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Contents

Page

Practical information about the BIPM Time Department 4
Access to electronic files on the FTP server and the data base of the BIPM Time Department 5
Leap second 8
Establishment of International Atomic Time and of Coordinated Universal Time 9
Geographical distribution of the laboratories that contribute to TAI and time transfer equipment 13
Relative frequency offsets and step adjustments of UTC - Table 1 14
Relationship between TAI and UTC - Table 2 15
Acronyms and locations of the timing centres which maintain a UTC(*k*) and/or a TA(*k*) - Table 3 15
Equipment and source of UTC(*k*) of the laboratories contributing to TAI in 2019 - Table 4 16
Differences between the normalized frequencies of EAL and TAI - Table 5 26
Measurements of the duration of the TAI scale interval - Table 6 27
Annexes to Table 6 31
Mean fractional deviation of the TAI scale interval from that of TT - Table 7 43
Independent local atomic time scales and local representations of UTC 44
Relations of UTC and TAI with GPS time, GLONASS time, UTC(USNO)_GPS and UTC(SU)_GLONASS 45
Clocks contributing to TAI in 2019
- Clocks characteristics 47
- Statistical data on the clock weights in 2019- Table 8 48

Time Signals 49
Time Dissemination Services 57

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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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.

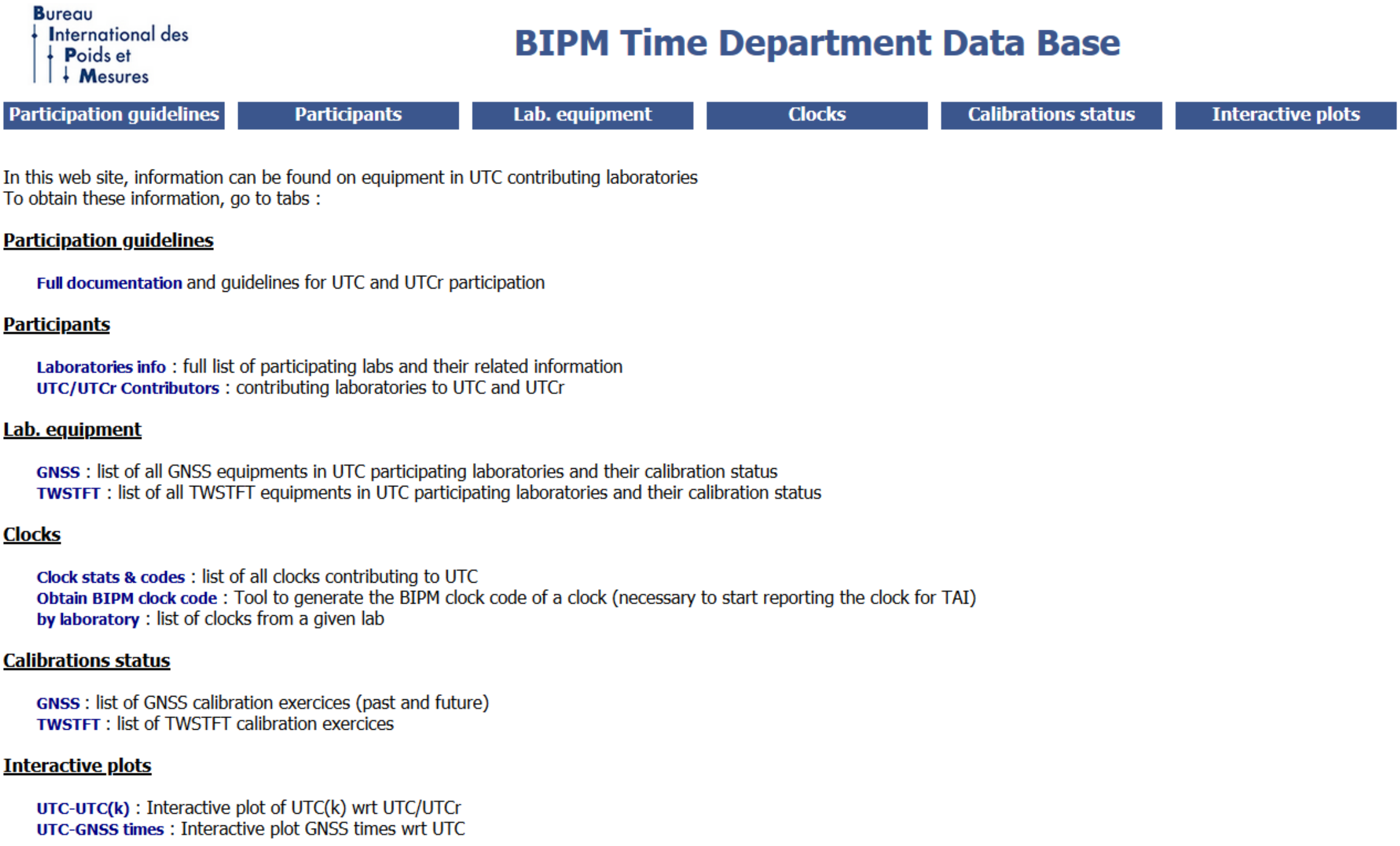
The files and information related to BIPM Time Activities are available from the website: https://www.bipm.org/en/bipm/tai/ .

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.



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

Lab. equipment

GNSS : list of all GNSS equipments in UTC participating laboratories and their calibration status
TWSTFT : list of all TWSTFT equipments in UTC participating laboratories and their calibration status

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

Calibrations status

GNSS : list of GNSS calibration exercices (past and future)
TWSTFT : list of TWSTFT calibration exercices

Interactive plots

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

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).

TT(BIPM) – 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)	PSFS-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	sitaiYYYY.pdf (starting 2000)
duration of TAI scale interval	

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 450 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 August 2020.

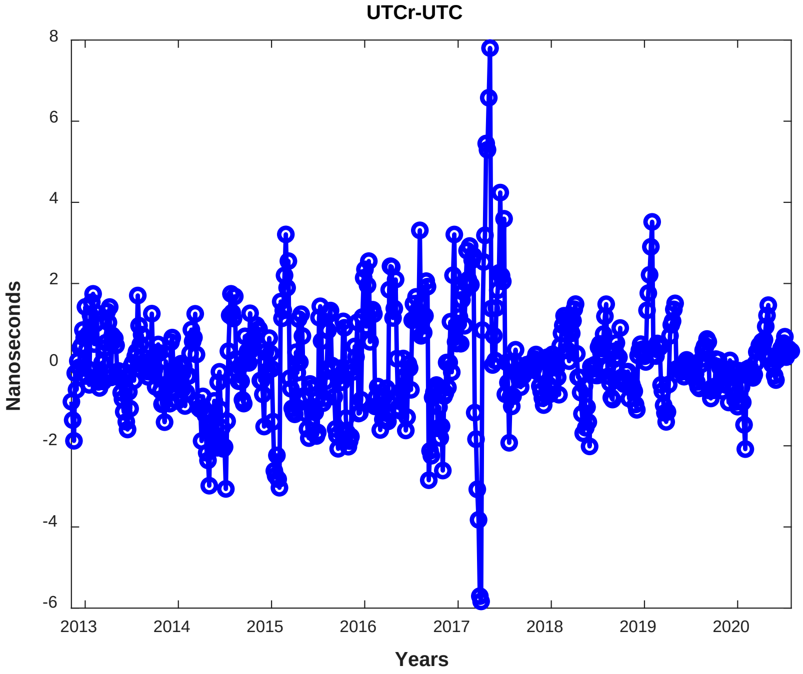


Figure 1. Difference between UTC and UTCr until May 2020.

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. They can also be used in a combination of GPS and GLONASS links [9].

Finally, a combination of individual TWSTFT and GPS PPP links [10] are currently used in the calculation of TAI. 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.

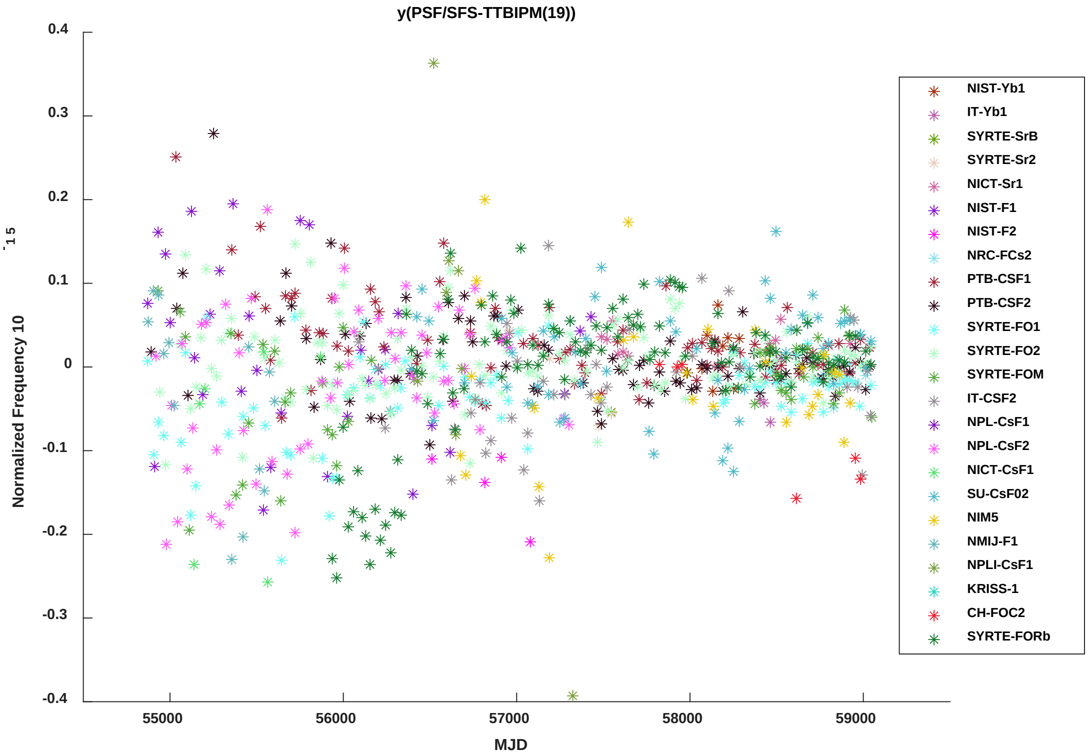


Figure 2. Difference between the frequency of PFS/SFS and TT(BIPM19).

