The generation of UTC and UTCr

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Presentation Plan

- Computation of UTC:
  - Stability
    - Atomic clock, time transfer
    - Algorithms (small example), new development
  - Accuracy
    - Primary and Secondary Frequency Standard, new development
- UTCr, the rapid UTC
  - Stability
    - Atomic locks, time transfer
  - Accuracy
    - steered to UTC
- Publication of UTC and other related products

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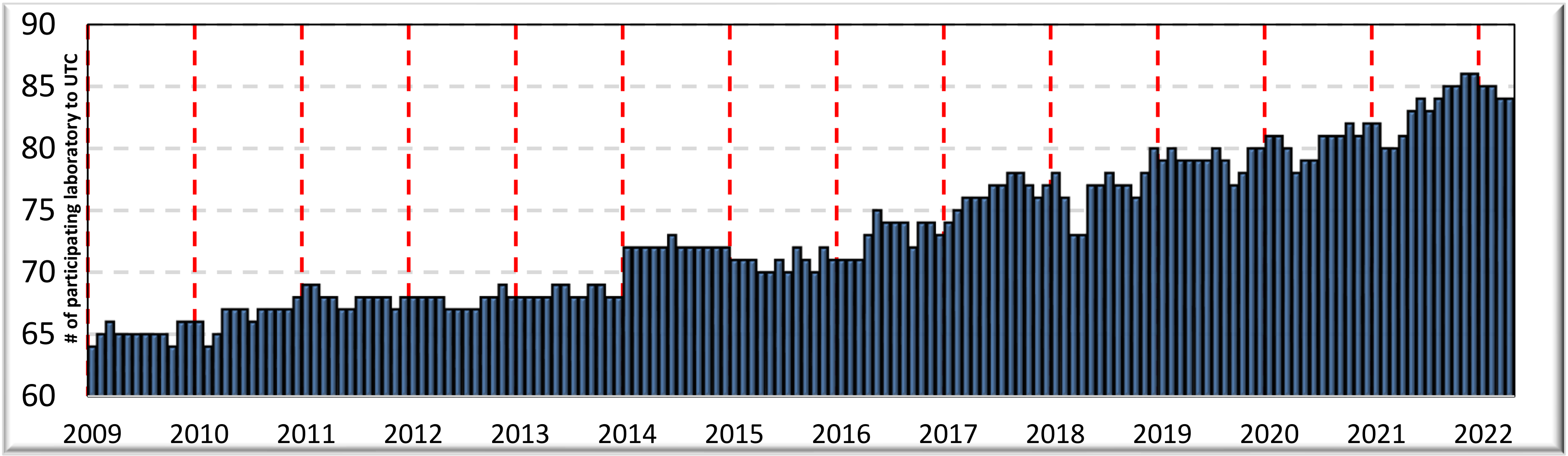
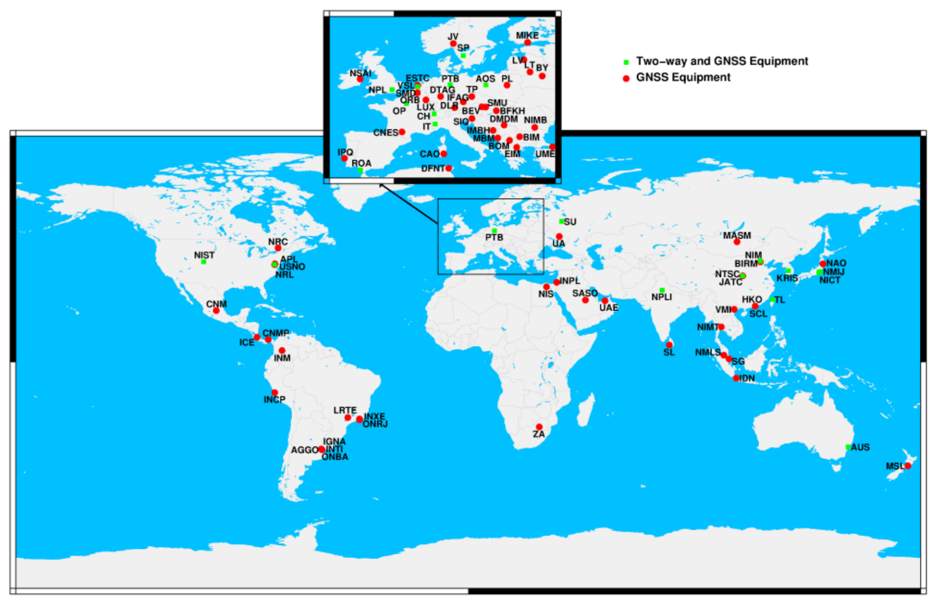
Number of laboratory distribution/geographical distribution



Geographical distribution of the laboratories that contribute to TAI and time transfer equipment (2021)



Even during the COVID-19 period the number of participating laboratories is continually increased.

