ind. Cs (4) 3 H-masers	1 H-maser (4) + microphase-stepper			*	
CNM	4 Ind. Cs 1 H-maser	1 H-maser + microphase-stepper	*	*	*	
CNMP	5 Ind. Cs	1 Cs + frequency offset generator		*	*	
DFNT (a)	2 Ind. Cs	1 Cs			*	
DLR	3 Ind. Cs 3 H-masers	1 Cs		*	*	
DMDM	2 Ind. Cs	1 Cs + microphase-stepper		*	*	
DTAG	3 Ind. Cs	1 Cs		*	*	
EIM	1 Ind. Cs	1 Cs			*	
ESTC	3 Ind. Cs 3 H-masers	1 H-maser + microphase-stepper		*	*	
HKO	2 Ind. Cs	1 Cs		*	*	
ICE	3 Ind. Cs	1 Cs + frequency offset generator		*	*	
IFAG	5 Ind. Cs 2 H-masers	1 Cs + microphase-stepper		*	*	
IGNA	1 Ind. Cs	1 Cs + time/frequency steering		*	*	

Table 4. Equipment and source of UTC(*k*) of the laboratories contributing to TAI in 2018 (Cont.)

Lab *k*	Atomic clock	Source of UTC(*k*) (1)	TA(*k*)	UTCr	Time transfer technique	
					GNSS	TWSTFT
IMBH	2 Ind. Cs	1 Cs + frequency offset generator		*	*	
INCP	2 Ind. Cs	1 Cs			*	
INM	2 Ind. Cs	1 Cs + microphase-stepper			*	
INPL	4 Ind. Cs	1 Cs			*	
INTI (a)	3 Ind. Cs	1 Cs		*	*	
INXE	3 Ind. Cs 1 Ind. Rb 1 Lab. Cs	1 Cs + microphase-stepper		*	*	
IPQ	1 Ind. Cs	1 Cs + microphase-stepper		*	*	
IT (a)	6 Ind. Cs 4 H-masers 2 Lab. Cs	1 H-maser + microphase-stepper		*	*	*
JATC	10 Ind. Cs 3 H-masers	1 H-maser + microphase-stepper	*		*	
JV	3 Ind. Cs 1 H-maser	1 H-maser + microphase-stepper		*	*	
KEBS	3 Ind. Cs	1 Cs + reference generator			*	
KIM (a)	2 Ind. Cs	1 Cs			*	
KRIS	5 Ind. Cs 4 H-masers	1 H-maser + microphase-stepper	*	*	*	*

Table 4. Equipment and source of UTC(*k*) of the laboratories contributing to TAI in 2018 (Cont.)

Lab *k*	Atomic clock	Source of UTC(*k*) (1)	TA(*k*)	UTCr	Time transfer technique: GNSS	Time transfer technique: TWSTFT
KZ (a)	5 Ind. Cs (5)	1 Cs + microphase-stepper			*	
LRTE	2 Ind. Cs	1 Cs + microphase-stepper		*	*	
LT	2 Ind. Cs	1 Cs + microphase-stepper		*	*	
LUX	1 Ind. Cs	1 Cs + microphase-stepper			*	
MASM	1 Ind. Cs	1 Cs + time/frequency steering		*	*	
MBM (a)	1 Ind. Cs	1 Cs			*	
MIKE	1 Ind. Cs 4 H-masers	1 H-maser + microphase-stepper		*	*	
MKEH	1 Ind. Cs	1 Cs			*	
MSL	2 Ind. Cs	1 Cs + microphase-stepper		*	*	
MTC (a)	11 Ind. Cs	1 Cs		*	*	
NAO	4 Ind. Cs 1 H-maser	1 Cs + microphase-stepper		*	*	
NICT	33 Ind. Cs 8 H-masers (6) 1 Lab. Cs 1 Lab. Sr (7)	1 H-maser (8) + microphase-stepper	* (9)	*	*	*
NIM	7 Ind. Cs 10 H-masers 1 Lab. Cs	1 H-maser + microphase-stepper		*	*	*

Table 4. Equipment and source of UTC(*k*) of the laboratories contributing to TAI in 2018 (Cont.)

Lab *k*	Atomic clock	Source of UTC(*k*) (1)	TA(*k*)	UTCr	Time transfer technique: GNSS	Time transfer technique: TWSTFT
NIMB (a)	2 Ind. Cs	1 Cs		*	*	
NIMT	5 Ind. Cs	1 Cs + microphase-stepper		*	*	
NIS (a)	2 Ind. Cs	1 Cs		*	*	
NIST	2 Lab. Cs 13 Ind. Cs 13 H-masers	5 Cs 7 H-masers + microphase-stepper	*	*	*	*
NMIJ	2 Ind. Cs 1 Lab. Cs 4 H-masers	1 H-maser + microphase-stepper		*	*	*
NMLS (a)	2 Ind. Cs	1 Cs		*	*	
NPL	2 Ind. Cs 5 H-masers	1 H-maser		*	*	*
NPLI	5 Ind. Cs 1 H-maser	1 H-maser + microphase-stepper		*	*	*
NRC	6 Ind. Cs (10) 2 H-masers	1 Cs + microphase-stepper	*	*	*	
NRL	9 H-masers	1 H-maser + steered by AOG to UTC(NRL)		*	*	
NTSC	25 Ind. Cs 6 H-masers	1 H-maser + microphase-stepper	*	*	*	*
ONBA	2 Ind. Cs	1 Cs			*	
ONRJ	7 Ind. Cs 2 H-masers	7 Cs 2 H-masers + frequency offset generator	* (11)	*	*	

Table 4. Equipment and source of UTC(*k*) of the laboratories contributing to TAI in 2018 (Cont.)

Lab *k*	Atomic clock	Source of UTC(*k*) (1)	TA(*k*)	UTCr	Time transfer technique: GNSS	Time transfer technique: TWSTFT
OP	5 Ind. Cs 3 Lab. Cs 1 Lab. Rb 4 H-masers	1 H-maser (12) + microphase-stepper	* (13)	*	*	*
ORB	3 Ind. Cs 1 H-maser	1 H-maser + femtostepper		*	*	
PL	12 Ind. Cs 4 H-masers	1 H-maser (14) + femtostepper	* (15)	*	*	* (16)
PTB	3 Ind. Cs 4 Lab. Cs (17) 4 H-masers	1 H-maser (18) + microphase-stepper	* (19)	*	*	*
ROA	6 Ind. Cs (20) 2 H-masers	1 H-maser (21) + frequency synthesizer steered to UTC(ROA)		*	*	*
SASO (a)	5 Ind. Cs	1 Cs		*	*	
SCL	2 Ind. Cs (22)	1 Cs + microphase-stepper		*	*	
SG	5 Ind. Cs 1 H-maser	1 H-maser + microphase-stepper		*	*	
SIQ (a)	1 Ind. Cs	1 Cs			*	
SL	1 Ind. Cs	1 Cs (23)		*	*	
SMD	4 Ind. Cs 1 H-maser	1 H-maser + microphase-stepper		*	*	
SMU	1 Ind. Cs	1 Cs + output frequency steering			*	
SP	19 Ind. Cs (24) 8 H-masers	1 H-maser + microphase-stepper		*	*	*

Table 4. Equipment and source of UTC(*k*) of the laboratories contributing to TAI in 2018 (Cont.)

Lab *k*	Atomic clock	Source of UTC(*k*) (1)	TA(*k*)	UTCr	Time transfer technique	
					GNSS	TWSTFT
SU	1 Lab. Cs (25) 4 Lab. Rb (26) 14-15 H-masers	10-14 H-masers (27)	* (28)	*	*	* (29)
TL	4 Ind. Cs 5 H-masers	1 H-maser (30) + microphase-stepper	* (30)	*	*	*
TP	5 Ind. Cs	1 Cs + output frequency steering		*	*	
UA	1 Ind. Cs + (2 Ind. CS (31)) 4 H-masers 2 Lab. Rb (31)	1 Cs 3 H-masers + microphase-stepper	*		*	
UAE	3 Ind. Cs	3 Cs (32)			*	
UME	5 Ind. Cs	1 Cs		*	*	
USNO	62 Ind. Cs 35 H-masers 6 Lab. Rb	1 H-maser (33) + frequency synthesizer steered to create UTC(USNO)	* (33)	*	*	*
VMI	3 Ind. Cs	1 Cs + microphase-stepper		*	*	
VSL	4 Ind. Cs	1 Cs + microphase-stepper		*	*	*
ZA	6 Ind. Cs 3 H-maser	1 H-maser			*	

Notes

(a)		Information based on the Annual Report for 2017, not confirmed by the laboratory.
(1)		When several clocks are indicated as a source of UTC(*k*), laboratory k computes a software clock, steered to UTC. Often a physical realization of UTC(*k*) is obtained using a Cs clock or H-maser and a micro-phase-stepper.
(2)	AOS	The UTC(AOS) is formed technically using 1 hydrogen maser and microstepper, it is steered using TA(PL) data as a reference. TA(PL) laboratories are linked via MC GPS-CV and/or two-directional optical fibre connections. Optical Fibre Link *UTC*(*AOS*)-*UTC*(*PL*) is 420 km long.
(3)	CH	All the standards are located in Bern at METAS (Swiss Federal Institute of Metrology). Since November 2007, UTC(CH) is defined in real time by a hydrogen maser steered to the paper time scale UTC(CH.P) which is defined as a weighted average of all the clocks, steered to UTC. TA(CH) is also a weighted average of all the clocks, but free running.
(4)	CNES	All the standards are located in Toulouse at CNES (French Space Agency). UTC(CNES) is defined in real time by a H-Maser steered to an ensemble of industrial high-performance Cs clocks. UTC(CNES) is steered monthly on UTC.
(5)	KZ	The standards are located as follows: *Kazakhstan Institute for Metrology (Astana) — 4 Cs *South-Kazakhstan branch of Kazakhstan Institute for Metrology (Almaty) — 1 Cs
(6)	NICT	The standards are located as follows: * Koganei Headquarters — 19 Cs, 6 H-masers * Ohtakadoya-yama LF station — 5 Cs * Hagane-yama LF station — 5 Cs * Advanced ICT Research Institute in Kobe — 5 Cs, 2 H-masers
(7)	NICT	The laboratory Sr (NICT-Sr1) is an optical lattice clock intermittently operated as a frequency standard. Contributions to TAI are made through comparison with a NICT's hydrogen maser.
(8)	NICT	UTC(NICT) is generated from the output of a hydrogen maser, steered to TA(NICT) regularly, and steered to UTC if necessary.
(9)	NICT	The NICT atomic timescale TA(NICT) is computed from the weighted average of 18 commercial Cs clocks at the Koganei HQ.
(10)	NRC	The standards are located as follows: * NRC Metrology (Ottawa) — 4 Cs, 2 H-masers * CHU Time signal radio station (Ottawa) — 2 Cs
(11)	ONRJ	The Brazilian atomic time scale TA(ONRJ) is computed by the National Observatory Time Service Division in Rio de Janeiro with data from 7 industrial caesium clocks and 2 hydrogen masers.
(12)	OP	Since MJD 56218 UTC(OP) is based on the output signal of a H-maser frequency steered towards UTC using the LNE-SYRTE fountains calibrations.

Notes (Cont.)

(13) OP The French atomic time scale TA(F) is computed by the LNE-SYRTE with data from up to 25 industrial caesium clocks in 2018 located as follows :

* Centre Electronique de l'Armement (CELAR, Rennes)	2 Cs
* Centre National d'Etudes Spatiales (CNES, Toulouse)	6 Cs
* France Telecom Recherche et Developpement (Lannion)	2 Cs
* Observatoire de la Côte d'Azur (OCA, Grasse)	2 Cs
* Observatoire de Paris (LNE-SYRTE, Paris)	5 Cs
* Observatoire de Besançon (OB, Besançon)	3 Cs
* Direction des Constructions Navales (DCN, Brest)	4 Cs
* Spectracom, Orolia (Les Ulis)	1 Cs

All laboratories are linked via GPS receivers. The TA(F) frequency is steered using the LNE-SYRTE PFS data. The difference TA(F) – UTC(OP) is published in the OP Time Service Bulletin.

(14) PL The Polish official timescale UTC(PL) is maintained by the GUM. UTC(PL) is based on the output of an active hydrogen maser steered in frequency since MJD 58225 (April 2018).

(15) PL The Polish atomic timescale TA(PL) is computed by the AOS and GUM with data from 13 caesium clocks and 4 hydrogen masers located as follows:

* Central Office of Measures (GUM, Warsaw)	3 Cs, 1 H-maser
* Astrogeodynamical Observatory, Space Research Center P.A.S. (AOS, Borowiec)	2 Cs, 2 H-masers
* National Institute of Telecommunications (IŁ, Warsaw)	2 Cs
* Polish Telecom (Orange Polska S.A., Warsaw)	1 Cs
* Military Primary Standards Laboratory (CWOM, Warsaw and Poznan)	3 Cs
* Poznan Supercomputing and Networking Center (PSNC, Poznan)	1 H-maser

and additionally

* Time and Frequency Standard Laboratory of the Center for Physical Science and Technology (FTMC), a guest laboratory from Lithuania (LT, Vilnius, Lithuania)	2 Cs

All laboratories are linked via MC GPS-CV and/or two-directional optical fibre connections.

(16) PL NIT/GUM station of TWSTFT is maintained and operated by the National Institute of Telecommunications (IŁ) and is connected to UTC(PL) using the stabilized optical fiber link of c. 30 km long.

(17) PTB The laboratory Cs, PTB CS1 and PTB CS2 are operated continuously as clocks. PTB CSF1 and CSF2 are fountain frequency standards using laser cooled caesium atoms. Both are intermittently operated as frequency standards. Contributions to TAI are made through comparisons with one of PTB's hydrogen masers.

(18) PTB UTC(PTB) is based on the output of an active hydrogen maser steered in frequency since MJD 55224 (February 2010).

(19) PTB Since MJD 56079 0:00 UTC TA(PTB) has been generated from an active hydrogen maser, steered in frequency so as to follow PTB caesium fountains as close as possible. The deviation *d* between the fountains and the TAI second is not taken into account. TAI-TA(PTB) got an initial arbitrary offset from TAI without continuity to the data reported in previous months.

Notes (Cont.)

(20)	ROA	The standards are located as follows:	
		* Real Observatorio de la Armada en San Fernando	5 Cs, 2 H-maser
		* Centro Español de Metrología	1 Cs
(21)	ROA	Since March 2009, UTC(ROA) is defined in real time by a hydrogen maser, steered to the paper time scale UTC(ROA), which is defined as a weighted average of all the clocks, steered to UTC.	
(22)	SCL	There are two caesium-clocks since 18 September 2018.	
(23)	SL	There is only one in-service caesium-clock operates from January 2018 and contributing to UTC from 1st May 2018.	
(24)	SP	The standards are located as follows (at the end of 2018):	
		* RISE Research Institutes of Sweden (RISE, Borås)	4 Cs, 2 H-masers
		* RISE Research Institutes of Sweden (RISE, Stockholm)	6 Cs, 2 H-masers
		* STUPI AB (Stockholm)	8 Cs, 2 H-masers
		* Onsala Space Observatory (Onsala)	1 Cs, 2 H-masers
(25)	SU	CsFO1 and CsFO2 are fountain frequency standards using laser cooled caesium atoms. CsFO2 operated as frequency standard almost regularly and contributed to TAI.	
(26)	SU	Rb01 to Rb04 are fountain frequency standards using laser cooled rubidium atoms. These standards run continuously, some times happened considerable gaps, and produce Rb(i) – H-maser(j) frequency difference at one day basis. These values contributed into time scale maintenance during 2018.	
(27)	SU	Laboratory computes UTC(SU) as a software clock, steered to UTC.	
(28)	SU	TA(SU) is generated from an ensemble of active hydrogen masers, software steered in frequency so as to follow SU caesium fountains as close as possible. The deviation d between the fountains and the TAI second published in Circular T was not taken into account. TAI-TA(SU) has an initial arbitrary offset from TAI.	
(29)	SU	TW time link was stopped at June 2017.	
(30)	TL	TA(TL) is generated from a 4-caesium-clock + 5-hydrogen-maser hybrid ensemble from January 2019. UTC(TL) is steered according to UTCr, UTC, and TA(TL).	
(31)	UA	Clocks will be added to the group after testing.	
(32)	UAE	UTC (UAE) is a software clock, steered to UTC, based on the weighted average of the Cs clocks. A physical realization of UTC(UAE) is obtained using a Cs clock and a frequency synthesizer.	
(33)	USNO	The time scales A.1(MEAN) and UTC(USNO) are computed by USNO. They are determined by a weighted average of Cs clocks, hydrogen masers, and rubidium fountains located at the USNO. A.1(MEAN) is a free atomic time scale, while UTC(USNO) is steered to UTC. Included in the total number of USNO atomic standards are the clocks located at the USNO Alternate Master Clock in Colorado Springs, CO.	