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_v0.3.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 .

References

[1] Panfilo G., Harmegnies A., Tisserand L., A new prediction algorithm for the generation of International Atomic Time, *Metrologia*, 2012, **49**(1), 49-56.

[2] Panfilo G., Harmegnies A., Tisserand L., A new weighting procedure for UTC, *Metrologia*, 2014, **51**(3), 285-292.

[3] Lewandowski W., Matsakis D., Panfilo G., Tavella P., The evaluation of uncertainties in [UTC – UTC(*k*)], *Metrologia*, 2006, **43**(3), 278-286.

[4] Petit G., Arias F., Harmegnies A., Panfilo G., Tisserand L., UTCr: a rapid realization of UTC, *Metrologia*, 2014, **51**, 33-39.

[5] Petit G., Jiang Z., GPS All in View time transfer for TAI computation, *Metrologia*, 2008, **45**(1), 35-45.

[6] Petit G., Jiang Z., Precise point positioning for TAI computation, IJNO, Article ID 562878, http://dx.doi.org/10.1155/2008/562878, 2008.

[7] Lewandowski W., Jiang Z., Use of GLONASS at the BIPM, *Proc. 41st PTTI Systems and Applications Meeting*, 2010, 5-14.

[8] Allan D.W., Weiss A.M., Accurate time and frequency transfer during common-view of a GPS satellite**,** *Proc. 34th Ann. Symp. Frequency Control (1980)*, 1980, 334-346.

[9] Jiang Z., Lewandowski W., Use of GLONASS for UTC time transfer, *Metrologia*, 2012, **49**(1), 57-61.

[10] Jiang Z., Petit G., Combination of TWSTFT and GNSS for accurate UTC time transfer, *Metrologia*, 2009, **46**(3), 305-314.

[11] Jiang Z., Zhang V., Huang Y.-I., Achkar J., Piester D., Lin S.-Y., Naumov A., Yang S.-h., Nawrocki J., Sesia I., Schlunegger C., Yang Z., Fujieda M., Czubla A., Esteban H., Rieck C., Whibberley P., Use of software-defined radio receivers in two-way satellite time and frequency transfers for UTC computation, Metrologia, 2018, 55(5), 685-698.

[12] Liang K., Arias F., Petit G., Jiang Z., Tisserand L., Wang Y., Yang Z., Zhang A., Evolution of BeiDou time transfer over multiple inter-continental baselines towards UTC contribution, Metrologia, 2018, 55(4), 513-525.

[13] Test of Galileo and BeiDou Links for UTC Petit, Gérard (BIPM), Harmegnies, Aurélie (BIPM), in Proc IEEE IFCS and EFTS, Orlando, USA, April 2019.

[14] Latest Developments on IPPP Time and Frequency Transfer Leute, Julia (LNE-SYRTE, Observatoire de Paris, Université PSL, CNRS, Sorbonne Universités, BIPM), Petit, Gérard (BIPM), in Proc IEEE IFCS and EFTF, Orlando, USA, April 2019.

[15] Guinot B., Atomic time scales for pulsar studies and other demanding applications, *Astron. Astrophys.*, 1988, **192**, 370-373.

[16] Petit G., A new realization of Terrestrial Time, *Proc. 35th PTTI*, 2003, 307-317.

[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 (2019)

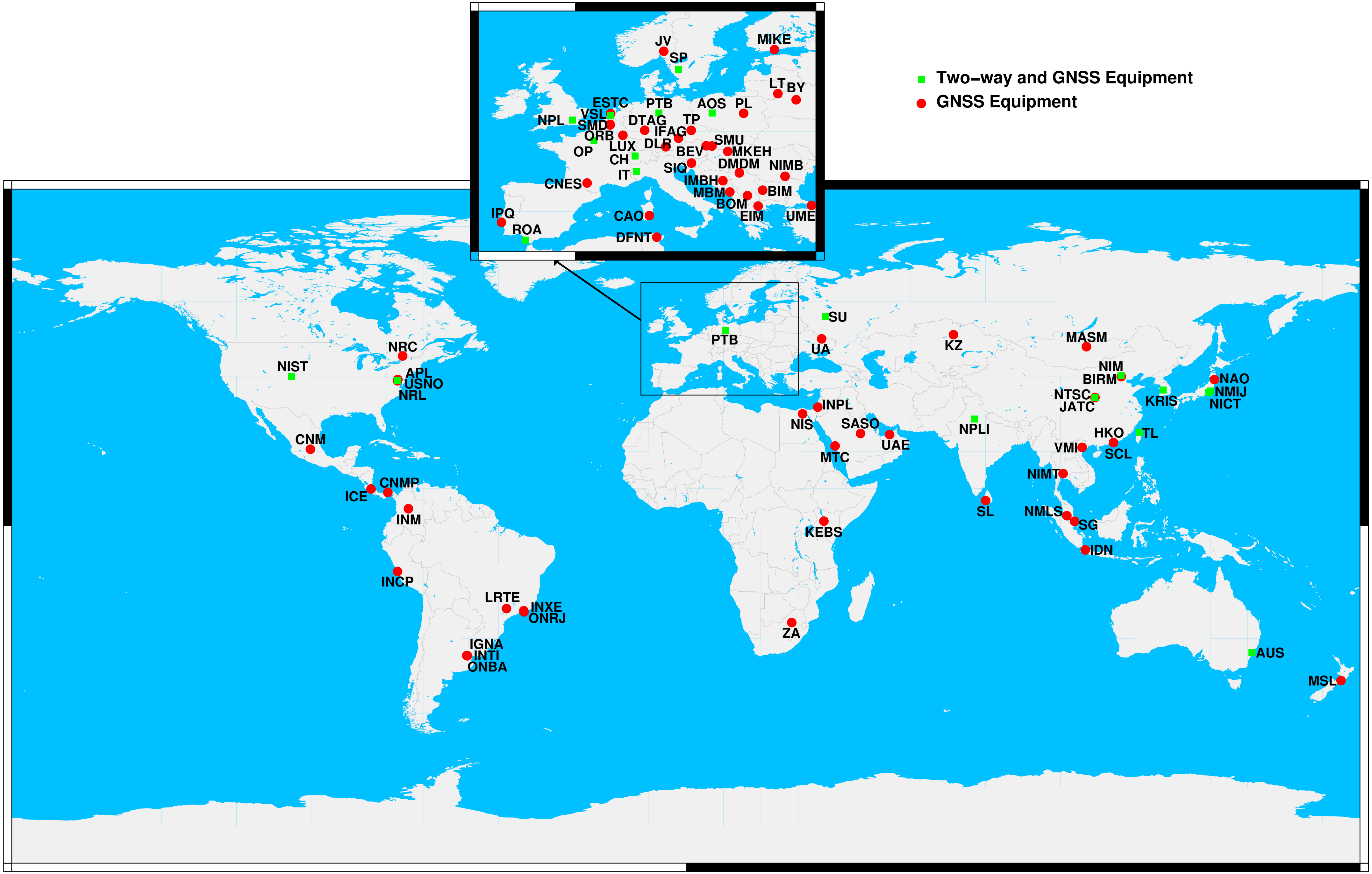


Table 1. Relative frequency offsets and step adjustments of UTC, up to 31 December 2020

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 2020

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 2019

Equipment abbreviation used in this table

Atomic clocks (details can be found here)

Ind. Cs:	industrial caesium standard
Ind. Rb:	industrial rubidium standard
Lab. Cs:	laboratory caesium standard
Lab. Rb:	laboratory rubidium standard
Lab. Sr:	laboratory strontium standard
Lab. Yb:	laboratory ytterbium 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 (a)	3 Ind. Cs 2 H-masers (15)	1 H-maser (2) + microphase-stepper	* (15)	*	*	*
APL	4 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 6 H-masers	1 H-maser + microphase-stepper		*	*	
BOM	2 Ind. Cs	1 Cs		*	*	
BY	7 H-masers	3-6 H-masers + microphase-stepper			*	
CAO	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 2019 (Cont.)