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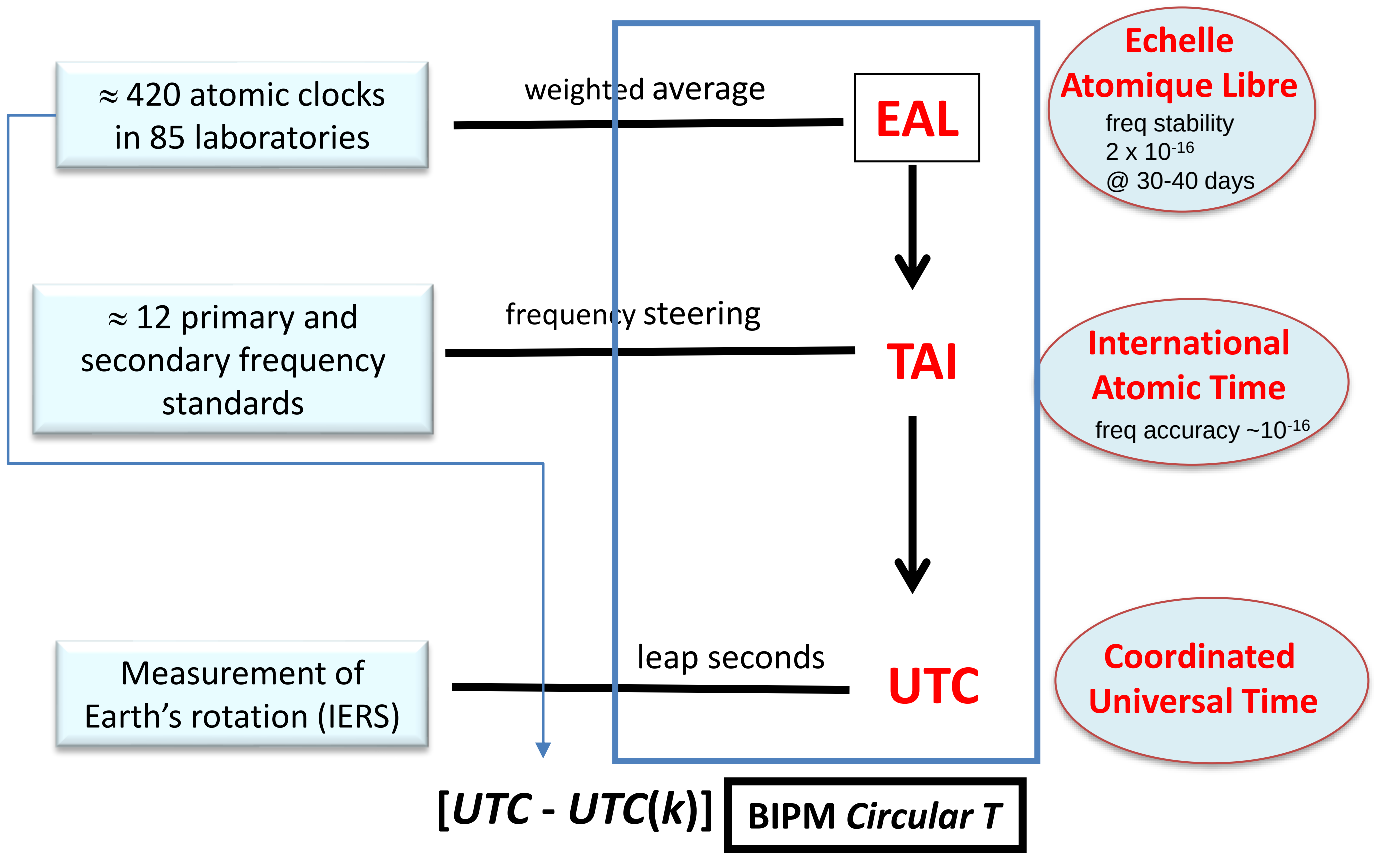
Computation of UTC (monthly) at the BIPM