Table 5. Differences between the normalized frequencies of EAL and TAI

Values of the difference between the normalized frequencies of EAL and TAI since the beginning of the steering, in 1977, are available at ftp://ftp2.bipm.org/pub/tai/other-products/ealtai/feal-ftai). This file is updated on a monthly basis, with Circular T publication.

As the time scales UTC and TAI differ by an integral number of seconds (see Tables 1 and 2), UTC is necessarily subjected to the same intentional frequency adjustment as TAI.

Table 6. Measurements of the duration of the TAI scale interval

(File available on ftp://ftp2.bipm.org/pub/tai/scale/UTAI/utai2018.pdf)

TAI is a realization of coordinate time TT. The following tables give the fractional deviation *d* of the scale interval of TAI from that of TT (in practice the SI second on the geoid), i.e. the fractional frequency deviation of TAI with the opposite sign: $d = -y_{\mathrm{TAI}}$.

In Table 6A, *d* is obtained on the given periods of estimation by comparison of the TAI frequency with that of the individual primary frequency standards (PFS) IT-CsF2, METAS-FOC2, NIM5, PTB-CS1, PTB-CS2, PTB-CSF1, PTB-CSF2, SU-CsFO2, SYRTE-FO1, SYRTE-FO2 and SYRTE-FOM reported on the year 2018.
In Table 6B, *d* is obtained on the given periods of estimation by comparison of the TAI frequency with that of the individual secondary frequency standards (SFS) NICT-Sr1, SYRTE-SrB and SYRTE-FORb reported on the year 2018.
Previous calibrations are available in the successive annual reports of the BIPM Time Section volumes 1 to 18 and in the BIPM Annual Report on Time Activities volumes 1 to 12 (web only since volume 4 for 2009).

Each comparison is provided with the following information:
u_{A} is the uncertainty originating in the instability of the PFS,
u_{B} is the combined uncertainty from systematic effects,
$u_{\mathrm{link/lab}}$ is the uncertainty in the link between the PFS and the clock participating to TAI, including the uncertainty due to dead-time,
$u_{\mathrm{link/TAI}}$ is the uncertainty in the link to TAI, computed using the standard uncertainty of [UTC-UTC(*k*)],
u is the quadratic sum of all four uncertainty values.

In addition, Table 6B includes the following information:
u_{SRep} is the recommended uncertainty of the secondary representation of the second, as specified in the CIPM Recommendation identified under Ref(u_{S}).

In these tables, a frequency over a time interval is defined as the ratio of the end-point phase difference to the duration of the interval.

The typical characteristics of the calibrations of the TAI frequency provided by the different primary and secondary standards reported in 2018 are indicated below. Reports of individual evaluations may be found at ftp://ftp2.bipm.org/pub/tai/data/PFS_reports. Ref(u_{B}) is a reference giving information on the value of u_{B} as stated in the 2018 reports, u_{B}(Ref) is the u_{B} value stated in this reference. Note that the current u_{B} values are generally not the same as the peer reviewed values given in Ref(u_{B}).

Primary Standard	**Type /selection**	**Type B std. uncertainty/ 10^{-15}**	**u_{B}(Ref)/10^{-15}**	**Ref(u_{B})**	**Comparison with**	**Number/typical duration of comp.**
IT-CsF2	**Fountain**	**0.17**	**0.18**	**[1]**	**H maser**	**2 / 10 d to 15 d**
METAS-FOC2	**Fountain**	**2.01**	**1.99**	**[2]**	**H maser**	**3 / 15 d to 25 d**
NIM5	**Fountain**	**0.9**	**1.4**	**[3]**	**H maser**	**3 / 15 d to 25 d**
PTB-CS1	**Beam /Mag.**	**8**	**8.**	**[4]**	**TAI**	**12 / 25 d to 35 d**
PTB-CS2	**Beam /Mag.**	**12**	**12.**	**[5]**	**TAI**	**12 / 25 d to 35 d**
PTB-CSF1	**Fountain**	**0.28 to 0.40**	**0.28**	**[6]**	**H maser**	**8 / 10 d to 30 d**
PTB-CSF2	**Fountain**	**0.18 to 0.21**	**0.17**	**[6]**	**H maser**	**11 / 10 d to 30 d**
SU-CsFO2	**Fountain**	**0.24**	**0.50**	**[7]**	**H maser**	**10 / 10 d to 30 d**
SYRTE-FO1	**Fountain**	**0.32 to 0.43**	**0.37**	**[8]**	**H maser**	**11 / 15 d to 35 d**
SYRTE-FO2	**Fountain**	**0.20 to 0.31**	**0.23**	**[8]**	**H maser**	**11 / 15 d to 35 d**
SYRTE-FOM	**Fountain**	**0.63 to 1.13**	**0.7**	**[8]**	**H maser**	**4 / 30 d**

Secondary Standard	**Type**	**Type B std. uncertainty/ 10^{-15}**	**u_{B}(Ref)/10^{-15}**	**Ref(u_{B})**	**Comparison with**	**Number/typical duration of comp.**
NICT-Sr1	**Lattice**	**0.06 to 0.08**	**0.06**	**[9]**	**H maser**	**8 / 10 d to 35 d**
SYRTE-SrB	**Lattice**	**0.10**	**0.05**	**[10]**	**H maser**	**1 / 10d**
SYRTE-FORb	**Fountain**	**0.24 to 0.30**	**0.34**	**[11]**	**H maser**	**12 / 15 d to 35 d**

More detailed information on the characteristics and operation of individual PFS and SFS may be found in the annexes supplied by the individual laboratories.

Table 6A. Measurements of the duration of the TAI scale interval by Primary Frequency Standards

Standard	Period of estimation		$d/10^{-15}$	$u_A/10^{-15}$	$u_B/10^{-15}$	$u_{link/lab}/10^{-15}$	$u_{link/TAI}/10^{-15}$	$u/10^{-15}$	Note
IT-CsF2	58219	58229	1.09	0.83	0.17	0.14	0.88	1.23	
IT-CsF2	58284	58299	0.43	0.69	0.17	0.22	0.49	0.89	
METAS-FOC2	57809	57839	-0.74	0.11	2.01	0.07	0.23	2.03	
METAS-FOC2	57919	57934	-0.02	0.20	2.01	0.13	0.49	2.08	
METAS-FOC2	57944	57964	-0.03	0.17	2.01	0.10	0.38	2.05	
NIM5	58124	58144	-0.59	0.30	0.90	0.20	0.38	1.04	
NIM5	58369	58384	1.01	0.30	0.90	0.30	0.49	1.11	
NIM5	58424	58449	0.62	0.20	0.90	0.20	0.31	0.99	
PTB-CS1	58114	58149	-16.86	8.00	8.00	0.00	0.11	11.31	(1)
PTB-CS1	58149	58174	-14.98	8.00	8.00	0.00	0.15	11.31	
PTB-CS1	58174	58204	-20.98	8.00	8.00	0.00	0.13	11.31	
PTB-CS1	58204	58234	-17.93	8.00	8.00	0.00	0.13	11.31	
PTB-CS1	58234	58269	-14.45	8.00	8.00	0.00	0.11	11.31	
PTB-CS1	58269	58299	-4.08	8.00	8.00	0.00	0.13	11.31	
PTB-CS1	58299	58329	-1.03	8.00	8.00	0.00	0.13	11.31	
PTB-CS1	58329	58359	3.98	8.00	8.00	0.00	0.13	11.31	
PTB-CS1	58359	58389	-2.34	8.00	8.00	0.00	0.13	11.31	
PTB-CS1	58389	58419	5.06	8.00	8.00	0.00	0.13	11.31	
PTB-CS1	58419	58449	1.98	8.00	8.00	0.00	0.13	11.31	
PTB-CS1	58449	58479	-0.72	8.00	8.00	0.00	0.13	11.31	
PTB-CS2	58114	58149	-0.86	5.00	12.00	0.00	0.11	13.00	(1)
PTB-CS2	58149	58174	-6.51	5.00	12.00	0.00	0.15	13.00	
PTB-CS2	58174	58204	-3.54	5.00	12.00	0.00	0.13	13.00	
PTB-CS2	58204	58234	3.64	5.00	12.00	0.00	0.13	13.00	
PTB-CS2	58234	58269	-3.44	5.00	12.00	0.00	0.11	13.00	
PTB-CS2	58269	58299	-3.46	5.00	12.00	0.00	0.13	13.00	
PTB-CS2	58299	58329	-5.28	5.00	12.00	0.00	0.13	13.00	
PTB-CS2	58329	58359	-6.55	5.00	12.00	0.00	0.13	13.00	
PTB-CS2	58359	58389	-1.57	5.00	12.00	0.00	0.13	13.00	
PTB-CS2	58389	58419	-6.59	5.00	12.00	0.00	0.13	13.00	
PTB-CS2	58419	58449	0.51	5.00	12.00	0.00	0.13	13.00	
PTB-CS2	58449	58479	-1.77	5.00	12.00	0.00	0.13	13.00	
PTB-CSF1	58114	58134	0.08	0.07	0.39	0.07	0.19	0.44	
PTB-CSF1	58139	58149	0.22	0.11	0.40	0.03	0.35	0.54	
PTB-CSF1	58149	58174	0.12	0.07	0.39	0.10	0.15	0.44	
PTB-CSF1	58174	58204	0.02	0.07	0.37	0.10	0.13	0.41	
PTB-CSF1	58284	58294	0.60	0.11	0.39	0.03	0.35	0.54	
PTB-CSF1	58359	58389	0.84	0.06	0.31	0.02	0.13	0.34	
PTB-CSF1	58424	58449	0.44	0.07	0.29	0.03	0.15	0.34	
PTB-CSF1	58449	58469	0.76	0.08	0.28	0.04	0.19	0.35	
PTB-CSF2	58139	58149	0.20	0.18	0.20	0.02	0.35	0.44	
PTB-CSF2	58149	58174	-0.07	0.09	0.20	0.04	0.15	0.27	
PTB-CSF2	58174	58204	-0.27	0.10	0.20	0.06	0.13	0.27	
PTB-CSF2	58204	58234	0.02	0.08	0.20	0.02	0.13	0.25	
PTB-CSF2	58234	58264	0.48	0.08	0.20	0.03	0.13	0.25	
PTB-CSF2	58274	58294	0.41	0.10	0.20	0.03	0.19	0.29	
PTB-CSF2	58294	58314	1.15	0.10	0.21	0.09	0.19	0.31	
PTB-CSF2	58359	58379	0.73	0.11	0.20	0.04	0.19	0.30	
PTB-CSF2	58389	58419	0.26	0.20	0.20	0.07	0.13	0.32	
PTB-CSF2	58424	58449	0.59	0.11	0.20	0.05	0.15	0.28	
PTB-CSF2	58449	58469	0.60	0.12	0.18	0.05	0.19	0.29	
SU-CsFO2	58139	58149	-0.65	0.37	0.24	0.13	2.28	2.33	
SU-CsFO2	58149	58174	-0.23	0.30	0.24	0.14	1.00	1.08	
SU-CsFO2	58174	58204	-1.09	0.29	0.24	0.13	0.85	0.94	
SU-CsFO2	58204	58234	-0.84	0.27	0.24	0.14	0.85	0.93	
SU-CsFO2	58234	58269	-0.98	0.31	0.24	0.14	0.74	0.85	

SU-CsFO2	58269	58299	-0.22	0.30	0.24	0.13	0.85	0.94
SU-CsFO2	58299	58329	0.24	0.28	0.24	0.13	0.85	0.93
SU-CsFO2	58329	58359	0.54	0.52	0.24	0.13	0.85	1.03
SU-CsFO2	58419	58449	1.59	0.33	0.24	0.16	0.85	0.95
SU-CsFO2	58449	58479	1.38	0.34	0.24	0.13	0.85	0.95
SYRTE-FO1	58184	58199	-0.41	0.50	0.42	0.09	0.49	0.82
SYRTE-FO1	58199	58214	-0.30	0.25	0.43	0.05	0.49	0.70
SYRTE-FO1	58219	58234	-0.05	0.20	0.43	0.05	0.49	0.68
SYRTE-FO1	58234	58269	0.44	0.25	0.41	0.06	0.23	0.53
SYRTE-FO1	58269	58299	0.33	0.20	0.35	0.07	0.26	0.49
SYRTE-FO1	58299	58329	0.56	0.25	0.34	0.06	0.26	0.50
SYRTE-FO1	58329	58359	0.48	0.20	0.34	0.05	0.26	0.48
SYRTE-FO1	58359	58389	0.34	0.20	0.33	0.05	0.26	0.47
SYRTE-FO1	58389	58419	0.32	0.20	0.32	0.06	0.26	0.46
SYRTE-FO1	58419	58449	0.37	0.25	0.32	0.05	0.26	0.49
SYRTE-FO1	58449	58479	0.51	0.25	0.32	0.05	0.26	0.49
SYRTE-FO2	58114	58149	-0.27	0.40	0.23	0.11	0.23	0.53
SYRTE-FO2	58149	58164	-0.17	0.50	0.31	0.11	0.49	0.77
SYRTE-FO2	58199	58214	-0.21	0.20	0.20	0.05	0.49	0.57
SYRTE-FO2	58219	58234	-0.05	0.20	0.20	0.05	0.49	0.57
SYRTE-FO2	58234	58269	0.42	0.40	0.20	0.06	0.23	0.51
SYRTE-FO2	58314	58329	0.30	0.30	0.23	0.07	0.49	0.62
SYRTE-FO2	58329	58359	0.49	0.20	0.21	0.05	0.26	0.39
SYRTE-FO2	58359	58389	0.74	0.20	0.20	0.06	0.26	0.39
SYRTE-FO2	58389	58419	0.40	0.20	0.20	0.05	0.26	0.39
SYRTE-FO2	58419	58449	0.90	0.30	0.21	0.06	0.26	0.45
SYRTE-FO2	58449	58479	0.59	0.20	0.20	0.05	0.26	0.39
SYRTE-FOM	58359	58389	0.13	0.25	0.85	0.05	0.26	0.93
SYRTE-FOM	58389	58419	0.73	0.20	1.13	0.05	0.26	1.18
SYRTE-FOM	58419	58449	0.73	0.50	0.81	0.07	0.26	0.99
SYRTE-FOM	58449	58479	0.79	0.25	0.63	0.09	0.26	0.73

Note:
(1) Continuously operating as a clock participating in TAI.