Lab *k*	Atomic clock	Source of UTC(*k*) (1)	TA(*k*)	UTCr	Time transfer technique	
					GNSS	TWSTFT
CNES	5 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	2 Ind. Cs	1 Cs			*	
DLR (a)	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		*	*	
IDN	3 Ind. Cs	1 Cs			*	
IFAG	5 Ind. Cs 2 H-masers	1 Cs + microphase-stepper		*	*	

Table 4. Equipment and source of UTC(*k*) of the laboratories contributing to TAI in 2019 (Cont.)

Lab *k*	Atomic clock	Source of UTC(*k*) (1)	TA(*k*)	UTCr	Time transfer technique	
					GNSS	TWSTFT
IGNA (a)	1 Ind. Cs	1 Cs + time/frequency steering		*	*	
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	3 Ind. Cs	1 Cs		*	*	
INXE	1 Ind. Cs 1 Ind. Rb 1 Lab. Cs	1 Cs + microphase-stepper		*	*	
IPQ	2 Ind. Cs	1 Cs + microphase-stepper		*	*	
IT	6 Ind. Cs 4 H-masers 2 Lab. Cs 1 Lab. Yb	1 H-maser + microphase-stepper + time scale switch		*	*	*
JATC	8 Ind. Cs 3 H-masers	1 H-maser + microphase-stepper	*		*	
JV (a)	3 Ind. Cs 1 H-maser	1 H-maser + microphase-stepper		*	*	
KEBS	3 Ind. Cs	1 Cs + reference generator			*	
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 2019 (Cont.)

Lab *k*	Atomic clock	Source of UTC(*k*) (1)	TA(*k*)	UTCr	Time transfer technique	
					GNSS	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		*	*	
LUX	2 Ind. Cs	1 Cs + microphase-stepper			*	
MASM	1 Ind. Cs	1 Cs + time/frequency steering		*	*	
MBM	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	37 Ind. Cs 8 H-masers (6) 1 Lab. Cs 1 Lab. Sr (7)	1 H-maser (8) + microphase-stepper	* (9)	*	*	*
NIM	7 Ind. Cs 13 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 2019 (Cont.)

Lab *k*	Atomic clock	Source of UTC(*k*) (1)	TA(*k*)	UTCr	Time transfer technique	
					GNSS	TWSTFT
NIMB (a)	2 Ind. Cs	1 Cs		*	*	
NIMT	4 Ind. Cs 1 H-maser	1 Cs + microphase-stepper		*	*	
NIS	3 Ind. Cs	1 Cs + microphase-stepper		*	*	
NIST	1 Lab. Cs 1 Lab. Yb 13 Ind. Cs 13 H-masers	4 Cs 7 H-masers + microphase-stepper	*	*	*	*
NMIJ	1 Ind. Cs 1 Lab. Cs 4 H-masers	1 H-maser + microphase-stepper		*	*	*
NMLS	2 Ind. Cs	1 Cs		*	*	
NPL	2 Ind. Cs 5 H-masers	1 H-maser		*	*	*
NPLI	5 Ind. Cs 5 H-maser	1 H-maser + microphase-stepper		*	*	*
NRC	6 Ind. Cs (10) 2 H-masers	1 Cs + microphase-stepper	*	*	*	
NRL	1 Ind. Cs 8 H-masers	1 H-maser + steered by AOG to UTC(NRL)		*	*	
NTSC	24 Ind. Cs 8 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 2019 (Cont.)

Lab *k*	Atomic clock	Source of UTC(*k*) (1)	TA(*k*)	UTCr	Time transfer technique	
					GNSS	TWSTFT
OP	3 Ind. Cs 3 Lab. Cs 1 Lab. Rb 2 Lab. Sr 4 H-masers	1 H-maser (12) + microphase-stepper	* (13)	*	*	*
ORB	3 Ind. Cs 2 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) 5 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	1 Cs + microphase-stepper		*	*	
SG	5 Ind. Cs 1 H-maser	1 H-maser + microphase-stepper		*	*	
SIQ	1 Ind. Cs	1 Cs			*	
SL	1 Ind. Cs	1 Cs		*	*	
SMD	4 Ind. Cs 1 H-maser	1 H-maser + microphase-stepper		*	*	
SMU (a)	1 Ind. Cs	1 Cs + output frequency steering			*	
SP	18 Ind. Cs (22) 10 H-masers	1 H-maser + microphase-stepper		*	*	*

Table 4. Equipment and source of UTC(*k*) of the laboratories contributing to TAI in 2019 (Cont.)

Lab *k*	Atomic clock	Source of UTC(*k*) (1)	TA(*k*)	UTCr	Time transfer technique	
					GNSS	TWSTFT
SU	1 Lab. Cs (23) 4 Lab. Rb (24) 14-15 H-masers	10-14 H-masers (25)	* (26)	*	*	* (27)
TL	6 Ind. Cs 4 H-masers	1 H-maser (28) + microphase-stepper	* (28)	*	*	*
TP	5 Ind. Cs 1 H-maser	1 Cs + output frequency steering		*	*	
UA	1 Ind. Cs + (2 Ind. CS (29)) 4 H-masers 2 Lab. Rb (29)	1 Cs 3 H-masers + microphase-stepper	*		*	
UAE	3 Ind. Cs	3 Cs (30)			*	
UME	5 Ind. Cs	1 Cs		*	*	
USNO	62 Ind. Cs 35 H-masers 6 Lab. Rb	1 H-maser (31) + frequency synthesizer steered to create UTC(USNO)	* (31)	*	*	*
VMI	3 Ind. Cs	1 Cs + microphase-stepper		*	*	
VSL	4 Ind. Cs	1 Cs + microphase-stepper		*	*	*
ZA	5 Ind. Cs 3 H-maser	1 H-maser			*	

Notes

(a) Information based on the Annual Report for 2018, 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	20 Cs, 6 H-masers
* Ohtakadoya-yama LF station	6 Cs
* Hagane-yama LF station	6 Cs
* Advanced ICT Research Institute in Kobe	6 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 22 industrial caesium clocks in 2019 located as follows :

* Direction Générale de l'Armement (DGA, Rennes)	2 Cs
* Centre National d'Etudes Spatiales (CNES, Toulouse)	6 Cs
* Orange Labs réseaux (Lannion)	1 Cs
* Observatoire de la Côte d'Azur (OCA, Grasse)	1 Cs
* Observatoire de Paris (LNE-SYRTE, Paris)	3 Cs
* Observatoire de Besançon (OB, Besançon)	3 Cs
* Marine Nationale (Brest)	5 Cs
* Spectracom, Orolia (Les Ulis)	1 Cs

All laboratories are linked via GPS receivers. The TA(F) frequency is steered using the LNE-SYRTE PSFS 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.

(15) PL The Polish atomic timescale TA(PL) is computed by the AOS and GUM with data from 12 caesium clocks and 4 hydrogen masers located as follows:

* Central Office of Measures (GUM, Warsaw)	2 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 optical fiber link, with stabilized propagation delay, 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. PTB operates four active masers and one passive 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) SP The standards are located as follows:

* RISE Research Institutes of Sweden (RISE, Borås)	3 Cs, 4 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

(23) SU CsFO1 and CsFO2 are fountain frequency standards using laser cooled caesium atoms. CsFO2 operated as frequency standard almost regularly and contributed to TAI.

(24) 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.

(25) SU Laboratory computes UTC(SU) as a software clock, steered to UTC.

(26) 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.

(27) SU TW time link was stopped at June 2017.

(28) 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).

(29) UA 2 Ind. Cs, 2 Lab. Rb were tested and left in reserve for use when necessary.

(30) 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.