Similarly (weekly) for rapid UTC



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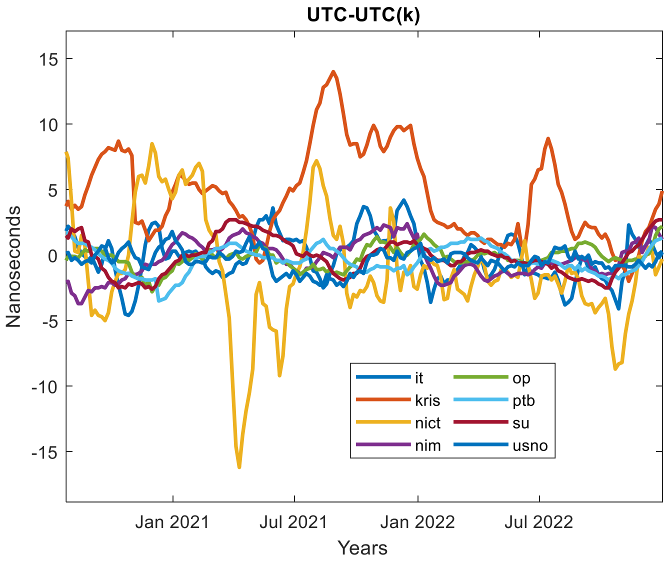
UTC, UTC(*k*) and [UTC-UTC(*k*)]

UTC	Stability based on the **atomic clocks** (420) Steering procedure based on PFSF availability
UTC(k)	Stability based on the **laboratory equipment** Steering procedure to be close to UTC
[UTC-UTC(k)]	UTC, UTC(k) and time links used to compare clocks



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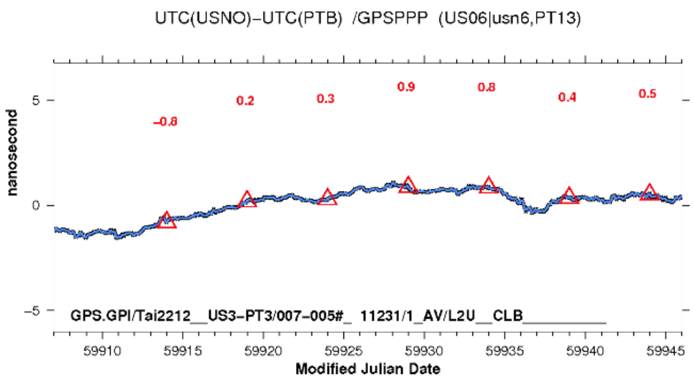
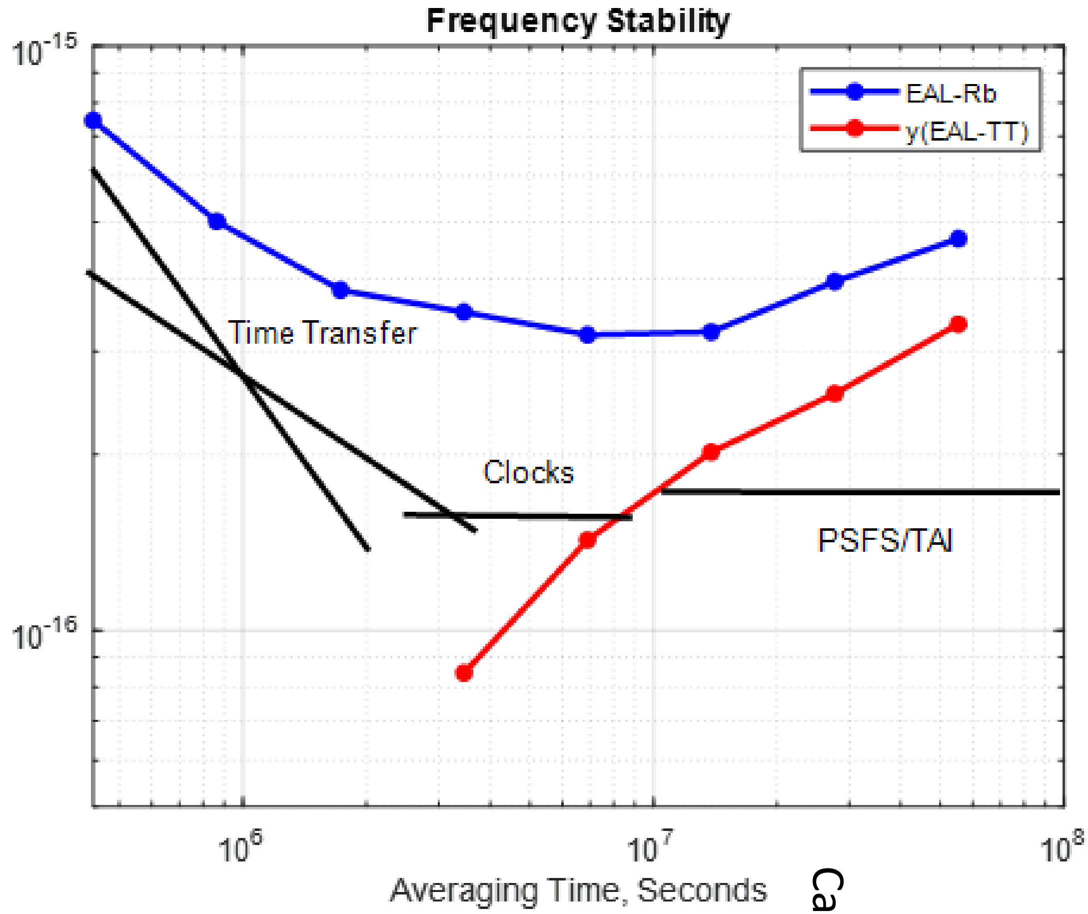
Estimation of UTC Instability