Table 6B. Measurements of the duration of the TAI scale interval by Secondary Frequency Standards

Standard	Period of estimation		$d/10^{-15}$	$u_A/10^{-15}$	$u_B/10^{-15}$	$u_{link/lab}$ $/10^{-15}$	$u_{link/TAI}$ $/10^{-15}$	$u/10^{-15}$	u_{SRep}	Ref(u_S)
NICT-Sr1	57474	57504	-0.34	0.03	0.08	0.36	0.20	0.42	0.4	[12]
NICT-Sr1	57504	57539	-0.37	0.03	0.07	0.31	0.17	0.37	0.4	
NICT-Sr1	57539	57569	-0.13	0.03	0.08	0.31	0.20	0.38	0.4	
NICT-Sr1	57569	57599	-0.57	0.03	0.06	0.30	0.20	0.37	0.4	
NICT-Sr1	57599	57629	-0.67	0.03	0.06	0.33	0.20	0.39	0.4	
NICT-Sr1	57629	57659	-0.92	0.03	0.06	0.35	0.20	0.40	0.4	
NICT-Sr1	58149	58174	-0.05	0.03	0.07	0.29	0.31	0.43	0.4	
NICT-Sr1	58454	58464	0.84	0.01	0.08	0.05	0.70	0.71	0.4	
SYRTE-FORb	58114	58149	0.14	0.30	0.28	0.11	0.23	0.48	0.7	[13]
SYRTE-FORb	58149	58174	0.57	0.20	0.28	0.11	0.31	0.47	0.7	
SYRTE-FORb	58174	58189	0.03	0.50	0.30	0.12	0.49	0.77	0.7	
SYRTE-FORb	58199	58214	-0.19	0.25	0.24	0.05	0.49	0.60	0.6	[12]
SYRTE-FORb	58219	58234	0.24	0.20	0.24	0.06	0.49	0.58	0.6	
SYRTE-FORb	58234	58269	0.50	0.25	0.24	0.06	0.23	0.42	0.6	
SYRTE-FORb	58269	58289	0.14	0.20	0.24	0.09	0.38	0.50	0.6	
SYRTE-FORb	58334	58359	0.44	0.20	0.25	0.08	0.31	0.45	0.6	
SYRTE-FORb	58374	58389	0.98	0.20	0.26	0.07	0.49	0.59	0.6	
SYRTE-FORb	58389	58419	0.57	0.20	0.25	0.06	0.26	0.42	0.6	
SYRTE-FORb	58419	58449	0.94	0.32	0.24	0.07	0.26	0.48	0.6	
SYRTE-FORb	58449	58479	0.74	0.30	0.24	0.05	0.26	0.47	0.6	
SYRTE-SrB	58454	58464	0.74	0.20	0.10	0.09	0.70	0.74	0.4	[12]

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Annex A: Operation of the METAS-FOC2 primary frequency standard in 2018

The Swiss continuous Cs fountain clock METAS-FOC2 was officially accepted in 2018 by the CCTF-WGPSFS as a contributor to the calibration of TAI. Three reports of measurements performed in 2017 were sent for that purpose to the WG in 2017 and were published in Circular T 371 in November 2018. The details of the evaluation of the primary frequency standard are available in [1]. The following table summarizes the published values.

#	Evaluation period	$d/10^{-15}$	$u_A/10^{-15}$	$u_B/10^{-15}$	$u_{lab}/10^{-15}$	$u_{TAI}/10^{-15}$	$u_{total}/10^{-15}$
1	57809-57839	-0.74	0.11	2.01	0.07	0.23	2.03
2	57919-57934	-0.02	0.20	2.01	0.13	0.49	2.08
3	57944-57964	-0.03	0.17	12.01	0.10	0.38	2.05

During each observation period, the standard was operated continuously, i.e. without deadtime. The local oscillator was the METAS hydrogen maser (HM, BIPM clock code 1405701). The typical short-term frequency instability of METAS-FOC2 was $2 \times 10^{-13} \ (\tau/s)^{-1/2}$.

The following table shows a typical uncertainty budget (k=1), which is updated for each calibration.

Physical effect	Frequency shift $/10^{-15}$	Uncertainty $/10^{-15}$
Second-order Zeeman	23.59	0.21
Gravitational	59.72	0.02
Second-order Doppler	-0.01	<0.01
Blackbody radiation	-16.67	0.04
Microwave spectrum purity	0.00	0.05
Light shift from source	-0.16	0.04
Cavity pulling	0.00	<0.01
Rabi pulling	0.00	0.02
Ramsey pulling	0.05	0.10
End-to-end	2.17	0.27
Collisional Cs-Cs	-1.91	1.47
Light shift from detection	-0.10	0.41
RF leakage	0.00	0.47
Majorana transitions	0.00	0.50
DCPS	—	1.03
Total	66.68	1.99

Reference

[1] A Jallageas et al., Metrologia **55** 366,(2018).

Annex B: Operation of IT-CsF2 in 2018

F. Levi and G.A. Costanzo

IT-CsF2 is the primary atomic frequency standard operated at INRIM. The frequency standard is based on a laser cooled Cs fountain apparatus operating at cryogenic temperature (88.5K), in order to reduce the blackbody radiation shift. The formal evaluation of the frequency standard is published in [1], while TAI calibration data are reported to BIPM since the end of 2013 and are published in the Circular T. The accuracy evaluation of the PFS involves periodical checks and validations of the whole set of parameters affecting the standard frequency: i.e. Zeeman shift, spectral purity of the microwave synthesis chain, interaction region temperature, atomic density shift, gravitational potential, and laser and microwave leakage.

During 2018 we reported to BIPM two formal TAI evaluations of the standard hereafter summarized. The two measurements have a duration of 10 days (from MJD 58219 to MJD 58229) and 15 days (from MJD 58284 to MJD 58299) with unwanted dead times of the order of 10% and 20% over the two evaluation periods. The total operating time of IT-CsF2 as PFS during 2018 was 25 days.

Circ T	Period	days	d (10^{-15})	uA (10^{-15})	uB (10^{-15})	Ul/Lab (10^{-15})	Ul/Tai (10^{-15})	u (10^{-15})
364	58219 58229	10	1.09	0.83	0.17	0.14	0.88	1.23
366	58284 58299	15	0.43	0.69	0.17	0.22	0.49	0.89

The accuracy of ITCsF2 is nearly the same that was reported in [1] and it is summarized in the following table. It is worth mentioning that the statistical uncertainty associated with the atomic density, is obtained with long measurement time and thus vary from case to case according to the available set of data. Typically the low density uncertainty can reach ~2x10^{-16}.

Typical accuracy evaluation

Physical effect	Bias (10^{-16})	Uncert. (10^{-16})
Zeeman effect	1074.9	0.8
Blackbody radiation	-1.45	0.12
Gravitational redshift	260.4	0.1
Microwave leakage	-1.2	1.4
DCP	-	0.2
2nd order cavity pulling	-	0.3
Background gas	-	0.5
Total Type B	1332.6	1.7
Atomic density (typical LD)	-6.3	1.9
Total	1326.3	2.5

[1] Accuracy evaluation of ITCsF2: a nitrogen cooled caesium fountain, F. Levi, D. Calonico, C.E. Calosso, A. Godone, S. Micalizio and G.A. Costanzo; Metrologia 51 (2014) 270–284

Annex C: Report of the operation of NICT-Sr1 for 2018

The frequency standard NICT-Sr1 is an ^{87}Sr optical lattice clock operated at NICT. Utilizing the method of intermittent evaluation, NICT-Sr1 has been used to measure the scale interval of TAI over six month-long intervals in 2016 and one in 2018. The results were reported to the CCTF Working Group on Primary and Secondary Frequency Standards for review. After acceptance of NICT-Sr1 for contribution to TAI calibration, the results were published in the *Circular T* 371 in Dec. 2018, covering the intervals of MJD 57474 to 57504 (30 days), MJD 57504 to 57539 (35 days), MJD 57539 to 57569 (30 days), MJD 57569 to 57599 (30 days), MJD 57599 to 57629 (30 days), MJD 57629 to 57659 (30 days), and MJD 58149 to 58174 (25 days).

Following acceptance, NICT-Sr1 was used to evaluate the scale interval in a nearly continuous measurement of more than 90% up-time over 10 days from MJD 58454 to 58464 in Dec. 2018.

Measurements of the scale interval use an optical frequency comb to down-convert the optical frequency at a wavelength of 698 nm stabilized to NICT-Sr1 to a signal in the microwave domain. This then serves as a reference to evaluate the frequency of a hydrogen maser (HM). In intermittent evaluation, the HM frequency was measured for three hours approximately once per week, and the mean frequency of the HM with respect to the frequency of NICT-Sr1 was determined from several such data blocks distributed homogeneously over the target period, taking into account the uncertainty due to non-operation time of NICT-Sr1 [1-3]. Additionally, an average over multiple HMs mitigates the effect of sporadic phase excursions of a specific HM [2]. In the evaluation of the continuous measurement the frequency of the chosen HM is directly determined by a weighted linear regression. Table 1 shows typical uncertainty contributions for evaluations based on the intermittent method and for continuous measurement. Intermittent evaluation reduces the contributions from the uncertainty ul/Tai of the satellite link to TAI, which limits measurements at short evaluation intervals.

In the evaluation of ul/Lab, representing the uncertainty of the link between NICT-Sr1 and the local HM, we separately consider Type A and Type B uncertainties, which add in quadrature to give ul/Lab as included in the circular-T.

Period of evaluation (MJD)	Evaluation mode	uA	uB	(uA) (uB) ul/Lab	ul/Tai	u	uSrep
58149 – 58174 (25 days)	Intermittent	0.29	0.73	(2.75) (1) 2.93	3.08	4.3	4
58454 – 58464 (10 days)	continuous	0.08	0.79	(0.47) (0.01) 0.47	7.02	7.1	4

Table 1: Exemplary uncertainty contributions for intermittent evaluation (top line) and for nearly continuous measurement (bottom line). Values are given in units of 10^{-16}.

The typical systematic corrections and their uncertainties for NICT-Sr1 as previously published [1-3] are summarized as follows:

Effect	Correction (10^{-17})	Uncertainty (10^{-17})
Blackbody radiation	513.9	3.0
Lattice scalar / tensor	2.7	3.8
Lattice hyperpolarizability	–0.2	0.1
Lattice E2/M1	0	0.5
Probe light	0.1	0.1
Dc Stark	0.1	0.2
Quadratic Zeeman	52.0	0.3
Density	2.2	1.5
Background gas collisions	0	1.8
Line pulling	0	0.1
Servo error	0.4	1.5
Total	571.2	5.6
Gravitational redshift	–834.1	2.2
Total (with gravitational effect)	–262.9	6.0

Table 2. Systematic corrections and their uncertainties for NICT-Sr1 between MJD 57629 and 57659.

References

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Annex D: Operation of the NIM5 primary frequency standard in 2018

The NIM5 Cs fountain primary frequency standard at NIM was reported to BIPM three times in 2018. In January, the frequencies of the hydrogen maser H271 against NIM5 were measured, and in September and November, the frequencies of the hydrogen maser H50 against NIM5 were measured. The results, including all relevant biases and uncertainties, were published in Circular T and shown in the following table.

MJD periods	$d/10^{-15}$	$u_A/10^{-15}$	$u_B/10^{-15}$	$U_{l/lab}/10^{-15}$	$U_{l/TAI}/10^{-15}$	$u/10^{-15}$
58124.0-58144.0	-0.59	0.30	0.90	0.20	0.38	1.04
58369.0-58384.0	1.01	0.30	0.90	0.30	0.49	1.11
58424.0-58449.0	0.62	0.20	0.90	0.20	0.31	0.99

Besides switching H-maser from H271 to H50, the computer control system has also been updated from a Labwindow version to a Labview version, so did some drivers be changed. No other changes have been made and the combined relative Type B uncertainty is still 0.9×10^{-15}.

A new fountain clock NIM6 has been built and evaluated. Due to a MOT loading OM scheme, atoms collecting rates increased a lot. An instability of $1\times10^{-13}/\sqrt{\tau}$ has been achieved due to a good stability of H-maser H50. The uncertainties due to second order Zeeman effect, black body radiation and cold collisional frequency shift have been evaluated and are all less than 1×10^{-16}. The microwave power related frequency shift is still under evaluation. The relative frequency difference between Ramsey π/2 pulse and 3π/2 has been measured, and is less than 5×10^{-16}. The relative frequency differences between two fountains are recorded for 20 days, and the averaged fractional frequency difference is 4.4×10^{-16}, consistent with the sum uncertainties of two fountain clocks.

Annex E: Operation of the SYRTE atomic fountain PSFS in 2018

In 2018, a total of 38 calibrations reports of the reference maser by the SYRTE fountains PSFS have been transmitted to BIPM to participate to the steering of TAI: 11 by the primary frequency standard (PFS) FO1, 11 by the PFS FO2-Cs, 12 by the secondary frequency standard (SFS) FO2-Rb, and 4 by the PFS FOM. FO2-Cs and FO2-Rb are the 2 parts of the dual fountain FO2 which operates simultaneously with caesium and rubidium atoms. FO2-Rb calibrations are included in *Circular T* as SYRTE-FORb SFS.

FO1 contributions were interrupted up to March 2018. In 2016-2017, a complete refurbishment of the fountain including its local environment has been performed. Most notably, the inner Stark plates dedicated to initial studies related to the black body (Stark) shift have been removed from the vacuum tube. Otherwise, the fountain geometry remains unchanged. The long term stability of the parameters and the reliability of the fountain have been notably improved. The uncertainty budget has also been revisited. The four first FO1 calibration values of the reference maser after this interruption were sent to the BIPM in June 2018. Monthly calibrations were then sent regularly.

Four calibration reports of the mobile fountain FOM have been sent to the BIPM in December 2018, after an interruption of more than 6 years. After the last report in August 2012, FOM fountain was transported to the French space agency CNES, in Toulouse, where it was operated for two years to serve as a reference for the ground tests of the space cold atom clock PHARAO. It came back at LNE-SYRTE in summer 2014 and installed in a new room, but was not in operation for a while, until a proper reference signal distribution was set-up. The vacuum chamber was open in winter 2016 in order to replace the caesium reservoir and to renew the pumping system. A complete new evaluation of the systematic effects has been performed in 2017-2018, although there were no modification in the system. We intend to pursue the provision of monthly calibration reports on a regular basis in the future.

The FO2 fountain was routinely operated in dual Cs/Rb mode in 2018, following a deep refurbishment performed between August and November 2017. The vacuum chamber was open in order to replace the pumping system and to renew the atom pre-sources based on 2D-MOTs, both for the caesium and the rubidium parts. New control computers together with new control cards and interfaces to the fountain have been implemented for FO2-Cs and for FO2-Rb. Long term measurements in nominal conditions resumed in December 2017. The first reports after re-evaluation of the systematics have been transmitted to BIPM starting January 2018.

The operation of the four fountains is similar. The microwave synthesizer of each fountain is referenced to the signal provided by an ultra-low phase noise cryogenic sapphire oscillator phase locked to a hydrogen maser, allowing to reach the quantum projection noise limit. The relative frequency instability is typically $\sigma_y(\tau) \sim 5.3 \times 10^{-14}\ \tau^{-1/2}$ for FO1 and $\sigma_y(\tau) \sim 5.6 \times 10^{-14}\ \tau^{-1/2}$ for both FO2-Cs and FO2-Rb. It has been slightly improved thanks to the replacement of the 2D-MOT cold atom pre-sources. Because FOM uses optical molasses only, its relative frequency instability is limited to $\sigma_y(\tau) \sim 8.8 \times 10^{-14}\ \tau^{-1/2}$. These instabilities result from the combination of low and high atomic density operations required for the real time extrapolation of the cold collisions frequency shift.

The typical uncertainty budgets are presented in Table 1 for the caesium fountains and in Table 2 for the rubidium fountain. As previously, the maser frequency is corrected from the quadratic Zeeman, the blackbody radiation, the cold collisions (+ cavity pulling), the first order Doppler, the microwave lensing shifts, and the redshift. The magnetic field and the temperature around the interrogation zone is measured every 1 hour or less in order to evaluate in real time the quadratic Zeeman and the blackbody radiation shift. To evaluate the cold collision shift and extrapolate, we alternate measurements between full and half atomic density either using the method proposed by K. Gibble (2012 EFTF Proceedings) in FO1, FO2-Rb and FOM, or using the adiabatic passage method in FO2-Cs. The distributed cavity phase shift is verified from time to time with differential measurements alternating the cavity feeds. Against possible residual microwave leakages, the microwave interrogation is pulsed and absence of synchronous phase transients is tested periodically. Improved relativistic redshift corrections with reduced uncertainties have been determined in the frame of the ITOC (International Timescales with Optical Clocks) project [1, 2]. This involved a combination of GNSS based height measurements, geometric levelling and a geoid model over Europe, refined by local gravity measurements, together with a fine determination of the average atomic trajectory with

respect to the local reference points. In the context of TAI calibrations we use a conservative uncertainty of 2.5 x 10^{-17}.
The dead time uncertainty estimation method has been updated according to [3, 4] starting April 2018.
For the second contribution to the $u_{Link\ Lab}$ uncertainty, between the maser and the PSFS, a new characterization of the signal distribution leads to a still conservative value of 5×10^{-17}.