(31) 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/other-products/utai/utai2019.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) METAS-FOC2, NIM5, PTB-CS1, PTB-CS2, PTB-CSF1, PTB-CSF2, SU-CsFO2, SYRTE-FO1, SYRTE-FO2 and SYRTE-FOM reported on the year 2019.
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) IT-Yb1, NICT-Sr1, NIST-Yb1 and SYRTE-FORb reported on the year 2019.
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 13 (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 (including the relativistic frequency shift),
$u_{\mathrm{link/lab}}$ 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 2019 are indicated below. Reports of individual evaluations may be found at ftp://ftp2.bipm.org/pub/tai/data/PSFS_reports. Ref(u_{B}) is a reference giving information on the value of u_{B} as stated in the 2019 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.
METAS-FOC2	Fountain	1.38	1.99	[1]	H maser	1 / 30 d
NIM5	Fountain	0.9	1.4	[2]	H maser	6 / 15 d to 25 d
PTB-CS1	Beam /Mag.	8	8.	[3]	TAI	12 / 25 d to 35 d
PTB-CS2	Beam /Mag.	12	12.	[4]	TAI	11 / 25 d to 35 d
PTB-CSF1	Fountain	0.26 to 0.32	0.28	[5]	H maser	9 / 10 d to 35 d
PTB-CSF2	Fountain	0.17 to 0.18	0.17	[5]	H maser	14 / 10 d to 30 d
SU-CsFO2	Fountain	0.22 to 0.24	0.50	[6]	H maser	10 / 30 d to 35 d
SYRTE-FO1	Fountain	0.31 to 0.32	0.37	[7]	H maser	12 / 25 d to 35 d
SYRTE-FO2	Fountain	0.21 to 0.24	0.23	[7]	H maser	12 / 15 d to 35 d
SYRTE-FOM	Fountain	0.61 to 0.66	0.7	[7]	H maser	12 / 15 d to 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.
IT-Yb1	Lattice	0.03	0.028	[8]	H maser	5 / 10 d to 30 d
NICT-Sr1	Lattice	0.07 to 0.08	0.06	[9]	H maser	3 / 20 d to 35 d
NIST-Yb1	Lattice	0.03	0.006	[10]	H maser	8 / 25 d to 35 d
SYRTE-FORb	Fountain	0.24 to 0.26	0.34	[11]	H maser	12 / 25 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
METAS-FOC2	58599 58629	-1.07	1.00	1.38	0.04	0.27	1.73	
NIM5	58544 58569	-0.14	0.20	0.90	0.20	0.31	0.99	
NIM5	58634 58659	0.55	0.20	0.90	0.20	0.23	0.97	
NIM5	58679 58694	-0.25	0.30	0.90	0.20	0.37	1.04	
NIM5	58694 58719	-0.21	0.20	0.90	0.20	0.23	0.97	
NIM5	58729 58749	-0.41	0.20	0.90	0.20	0.28	0.98	
NIM5	58764 58784	-0.14	0.20	0.90	0.20	0.28	0.98	
PTB-CS1	58479 58514	-14.78	8.00	8.00	0.00	0.11	11.31	(1)
PTB-CS1	58514 58539	-10.35	8.00	8.00	0.00	0.15	11.31	
PTB-CS1	58539 58569	-22.91	8.00	8.00	0.00	0.13	11.31	
PTB-CS1	58569 58599	-9.30	8.00	8.00	0.00	0.13	11.31	
PTB-CS1	58599 58634	-10.52	8.00	8.00	0.00	0.09	11.31	
PTB-CS1	58634 58664	-4.67	8.00	8.00	0.00	0.07	11.31	
PTB-CS1	58664 58694	-4.80	8.00	8.00	0.00	0.07	11.31	
PTB-CS1	58694 58724	3.61	8.00	8.00	0.00	0.07	11.31	
PTB-CS1	58724 58754	-3.26	8.00	8.00	0.00	0.07	11.31	
PTB-CS1	58754 58784	2.33	8.00	8.00	0.00	0.07	11.31	
PTB-CS1	58784 58814	4.07	8.00	8.00	0.00	0.07	11.31	
PTB-CS1	58814 58844	-7.50	8.00	8.00	0.00	0.07	11.31	
PTB-CS2	58479 58514	-2.97	5.00	12.00	0.00	0.11	13.00	(1)
PTB-CS2	58514 58539	5.90	5.00	12.00	0.00	0.15	13.00	
PTB-CS2	58539 58569	-10.68	5.00	12.00	0.00	0.13	13.00	
PTB-CS2	58569 58599	-0.23	5.00	12.00	0.00	0.13	13.00	
PTB-CS2	58634 58664	0.42	5.00	12.00	0.00	0.07	13.00	
PTB-CS2	58664 58694	-7.38	5.00	12.00	0.00	0.07	13.00	
PTB-CS2	58694 58724	-2.79	5.00	12.00	0.00	0.07	13.00	
PTB-CS2	58724 58754	4.92	5.00	12.00	0.00	0.07	13.00	
PTB-CS2	58754 58784	8.04	5.00	12.00	0.00	0.07	13.00	
PTB-CS2	58784 58814	-3.45	5.00	12.00	0.00	0.07	13.00	
PTB-CS2	58814 58844	-12.52	5.00	12.00	0.00	0.07	13.00	
PTB-CSF1	58469 58479	0.57	0.11	0.27	0.03	0.35	0.46	
PTB-CSF1	58479 58514	0.52	0.06	0.27	0.02	0.11	0.30	
PTB-CSF1	58514 58539	0.66	0.08	0.30	0.05	0.15	0.35	
PTB-CSF1	58554 58569	1.23	0.08	0.28	0.02	0.24	0.38	
PTB-CSF1	58624 58634	0.45	0.11	0.32	0.03	0.18	0.38	
PTB-CSF1	58694 58724	0.43	0.06	0.31	0.02	0.07	0.32	
PTB-CSF1	58724 58754	-0.05	0.06	0.31	0.04	0.07	0.32	
PTB-CSF1	58754 58784	-0.20	0.06	0.28	0.03	0.07	0.30	
PTB-CSF1	58784 58814	-0.13	0.07	0.26	0.02	0.07	0.28	
PTB-CSF2	58469 58479	0.57	0.16	0.17	0.03	0.35	0.42	
PTB-CSF2	58479 58514	0.42	0.09	0.17	0.06	0.11	0.23	
PTB-CSF2	58514 58539	0.49	0.17	0.18	0.06	0.15	0.30	
PTB-CSF2	58539 58569	0.44	0.09	0.17	0.05	0.13	0.24	
PTB-CSF2	58569 58599	0.44	0.09	0.17	0.05	0.13	0.24	
PTB-CSF2	58599 58624	0.62	0.10	0.17	0.06	0.12	0.24	
PTB-CSF2	58624 58634	0.51	0.22	0.17	0.06	0.18	0.33	
PTB-CSF2	58634 58664	0.59	0.11	0.17	0.06	0.07	0.22	
PTB-CSF2	58664 58684	0.45	0.12	0.17	0.03	0.09	0.23	
PTB-CSF2	58694 58724	0.31	0.10	0.17	0.03	0.07	0.21	
PTB-CSF2	58724 58754	-0.22	0.09	0.17	0.04	0.07	0.21	
PTB-CSF2	58754 58784	-0.37	0.10	0.17	0.03	0.07	0.21	
PTB-CSF2	58784 58814	-0.42	0.11	0.17	0.02	0.07	0.21	
PTB-CSF2	58814 58834	-0.61	0.13	0.17	0.02	0.09	0.23	
SU-CsFO2	58479 58514	2.20	0.24	0.24	0.13	0.74	0.82	
SU-CsFO2	58539 58569	0.69	0.25	0.24	0.12	0.85	0.92	
SU-CsFO2	58569 58599	1.07	0.22	0.24	0.11	0.85	0.92	
SU-CsFO2	58634 58664	1.17	0.37	0.22	0.13	0.46	0.64	

SU-CsFO2	58664	58694	0.86	0.21	0.22	0.12	0.46	0.56	
SU-CsFO2	58694	58724	1.12	0.31	0.22	0.12	0.46	0.61	
SU-CsFO2	58724	58754	0.51	0.22	0.22	0.11	0.46	0.56	
SU-CsFO2	58754	58784	-0.02	0.16	0.22	0.11	0.46	0.54	
SU-CsFO2	58784	58814	-0.11	0.20	0.22	0.10	0.46	0.55	
SU-CsFO2	58814	58844	-0.69	0.21	0.22	0.11	0.46	0.56	

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
SYRTE-FO1	58479	58514	0.39	0.25	0.32	0.05	0.23	0.47	
SYRTE-FO1	58514	58539	0.16	0.25	0.32	0.06	0.31	0.51	
SYRTE-FO1	58539	58569	0.31	0.20	0.31	0.06	0.26	0.46	
SYRTE-FO1	58569	58599	0.08	0.20	0.31	0.05	0.26	0.45	
SYRTE-FO1	58599	58634	0.66	0.20	0.32	0.06	0.20	0.43	
SYRTE-FO1	58634	58664	0.18	0.15	0.32	0.05	0.20	0.41	
SYRTE-FO1	58664	58694	0.62	0.30	0.32	0.10	0.20	0.49	
SYRTE-FO1	58694	58724	0.08	0.20	0.32	0.05	0.20	0.43	
SYRTE-FO1	58724	58754	-0.25	0.20	0.32	0.06	0.20	0.43	
SYRTE-FO1	58754	58784	-0.78	0.30	0.32	0.05	0.20	0.48	
SYRTE-FO1	58789	58814	-0.62	0.30	0.32	0.06	0.23	0.50	
SYRTE-FO1	58814	58844	-0.59	0.50	0.32	0.07	0.20	0.63	
SYRTE-FO2	58479	58514	0.66	0.35	0.23	0.07	0.23	0.48	
SYRTE-FO2	58514	58539	0.38	0.30	0.22	0.06	0.31	0.49	
SYRTE-FO2	58549	58569	0.94	0.30	0.22	0.06	0.38	0.53	
SYRTE-FO2	58569	58599	0.44	0.25	0.21	0.05	0.26	0.42	
SYRTE-FO2	58599	58634	0.57	0.20	0.21	0.06	0.20	0.36	
SYRTE-FO2	58634	58664	0.75	0.20	0.21	0.08	0.20	0.36	
SYRTE-FO2	58664	58694	0.95	0.20	0.24	0.16	0.20	0.40	
SYRTE-FO2	58694	58724	0.14	0.20	0.21	0.06	0.20	0.36	
SYRTE-FO2	58724	58754	0.05	0.25	0.21	0.05	0.20	0.38	
SYRTE-FO2	58754	58784	-0.67	0.30	0.21	0.08	0.20	0.42	
SYRTE-FO2	58789	58814	-0.51	0.30	0.22	0.09	0.23	0.45	
SYRTE-FO2	58829	58844	-0.42	0.30	0.23	0.09	0.37	0.53	
SYRTE-FOM	58484	58514	0.48	0.20	0.64	0.07	0.26	0.72	
SYRTE-FOM	58514	58539	0.36	0.25	0.65	0.05	0.31	0.76	
SYRTE-FOM	58539	58569	0.21	0.25	0.66	0.05	0.26	0.75	
SYRTE-FOM	58569	58599	0.23	0.20	0.65	0.06	0.26	0.73	
SYRTE-FOM	58599	58629	0.73	0.20	0.65	0.06	0.23	0.72	
SYRTE-FOM	58649	58664	0.44	0.20	0.61	0.05	0.37	0.74	
SYRTE-FOM	58664	58694	0.56	0.25	0.61	0.06	0.20	0.69	
SYRTE-FOM	58694	58724	0.26	0.20	0.64	0.05	0.20	0.70	
SYRTE-FOM	58724	58754	0.27	0.25	0.64	0.12	0.20	0.72	
SYRTE-FOM	58754	58784	-0.11	0.30	0.60	0.13	0.20	0.71	
SYRTE-FOM	58789	58814	-0.44	0.30	0.61	0.06	0.23	0.72	
SYRTE-FOM	58814	58844	-0.93	0.40	0.66	0.06	0.20	0.80	