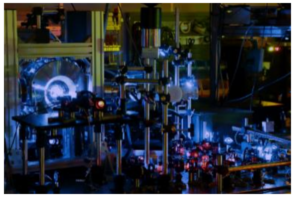




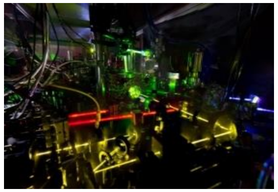
NTSC Rubidium Fountain

Credit: NTSC

Hydrogen Masers



Sr lattice Clock (NICT)



Yb Lattice Clock (NIST)

Caesium Clock

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EAL calculation

First step: EAL - 1

Weighting algorithm

Prediction algorithm

$$EAL(t) = \sum_{i=1}^{N} w_i \left[h_i(t) + h_i'(t) \right]$$

- ***N*** is the number of atomic clocks
- $\boldsymbol{w_i}$ the relative weight of the clock H_i.
- $\boldsymbol{h_i(t)}$ is the reading of clock H_i at time t
- $\boldsymbol{h_i'(t)}$ is the prediction of the reading of clock H_i

The weights of the clocks obey the relation: $\sum_{i=1}^{N} w_i = 1$

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First step: EAL - 2

The system solved by the algorithm:

$$\begin{cases} \sum_{i=1}^{N} w_i x_i(t) = \sum_{i=1}^{N} w_i h_i'(t) \\ x_i(t) - x_j(t) = x_{i,j}(t) \end{cases}$$

where $x_i(t) = EAL(t) - h_i(t)$

The solution is:

Weigth

$$x_j(t) = EAL - h_j = \sum_{i=1}^{N} w_i \left[h_i'(t) - x_{i,j}(t) \right]$$

Prediction

EAL – simple example

- The laboratories contribute to UTC with:

Time transfer data

UTC(KRIS) – REFGPS

```
INT DLY =  -33.7 ns (GPS C1), -35.7 ns (GPS P1),   0.0 ns (GPS C:
CAB DLY =  193.1 ns
REF DLY =  109.6 ns
REF = UTC(KRIS)
COMMENTS = PsdGPS with CggttsHeader based on: X:\TaN\2212\Obs\KR:
COMMENTS = Total_DLY/Mjd,DLY_P1,P2,Cab,Ref: 1   0.000  58484.000(
CKSUM = ??

PRN CL  MJD  STTIME TRKL ELV AZTH   REFSV      SRSV     REFGPS  I
             hhmmss  s  .1dg .1dg   .1ns     .1ps/s      .1ns

 99    59907 010942    0 444                              -46.97
 99    59907 011442    0 444                              -46.94
 99    59907 011942    0 444                              -46.99
 99    59907 012442    0 444                              -46.73
 99    59907 012942    0 444                              -46.80
 99    59907 013442    0 444                              -46.47
 99    59907 013942    0 444                              -46.50
 99    59907 014442    0 444                              -46.52
 99    59907 014942    0 444                              -46.33
 99    59907 015442    0 444                              -46.48
 99    59907 015942    0 444                              -46.49
 99    59907 020442    0 444                              -46.29
 99    59907 020942    0 444                              -46.36
 99    59907 021442    0 444                              -46.09
 99    59907 021942    0 444                              -46.29
 99    59907 022442    0 444                              -46.31
```

Clock data

UTC(KRIS)-clocks

```
59914 10056   20056   80347.6 1351135   47935.3 1351783   14250.2 1405624   22747.3 1405625   71431.3
59914 10056 1405626   12985.4 1405628   72973.4       0       0.0       0       0.0       0       0.0
99999
59919 10056   20056   80538.0 1351135   47992.1 1351783   14390.6 1405624   23134.6 1405625   72518.6
59919 10056 1405626   13062.6 1405628   73298.7       0       0.0       0       0.0       0       0.0
99999
59924 10056   20056   80729.5 1351135   48043.6 1351783   14526.1 1405624   23524.9 1405625   73612.8
59924 10056 1405626   13140.2 1405628   73626.0       0       0.0       0       0.0       0       0.0
99999
59929 10056   20056   80922.3 1351135   48098.9 1351783   14666.2 1405624   23917.5 1405625   74713.2
59929 10056 1405626   13217.4 1405628   73955.5       0       0.0       0       0.0       0       0.0
99999
59934 10056   20056   81116.2 1351135   48149.0 1351783   14802.2 1405624   24312.4 1405625   75819.9
59934 10056 1405626   13294.8 1405628   74286.9       0       0.0       0       0.0       0       0.0
99999
59939 10056   20056   81311.3 1351135   48210.1 1351783   14936.9 1405624   24710.3 1405625   76933.3
59939 10056 1405626   13372.6 1405628   74620.4       0       0.0       0       0.0       0       0.0
99999
59944 10056   20056   81507.4 1351135   48270.4 1351783   15074.8 1405624   25109.7 1405625   78052.3
59944 10056 1405626   13449.4 1405628   74955.5       0       0.0       0       0.0       0       0.0
99999
```

- By combining these data (and using the PTB as pivot we have UTC(KRIS)-UTC(PTB)), we obtain:
  - EAL-1351135
  - EAL-1405628 etc.
  - but also, EAL-UTC(KRIS)

EAL – simple example

- We solve a system **Ax=b** to obtain **x** where:

- $$\begin{bmatrix} 1 & 0 & -1 & 0 \\ 0 & 1 & -1 & 0 \\ 0 & -1 & 1 & 0 \\ w_1 & w_2 & 0 & 0 \end{bmatrix} \times \begin{bmatrix} EAL - 1351135 \\ EAL - 1405628 \\ EAL - UTC(KRIS) \\ EAL - UTC(PTB) \end{bmatrix} = \begin{bmatrix} UTC(KRIS) - 1351135 \\ UTC(KRIS) - 1405628 \\ UTC(KRIS) - UTC(PTB) \\ prediction\ term \end{bmatrix}$$

A design matrix

x solution

b input data

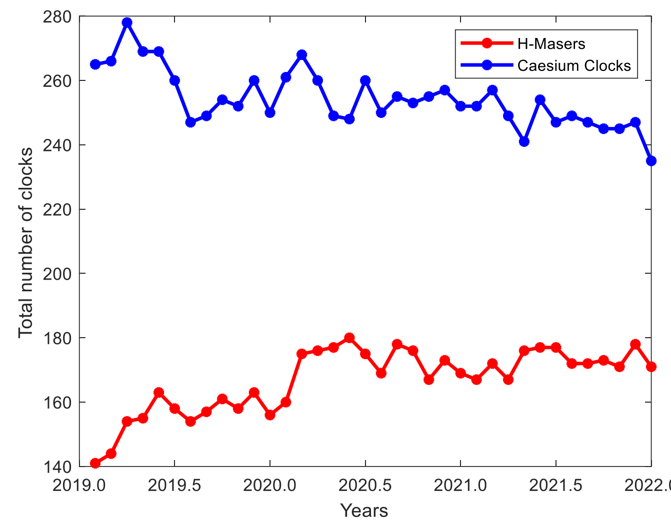
Many complex algorithms are used at this stage:

- **Weighting algorithm**
- **Prediction algorithm**
- Outliers, time and frequency steps detection etc.