The calibration values are given with typical uncertainties u_A = 2 - 4 x 10^{-16}, and 1 - 2 x 10^{-16} for the uncertainty due to the link between the reference maser and the standard. For FO1, FO2-Cs and FO2-Rb, the systematic uncertainty u_B is ~ 2.0-3.4 x 10^{-16}, and for FOM, ~ 6-8 x 10^{-16}.
For the FO2-Rb SFS, the three first calibration reports in 2018 were made using the 2015 recommended value for the ^{87}Rb secondary representation (20th CCTF, [5]). It was updated to the 2017 recommended value (21st CCTF, [6]) starting April 2018. The uncertainty on the secondary representation value has been updated accordingly.

Throughout 2018, the frequency calibrations of the reference H-maser by the SYRTE fountains were also used to produce a daily steering of the H-maser output signal for the generation of the French timescale UTC(OP) [9].

Fountain	FO1		FO2-Cs		FOM	
Physical origin	Correction	Uncertainty	Correction	Uncertainty	Correction	Uncertainty
2nd order Zeeman	-1280.72	0.40	-1934.02	0.30	-323.06	1.90
Blackbody Radiation	169.66	0.60	171.28	0.60	166.80	2.30
Cold Collisions + cavity pulling	120.96	1.42	96.21	0.96	29.54	4.43
Distributed cavity phase shift	-0.07	2.4	-0.90	1.00	-0.70	2.75
Microwave lensing	-0.65	0.65	-0.70	0.70	-0.90	0.90
Microwave Leaks, spectral purity	0	1	0	0.50	0	1.50
Ramsey & Rabi pulling	0	0.2	0	0.10	0	0.10
Second order Doppler	0	0.1	0	0.10	0	0.10
Background gas collisions	0	0.3	0	1.00	0	1.00
Red shift	- 69.08	0.25	- 65.54	0.25	- 68.24	0.25
Total uncertainty u_B		**3.2**		**2.0**		**6.3**

Table 1: Typical accuracy budgets for the SYRTE PFS FO1, FO2-Cs and FOM adapted from those given in [7] and [8]. (Values given in units of 10^{-16})

Fountain	FO2-Rb	
Physical origin	Correction	Uncertainty
2nd order Zeeman	-3501.60	0.70
Blackbody Radiation	126.55	1.35
Cold Collisions + cavity pulling	3.47	0.88
First order Doppler	-0.35	1.00
Microwave lensing	-0.70	0.70
Microwave Leaks, spectral purity	0	0.50
Ramsey & Rabi pulling	0	0.10
Second order Doppler	0	0.10
Background gas collisions	0	1.00
Red shift	- 65.45	0.25
Total uncertainty u_B		**2.4**

Table 2: Typical accuracy budgets for the SYRTE SFS FO2-Rb adapted from those given in [7] and [8]. (Values given in units of 10^{-16})

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Annex F: Report of the SYRTE SrB contribution published in 2018

Two optical lattice clocks with ^{87}Sr atoms have been operated at SYRTE for several years. The frequency of the clock laser probing the clock transition is split into three branches. Two of them are locked to the $^1S_0 \longrightarrow {}^3P_0$ transition of Sr2 and SrB respectively, while the third one is measured by a fiber frequency comb connected by a compensated microwave link to other optical oscillator and to the microwave reference (a cryogenic sapphire oscillator (CSO) phase locked to a hydrogen Maser). By combining the frequency offset and beat-notes of these branches, we can deduce the frequency of the H Maser with respect to the ^{87}Sr clock transition. After a first appearance of the LNE-SYRTE Sr clocks in the Circular T #350 (2017), a new 10 days calibration has been conducted in December 2018 with the SrB clock, spanning MJD 58454 to 58464.

The single clock instability of the SrB clock is 7×10^{-16} for a 1 s integration time, deduced from local and remote clock comparisons. A statistical uncertainty of 10^{-17} is therefore reached after a few hours of integration. This stability is not a limitation when comparing with microwave oscillators. The systematic uncertainty of the SrB clock for this period was 10^{-16}, accidentally away from the few 10^{-17} that can be reached. The total uncertainty budget is reported in Table 1.

	Correction (10^{-18})	**Uncertainty (10^{-18})**
Black body radiation	*5143*	*10*
Quadratic Zeeman effect	*671*	*6*
Lattice light-shift	*-10*	*5*
Lattice spectrum	*0*	*1*
Density shift	*0*	*10*
Line pulling	*0*	*10*
Probe light shift	*0.4*	*0.4*
AOM phase chirp	*0*	*<1*
Servo error	*0*	*3*
Static charges	*200*	*100*
Blackbody radiation oven	*0*	*10*
Background gas collisions	*40*	*4*
Total (1 σ uncertainty u_B)	*6044.4*	*102*
Red shift	*-6114.6*	*10*
Total with red shift	***-70.2***	***103***

Table 1: uncertainty budget of the two SrB clock for the December 2018 calibration report. During this period, the presence of static charges shifting the clock transition has been assed by comparing SrB with the other clocks Sr2 while UV light was shone on the SrB clock. This uncertainty budget deviates from the nominal accuracy budget usually at the 10^{-17} level.

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Annex G: Operation of the PTB primary clocks in 2018

PTB's primary clocks with a thermal beam

During 2018 PTB's primary clocks CS1 and CS2 were operated almost continuously. Time differences UTC(PTB) - clock in the standard ALGOS format were reported to BIPM, so that $u_{\mathrm{l/lab}}$ is zero. The mean (MJD 58119 to 58479) relative frequency offset y(CS1 – CS2) amounted to -3.9×10^{-15}, which is compliant with the stated u_{B} values [1,2].

The clocks' operational parameters were checked periodically and validated to estimate the clock uncertainty. These parameters are the Zeeman frequency, the temperature of the beam tube (vacuum enclosure), the line width of the clock transition as a measure of the mean atomic velocity, the microwave power level, the spectral purity of the microwave excitation signal, and some characteristic signals of the electronics. Using a high-resolution phase comparator, the 5 MHz output signals of both clocks have been continuously compared to 5 MHz of superior frequency instability to assess the frequency instability of CS1 and CS2, respectively. Data analysis has been made based on several 15 to 20-day batches distributed during 2018.

CS1

The CS1 relative frequency instability $\sigma_y(\tau = 5000\ \mathrm{s})$ was found to vary between 90×10^{-15} and 102×10^{-15} during 2018, in reasonable agreement with the prediction based on the prevailing parameters beam flux, clock transition signal and line width. With reference to TAI, the standard deviation of *d*(CS1) (Circular T Section 3, 12 months) was 9.5×10^{-15}, in some excess of the value $u_{\mathrm{A}}(\tau = 30\ \mathrm{d, CS1}) = 8\times10^{-15}$ stated in Circular T. The scatter of data is larger than in previous years, but no root cause can be given. During the year, two reversals of the beam direction were performed on CS1. No findings call for a modification of the previously stated relative frequency uncertainty u_{B}, which is 8×10^{-15} for CS1 [2]. This value complies with the mean offset between CS1 and TAI during 2018 (mean of the 12 *d*-values reported in Circular T) of -6.9×10^{-15}.

CS2

The relative CS2 frequency instability of $\sigma_y(\tau = 5000\ \mathrm{s})$ was measured between 50×10^{-15} and 56×10^{-15} during 2018. The standard deviation of the 12 *d*-values reported in Circular T for 2018 amounted to 3.1×10^{-15}, well below the stated uncertainty contribution $u_{\mathrm{A}}(\tau = 30\ \mathrm{d, CS2}) = 5\times10^{-15}$ reported in Circular T. During the year, two reversals of the beam direction were performed on CS2.The uncertainty estimate as detailed in [1, 2] is considered as still valid, and the CS2 u_{B} is thus estimated as 12×10^{-15}. This value complies well with the mean offset between CS2 and TAI during 2018 (mean of the 12 *d*-values reported in Circular T) of -3.0×10^{-15}.

PTB's primary caesium fountain clocks

In 2018 both caesium fountain clocks, CSF1 and CSF2, were operated regularly with a high duty cycle. The frequency synthesis for both fountains routinely makes use of an optically stabilized microwave oscillator [3-5] instead of employing quartz based microwave synthesis. For the generation of UTC(PTB) the data of both fountains were routinely used for the steering of a hydrogen maser output frequency [6]. The steering data was obtained from the weighted average of the data of the two fountains, by taking the systematic and statistical uncertainties of either fountain data into account.

In 2018 a comprehensive update of the uncertainty budget of CSF1 and CSF2 has been published, together with detailed descriptions of both fountains and their performance [7]. Over the last years most significant progress has been achieved in the assessment of distributed cavity phase shifts, microwave lensing, AC Stark shifts, pulling by neighbouring transitions, microwave leakage, electronics and background gas collisions.

Moreover, according to the new definition of TAI (26th CGPM in November 2018, Resolution 2), the relativistic redshift of a clock contributing to TAI is to be computed with respect to the conventionally adopted equipotential $W_0 = 62\ 636\ 856.0\ \mathrm{m^2s^{-2}}$ of the Earth's gravity potential. The new definition eliminates the former ambiguity regarding the definition of the geoid, resulting in lower uncertainties for the determination of the relativistic redshift [7, 8].

CSF1

In 2018 nine measurements of the TAI scale unit of 10 (3×), 20 (2×), 25 (2×) and 30 (2×) days duration were performed and reported to the BIPM. The difference between the mean fractional deviation *d* of the scale interval of TAI from that of TT, measured during 180 days by CSF1, and the mean BIPM estimate of *d* based on all simultaneous Primary and Secondary Frequency Standard measurements was 1.2×10^{-16}.

Due to the performance and reliability of the laser systems, dead times are normally kept between 2-3% (in two cases 8%) of the nominal measurement duration, where about 1% dead time is caused by the periodic switching between low and high density operation modes and periodical magnetic field measurements. The resulting clock link uncertainty $u_{l/lab}$ was in the range 0.2×10^{-16} to 1.0×10^{-16}.

The statistical uncertainty of CSF1 measurements was calculated with the assumption of white frequency noise during the measurement intervals. For the TAI contributions in 2018 typically statistical uncertainties $u_A < 1\times10^{-16}$ were achieved.

Below we compile typical frequency biases and the updated type B uncertainty budget of CSF1, valid for TAI scale unit measurements [7].

Physical effect	Bias / 10^{-16}	Type B uncertainty / 10^{-16}
Quadratic Zeeman shift	1078.35	0.10
Black body radiation shift	- 165.84	0.80
Relativistic redshift and Doppler effect	85.56	0.02
Collisional shift	2.1	2.4
Distributed cavity phase shift	0.04	0.93
Microwave lensing	0.4	0.2
AC Stark shift (light shift)		0.01
Rabi and Ramsey pulling		0.013
Microwave leakage		0.01
Electronics		0.1
Background gas collisions		0.4
Total type B uncertainty		2.7

CSF2

In 2018 twelve measurements of the TAI scale unit of 10 (2×), 20 (4×), 25 (2×) and 30 (4×) days duration were performed and reported to the BIPM. The difference between the mean fractional deviation *d* of the scale interval of TAI from that of TT, measured during 270 days by CSF2, and the mean BIPM estimate of *d* based on all simultaneous Primary and Secondary Frequency Standard measurements was 0.5×10^{-16}.

The dead times of the above measurements were in most cases ≤5% and in two cases 7-11%, where about 1% dead time is caused by the periodic switching between low and high density operation modes and periodical magnetic field measurements. The resulting clock link uncertainty $u_{l/lab}$ was typically below 0.5×10^{-16} and only in one case 0.9×10^{-16}.

The statistical uncertainty of CSF2 measurements was calculated with the assumption of white frequency noise for the total measurement intervals and includes a statistical uncertainty contribution from the collisional shift evaluation [7]. For the twelve TAI contributions in 2018 we arrived at statistical uncertainties u_A between $0.8\text{-}2.0\times10^{-16}$.

Below we compile typical frequency biases and an updated type B uncertainty budget of CSF2, valid for TAI scale unit measurements [7].

Physical effect	Bias / 10^{-16}	Type B uncertainty / 10^{-16}
Quadratic Zeeman shift	1004.54	0.10
Black body radiation shift	- 165.33	0.63
Relativistic redshift and Doppler effect	85.45	0.02
Collisional shift	-99.7	0.5
Distributed cavity phase shift	0.28	1.52
Microwave lensing	0.7	0.2
AC Stark shift (light shift)		0.01
Rabi and Ramsey pulling		0.013
Microwave leakage		0.01
Electronics		0.1
Background gas collisions		0.1
Total type B uncertainty		1.7

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Annex H: Operation of CsFO2 in 2018

For the year 2018 the SU-CsFO2 results were reported to TAI a few times.

An algorithm to process the measurement data was farther improved . The algorithm is based on the fountain noise model presented in [1]. It was recognized that for finite time of measurement there is always a frequency shift presented due to the residual phase. The dispersion of a process may be presented as $(\sigma + i\delta/\tau)^2$, where σ is a standard deviation and δ is a starting phase for the measurement session. The value $(\sigma + i\delta/\tau)^2$ really turns to the dispersion with infinite time.

The key stone of the fountain frequency measurements is the influence of a residual phase on the result in the session. Only fountain leads to the highest precision because one may take into the account the influence of a residual phase. The precision may be a few units of 10-17 for a month, while the precision of optical standard should be at the level a few units of 10-16 for a month.

Write the fountain equation: $\alpha^2F^2 + \alpha\Phi^2 + N2 + \alpha^{-1}C^2 + \alpha^{-2}S^2 = \sigma^2_\alpha$
Here F^2 **-** the dispersion due to photodetector noise, Φ^2 **-** the dispersion due to quantum projection noise, **N2 -** backgraund noise, C^2 **-** probing signal (synthesizer) noise, S^2- spin-exchange noise and σ^2_α **–** “a standard deviation” for a given atoms flux **α/**

. Five equations are compiled for five fluxes of atoms. The solution of the equations enables us to determine the total frequency shift due to non-zero income from any shift, presented in a fountain. As a result we have a meaning of fountain frequency, which is referenced to zero number of atoms. All shifts are taken into account via uncertainty u_a **and do not included in** uncertainty u_b**.** The farther matching of algorithm was performed [2]. For practical realization the measurements were grouped by five parts containing one hundred cycle each. Every part correspond to it’s own number of atoms in a cycle. The number of atoms is changed by changing selecting cavity power

Reference

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Table 7. Mean fractional deviation of the TAI scale interval from that of TT

The fractional deviation *d* of the scale interval of TAI from that of TT (in practice the SI second on the geoid), and its relative uncertainty, are computed by the BIPM for all the intervals of computation of TAI, according to the method described in 'Azoubib J., Granveaud M., Guinot B., *Metrologia* 1977, **13**, pp. 87-93', using all available measurements from the most accurate primary frequency standards (PFS) IT-CSF2, METAS-FOC2, NIM5, NIST-F1, PTB-CS1, PTB-CS2, PTB-CSF1, PTB-CSF2, SU-CSFO2, SYRTE-FO1, SYRTE-FO2, SYRTE-FOM and secondary frequency standard (SFS) SYRTE-FORb, SYRTE-SR2, SYRTE-SrB and NICT-Sr1 consistently corrected for the black-body radiation shift.
In this computation, the uncertainty of the link to TAI has been computed using the standard uncertainty of [UTC-UTC(*k*)], following the recommendation of the CCTF working group on PFS. The model for the instability of EAL has been expressed as the quadratic sum of three components: a white frequency noise $1.7 \times 10^{-15}/\sqrt{(\tau)}$ in 2013 and 2014 and $1.4 \times 10^{-15}/\sqrt{(\tau)}$ from 2015 to 2018, a flicker frequency noise 0.35×10^{-15} in 2013 and 2014 and 0.3×10^{-f} from 2015 to 2018 and a random walk frequency noise $0.4 \times 10^{-16}x\sqrt{(\tau)}$ in 2013 and $0.2 \times 10^{-16}x\sqrt{(\tau)}$ from 2014 to 2018, with τ in days. The relation between EAL and TAI is given in the following ftp://ftp2.bipm.org/pub/tai/other-products/ealtai/feal-ftai.