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)
IT-Yb1	58389 58419	0.17	0.01	0.03	0.32	0.26	0.41	0.5	[12]
IT-Yb1	58419 58434	0.14	0.01	0.03	0.57	0.49	0.75	0.5	[12]
IT-Yb1	58459 58469	-0.10	0.01	0.03	0.59	0.70	0.92	0.5	[12]
IT-Yb1	58489 58514	0.65	0.01	0.03	0.39	0.31	0.50	0.5	[12]
IT-Yb1	58514 58539	0.75	0.01	0.03	0.26	0.31	0.40	0.5	[12]
NICT-Sr1	58479 58509	0.90	0.04	0.08	0.32	0.23	0.40	0.4	[12]
NICT-Sr1	58514 58534	1.21	0.02	0.07	0.22	0.28	0.37	0.4	[12]
NICT-Sr1	58644 58679	0.68	0.01	0.07	0.21	0.17	0.28	0.4	[12]
NIST-Yb1	58054 58084	-0.21	0.01	0.03	0.29	0.26	0.39	0.5	[12]
NIST-Yb1	58084 58114	0.20	0.01	0.03	0.35	0.26	0.44	0.5	[12]
NIST-Yb1	58114 58149	-0.43	0.01	0.03	0.26	0.23	0.35	0.5	[12]
NIST-Yb1	58149 58174	0.67	0.01	0.03	0.32	0.31	0.45	0.5	[12]
NIST-Yb1	58174 58204	0.27	0.01	0.03	0.26	0.26	0.37	0.5	[12]
NIST-Yb1	58204 58234	0.48	0.01	0.03	0.48	0.26	0.55	0.5	[12]
NIST-Yb1	58234 58269	0.01	0.01	0.03	0.48	0.23	0.53	0.5	[12]
NIST-Yb1	58269 58299	0.77	0.01	0.03	0.22	0.26	0.34	0.5	[12]
SYRTE-FORb	58479 58514	0.76	0.32	0.24	0.05	0.23	0.46	0.6	[12]
SYRTE-FORb	58514 58539	0.53	0.25	0.26	0.06	0.31	0.48	0.6	[12]
SYRTE-FORb	58539 58569	0.63	0.20	0.25	0.05	0.26	0.42	0.6	[12]
SYRTE-FORb	58569 58599	0.38	0.20	0.25	0.06	0.26	0.42	0.6	[12]
SYRTE-FORb	58599 58634	0.95	0.20	0.25	0.06	0.20	0.38	0.6	[12]
SYRTE-FORb	58634 58664	0.77	0.18	0.25	0.07	0.20	0.37	0.6	[12]
SYRTE-FORb	58664 58694	0.87	0.15	0.25	0.07	0.20	0.36	0.6	[12]
SYRTE-FORb	58694 58724	0.38	0.17	0.25	0.06	0.20	0.37	0.6	[12]
SYRTE-FORb	58724 58754	0.02	0.20	0.25	0.08	0.20	0.38	0.6	[12]
SYRTE-FORb	58754 58784	-0.42	0.30	0.25	0.05	0.20	0.44	0.6	[12]
SYRTE-FORb	58789 58814	-0.34	0.30	0.25	0.06	0.23	0.46	0.6	[12]
SYRTE-FORb	58814 58844	-0.47	0.40	0.25	0.07	0.20	0.52	0.6	[12]

References:

[1] Jallageas A. *et al*., Metrologia 55, 366, 2018.
[2] Fang F. *et al*., *Metrologia* **52,** 454, 2015.
[3] Bauch A. *et al*., *Metrologia* **35**, 829, 1998; Bauch A., *Metrologia* **42**, S43, 2005.
[4] Bauch A. *et al*., *IEEE Trans. IM* **36**, 613, 1987; Bauch A., *Metrologia* **42**, S43, 2005.
[5] Weyers S. *et al*., Metrologia 55, 789, 2018.
[6] Domnin Y.S. *et al*., *Measurement Techniques*, Vol. 55, No. 10, January, 2013.
[7] Guéna J. *et al*., *IEEE Trans. Ultr. Ferr. Freq. Contr*. **59** (3), 391-410, 2012.
[8] Pizzocaro M., Bregolin F., Barbieri P. et al., Metrologia 57 035007, 2020.
[9] Hachisu H. *et al*., *Opt. Express* **25**, 8511, 2017.
[10] McGrew W.F., Zhang X., Fasano R.J. *et al*., *Nature* 564, 87-93, 2018.
[11] Guéna J. *et al*., *Metrologia*. **51**, 108, 2014.
[12] CCTF Recommendation 2 (2017) : Updates to the CIPM list of standard frequencies in Consultative Committee for Time and Frequency Report of the 21st meeting (2017), 2017, 56 p.

Operation of the METAS-FOC2 primary frequency standard in 2019

The Swiss continuous Cs fountain clock METAS-FOC2 [1] delivered one contribution to the calibration of TAI, which was published in Circular T 377 in May 2019. During this observation period, the standard was operated without dead time. The local oscillator was the METAS hydrogen maser (HM, BIPM clock code 1405701). The typical short-term frequency instability of METAS-FOC2 was $4 \times 10^{-13}\ (\tau/s)^{-1/2}$. 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	-1.07	1.00	1.38	0.04	0.27	1.73

Important maintenance works were carried out during this year, with the replacement of the main ion pump and of the light-trap [2], and with a Cs refill. These modifications took a few months and were the opportunity to update some other minor hardware parts.

Four other 30-days long measurement series were accumulated in July, September, November and December 2019 for control purposes.

The following table shows the uncertainty budget (k=1) used for the calibration in May 2019:

Physical effect	Frequency shift / 10^{-15}	Uncertainty / 10^{-15}
Second-order Zeeman	23.53	0.20
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	-0.33	1.26
Light shift from detection	-0.10	0.41
RF leakage	0.00	0.47
Majorana transitions	0.00	0.50
DCPS	—	1.03
Total	66.19	1.38

Reference

[1] A. Jallageas et al., Metrologia **55** 366, (2018).
[2] F. Füzesi et al., Rev. Sci. Instrum. **78** 103–109, (2007).

Operation of IT-Yb1 in 2019

The frequency standard IT-Yb1 is a ^{171}Yb optical lattice clock operated at INRIM since 2016 [1]. The standard uses a clock laser at 578 nm generated from the second-harmonic of a laser at 1156 nm. The 578 nm laser is stabilized on an ultrastable cavity and probes the atoms trapped in an one-dimensional horizontal optical lattice at the magic frequency. The clock laser frequency is kept in resonance with the atoms by a digital control loop acting on an acousto-optic modulator. The fundamental 1156 nm laser is sent to a fibre frequency comb referenced to a local hydrogen maser. The frequency ratio between the maser and the ^{171}Yb transition is calculated from the comb measurement and from the corrections used for steering the acousto-optic modulator. Following this operation it was possible to calibrate the maser frequency from October 2018 to February 2019 in the periods MJD 58389 to 58419 (30 days), MJD 58419 to 58434 (15 days), MJD 58459 to 58469 (10 days), MJD 58489 to 58514 (25 days), MJD 58514 to 58539 (25 days). These calibrations were submitted to the BIPM and, after review, the results were published in Circular T 383 in November 2019. The calibration was based on the 2017 recommendation of the frequency for ^{171}Yb as a secondary representation of the second, $f(^{171}\text{Yb})$ = 518 295 836 590 863.6(3) Hz.