Status of atomic clocks in UTC

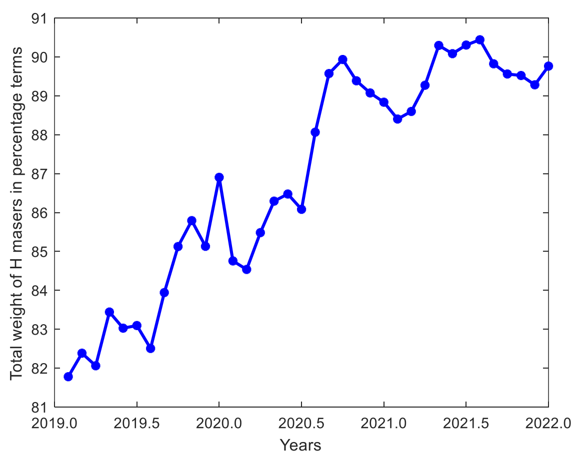
420 atomic clocks contributing to UTC of which:

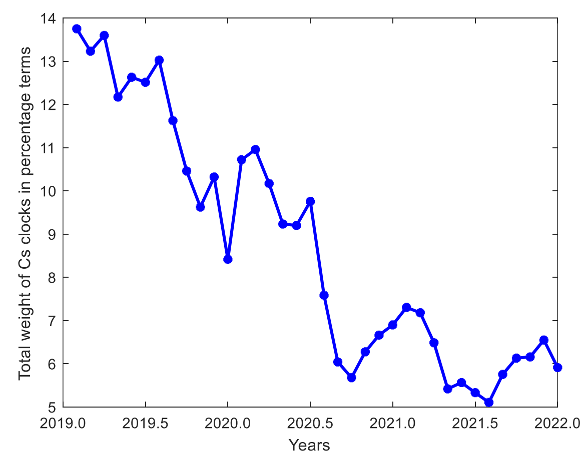
- ~180 H-Masers (from 140 to 180 in 2 years)
- ~230 Cs-clocks (from 270 to 230)



The weight of the clocks:

- ~ 90 % is assigned to H-masers
- ~ 7 % to Cs-clocks





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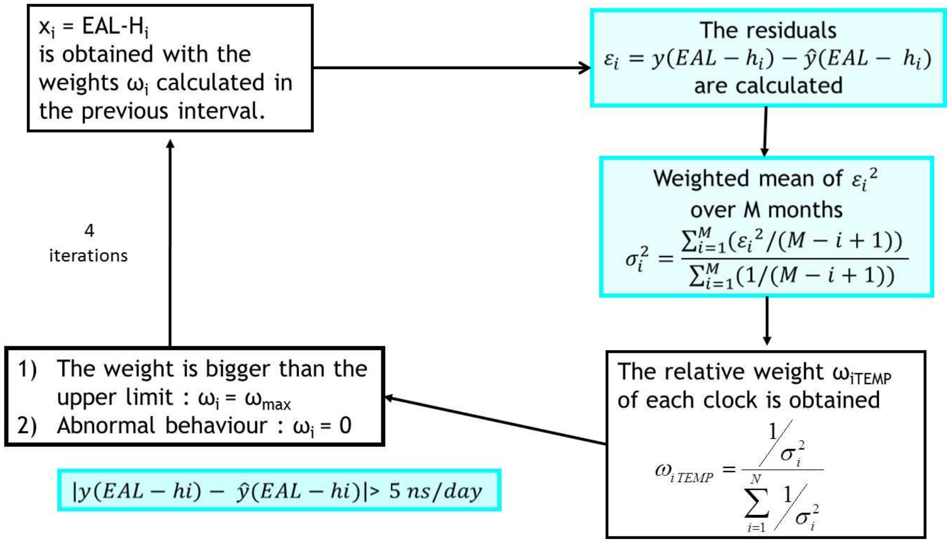
Weighting algorithm – new development

The algorithm is an iterative procedure where the weight is calculated as the inverse of a statistical estimator and subject to a maximum weight (6/N, N is the total number of clocks).