Month	Interval	$d/10^{-15}$	uncertainty/10^{-15}
Jan. 2016	57384-57414	-0.36	0.25
Feb. 2016	57414-57444	-0.42	0.26
Mar. 2016	57444-57474	-0.78	0.23
Apr. 2016	57474-57504	-1.00	0.16
May 2016	57504-57539	-0.80	0.23
Jun. 2016	57539-57569	-0.49	0.17
Jul. 2016	57569-57599	-0.55	0.18
Aug. 2016	57599-57629	-0.75	0.16
Sep. 2016	57629-57659	-0.89	0.21
Oct. 2016	57659-57689	-1.33	0.21
Nov. 2016	57689-57719	-1.55	0.22
Dec. 2016	57719-57749	-1.34	0.20
Jan. 2017	57749-57784	-1.57	0.22
Feb. 2017	57784-57809	-1.28	0.23
Mar. 2017	57809-57839	-0.79	0.21
Apr. 2017	57839-57869	-0.47	0.20
May 2017	57869-57904	0.35	0.19
Jun. 2017	57904-57934	0.06	0.21
Jul. 2017	57934-57964	-0.02	0.24
Aug. 2017	57964-57994	-0.20	0.24
Sep. 2017	57994-58024	-0.25	0.22
Oct. 2017	58024-58054	-0.33	0.20
Nov. 2017	58054-58084	-0.04	0.19
Dec. 2017	58084-58114	-0.16	0.20
Jan. 2018	58114-58149	-0.06	0.22
Feb. 2018	58149-58174	-0.03	0.18
Mar. 2018	58174-58204	-0.21	0.18
Apr. 2018	58204-58234	-0.01	0.18
May 2018	58234-58269	0.34	0.19
Jun. 2018	58269-58299	0.42	0.21
Jul. 2018	58299-58329	0.65	0.24
Aug. 2018	58329-58359	0.49	0.23
Sep. 2018	58359-58389	0.67	0.17
Oct. 2018	58389-58419	0.39	0.19
Nov. 2018	58419-58449	0.62	0.17
Dec. 2018	58449-58479	0.65	0.19

Independent local atomic time scales

Local atomic time scales are established by the time laboratories which contribute with the appropriate clock data to the BIPM. Starting on 1 January 1998, the differences between TAI and the atomic scale maintained by each laboratory are available on the Publications page of the Time Department's FTP Server, including the relevant notes. For each time laboratory 'lab' a separate file TAI-lab is provided; it contains the respective values of the differences [*TAI - TA(lab)*] in nanoseconds, for the standard dates.

For dates from January 1982 to December 1992 and from January 1993 to December 1998, the differences between TAI and the atomic scale maintained by each laboratory are available on the Scales page of the Time Department's FTP server including the relevant notes. The values of [*TAI - TA(lab)*] are given in yearly files. Note that the formats of the [TAI – TA(lab)] files are different in the two intervals.

Local representations of UTC

The time laboratories which submit data to the BIPM keep local representations of UTC. Starting on 1 January 1998, the computed differences between UTC and each local representation are available on the Publications page of the Time Department's FTP Server including the relevant notes. For each time laboratory 'lab' a separate file UTC-lab is provided; it contains the values of the differences [*UTC - UTC(lab)*] in nanoseconds, for the standard dates.

For dates from January 1990 to December 1992 and from January 1993 to December 1998, the computed differences between UTC and each local representation maintained by each laboratory are available on the Scales page of the Time Department's FTP server including the relevant notes. The values of [*UTC - UTC(lab)*] are given in yearly files. Note that the formats of the files [*UTC* – *UTC*(*lab*)] are different in the two intervals.

Starting on MJD 56467 daily values of the differences [*UTCr-UTC(lab)*] in nanoseconds are given in one file per laboratory. The results during the UTCr Pilot Experiment (February 2012-June 2013) are also available.

Relations of UTC and TAI with GPS time, GLONASS time, UTC(USNO)_GPS and UTC(SU)_GLONASS

(File available at ftp://ftp2.bipm.org/pub/tai/other-products/utcgnss/utc-gnss)

[*TAI - GPS time*] and [*UTC - GPS time*]

The GPS satellites disseminate a common time scale designated 'GPS time'. The relation between GPS time and TAI is:

$$[\mathit{TAI} - \mathit{GPS\ time}] = 19 \text{ s} + C_0,$$

where the time difference of 19 seconds is kept constant and C_0 is a quantity of the order of tens of nanoseconds, varying with time.

The relation between GPS time and UTC involves a variable number of seconds as a consequence of the leap seconds of the UTC system and is as follows:

From 1 January 2017, 0 h UTC, until further notice, $[\mathit{UTC} - \mathit{GPS\ time}] = -18 \text{ s} + C_0$,

Here C_0 is given at 0 h UTC every day.

C_0 is computed as follows. The GPS data recorded at the Paris Observatory for highest-elevation satellites are first corrected for precise satellite ephemerides and for ionospheric delays derived from IGS maps, and then smoothed to obtain daily values of [*UTC*(*OP*) - *GPS time*] at 0 h UTC. Daily values of C_0 are then derived by linear interpolation of [*UTC* - *UTC*(*OP*)].

The standard deviation σ_0 characterizes the dispersion of individual measurements for a month. The actual uncertainty of user's access to GPS time may differ from these values. N_0 is the number of measurements.

[*TAI – UTC(USNO)_GPS*] and [*UTC – UTC(USNO)_GPS*]

The GPS satellites broadcast a prediction of UTC(USNO) calculated at the USNO, indicated by UTC(USNO)_GPS. The relation between UTC(USNO)_GPS and TAI involves a variable number of seconds as a consequence of the leap seconds of the UTC system, and is as follows:

From 1 January 2017, 0 h UTC, until further notice, $[\mathit{TAI} - \mathit{UTC(USNO)\_GPS}] = 37 \text{ s} + C_0'$

Here C_0' is given at 0 h UTC every day.

C_0' is computed using the values of [*UTC* - *UTC*(*OP*)] similarly than the computation of C_0.

The relation between UTC(USNO)_GPS and UTC is $[\mathit{UTC} - \mathit{UTC(USNO)\_GPS}] = 0 \text{ s} + C_0'$

The standard deviation σ_0' characterizes the dispersion of individual measurements for a month. The actual uncertainty of user's access to UTC(USNO)_GPS may differ from these values. N_0' is the number of measurements.

Relations of UTC and TAI with GPS time, GLONASS time, UTC(USNO)_GPS and UTC(SU)_GLONASS (Cont.)

(File available at ftp://ftp2.bipm.org/pub/tai/other-products/utcgnss/utc-gnss)

[*UTC - GLONASS time*] and [*TAI - GLONASS time*]

The GLONASS satellites disseminate a common time scale designated 'GLONASS time'. The relationship between GLONASS time and UTC is

$$[UTC - GLONASS\ time] = 0\ \mathrm{s} + C_1,$$

where the time difference 0 s is kept constant by the application of leap seconds so that GLONASS time follows the UTC system, and C_1 is a quantity of the order of tens of nanoseconds (tens of microseconds until 1 July 1997), which varies with time.

The relation between GLONASS time and TAI involves a variable number of seconds and is as follows:

From 1 January 2017, 0 h UTC, until further notice, $[TAI - GLONASS\ time] = 37\ \mathrm{s} + C_1$.

Here C_1 is given at 0 h UTC every day.

C_1 is computed as follows. The GLONASS data recorded at the Astrogeodynamical Observatory, Borowiec, Poland for the highest-elevation satellites are smoothed to obtain daily values of [*UTC*(*AOS*) - *GLONASS time*] at 0 h UTC. Daily values of C_1 are then derived by linear interpolation of [*UTC* - *UTC*(*AOS*)].

To ensure the continuity of C_1 estimates, the following corrections are applied:

+1285 ns from 1 January 1997 (MJD 50449) to 22 March 1999 (MJD 51259)
+107 ns for 23 March 1999 and 24 March (MJD 51260 and MJD 51261)
0 ns since 25 March 1999, (MJD 51262).

The standard deviation σ_1 characterizes the dispersion of individual measurements for a month. The actual uncertainty of user's access to GLONASS time may differ from these values. N_1 is the number of measurements.

[*TAI – UTC(SU)_GLONASS*] and [*UTC – UTC(SU)_GLONASS*]

The satellites broadcast a prediction of UTC(SU) calculated at the SU, indicated by UTC(SU)_GLONASS. The relation between UTC(SU)_GLONASS and TAI involves a variable number of seconds as a consequence of the leap seconds of the UTC system, and is as follows:

From 1 January 2017, 0 h UTC, until further notice, $[TAI – UTC(SU)\_GLONASS] = 37\ \mathrm{s} + C_1'$

Here C_1' is given at 0 h UTC every day.

C_1' is computed using the values of [*UTC* - *UTC*(*AOS*)] similarly than the computation of C_1.

The relation between UTC(SU)_GLONASS and UTC is $[UTC– UTC(SU)\_GLONASS] = 0\ \mathrm{s} + C_1'$

The standard deviation σ_1' characterizes the dispersion of individual measurements for a month. The actual uncertainty of user's access to UTC(SU)_GPS may differ from these values. N_1' is the number of measurements.

Clocks contributing to TAI in 2018

Clocks characteristics

The annual tables of clock weight, rate, and drift, are no more published, the info can be found in the reported links in monthly files
YY represents the last two digits of the year (20YY) and MM represents the month number of the year (1-12).

Relative clock weights for intervals of one month

Monthly clock weights results are available in file wYY.MM in ftp://ftp2.bipm.org/pub/tai/other-products/weights/.

Monthly rates of TAI- clocks for intervals of one month

Monthly clock rates results are available in file rYY.MM in ftp://ftp2.bipm.org/pub/tai/other-products/rates/.

Frequency drifts of the clocks using a monthly realization of TT(BIPM) as reference

Monthly clock frequency drifts results are available in file dYY.MM in ftp://ftp2.bipm.org/pub/tai/other-products/clkdrifts/.

Table 8 reports the statistical data on the weights attributed to the clocks in 2018

Table 8: Statistical data on the weights attributed to the clocks in 2018

		Number of Clocks			Number of clocks with a given weight									
					Weight = 0*			Weight = 0**			Max weight			Max relative
Interval		HM	5071A	Total	HM	5071A	Total	HM	5071A	Total	HM	5071A	Total	weight
2018	Jan.	139	248	438	9	11	26	11	7	23	62	0	66	0.971
2018	Feb.	145	257	451	16	19	41	13	8	25	62	0	66	0.976
2018	Mar.	150	248	444	17	25	48	13	7	23	63	0	67	1.010
2018	Apr.	151	244	440	22	26	53	7	8	19	62	0	66	1.034
2018	May	153	248	447	21	31	56	7	8	18	62	0	66	1.023
2018	June	155	243	445	17	26	49	8	7	19	63	0	67	1.010
2018	July	153	237	434	11	20	38	7	8	17	64	0	68	1.010
2018	Aug.	144	232	420	8	24	41	9	7	18	63	0	67	1.055
2018	Sep.	149	240	438	11	35	61	8	8	18	63	0	67	1.061
2018	Oct.	148	237	435	9	32	54	6	7	14	59	0	63	1.050
2018	Nov.	148	231	429	10	32	54	5	6	13	60	0	64	1.067
2018	Dec.	143	227	418	11	33	53	6	6	17	61	0	65	1.096

Wmax=A/N, here N is the number of clocks, excluding those with a priori null weight, A=4.00.

* A priori null weight (test interval of new clocks).

** Null weight resulting from the statistics.

HM designates hydrogen masers and 5071A designates Hewlett-Packard 5071A units with high performance tube.

Clocks with missing data during an one-month interval of computation are excluded.

TIME SIGNALS

The time signal emissions reported here follow the UTC system, in accordance with the Recommendation 460-4 of the Radiocommunication Bureau (RB) of the International Telecommunication Union (ITU) unless otherwise stated.

Their maximum departure from the Universal Time UT1 is thus 0.9 seconds.

The following tables are based on information received at the BIPM between March and May 2019.

AUTHORITIES RESPONSIBLE FOR TIME SIGNAL EMISSIONS

Signal	Authority
ALS162 (previoulsy TDF)	France Horlogerie (previously CFHM : Chambre française de l'horlogerie et des microtechniques) 22 avenue Franklin Roosevelt 75008 Paris, France and ANFR Agence nationale des fréquences 78, avenue du général de Gaulle 94704 Maisons-Alfort, France and LNE Laboratoire national de métrologie et d'essais 1 rue Gaston Boissier 75724 Paris Cedex 15, France
BPC, BPL, BPM	National Time Service Center, NTSC Chinese Academy of Sciences 3 East Shuyuan Rd, Lintong District, Xi'an Shaanxi 710600, China
CHU	National Research Council of Canada Metrology Frequency and Time Standards Bldg M-36, 1200 Montreal Road Ottawa, Ontario, K1A 0R6, Canada
DCF77	Physikalisch-Technische Bundesanstalt Time and Frequency Department, WG 4.42 Bundesallee 100 D-38116 Braunschweig Germany
HLA	Center for Time and Frequency Division of Physical Metrology Korea Research Institute of Standards and Science 267 Gajeong-Ro, Yuseong, Daejeon 34113 Republic of Korea
JJY	Space-Time Standards Laboratory National Institute of Information and Communications Technology 4 -2- 1, Nukui-kitamachi Koganei, Tokyo 184-8795 Japan

Signal	Authority
LOL	Servicio de Hidrografía Naval Observatorio Naval Buenos Aires Av. España 2099 C1107AMA – Buenos Aires, Argentina
MIKES	VTT Technical Research Centre of Finland Ltd Centre for Metrology MIKES P.O. Box 1000, FI-02044 VTT, Finland
MSF	National Physical Laboratory Time and Frequency Group Hampton Road Teddington, Middlesex TW11 0LW United Kingdom
RAB-99, RBU, RJH-63, RJH-69, RJH-77, RJH-86, RJH-90,RTZ,RWM	All-Russian Scientific Research Institute for Physical Technical and Radiotechnical Measurements FGUP “VNIIFTRI” Meendeleevo, Moscow Region 141570 Russia
WWV, WWVB, WWVH	Time and Frequency Division, 688.00 National Institute of Standards and Technology - 325 Broadway Boulder, Colorado 80305, U.S.A.