The instability of IT-Yb1 has been estimated to be about 2e-15 at 1 s from interleaved measurements [2] so that the statistical uncertainty is u_A<1e-17 after a few hours of measurement time. The most recent evaluation of the systematic uncertainty is u_B = 3e-17 [2] with an uncertainty budget reported in the table. This value corresponds to the uncertainty appeared in the Circular T. The uncertainty $u_{l/lab}$ of the link between the standard and the maser is dominated by the extrapolation uncertainty due to the intermittent operation of the standard [3], which had duty time ranging from 4% to 37% for each 5 days of measurements. Extrapolation uncertainty has been calculated from numerical simulation given the characteristic maser noise [2,4]. Moreover, a systematic uncertainty of 8e-17 has been assigned to $u_{l/lab}$ coming from the optical to microwave comparison at the comb.

Effect	Rel. Shift / 1e-17	Rel. Unc. /1e-17
Density shift	−5.9	0.2
Lattice shift	7.6	2
Zeeman shift	−0.693	0.014
Blackbody radiation	−235	1.2
Blackbody radiation oven	−1.7	0.8
Static Stark shift	−1.6	0.9
Background gas shift	−0.5	0.2
Probe light shift	0.09	0.05
Others	-	0.6
Gravitational redshift	2599.5	0.3
Total	2361.8	2.8

Table 1: typical systematic shift and uncertainties for IT-Yb1 between October 2018 and February 2019 (MJD 58389 to 58784).

References:

[1] M. Pizzocaro, P. Thoumany, B. Rauf, F. Bregolin, G. Milani, C. Clivati, G. A. Costanzo, F. Levi, and D. Calonico, “Absolute frequency measurement of the 1 S 0 – 3 P 0 transition of 171 Yb,” Metrologia 54, 102 (2017).
[2] M. Pizzocaro, F. Bregolin, P. Barbieri, B. Rauf, F. Levi, and D. Calonico, “Absolute frequency measurement of the 1 S 0 – 3 P 0 transition of 171 Yb with a link to International Atomic Time,” Metrologia (2019), not yet published in print
[3] D.-H. Yu, M. Weiss, and T. E. Parker, “Uncertainty of a frequency comparison with distributed dead time and measurement interval offset,” Metrologia 44, 91 (2007).
[4] H. Hachisu and T. Ido, “Intermittent optical frequency measurements to reduce the dead time uncertainty of frequency link,” Japanese Journal of Applied Physics 54, 112401 (2015).

Report of the operation of NICT-Sr1 in 2019

The frequency standard NICT-Sr1 is an ^{87}Sr optical lattice clock operated at NICT. Utilizing the method of intermittent evaluation [1], NICT-Sr1 contributed to TAI calibration as published in the *Circular T* for the following intervals*:*

MJD 58479 to 58509 (30 days) for Jan. 2019, *Circular T* 373
MJD 58514 to 58534 (20 days) for Feb. 2019, *Circular T* 374
MJD 58644 to 58679 (35 days) for June/July 2019, *Circular T* 379.

The last one in June/July contains three measurements on MJD 58646, MJD 58658 to 58666 and MJD 58675, with an 87% coverage of the central 9 day period.

Measurements of the scale interval use an optical frequency comb to down-convert the optical frequency of 429 THz 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 typical intermittent evaluation, the HM frequency is measured for three hours approximately once per week, and the mean frequency of the HM with respect to the frequency of NICT-Sr1 is determined from several such data blocks distributed over the target period. The uncertainty due to non-operation time of NICT-Sr1 [1-3] is then included in ul/Lab. Additionally, an average over multiple HMs mitigates the effect of sporadic phase excursions of a specific HM [3]. Intermittent evaluation makes it easier to extend the evaluation interval longer, reducing the uncertainty ul/Tai of the satellite link to TAI. The uncertainty ul/Tai often limits the overall uncertainty particularly at short evaluation intervals. Table 1 shows uncertainty contributions for such evaluations.

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

Period of evaluation (MJD)	Evaluation mode	uA	uB	(uA/Lab)	(uB/Lab)	ul/Tai	u	uSrep
				ul/Lab				
58479 – 58509 (30 days)	Intermittent	0.37	0.77	(3.08)	(0.80)	2.3	4.0	4
				3.18				
58514 – 58534 (20 days)	Intermittent	0.20	0.73	(2.09)	(0.80)	2.8	3.7	4
				2.24				
58644 – 58679 (35 days)	Intermittent	0.08	0.71	(2.08)	(0.14)	1.7	2.8	4
				2.08				

Table 1: Reported uncertainty contributions applying the method of intermittent evaluation. The last interval includes an extended center measurement period of near continuous operation. Values are given in units of 10^{-16}.

The typical systematic corrections and their uncertainties for NICT-Sr1 as previously published [1, 3, 4] are summarized as follows:

Effect	Correction (10^{-17})	Uncertainty (10^{-17})
Blackbody radiation	513.1	3.4
Lattice scalar / tensor	0	5.3
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	51.2	0.3
Density	0.4	0.9
Background gas collisions	0	1.8
Line pulling	0	0.1
Servo error	1.8	1.5
Total	566.6	6.8
Gravitational redshift	–834.1	2.2
Total (with gravitational effect)	–267.5	7.1

Table 2. Systematic corrections and their uncertainties for NICT-Sr1 between MJD 58644 and 58679.

References

[1] H. Hachisu and T. Ido, “Intermittent optical frequency measurements to reduce the dead time uncertainty of frequency link,” Jpn. J. Appl. Phys. **54**, 112401 (2015).

[2] C. Grebing, A. A-Masoudi, S. Dörcher, S Häfner, V. Gerginov, S. Weyers, B. Lipphardt, F. Riehle, U. Sterr, and C. Lisdat, “Realization of a timescale with an accurate optical lattice clock,” Optica **3**, 563 (2016).

[3] H. Hachisu, G. Petit, F. Nakagawa, Y. Hanado and T. Ido, “SI-traceable measurement of an optical frequency at low 10^{-16} level without a local primary standard,” Opt. Express **25**, 8511 (2017).

[4] H. Hachisu, F. Nakagawa, Y. Hanado and T. Ido, “Months-long real-time generation of a time scale based on an optical clock,” Sci. Reports **8**, 4243 (2018).

Operation of the NIM5 primary frequency standard in 2019

The NIM5 Cs fountain primary frequency standard at NIM was operated for 7 months and the average frequencies of the hydrogen maser H50 (1404850) against NIM5 were measured and the results, including all relevant biases and uncertainties, were reported to the BIPM and published in Circular T as shown in the following table.

MJD periods	$d/10^{-15}$	$u_A/10^{-15}$	$u_B/10^{-15}$	$U_{l/lab}/10^{-15}$	$U_{l/TAI}/10^{-15}$	$u/10^{-15}$
58544.0-58569.0	-0.14	0.20	0.90	0.20	0.31	0.99
58634.0-58659.0	0.55	0.20	0.90	0.20	0.23	0.97
58679.0-58694.0	-0.25	0.30	0.90	0.20	0.37	1.04
58694.0-58719.0	-0.21	0.20	0.90	0.20	0.23	0.97
58729.0-58749.0	-0.41	0.20	0.90	0.20	0.28	0.98
58764.0-58784.0	-0.14	0.20	0.90	0.20	0.28	0.98
58819.0-58849.0	-0.58	0.20	0.90	0.20	0.20	0.96

During a formal evaluation, NIM5 operated alternatively in the high and low densities with a ratio about 2 to determine frequencies at zero density.

The new NIM6 fountain clock has been built and evaluated, the preliminary result of type B evaluation is 6×10^{-16} limited by the microwave-related frequency shift. With an ultra-stable microwave local oscillator generated from an optical comb which locked to an ultra-stable laser, the frequency instability of NIM6 fountain clock reached $5\times10^{-14}/\tau^{1/2}$ at high density. The direct comparison of two fountain clocks has also been done, a relative frequency difference of 4.4×10^{-16} was obtained for 20 days averaging time, consistent with the total uncertainties of the two clocks [1].

Meanwhile, a Rb fountain clock is also under developing and aiming to achieve a robust and high stability. The design of this new fountain is different from the Cs fountain clocks. The Ramsey cavity is used as the vacuum seal to simplify the system and the cooling laser is obtained from frequency doubling of the 1.5 μ DBR laser which has a linewidth about 300 kHz and is working much more robust compared with a ECLD. The clock signal has been obtained with a instability of 2×10^{-13} at 1 s. The evaluation and further improvement is undergoing. The fountain clock will be used in NIM to steer a H-maser directly.

[1] F. Fang, et al, "Advances in the NIM Cs fountain clocks", IFCS-EFTF Proceedings, Orlando, 14-16 (2019),

2019 Report of TAI Measurements with NIST-Yb1

During the period from November 2017 to June 2018, an ytterbium optical lattice frequency standard at NIST (NIST-Yb1) was measured with respect to TAI and PSFS. In December 2018, reports of these measurements were submitted to the BIPM Time Department, to be considered for a first-time calibration of TAI. In February 2019, the Working Group on PSFS approved the NIST-Yb1 data for TAI steering, which was subsequently included in Circular T 374.

Over the course of these measurements, the type B uncertainty of NIST-Yb1 was u_B=1.4x10^{-18}, as reported in [1]. As of the writing of this report, this uncertainty evaluation remains up-to-date. The type A uncertainty of NIST-Yb1 was u_A<1x10^{-17}, whereas $u_{l/lab}$ varied within the range of 2.2 x10^{-16} to 4.83x10^{-16}, for each month reported.