Generalization maximum weight constraints by using the Karush–Kuhn–Tucker conditions.

The idea is to allow the weight algorithm to select the correct number of most stable/predictable clocks and assign them the maximum weight.

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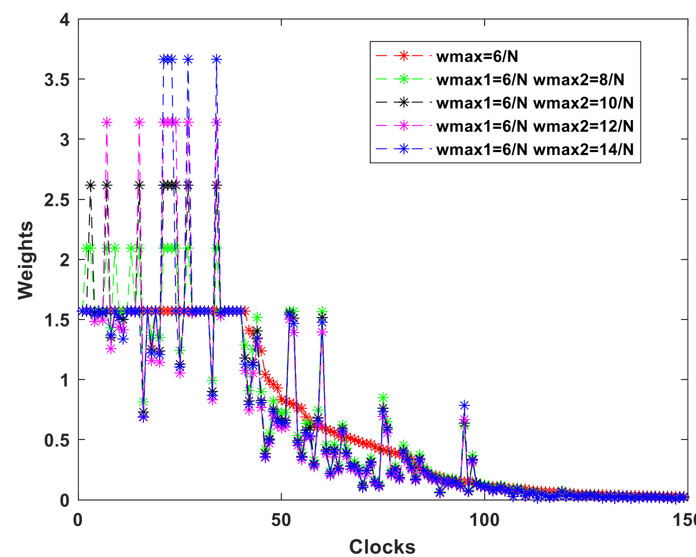
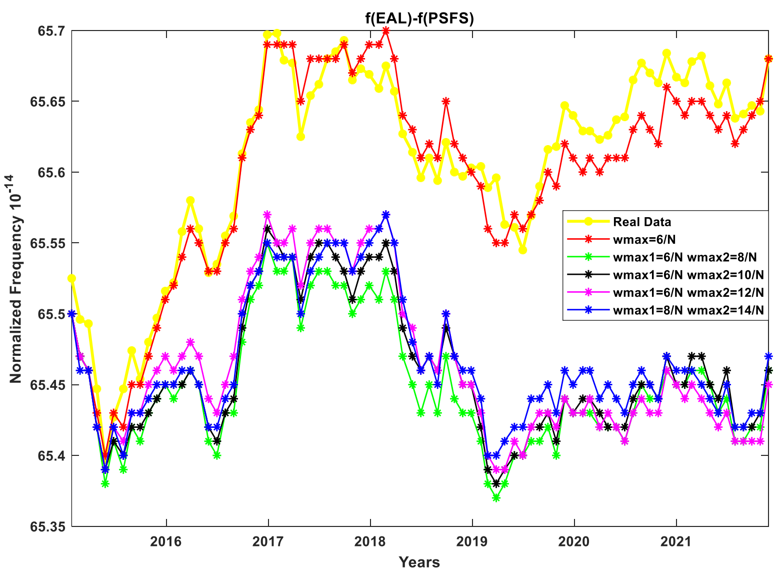
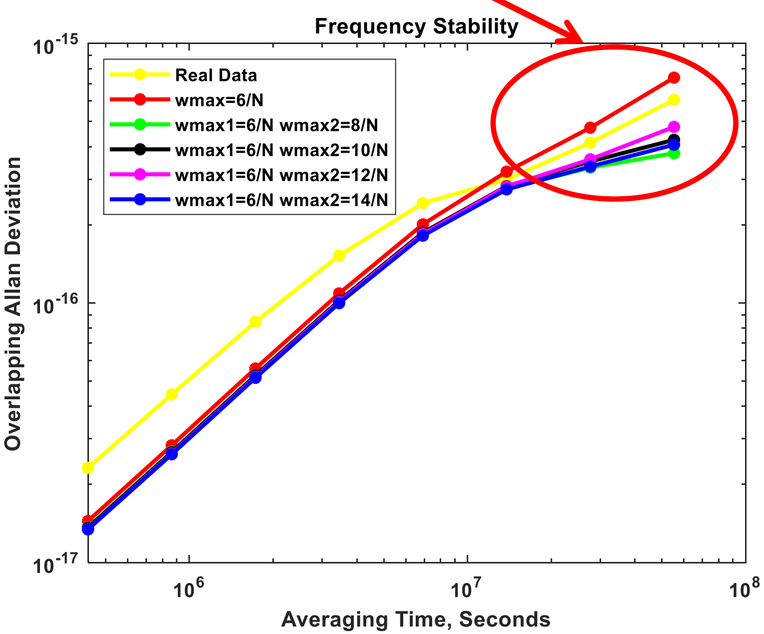


f(EAL)-f(PSFS) (TT(BIPM))