TIME SIGNALS EMITTED IN THE UTC SYSTEM

Station	Location Latitude Longitude	Frequency (kHz)	Schedule (UTC)	Form of the signal
ALS162 (previously TDF)	Allouis France 47° 10'N 2° 12'E	162	Continuous, except every Tuesday from 8 h to12 h (French time)	Phase modulation of the carrier by +1 and -1 rd in 0.1 s every second except the 59th second of each minute. This modulation is doubled to indicate binary 1. The numbers of the minute, hour, day of the month, day of the week, month and year are transmitted each minute from the 21st to the 58th second, in accordance with the French legal time scale. In addition, a binary 1 at the 17th second indicates that the local time is 2 hours ahead of UTC (summer time); a binary 1 at the 18th second indicates that the local time is 1 hour ahead of UTC (winter time); a binary 1 at the 14th second indicates that the current day is a public holiday (Christmas, 14 July, etc...); a binary 1 at the 13th second indicates that the current day is a day before a public holiday.
BPC	Shangqiu China 34° 27'N 115° 50'E	68.5	00 h 00 m to 21 h 00 m	UTC second pulse modulation of the phase shift keying of the carrier. The additional pulse width modulation includes calendar and local time information.
BPL	Pucheng China 34° 56'N 109° 32'E	100	Continuous	The BPL time signals are generated by NTSC and are in accordance with the legal time of China which is UTC(NTSC)+8 . The BPL system is the same as the Loran-C system, utilizing the multi-pulse phase coding scheme. Carrier Frequency of 100KHz. The information that BPL broadcasts contains minutes, seconds, year, month, day, and other information. Using pulse shift modulation.
BPM	Pucheng China 35° 0'N 109° 31'E	2 500 5 000 10 000 15 000	7 h 30 m to 1 h Continuous Continuous 1 h to 9 h	The BPM time signals are generated by NTSC and are in accordance with UTC(NTSC)+8 h. Signals emitted in advance on UTC by 20 ms. Second pulses of 10 ms duration with 1 kHz modulation. Minute pulses of 300 ms duration with 1 kHz modulation. UTC time signals are emitted from minute 0 to 10, 15 to 25, 30 to 40, 45 to 55. UT1 time signals are emitted from minute 25 to 29, 55 to 59.
CHU	Ottawa Canada 45° 18'N 75° 45'W	3 330 7 850 14 670	Continuous	Second pulses of 300 cycles of a 1 kHz modulation, with 29th and 51st to 59th pulses of each minute omitted. Minute pulses are 0.5 s long. Hour pulses are 1.0 s long, with the following 1st to 9th pulses omitted. A bilingual (Fr. Eng.) announcement of time (UTC) is made each minute following the 50th second pulse. FSK code (300 bps, Bell 103) after 10 cycles of 1 kHz on seconds 31 to 39. Year, DUT1, leap second information, TAI-UTC and Canadian daylight saving time format on 31, and time code on 32-39. Broadcast is single sideband; upper sideband with carrier reinsert. DUT1 : ITU-R code by double pulse.

Station	Location Latitude Longitude	Frequency (kHz)	Schedule (UTC)	Form of the signal
DCF77	Mainflingen Germany 50° 1'N 9° 0'E	77.5	Continuous	The DCF77 time signals are generated by PTB and are in accordance with the legal time of Germany which is UTC(PTB)+1 h or UTC(PTB)+2 h. At the beginning of each second (except in the last second of each minute) the carrier amplitude is reduced to about 15 % for a duration of 0.1 or 0.2 s corresponding to “binary 0” or “binary 1”, respectively, referred to as second marks 0 to 59 in the following. The number of the minute, hour, day of the month, day of the week, month and year are transmitted in BCD code using second marks 20 to the 58, including overhead. Information emitted during minute n is valid for minute n+1. The information transmitted during the second marks 1 to the 14 is provided by third parties. Information on that additional service can be obtained from PTB. To achieve a more accurate time transfer and a better use of the frequency spectrum available an additional pseudo-random phase shift keying of the carrier is superimposed on the AM second markers. No transmission of DUT1.
HLA	Daejeon Rep. of Korea 36° 23'N 127° 22'E	5 000	Continuous	Second pulses of 9 cycles of 1 800 Hz tones. 29th and 59th second pulses omitted. Hour identified by 0.8 s long 1 500 Hz tones. Beginning of each minute identified by 0.8 s long 1 800 Hz tones. BCD time code given on 100 Hz subcarrier.
JJY	Tamura-shi Fukushima Japan 37° 22'N 140° 51'E	40	Continuous	A1B type 0.2 s, 0.5 s and 0.8 s second pulses, spacings are given by the reduction of the amplitude of the carrier. Coded announcement of hour, minute, day of the year, year, day of the week and leap second. Transmitted time refers to UTC(NICT) + 9 h.
JJY	Saga-shi Saga Japan 33° 28'N 130° 11'E	60	Continuous	A1B type 0.2 s, 0.5 s and 0.8 s second pulses, spacings are given by the reduction of the amplitude of the carrier. Coded announcement of hour, minute, day of the year, year, day of the week and leap second same as JJY(40). Transmitted time refers to UTC(NICT) + 9 h.
LOL	Buenos Aires Argentina 34° 37'S 58° 21'W	10 000	11 h to 12 h except Saturday, Sunday and national holidays.	Second pulses of 5 cycles of 1000 Hz modulation. Second 59 is omitted. Announcement of hours and minutes every 5 minutes, followed by 3 minutes of 1000 Hz or 440 Hz modulation. DUT1: ITU-R code by lengthening.
MIKES	Espoo Finland 60° 11'N 24° 50'E	25 000	Continuous	Modulation as in DCF77, but with 1 kHz amplitude modulation added and without pseudo-random phase shift keying of the carrier. Time code in UTC.

Station	Location Latitude Longitude	Frequency (kHz)	Schedule (UTC)	Form of the signal
MSF	Anthorn United Kingdom 54° 54'N 3° 16'W	60	Continuous, except for interruptions for maintenance from 10 h 0 m to 14 h 0 m on the second Thursday of December and March, and from 09 h 0 m to 13 h 0 m on the second Thursday of June and September. A longer period of maintenance during the summer is announced annually.	The carrier is interrupted for 0.1 s at the start of each second, except during the first second of each minute (second 0) when the interruption is 0.5 s. Two data bits are transmitted each second (except second 0): data bit “A” between 0.1 and 0.2 s after the start of the second and data bit “B” between 0.2 and 0.3 s after the start of the second. Presence of the carrier represents “binary 0” and an interruption represents “binary 1”. The values of data bit “A” provide year, month, day of the month, day of the week, hour and minute in BCD code. The time represented is UTC(NPL) in winter and UTC(NPL)+1h when DST is in effect. The values of data bit “B” provide DUT1 and an indication whether DST is in effect. The information transmitted applies to the following minute. DUT1: ITU-R code by double pulse.
RAB-99	Khabarovsk Russia 48° 30'N 134° 50'E	25.0 25.1 25.5 23.0 20.5	02 h 06 m to 02 h 36 m 06 h 06 m to 06 h 36 m	A1N type signals are transmitted between minutes 9 and 20 : 0.025 second pulses of 12.5 ms duration are transmitted between minutes 9 and 11; second pulses of 0.1 s duration, 10 second pulses of 1 s duration, 0.1 second pulses of 25 ms and minute pulses of 10 s duration are transmitted between minutes 11 and 20.
RBU	Moscow Russia 56° 44'N 37° 40'E	200/3	Continuous	DXXXW type 0.1 s signals. The numbers of the minute, hour, day of the month, day of the week, month, year of the century, difference between the universal time and the local time, TJD and DUT1+dUT1 are transmitted each minute from the 1st to the 59th second. DUT1+dUT1 : by double pulse.
RJH-63	Krasnodar Russia 44° 46'N 39° 34'E	25.0 25.1 25.5 23.0 20.5	11 h 06 m to 11 h 40 m	A1N type signals are transmitted between minutes 9 and 20 : 0.025 second pulses of 12.5 ms duration are transmitted between minutes 9 and 11 ; 0.1 second pulses of 25 ms duration, 10 second pulses of 1 s duration and minute pulses of 10 s duration are transmitted between minutes 11 and 20.
RJH-69	Molodechno Belarus 54° 28'N 26° 47'E	25.0 25.1 25.5 23.0 20.5	07 h 06 m to 07 h 47 m	A1N type signals are transmitted between minutes 10 and 22 : 0.025 second pulses of 12.5 ms duration are transmitted between minutes 10 and 13; second pulses of 0.1 s duration, 10 second pulses of 1 s duration, 0.1 second pulses of 25 ms and minute pulses of 10 s duration are transmitted between minutes 13 and 22.
RJH-77	Arkhangelsk Russia 64° 22'N 41° 35'E	25.0 25.1 25.5 23.0 20.5	09 h 06 m to 09 h 47 m	A1N type signals are transmitted between minutes 10 and 22 : 0.025 second pulses of 12.5 ms duration are transmitted between minutes 10 and 13; second pulses of 0.1 s duration, 10 second pulses of 1 s duration, 0.1 second pulses of 25 ms and minute pulses of 10 s duration are transmitted between minutes 13 and 22.

Station	Location Latitude Longitude	Frequency (kHz)	Schedule (UTC)	Form of the signal
RJH-86	Bishkek Kirgizstan 43° 03'N 73° 37'E	25.0 25.1 25.5 23.0 20.5	04 h 06 m to 04 h 47 m 10 h 06 m to 10 h 47 m	A1N type signals are transmitted between minutes 10 and 22 : 0.025 second pulses of 12.5 ms duration are transmitted between minutes 10 and 13; second pulses of 0.1 s duration, 10 second pulses of 1 s duration, 0.1 second pulses of 25 ms and minute pulses of 10 s duration are transmitted between minutes 13 and 22.
RJH-90	Nizhni Novgorod Russia 56° 11'N 43° 57'E	25.0 25.1 25.5 23.0 20.5	08 h 06 m to 08 h 47 m	A1N type signals are transmitted between minutes 10 and 22 : 0.025 second pulses of 12.5 ms duration are transmitted between minutes 10 and 13; second pulses of 0.1 s duration, 10 second pulses of 1 s duration, 0.1 second pulses of 25 ms and minute pulses of 10 s duration are transmitted between minutes 13 and 22.
RTZ	Irkutsk Russia 52° 26'N 103° 41'E	50	00 h 00 m to 19 h 00 m 20 h 00 m to 24 h 00 m	DXXXW type 0.1 s signals. The numbers of the minute, hour, day of the month, day of the week, month, year of the century, difference between the universal time and the local time, TJD and DUT1+dUT1 are transmitted each minute from the 1st to the 59th second. DUT1+dUT1: by double pulse.
RWM (1)	Moscow Russia 56° 44'N 37° 38'E	4 996 9 996 14 996	The station operates simultaneously on the three frequencies.	A1X type second pulses of 0.1 s duration are transmitted between minutes 10 and 20, 40 and 50. The pulses at the beginning of the minute are prolonged to 0.5 s. A1N type 0.1 s second pulses of 0.02 s duration are transmitted between minutes 20 and 30. The pulses at the beginning of the second are prolonged to 40 ms and of the minute to 0.5 ms. DUT1+dUT1: by double pulse.
WWV	Fort-Collins CO, USA 40° 41'N 105° 3'W	2 500 5 000 10 000 15 000 20 000 25 000	Continuous	Second pulses are 1 000 Hz tones, 5 ms in duration. 29th and 59th second pulses omitted. Hour is identified by 0.8 second long 1 500 Hz tone. Beginning of each minute identified by 0.8 second long 1 000 Hz tones. DUT1: ITU-R code by double pulse. BCD time code given on 100 Hz subcarrier, includes DUT1 correction.
WWVB	Fort-Collins CO, USA 40° 41'N 105° 3'W	60	Continuous	Second pulses given by reduction of the amplitude, reversal of phase, and by binary phase shift keying of the carrier, AM, PM and BPSK coded announcement of the date, time, DUT1 correction, daylight saving time in effect, leap year and leap second.
WWVH	Kauai HI, USA 21° 59'N 159° 46'W	2 500 5 000 10 000 15 000	Continuous	Second pulses are 1 200 Hz tones, 5 ms in duration. 29th and 59th second pulses omitted. Hour is identified by 0.8 second long 1 500 Hz tone. Beginning of each minute identified by 0.8 second long 1 200 Hz tones. DUT1: ITU-R code by double pulse. BCD time code given on 100 Hz subcarrier, includes DUT1 correction.

(1) RWM is the radiostation emitting DUT1 information in accordance with the ITU-R code and also giving an additional information, dUT1, which specifies more precisely the difference UT1-UTC down to multiples of 0.02 s, the total value of the correction being DUT1+dUT1.
Positive values of dUT1 are transmitted by the marking of *p* second markers within the range between the 21st and 24th second so that dUT1 = +*p* x 0.02 s.
Negative values of dUT1 are transmitted by the marking of *q* second markers within the range between the 31st and 34th second, so that dUT1 = -*q* x 0.02 s.

ACCURACY OF THE CARRIER FREQUENCY

Station	Relative uncertainty of the carrier frequency in 10^{-10}	
ALS162	0.02	**(previously TDF)**
BPM	0.01	
CHU	0.05	
DCF77	0.02	
HLA	0.02	
JJY	0.01	
LOL	0.1	
MIKES	0.01	
MSF	0.02	
RAB-99,RJH-63	0.05	
RBU,RTZ	0.02	
RJH-69, RJH-77	0.05	
RJH-86, RJH-90	0.05	
RWM	0.05	
WWV	0.01	
WWVB	0.01	
WWVH	0.01	

TIME DISSEMINATION SERVICES

The following tables are based on information received at the BIPM between March and May 2019.

AUTHORITIES RESPONSIBLE FOR TIME DISSEMINATION SERVICES

AOS	Astrogeodynamical Observatory Borowiec near Poznan Space Research Centre P.A.S. PL 62-035 Kórnik - Poland
AUS	Electricity Section National Measurement Institute 36 Bradfield Rd Lindfield NSW 2070 - Australia
BelGIM	Belarussian State Institute of Metrology National Standard for Time, Frequency and Time-scale of the Republic of Belarus Minsk, Minsk Region – 220053 Belarus
BEV	Bundesamt für Eich- und Vermessungswesen Arltgasse 35 A-1160 Wien, Vienna - Austria
BoM	Ministry of economy - Bureau of metrology Jane Sandanski 109a 1000 Skopje, Macedonia
CENAM	Centro Nacional de Metrología Dirección de Tiempo y Frecuencia km. 4.5 carretera a Los Cués El Marqués, Querétaro 76246, México.
CENAMEP	Centro Nacional de Metrología de Panamá AIP CENAMEP AIP Ciudad del Saber Edif. 206 Panama
DMDM	Directorate of Measures and Precious Metals Group for Time, Frequency and Time Dissemination. Mike Alasa 14 11000 Belgrade Serbia
EIM	Hellenic Institute of Metrology Electrical Measurements Department Block 45, Industrial Area of Thessaloniki PO 57022, Sindos Thessaloniki, Greece
GUM	Time and Frequency Laboratory Główny Urząd Miar – Central Office of Measures ul. Elektoralna 2 PL 00 – 950 Warszawa P–10, Poland
HKO	Hong Kong Observatory 134A, Nathan Road Kowloon, Hong Kong, China

ICE	Instituto Costarricense de Electricidad ICE San Jose Costa Rica
IGNA	Instituto Geográfico Nacional Argentino Servicio Internacional de la Hora General Manuel N. Savio 1898 B1650KLP – Villa Maipú, Provincia de Buenos Aires, Argentina
IMBH	Institute of Metrology of Bosnia and Herzegovina (IMBH) Laboratory for time and frequency Augusta Brauna 2 71000 Sarajevo, Bosnia and Herzegovina
INACAL	Instituto Nacional de Calidad Calle De La Prosa 150 San Borja, Lima 41, Peru
INM	Instituto Nacional de Metrología de Colombia Avenida Carrera 50 No. 26 – 55 Interior 2 Bogotá D.C. – Colombia
INPL	National Physical Laboratory Danciger A bldg Givat - Ram, The Hebrew university 91904 Jerusalem, Israel
INRIM	Istituto Nazionale di Ricerca Metrologica Strada delle Cacce, 91 I – 10135 Turin, Italy
INTI	Instituto Nacional de Tecnología Industrial Av. General Paz Nº 5445 B1650WAB San Martín Buenos Aires, República Argentina
JV	Justervesenet Norwegian Metrology Service PO Box 170 2027 Kjeller, Norway
KIM	Puslit Kalibrasi, Instrumentasi dan Metrologi -- Lembaga Ilmu Pengetahuan Indonesia Research Centre for Calibration, Instrumentation and Metrology -- Indonesian Institute of Sciences (Puslit KIM – LIPI) Kawasan PUSPIPTEK Serpong Tangerang 15314 Banten - Indonesia
KRISS	Center for Time and Frequency Division of Physical Metrology Korea Research Institute of Standards and Science 267 Gajeong-Ro, Yuseong Daejeon 34113 Republic of Korea
KZ	Kazakhstan Institute of Metrology Orynbor str., 11 Astana, Republic of Kazakhstan