[1] W. McGrew, et al., “Atomic clock performance enabling geodesy below the centimetre level,” Nature **564** 87–90 (2018).

Operation of the SYRTE PSFS in 2019

In 2019, 12 calibration reports of the reference maser by each of the four SYRTE fountains, the primary frequency standards (PFS) FO1, FO2Cs and FOM and the secondary frequency standard (SFS) FO2-Rb, have been transmitted to BIPM to participate to the steering of TAI, leading to a total number of 48 contributions. The interval durations range from 15 to 35 d. The uptime of the fountains is typically 90% or higher.

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 $\sigma_y(\tau) \sim 5 \times 10^{-14}\ \tau^{-1/2}$ for FO1, FO2-Cs and FO2-Rb. Because FOM uses optical molasses only, its relative frequency instability is limited to $\sigma_y(\tau) \sim 9 \times 10^{-14}\ \tau^{-1/2}$. 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 to zero density, we alternate measurements between full and half atomic density either using the method proposed by K. Gibble [1] 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 [2, 3]. 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 2.5×10^{-17}.

The dead time uncertainty is estimated according to the method described in [4, 5]. We apply a conservative uncertainty of 5×10^{-17} to account for possible phase fluctuations due to the cables between the maser and the PSFS. The $u_{\text{Link Lab}}$ uncertainty corresponds to the quadratic sum of these two terms.

The calibration values are given with typical uncertainties $u_A = 1.5 – 5.0 \times 10^{-16}$, and $0.5 – 1.6 \times 10^{-16}$ 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 $\sim 2.0\text{-}3.5 \times 10^{-16}$, and for FOM, $\sim 6\text{-}7 \times 10^{-16}$.
The FO2-Rb SFS calibration reports were made using the 2017 recommended value (21st CCTF, [6]).

Throughout 2019, 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) [7].

Fountain	FO1		FO2-Cs		FOM	
Physical origin	Correction	Uncertainty	Correction	Uncertainty	Correction	Uncertainty
2nd order Zeeman	-1280.85	0.40	-1935.93	0.30	-322.82	1.90
Blackbody Radiation	169.73	0.60	174.63	0.60	166.73	2.30
Cold Collisions + cavity pulling	129.17	1.48	149.63	1.19	27.25	4.09
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	- 68.26	0.25
Total uncertainty u_B		**3.2**		**2.2**		**6.1**

Table 1: Typical accuracy budgets for the SYRTE PFS FO1, FO2-Cs and FOM adapted from those given in [8] and [9]. (Values given in units of 10^{-16})

Fountain	FO2-Rb	
Physical origin	Correction	Uncertainty
2nd order Zeeman	-3502.25	0.70
Blackbody Radiation	126.10	1.45
Cold Collisions + cavity pulling	2.35	0.84
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		**2.5**

Table 2: Typical accuracy budgets for the SYRTE SFS FO2-Rb adapted from those given in [8] and [9]. (Values given in units of 10^{-16})

The SYRTE Strontium optical lattice clocks SrB and Sr2 did not contribute to TAI in 2019, but are expected to provide new calibration values in 2020.

References

[1] K. Gibble, Proc. 2012 EFTF, pp 16-18
[2] H. Denker, *et al*, J Geod (2018) 92:487–516
[3] P. Delva, *et al*, Fundam.Theor.Phys. 196 (2019) 25-85
[4] R.J. Douglas, *et al*, in Proc. 11th EFTF 1997 pp 345–9
[5] D.H. Yu, *et al*, Metrologia, vol. 44, no. 1, p. 91, Feb. 2007.
[6] Consultative Committee for Time and Frequency (CCTF) 2017, Report of the 21st meeting (8-9 June 2017) to the International Committee for Weights and Measures www.bipm.org/utils/common/pdf/CC/CCTF/CCTF21.pdf
[7] G. D. Rovera, *et al*, Metrologia **53,** (2016) S81-S88.
[8] J. Guéna, *et al*, IEEE Trans. Ultr. Ferr. Freq. Contr. **59** (3), 391-410 (2012)
[9] J. Guéna, *et al*, Metrologia **51**, 108 (2014)

Operation of the PTB primary clocks in 2019

PTB's primary clocks with a thermal beam

During 2019 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 58484 to 58849) relative frequency offset y(CS1 – CS2) amounted to -4.3×10^{-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 2019.

CS1

The CS1 relative frequency instability $\sigma_y(\tau = 5000\ \mathrm{s})$ was found to vary between 73×10^{-15} and 97×10^{-15} during 2019, almost in 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 7.9×10^{-15}, in agreement with the value $u_{\mathrm{A}}(\tau = 30\ \mathrm{d, CS1}) = 8\times10^{-15}$ stated in Circular T. 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 2019 (mean of the 12 *d*-values reported in Circular T) of -6.5×10^{-15}.

CS2

The relative CS2 frequency instability of $\sigma_y(\tau = 5000\ \mathrm{s})$ was measured between 54×10^{-15} and 73×10^{-15} during 2019, in reasonable agreement with the prediction based on the prevailing parameters beam flux, clock transition signal and line width. The standard deviation of the 12 *d*-values reported in Circular T for 2019 amounted to 6.3×10^{-15}. The scatter of data is larger than in previous years and slightly exceeds the stated uncertainty contribution $u_{\mathrm{A}}(\tau = 30\ \mathrm{d, CS2}) = 5\times10^{-15}$ reported in Circular T. During 2019, the air conditioning system in PTB’s clock hall was not always working properly, and CS2 is known to be more susceptible to temperature changes than CS1. 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 2019 (mean of the 12 *d*-values reported in Circular T) of -1.88×10^{-15}.

PTB’s primary caesium fountain clocks

In 2019 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.

CSF1

In 2019 eight measurements of the TAI scale unit of 10 (1×), 15 (1×), 25 (1×), 30 (4×) and 35 (1×) 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 205 days by CSF1, and the mean BIPM estimate of *d* based on all simultaneous Primary and Secondary Frequency Standard measurements was 1.0×10^{-16}.

Due to the performance and reliability of the laser systems, dead times are normally kept between 1%-3% (in three cases between 4%-6%) 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 $u_{\mathrm{l/lab}}$ was in the range 0.2×10^{-16} to 0.5×10^{-16}.

The statistical uncertainty of CSF1 measurements was calculated with the assumption of white frequency noise during the measurement intervals. For the eight TAI contributions in 2019 typically statistical uncertainties $u_{\mathrm{A}} <1\times10^{-16}$ 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	1078.88	0.10
Black body radiation shift	- 165.80	0.80
Relativistic redshift and Doppler effect	85.56	0.02
Collisional shift	9.3	2.5
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		2.8

CSF2

In 2018 fourteen measurements of the TAI scale unit of 10 (2×), 20 (2×), 25 (2×), 30 (7×) and 35 (1×) 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 355 days by CSF2, and the mean BIPM estimate of *d* based on all simultaneous Primary and Secondary Frequency Standard measurements was -1.1×10^{-16}.

The dead times of the above measurements were in most cases between 2%-6% (in five cases 6%-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 $u_{\mathrm{l/lab}}$ was $\leq 0.6\times10^{-16}$.

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 fourteen TAI contributions in 2019 we arrived at statistical uncertainties u_{A} between $0.9\text{-}2.2\times10^{-16}$.

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	1003.99	0.10
Black body radiation shift	- 165.39	0.63
Relativistic redshift and Doppler effect	85.45	0.02
Collisional shift	-73.5	0.4
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

References

[1] A. Bauch, Metrologia **42**, S43–S54 (2005)

[2] T. Heindorff, A. Bauch, P. Hetzel, G. Petit, S. Weyers, Metrologia **38**, 497–502 (2001)

[3] B. Lipphardt, G. Grosche, U. Sterr, Chr. Tamm, S. Weyers and H. Schnatz, IEEE Transactions on Instrumentation and Measurement **58**(4), pp. 1258–1262 (2009)

[4] S. Weyers, B. Lipphardt, and H. Schnatz, Phys. Rev. A **79**, 031803(R) (2009)

[5] B. Lipphardt, V. Gerginov and S. Weyers, IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control **64**(4), pp. 761–766 (2017)

[6] A. Bauch, S. Weyers, D. Piester, E. Staliuniene, W. Yang, Metrologia **49,** 180–188 (2012)

[7] S. Weyers, V. Gerginov, M. Kazda, J. Rahm, B. Lipphardt, G. Dobrev and K. Gibble, Metrologia **55**, 789–805 (2018)