LNE-SYRTE	Laboratoire National de Métrologie et d'Essais Systèmes de Référence Temps-Espace Observatoire de Paris 61, avenue de l'Observatoire, 75014 Paris – France
LT	Time and Frequency Standard Laboratory Center for Physical Sciences and Technology Savanoriu av. 231 Vilnius LT-02300, Lithuania
MASM	Time and Frequency Standard Laboratory Mongolian Agency for Standardization and Metrology Peace avenue 46A, Bayanzurkh district, Ulaanbaatar 13343 Mongolia
METAS	Federal Institute of Metrology Sector Length, Optics and Time Lindenweg 50 CH-3003 Bern-Wabern Switzerland
MIKES	VTT Technical Research Centre of Finland Ltd Centre for Metrology MIKES P.O. Box 1000, FI-02044 VTT, Finland
MSL	Measurement Standards Laboratory Callaghan Innovation 69 Gracefield Road PO Box 31-310 Lower Hutt – New Zealand
NAO	Time Keeping Office Mizusawa VLBI Observatory National Astronomical Observatory of Japan 2-12, Hoshigaoka, Mizusawa, Oshu, Iwate 023-0861 Japan
NICT	Space-Time Standards Laboratory National Institute of Information and Communications Technology 4 -2 -1, Nukui-kitamachi Koganei, Tokyo 184-8795 - Japan
NIM	Time & Frequency Laboratory National Institute of Metrology No. 18, Bei San Huan Dong Lu Beijing 100029 - People's Republic of China
NIMB	Time and Frequency Laboratory National Institute of Metrology Sos. Vitan - Barzesti, 11 042122 Bucharest, Romania
NIMT	Time and Frequency Laboratory National Institute of Metrology (Thailand) 3/5 Moo 3, Klong 5, Klong Luang, Pathumthani 12120, Thailand

NIST	National Institute of Standards and Technology Time and Frequency Division, 688.00 325 Broadway Boulder, Colorado 80305, USA
NMIJ	Time Standards Group National Metrology Institute of Japan (NMIJ), AIST Umezono 1-1-1, Tsukuba, Ibaraki 305-8563, Japan
NMISA	Time and Frequency Laboratory National Metrology Institute of South Africa Private Bag X34 Lynnwood Ridge 0040, Pretoria - South Africa
NMLS	Time and Frequency Laboratory National Metrology Institute of Malaysia Lot PT 4803, Bandar Baru Salak Tinggi, 43900 Sepang - Malaysia
NPL	National Physical Laboratory Time and Frequency Group Hampton Road Teddington, Middlesex TW11 0LW United Kingdom
NPLI	Time and Frequency Metrology Section CSIR-National Physical Laboratory Dr.K.S.Krishnan Road New Delhi 110012 - India
NRC	National Research Council of Canada Metrology Frequency and Time Standards Bldg M-36, 1200 Montreal Road Ottawa, Ontario, K1A 0R6, Canada
NSC IM	Time and Frequency Section National Scientific Center "Institute of Metrology" Kharkov - Ukraine Str. Mironositska 42 Region – 61002 Ukraine
NTSC	National Time Service Center Chinese Academy of Sciences 3 East Shuyuan Rd, Lintong District, Xi’an Shaanxi 710600, China
ONBA	Servicio de Hidrografía Naval Observatorio Naval Buenos Aires Servicio de Hora Av. España 2099 C1107AMA – Buenos Aires, Argentina

ONRJ	Observatorio Nacional (MCTIC) Divisão Serviço da Hora Rua General José Cristino, 77 São Cristovão 20921-400 Rio de Janeiro, Brazil
ORB	Royal Observatory of Belgium Avenue Circulaire, 3 B-1180 Brussels, Belgium
PTB	Physikalisch-Technische Bundesanstalt Time and Frequency Department, WG 4. 42 Bundesallee 100 D-38116 Braunschweig, Germany
RISE	RISE Research Institutes of Sweden Box 857 S-501 15 Borås Sweden
ROA	Real Instituto y Observatorio de la Armada Plaza de las Tres Marinas s/n 11.100 San Fernando Cádiz, Spain
SG	National Metrology Centre Agency for Science, Technology and Research (A*STAR) 1 Science Park Drive 118221 Singapore
SIQ	SIQ Ljubljana Metrology department Trzaska ul. 2 1000 Ljubljana Slovenia
SL	Measurement Units, Standards and Services Department (MUSSD), Mahenawatta, Pitipana, Homagama, - Sri Lanka
TL	National Standard Time and Frequency Laboratory Telecommunication Laboratories Chunghwa Telecom. Co., Ltd. No. 99, Dianyan Road Yang-Mei, Taoyuan, 32661 Taiwan Chinese Taipei
TP	Institute of Photonics and Electronics Czech Academy of Sciences Chaberská 57, 182 51 Praha 8 Czech Republic
UME	Ulusal Metroloji Enstitüsü Baris Mah. Dr. Zeki Acar Cad. No: 1 41470 Gebze - Kocaeli Turkey
USNO	U.S. Naval Observatory 3450 Massachusetts Ave., N.W. Washington, D.C. 20392-5420 USA

VMI	Laboratory of Time and Frequency (TFL) Vietnam Metrology Institute (VMI) No 8, Hoang Quoc Viet Rd, Cau Giay Dist., Hanoi Vietnam.
VNIIFTRI	All-Russian Scientific Research Institute for Physical Technical and Radiotechnical Measurements, Moscow Region 141570 Russia
VSL	VSL Dutch Metrology Institute Postbus 654 2600 AR Delft Netherlands

TIME DISSEMINATION SERVICES

AOS	AOS Computer Time Service: vega.cbk.poznan.pl (150.254.183.15) Synchronization: NTP V3 primary (Caesium clock), PC Pentium, RedHat Linux Service Area: Poland/Europe Access Policy: open access Contact: Jerzy Nawrocki (nawrocki@cbk.poznan.pl) Robert Diak (kondor@cbk.poznan.pl)
AUS	Network Time Service Computers connected to the Internet can be synchronized to UTC(AUS) using the NTP protocol. The NTP servers are referenced to UTC(AUS) either directly or via a GPS common view link. Please see http://www.measurement.gov.au/Services/Pages/TimeandFrequencyDisseminationService.aspx for information on access or contact time@measurement.gov.au Dial-up Computer Time Service Computers can also obtain time via a modem connection to our dial-up timeserver. For further information, please see our web pages as above.
BelGIM	Internet Time Service: BelGIM operates one time server Stratum 1 using the "Network Time Protocol" (NTP). The server host name is: http://www.belgim.by (Stratum 1)
BEV	Three NTP servers are available; addresses: bevtime1.metrologie.at bevtime2.metrologie.at time.metrologie.at more information on http://www.metrologie.at Provides a time dissemination service via phone and modem to synchronize PC clocks. Uses the Time Distribution System from TUG. It has a baud rate of 1200 and everyone can use it with no cost. Access phone number is +43 1 21110 826381 The system will be updated periodically (DUT1, Leap Second…).
BoM	Internet Time Service BoM operates two Stratum 1 NTP servers referenced to UTC(BoM). BoM also operates one time server Stratum 2 using the "Network Time Protocol" (NTP). Server Host Name: time.bom.gov.mk
CENAM	CENAM operates a telephone voice system that provides the local time for time zones in Mexico. Phone numbers and zones: +52 (442) 211 0505 → Southeast Time +52 (442) 211 0506 → Central Time +52 (442) 211 0507 → Pacific Time +52 (442) 211 0508 → Northwest Time +52 (442) 211 0509 → UTC(CNM)

	Telephone Code CENAM provides a telephone code for setting time in computers. For more information about this service please contact time@cenam.mx Network Time Protocol (NTP) Operates two time servers using NTP (located at CENAM). Further information at http://www.cenam.mx/hora_oficial/ Web-based time-of-day clock which displays local time for all Mexican time zones. Referenced to CENAM Internet Time Service. Available at http://www.cenam.mx/hora_oficial/
CENAMEP	Network Time Server A Stratum 1 time server is used to synchronize computer networks of the government institutions and companies in the private sector using the NTP protocol. To access the Network time service, send an email to servicios@cenamep.org.pa Web Clock A web clock is used to display the time of day in real time. To access the Web Clock, enter the link http://horaexacta.cenamep.org.pa/ Voice Time Server An assembly of computers provides the local time. To access the service, call the telephone numbers (507) 5173201, (507) 5173202 and (507) 5173203
DMDM	Internet Time Service (ITS) DMDM operates two Stratum 1 time servers using the “Network Time Protocol” (NTP), synchronized to UTC(DMDM). Access policy: restricted. DMDM also operates two Stratum 2 NTP servers: vreme1.dmdm.rs or vreme1.dmdm.gov.rs vreme2.dmdm.rs or vreme2.dmdm.gov.rs Access policy: free. More information on: http://www.dmdm.rs/en/GrupaZaVremeFrekfencijuIDistribucijuVremena.php#TacnoVreme Web-based time-of-day clock that displays local time for Serbia referenced to the DMDM ITS. Available at the web page: http://www.dmdm.rs/en/index.php
EIM	Internet Time Service EIM operates a time server using the “Network Time Protocol” (NTP). The address hercules.eim.gr is also accessible through IP address 83.212.233.6. This route is offered under a restricted access policy. The server uses the 10 MHz signal from our primary standard as reference and is synchronized to UTC(EIM).
GUM	Telephone Time Service providing the European time code by telephone modem for setting time in computers. Includes provision for compensation of propagation time delay. Access phone number : +48 22 654 88 72 Network Time Service Two NTP servers are available: tempus1.gum.gov.pl tempus2.gum.gov.pl with an open access policy. It provides synchronization to UTC(PL). Contact: timegum@gum.gov.pl

HKO	Internet Clock Services HKO operates time-of-day clocks that display Hong Kong Standard Time (=UTC(HKO) + 8 h) Available as: 1. Web Clock (Flash): http://www.hko.gov.hk/gts/time/HKSTime.htm 2. Web Clock (HTML): http://www.hko.gov.hk/gts/time/clock_e.html 3. Palm Clock (HTML5): http://www.hko.gov.hk/m/clock.htm Speaking Clock Service HKO operates an automatic “Dial-a-weather System” that provides a voice announcement of Hong Kong Standard Time. Access phone number: +852 1878200 (when connected, press “3”, “6”, “1” in sequence) Network Time Service HKO operates network time service using Network Time Protocol (NTP). Host names of the NTP servers: stdtime.gov.hk; time.hko.hk (for IPv6 users) Further information at http://www.hko.gov.hk/nts/ntime.htm
ICE	Network Time Server A Stratum 1 time server is used to synchronize computer networks of the government institutions and companies in the private sector using the NTP protocol. To access the Network time service, send an email to ofallasc@ice.go.cr Web Clock A web clock is used to display the time of day in real time. To access the Web Clock, enter the link: https://www.grupoice.com/wps/portal/ICE/Electricidad/servicios-especiales/laboratorios Voice Time Server An assembly of computers provides the local time. To access the service, call the telephone numbers (506) 1112
IGNA	GPS common-view data GPS common-view data using CGGTTS format referred to UTC(IGNA) is available through our website at http://www.ign.gob.ar/NuestrasActividades/Geodesia/ServicioInternacionalHora/TransferenciaDeTiempo
IMBH	Internet Time Service IMBH operates several Stratum 1 time servers using the NTP protocol. These servers are directly synchronized to UTC(IMBH). The servers are available at IP address: 185.12.78.85 Common-view data GPS and GLONASS common-view data using CGGTTS format referred to UTC(IMBH) are available at request. Further information can be found at: http://met.gov.ba
INACAL	Network Time Server A time server is used to synchronize computer networks of the government institutions and companies in the private sector using the NTP protocol. To access the Network time enter the link https://www.inacal.gob.pe/metrologia/categoria/sincronizacion-de-sistemas-de-computo Web Clock A web clock is used to display the time of day in real time. To access the Web Clock, enter the link https://www.inacal.gob.pe/

INM	Network Time Protocol Operates a time server using the “Network Time Protocol”, it is located at the Instituto Nacional de Metrología de Colombia, Bogotá D.C., Colombia. Further information at: http://www.inm.gov.co/index.php/servicios-inm/hora-legal Web Clock Service A web clock is used to display the time of day in real time. The web clock is available at: http://horalegal.inm.gov.co/
INPL	Time dissemination service is performed in Israel by telecommunication companies, whose time and frequency standards are traceable to local UTC(INPL) time and are calibrated regularly once a year against the Israeli Time and Frequency National Standard kept by INPL.
INRIM (1)	CTD Telephone Time Code Time signals dissemination, according to the European Time code format, available via modem on regular dial-up connection. Access phone numbers : 0039 011 3919 263 and 0039 011 3919 264. Provides a synchronization to UTC(IT) for computer clocks without compensation for the propagation time. Internet Time Service INRIM operates two time servers using the "Network Time Protocol" (NTP); host names of the servers are ntp1.inrim.it and ntp2.inrim.it. More information on this service can be found on the web pages: http://rime.inrim.it/labtf/ntp/. SRC (Segnale RAI Codificato) coded time signal broadcast 20 – 30 times per day by “Radio Uno” and “Radio Tre” FM radio stations of the national broadcasting company RAI. The SRC code dissemination to RAI by INRIM, was definitively interrupted since 2017 January 1st. RAI could decide to continue to disseminate the SRC code to the country via Radio1 and Radio3 channels, but the traceability to UTC will not be guaranteed anymore by INRIM. It is worth highlighting that the SRC code is listed among the ITU Time Dissemination Codes (Rec. ITU-R TF.583-4). Web-based time-of-day clock that displays UTC or local time for Italy (Central Europe Time), referenced to INRIM Internet Time Service. Provides a snapshot of time with any web browser. A continuous time display requires a web browser with Java plug-in installed.
INTI	Network Time Service: INTI operates an open access NTP server referenced to UTC(INTI). Server Host Name: ntp.inti.gob.ar
JV	Network Time Protocol JV operates an open access stratum 1 server referenced to UTC(JV) ntp.justervesenet.no Other stratum 1 servers over a separate network are available by special agreement. Contact: hha@justervesenet.no

(1) Information based on the Annual Report 2017, not confirmed by the Laboratory.

KIM (1)	Network Time Protocol (NTP) Service The NTP time information referenced to UTC(KIM) is generated by Stratum-1 NTP server at URL: ntp.kim.lipi.go.id or IP: 203.160.128.178 The server also provides time services using Daytime Protocol, and Time Protocol.
KRISS	Telephone Time Service Provides digital time code to synchronize computer clocks to Korea Standard Time (=UTC(KRIS) + 9 h) via modem. Access phone number: + 82 42 868 5116 Network Time Service KRISS operates three time servers using the NTP to synchronize computer clocks to Korea Standard Time via the Internet. Host name of the server: time.kriss.re.kr (210.98.16.100). Software for the synchronization of computer clocks is available at http://www.kriss.re.kr
KZ (1)	Network Time Service Stratum-1 time server using the "Network Time Protocol" (NTP). Restricted access and free access ip 89.218.41.170 Stratum-2 time server using the "Network Time Protocol" (NTP). Free access. Stratum-2 is available: ip 88.204.171.178 Web-based Time Services: A real-time clock aligned to UTC(KZ) and corrected for internet transmission delay. “Six-pip time signals” are broadcast by FM radio stations hourly every day.
LNE-SYRTE	LNE-SYRTE operates several time servers using the “Network Time Protocol” (NTP) : Stratum-1 time server: ntp-p1.obspm.fr (restricted access) Stratum-2 time server: ntp.obspm.fr (free access) Futher information at: http://syrte.obspm.fr/informatique/ntp_infos.php
LT	Network Time Service via NTP protocol NTP v3 Host name: laikas.pfi.lt Synchronization from caesium clock (1 pps) System: Datum TymeServe 2100 NTP server Access policy: free Contact: Rimantas Miškinis Mail: Laikas@pfi.lt https://www.ftmc.lt/department-of-metrology
MASM	Network Time Service via NTP It provides synchronization to UTC(MASM) Adress: ntp.mn System: LANTIME 600 Ascess policy: free

(1) Information based on the Annual Report 2017, not confirmed by the Laboratory.

METAS	Internet Time Service METAS operates stratum-1 public NTP servers in free access. Host names: ntp.metas.ch metasntp11.admin.ch metasntp12.admin.ch metasntp13.admin.ch More information available at http://www.metas.ch/metas/en/home/fabe/zeit-und-frequenz/time-dissemination.html
MIKES	VTT MIKES provides an official stratum-1 level NTP service to paying organizations and institutions. Stratum-2 level NTP service is freely available to everyone. Both NTP services are provided over public internet. PTP and PTP White Rabbit services are provided to individual customers over dedicated links. Further information can be found at http://www.mikes.fi/ntp-palvelu/
MSL	Network Time Service Computers connected to the Internet can be synchonized to UTC(MSL) using the NTP protocol. Access is available for users within New Zealand. Servers are available at pool.msltime.measurement.govt.nz and msltime1.measurement.govt.nz Speaking Clock A speaking clock gives New Zealand time. Because it is a pay service, access is restricted to callers within New Zealand. Further information about these services can be found at http://measurement.govt.nz/about-us/official-new-zealand-time
NAO	Network Time Service Three stratum 2 NTP servers are available. The NTP servers internally refer stratum 1 NTP server that is linked to UTC(NAO). One of the three stratum 2 NTP servers are selected automatically by a round-robin DNS server to reply for an NTP access. The server host name is s2csntp.miz.nao.ac.jp.
NICT	Telephone Time Service (TTS) NICT provides digital time code accessible by computer at 300/1200/2400 bps, 8 bits, no parity. Access number to the lines: + 81 42 327 7592. Optical IP Telephone Time Service (OTTS) NICT provides digital time code accessible by computer using Network Time Protocol, on Specific Optical IP Telephone lines and available only to agreement users. Network Time Service (NTS) NICT operates four Stratum 1 NTP time servers linked to UTC(NICT) through a leased line. Internet Time Service (ITS) NICT operates four Stratum 1 NTP time servers linked to UTC(NICT) through the Internet. Host name of the servers: ntp.nict.jp (Round robin). GPS common view data NICT provides the GPS common view data based on UTC(NICT) to the time business service in Japan.

NIM	Telephone Time Service The coded time information generated by NIM time code generator, referenced to UTC(NIM). Telephone Code provides digital time code at 1200 to 9600 bauds, 8 bits, no parity, 1 stop bit. Access phone number: 8610 6422 9086. Network Time Service Provides digital time code across the Internet using NTP server via free IP access: ntp1.nim.ac.cn ntp2.nim.ac.cn Further information at: http://en.nim.ac.cn/page/976
NIMB	1 NTP server is available: Address: ntp.inm.ro (STRATUM 1) with an open access policy Server is referenced to UTC(NIMB).
NIMT	Internet Time Services NIMT operates 3 NTP servers at: time1.nimt.or.th time2.nimt.or.th time3.nimt.or.th The NTP servers are referenced to UTC(NIMT). FM/RDS Radio Transmission The time code is applied to the sub-carrier frequency of 57 kHz using the Radio Data System protocol. The accuracy of time transmission is around 30 ms of UTC(NIMT) depending on the internet traffic. The time code is broadcast via 40 radio stations across the country.
NIST	Automated Computer Time Service (ACTS) Provides digital time code by telephone modem for setting time in computers. Free software and source code available for download from NIST. Includes provision for calibration of telephone time delay. Access phone numbers : +1 303 494 4774 (4 phone lines) and +1 808 335 4721 (2 phone lines). Further information at https://www.nist.gov/pml/time-and-frequency-division/services/automated-computer-time-service-acts Internet Time Service (ITS) Provides digital time code across the Internet using three different protocols: Network Time Protocol (NTP), Daytime Protocol, and Time Protocol. (Time Protocol is not supported by all servers) Geographically distributed set of multiple time servers at multiple locations within the United States of America. For most current listing of time servers and locations, see: http://tf.nist.gov/tf-cgi/servers.cgi Free software and source code available for download from NIST. Further information at https://www.nist.gov/pml/time-and-frequency-division/services/internet-time-service-its Telephone voice announcement: Audio portions of radio broadcasts from time and frequency stations WWV and WWVH can be heard by telephone: +1 303 499 7111 for WWV and +1 808 335 4363 for WWVH. For more information see: https://www.nist.gov/pml/time-and-frequency-division/radio-stations/wwv/telephone-time-day-service
NMIJ	GPS common-view data GPS common-view data using CGGTTS format referred to UTC(NMIJ) are available through the NMIJ's web site for the remote frequency calibration service.
NMISA	Network Time Service One open access NTP server is available at address time.nmisa.org. More information is available at http://time.nmisa.org/

NMLS (1)	Web-based time-of-day clock A web clock is used to display the local time for Malaysia. The service is available at http://mst.sirim.my. Network Time Service The NTP time information is referenced to UTC(NMLS) and is currently generated by Stratum-1 NTP servers, made available to the public freely. The NTP server host names are ntp1.sirim.my and ntp2.sirim.my.
NPL	Telephone Time Service A TUG time code generator provides the European Telephone Time Code, referenced to UTC(NPL), by telephone modem. Software for synchronising computers is available from the NPL web site at www.npl.co.uk/time. The service telephone number is 020 8943 6333. Internet Time Service Two servers referenced to UTC(NPL) provide Network Time Protocol (NTP) time code across the internet. More information is available from the NPL web site at www.npl.co.uk/time. The server host names are: ntp1.npl.co.uk ntp2.npl.co.uk
NPLI	Web Clock Web-based time-of-day clock that displays Indian Standard Time (IST) and UTC(NPLI). It also displays local time in user's time zone, time-of-day of the user's device clock and its difference. Available at the web page: http://www.nplindia.in/clockcode/html/index.php Internet Time Service Two servers referenced to UTC(NPLI) provide Network Time Protocol (NTP) time code across the internet. The server host names are: time1.nplindia.org time2.nplindia.org
NRC	Telephone Code Provides digital time code by telephone modem for setting time in computers. Access phone number: +1 613 745 3900. http://www.nrc-cnrc.gc.ca/eng/services/time/time_date.html Talking Clock Service Voice announcements of Eastern Time are at ten-second intervals followed by a tone to indicate the exact time. The service is available to the public in English at +1 613 745 1576 and in French at +1 613 745 9426. For more information see: http://www.nrc-cnrc.gc.ca/eng/services/time/talking_clock.html Web Clock Service The Web Clock shows dynamic clocks in each Canadian Time zone, for both Standard time and daylight saving time. The web page is at: http://www.nrc-cnrc.gc.ca/eng/services/time/web_clock.html. Short Wave Radio CHU radio station broadcasts the time of day with voice announcements in English and French and time code at three different frequencies: 3.330 MHz, 7.850 MHz and 14.670 MHz. Further information at: http://www.nrc-cnrc.gc.ca/eng/services/time/short_wave.html

(1) Information based on the Annual Report 2017, not confirmed by the Laboratory.

Network Time Protocol
Operates multiple time servers using the " Network Time Protocol " at different locations and on two networks. Host names:
time.nrc.ca and time.chu.nrc.ca. Further information at:
http://www.nrc-cnrc.gc.ca/eng/services/time/network_time.html

The official website for the Frequency and Time group is:
http://www.nrc-cnrc.gc.ca/eng/services/time/index.html

The contact email is: MSS-SMETime@nrc-cnrc.gc.ca

NSC IM

Network Time Service.
National Science Center Institute of Metrology (Kharkiv, Ukraine) operates time server Stratum 1 using the “Network Time Protocol” (NTP).
Stratum-1 time server using the "Network Time Protocol" (NTP).
Free access.
ip **81.17.128.133**
ip **81.17.128.182**
The server host name is: http://www.metrology.kharkov.ua/

NTSC

Network Time Service (NTS)
NTSC operates a time server directly referenced to UTC(NTSC). Software for the synchronization of computer clocks is available on the NTSC Time and Frequency web page: http://www.ntsc.ac.cn/
Access Policy: free
Contact: Shaowu DONG (sdong@ntsc.ac.cn).

ONBA

Speaking clock access phone number 113 (only accessible in Argentina).
Hourly and half hourly radio-broadcast time signal.
Internet time service at web site http://www.hidro.gov.ar/observatorio/lahora.asp

ONRJ

Telephone Voice Announcer (55) 21 25806037.
Telephone Code (55) 21 25800677 provides digital time code at
300 bauds, 8 bits, no parity, 1 stop bit (Leitch CSD5300)

Internet Time Service at the address : 200.20.186.75 and 200.20.186.94
SNTP at port 123
Time/UDP at port 37
Time/TCP at port 37
Daytime/TCP at port 13

WEB-based Time Services:
1) A real-time clock aligned to UTC(ONRJ) and corrected for internet transmission delay.
Further information at: http://200.20.186.71/asp/relogio/horainicial.asp
2) Voice Announcer, in Portuguese, each ten seconds, after download of the Web page at: http://200.20.186.71.

Broadcast Brazilian legal time (UTC – 3 hours) announced by a voice starting with “Observatório Nacional” followed by the current time (hh:mm:ss) each ten seconds with a beep for each second with a 1KHz modulation during 5ms and a long beep with 1KHz modulation during 200ms at the 58 , 59 and 00 seconds. The signal is transmitted every day of the year by the radio station PPE, whose signal is at 10 MHz with kind of modulation A3H and HF transmission power of 1 kW.

ORB

Network Time Service via NTP protocol
Hostname : ntp1.oma.be and ntp2.oma.be
Access policy : free
Synchronization to UTC(ORB)
Contact : ntp-as@oma.be
Information on the web pages
http://www.betime.be/

ORB provides a time dissemination via phone and modem to synchronize PC clocks on UTC(ORB). The system used is the Time Distribution System from TUG, which produces the telephone time code mostly used in Europe.
The baud rate used is 1200. The access phone number is 32 (0) 2 373 03 20. The system is updated periodically with DUT1 and leap seconds

PTB

Telephone Time Service
The coded time information is referenced to UTC(PTB) and generated by a TUG type time code generator using an ASCII-character code.
The time protocols are sent in a common format, the "European Telephone Time Code". Access phone number: +49 531 51 20 38.

Internet Time Service
The PTB operates three time servers using the " Network Time Protocol " (NTP), see http://www.ptb.de/cms/en/ptb/fachabteilungen/abtq/fb-q4/ag-q42.html for details and explanations.

The hostnames of the servers:
ptbtime1.ptb.de
ptbtime2.ptb.de
ptbtime3.ptb.de
PTB also provides a secured NTP time service. This service applies NTP's pre-shared key approach. It arose from PTB's particular duty to provide a secured NTP service for the smart grid initiative of the German Federal Ministry of Economic Affairs and Energy. The service is restricted to authenticated access only.

The hostnames of the servers
ntpsmgw1.ptb.de
ntpsmgw2.ptb.de

RISE

The coded time information is referenced to UTC(SP) and generated by two TUG type time code generators using an ASCII-character code.
The time protocols are sent in a common format, the "European Telephone Time Code".
Access phone number: +46 33 41 57 83

The coded time information is referenced to UTC(SP) and generated by several NTP servers using the Network Time Protocol (NTP) for both IPv4 and IPv6.
Access host names: ntp1.sptime.se, ntp2.sptime.se, ntp3.sptime.se and ntp4.sptime.se

Speaking Clock
The speaking clock service is operated by Telia AB in Sweden.
The time announcement is referenced to UTC(SP) and disseminated from a computer-based system operated and maintained at SP.
Access phone number : 90510 (only accessible in Sweden).
Access phone number : +4633 90510 (from outside Sweden).

More information about these services are found on the web site www.sp.se

ROA

Telephone Code
The coded time information is referenced to UTC(ROA) and generated by a TUG type time code generator using an ASCII-character code. The time protocols are sent in a common format, the "European Telephone Time Code". Access phone number : +34 956 599 429

	Network Time Protocol More information is available from the ROA web site at www.roa.es Host names of the servers: hora.roa.es minuto.roa.es
SG	Network Time Service (NeTS) Transmit digital time code via the Internet using three protocols - Time Protocol, Daytime Protocol and Network Time Protocol. Operate one time server at domain name: nets.org.sg Automated Computer Time Service (ACTS) Transmit digital time code (NIST format) via telephone modem for setting time in computers. The coded time information is referenced to UTC(SG). Include provision for correcting telephone time delay. Access phone number: +65 67799978.
SIQ (1)	Internet Time Service (Network Time Protocol) One server referenced to UTC(SIQ) provides Network Time Protocol (NTP) time code across the internet. There is free access to the server for all users. The server host names are:ntp.siq.si or time.siq.si (two URL's for the same server; IP: 194.249.234.70)
SL	Network Time Service Computers connected to the Internet can be synchronized to UTC(SL) Using the NTP protocol using NTP Time Server at http://www.sltime.org. For more information please visit http://www.sltime.org and http://www.measurementsdept.gov.lk or contact through email; adelec@measurementsdept.gov.lk.
TL	Speaking Clock Service Traceable to UTC(TL). Broadcast through PSTN (Public Switching Telephone Network) automatically and provides an accurate voice time signal to public users. Local access phone number: 117. The Computer Time Service Provides ASCII time code by telephone modem for setting time in computers. Access phone number: +886 3 4245117. NTP Service TL operates the network time service using the "Network Time Protocol" (NTP). Host name of the server: time.stdtime.gov.tw, further information in http://www.stdtime.gov.tw/english/e-home.aspx
TP	Internet Time Service UFE operates time servers directly referenced to UTC(TP). Time information is accessible through Network Time Protocol (NTP). Server host name: ntp2.ufe.cz More information at http://www.ufe.cz/
UME	Network Time Service UME operates an NTP server referenced to UTC(UME). Server Host Name: time.ume.tubitak.gov.tr

(1) Information based on the Annual Report 2017, not confirmed by the Laboratory.

USNO	Telephone Voice Announcer +1 202 762-1401 Backup voice announcer: +1 719 567-6742 GPS via subframe 4 page 18 of the GPS broadcast navigation message Web site for time and for data files: https://www.usno.navy.mil/USNO/time Network Time Protocol (NTP) see https://www.usno.navy.mil/USNO/time/ntp for software and site closest to you.
VMI	Network Time Service VMI operates one time server Stratum 1 using the Network Time Protocol (NTP). For information on access to the website, please contact phuongtv@vmi.gov.vn. The server host name is: http://standardtime.vmi.gov.vn/ or IP: 113.160.59.166 port 123
VNIIFTRI	Internet Time Service VNIIFTRI operates eight time servers Stratum 1 and one time server Stratum 2 using the “Network Time Protocol” (NTP). The server host names are: ntp1.vniiftri.ru (Stratum 1) ntp2.vniiftri.ru (Stratum 1) ntp3.vniiftri.ru (Stratum 1) ntp4.vniiftri.ru (Stratum 1) ntp1. niiftri.irkutsk.ru (Stratum 1) ntp2. niiftri.irkutsk.ru (Stratum 1) vniiftri.khv.ru (Stratum 1) vniiftri2.khv.ru (Stratum 1) ntp21.vniiftri.ru (Stratum 2).
VSL	Internet Time Service VSL operates a time server directly referenced to UTC(VSL). Time information is accessible through Network Time Protocol (NTP). The URL for the NTP server is: ntp.vsl.nl