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) IT-Yb1, NICT-Sr1, NIST-Yb1, SYRTE-FORb, SYRTE-SR2 and SYRTE-SrB 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 2019,** a flicker frequency noise 0.35×10^{-15} in **2013** and **2014** and 0.3×10^{-15} **from 2015 to 2019** and a random walk frequency noise $0.4 \times 10^{-16}\mathrm{x}\sqrt{(\tau)}$ in **2013** and $0.2 \times 10^{-16}\mathrm{x}\sqrt{(\tau)}$ from **2014** to **2019,** 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. 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	0.19
Nov. 2017	58054-58084	-0.05	0.18
Dec. 2017	58084-58114	-0.13	0.19
Jan. 2018	58114-58149	-0.10	0.21
Feb. 2018	58149-58174	0.02	0.18
Mar. 2018	58174-58209	-0.17	0.18
Apr. 2018	58204-58234	0.02	0.18
May 2018	58234-58269	0.33	0.18
Jun. 2018	58269-58295	0.46	0.20
Jul. 2018	58299-58329	0.65	0.24
Aug. 2018	58329-58359	0.50	0.23
Sep. 2018	58359-58389	0.67	0.17
Oct. 2018	58389-58419	0.38	0.18
Nov. 2018	58419-58449	0.60	0.17
Dec. 2018	58449-58479	0.63	0.14
Jan. 2019	58479-58514	0.57	0.14
Feb. 2019	58514-58539	0.56	0.16
Mar. 2019	58539-58564	0.50	0.16
Apr. 2019	58569-58599	0.43	0.16
May 2019	58599-58634	0.57	0.14
Jun. 2019	58634-58664	0.59	0.15
Jul. 2019	58664-58694	0.57	0.17
Aug. 2019	58694-58724	0.31	0.13
Sep. 2019	58724-58754	-0.10	0.13
Oct. 2019	58754-58784	-0.35	0.13
Nov. 2019	58784-58814	-0.34	0.14
Dec. 2019	58814-58844	-0.56	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:

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

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, $[UTC - GPS\ time] = -18\ \text{s} + C_0$,

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, $[TAI – UTC(USNO)\_GPS] = 37\ \text{s} + C_0'$

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 $[UTC– UTC(USNO)\_GPS] = 0\ \text{s} + C_0'$

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

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

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, $[TAI\text{ - }GLONASS\ time] = 37\text{ s} + C_1$.

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, $[TAI – UTC(SU)\_GLONASS] = 37\text{ s} + C_1'$

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 $[UTC– UTC(SU)\_GLONASS] = 0\text{ s} + C_1'$

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 2019

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 2019

Table 8: Statistical data on the weights attributed to the clocks in 2019

	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
2019 Jan.	141	226	412	8	21	34	5	5	14	58	0	62	1.058
2019 Feb.	144	226	417	11	19	38	5	4	12	62	0	66	1.055
2019 Mar.	154	237	439	21	30	61	5	5	12	59	0	63	1.058
2019 Apr.	155	229	431	19	31	60	6	6	14	58	0	62	1.078
2019 May	163	232	437	26	33	65	6	7	15	59	0	63	1.075
2019 June	158	228	425	22	26	57	5	7	14	57	0	61	1.087
2019 July	154	213	408	17	16	46	6	6	15	54	0	58	1.105
2019 Aug.	157	210	414	21	12	49	4	5	14	50	0	54	1.096
2019 Sep.	161	216	423	18	23	57	4	6	14	55	0	59	1.093
2019 Oct.	158	215	418	19	32	63	5	3	14	56	0	60	1.127
2019 Nov.	163	221	431	22	40	73	6	3	16	58	0	62	1.117
2019 Dec.	156	214	414	17	43	67	3	5	12	59	0	63	1.153

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 a 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 2020.

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 Department 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 2020.

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
Section for electrical quantities, time and frequency
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 – 139 Warszawa, 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

ILNAS
Bureau Luxembourgeois de Métrologie
Laboratoire Temps Fréquence
22 avenue des Hauts Fourneaux
L-4362 Esch-sur-Alzette, Luxembourg

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 of Israel
Ministry of Economy and Industry
Bank of Israel Street, 5, Jerusalem 9103101
P.O.B. 3166; Tel.: +972-(0)74-7215923
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

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

LRTE
Laboratório de Referências de Tempo e Espaço
Grupo de Óptica
University of São Paulo
Av. Trabalhador Saocarlense, 400
13566-590 São Carlos, Brazil

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 Division
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 Department
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
Mašera-Spasićeva ulica 10
1000 Ljubljana
Slovenia

SL
Measurement Units, Standards and Services Department (MUSSD),
Mahenawatta, Pitipana,
Homagama, - Sri Lanka

SNSU-BSN
Standar Nasional Satuan Ukuran --
Badan Standardisasi Nasional
National Measurement Standards --
National Standardization Agency
(SNSU-BSN)
Kawasan PUSPIPTEK Gedung 420
Serpong Tangerang 15314 Banten - Indonesia

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 (1)	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 tiempo@cenam.mx

(1) Information based on the Annual Report 2018, not confirmed by the Laboratory.

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.

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: time@gum.gov.pl

Web Clock
A web clock is used to display the local time in Poland referred to the GUM NTP servers. Available at the web page: http://czas.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 web clock at https://www.hko.gov.hk/en/gts/time/clock_e.html

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 https://www.hko.gov.hk/en/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

IGNA (1)

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

ILNAS

Network Time Service via NTP Protocol
Stratum-1 time server with monitoring (restricted access)
Host names:
ntp1.ilnas.blm.lu
ntp2.ilnas.blm.lu
ntp3.ilnas.blm.lu
Further information at:
https://portail-qualite.public.lu/fr/metrologie/etalonnages.html

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 addresses: 185.12.78.85 and 77.78.199.17

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/

(1) Information based on the Annual Report 2018, not confirmed by the Laboratory.

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/

Voice Time Service
Telephone voice announcements are followed by a tone to indicate the local time. The service is available

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

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/.

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: http://rime.inrim.it/labtf/tempo-legale-italiano/.

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).

INTI

Network Time Service:
INTI operates an open access NTP server referenced to UTC(INTI).
Server Host Name: ntp.inti.gob.ar

JV (1)

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

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(1) Information based on the Annual Report 2018, not confirmed by the Laboratory.

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
LRTE	Internet Time Service LRTE operates Stratum 1 and Stratum 2 time servers using the NTP protocol. The servers are directly synchronized to UTC(LRTE). The servers are available on free access at hostnames/ip : lrte.ntp.ifsc.usp.br / 143.107.229.211 -> stratum 1 ntp1.ifsc.usp.br / 143.107.229.210 -> stratum 2 Further information available at http://lrte.ntp.ifsc.usp.br/ https://www.ntppool.org/scores/143.107.229.211 https://www.ntppool.org/scores/143.107.229.210 https://thingspeak.com/channels/691405
LT	Network Time Service via NTP protocol NTP v3 Host name: laikas.pfi.lt Directly referenced to UTC(LT) System: Datum TymeServe 2100 NTP server Access policy: free Further information available at https://www.ftmc.lt/time-and-frequency-standard-laboratory
MASM	Network Time Service via NTP It provides synchronization to UTC(MASM) Address: ntp.mn System: LANTIME M600 Access policy: free

(1) Information based on the Annual Report 2018, 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 three 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
NIMB (1)	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 Web-based time-of-day clock: https://time.gov 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

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(1) Information based on the Annual Report 2018, not confirmed by the Laboratory.

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	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	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. https://nrc.canada.ca/en/certifications-evaluations-standards/canadas-official-time/computer-time-date 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: https://nrc.canada.ca/en/certifications-evaluations-standards/canadas-official-time/telephone-talking-clock 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: https://nrc.canada.ca/en/web-clock/

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:
https://nrc.canada.ca/en/certifications-evaluations-standards/canadas-official-time/nrc-shortwave-station-broadcasts-chu

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:
https://nrc.canada.ca/en/certifications-evaluations-standards/canadas-official-time/network-time-protocol-ntp

The official website for the Frequency and Time group is:
https://nrc.canada.ca/en/certifications-evaluations-standards/canadas-official-time

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

Contact : time@ptb.de
Information on the web pages
http://www.ptb.de/time

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 are:
ptbtime1.ptb.de
ptbtime2.ptb.de
ptbtime3.ptb.de

PTB also provides a fee-based authenticated NTP service based on the NTP’s pre-shared key approach specified in RFC 5905. In 2018, the IETF published RFC 8673, which deprecates the usage of MD5 for the pre-shared key approach and replaces it with a message authentication code based on AES-CMAC as specified in RFC 4493. PTB’s authenticated time service has been enhanced in order to comply to RFC 8673.
The hostnames of the servers are:
ntpsmgw1.ptb.de
ntpsmgw2.ptb.de
Since last year PTB provides a test bed for a secure NTP time service based on Network Time Security (NTS). NTS is a security protocol specified by IETF’s NTP working group which aims to provide a scalable approach for the protection of NTP time synchronization packets. Participation at this test bed is possible via mandatory registration (Contact: ntp-admin@ptb.de).

PTB created a new service to distribute legal time via the WWW. The PTB clock is completely programmed in pure Hypertext Markup Language (HTML). The time queries at the PTB server are performed via WebSocket (WS), a supplement to the established Hypertext Transfer Protocol (HTTP) specified by the Internet Engineering Taskforce (IETF).
URL: httpps://uhr.ptb.de

RISE

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 RISE. 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.ri.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	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: 153.5.147.30) New IP for NTP server on new location
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.
SNSU-BSN	Network Time Service The NTP time information referenced to UTC(IDN) is generated by Stratum-1 NTP server at URL: ntp.bsn.go.id Access Policy : free
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
USNO	Telephone Voice Announcer +1 202 762-1401 Backup voice announcer: +1 719 567-6742 Backup voice announcer: +1 202-762-1069 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