TT(BIPM) is a time scale calculated at BIPM and representing the best reference in frequency ⟹ used as reference to estimate the long-term stability of EAL.

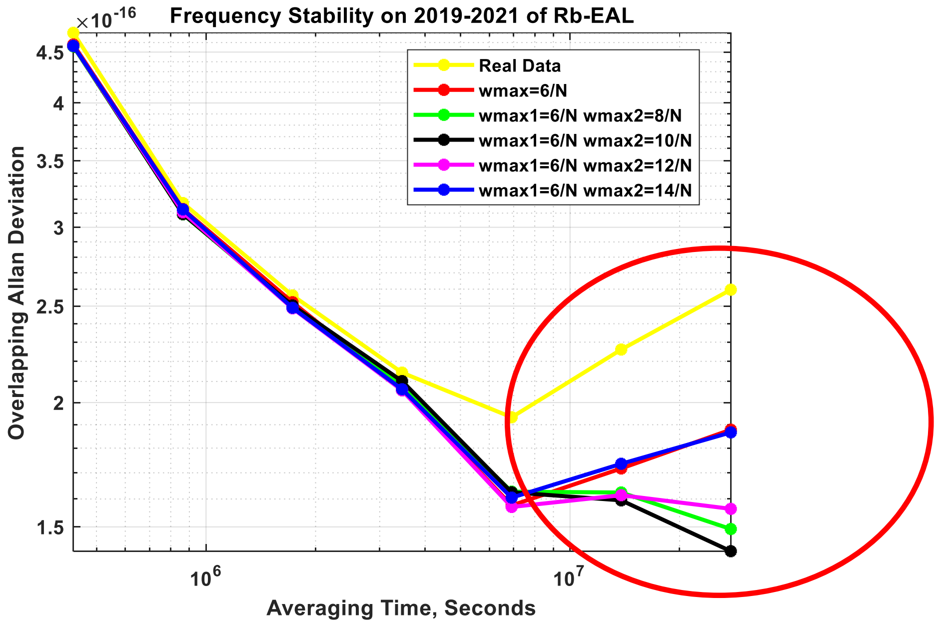
Improvement in the long term stability of EAL, UTC





Rb-EAL analysis

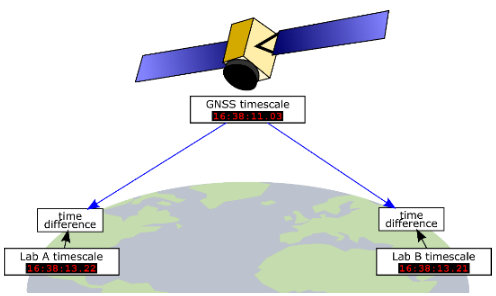
The Rb fountains (USNO) contribute to EAL (UTC) each month and represent a good reference to estimate the frequency stability of EAL.



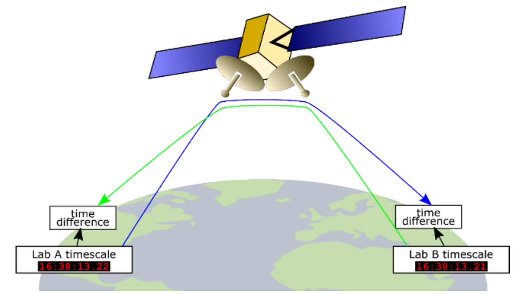
The use K-K-T conditions shows consistent results with the previous analysis i.e., improved results.

Clocks in different laboratories are compared by suitable time and frequency transfer techniques

Global Navigation Satellite Systems (GNSS)
GNSS are based on time broadcasting from satellites to ground receivers (one-way time transfer). Distant labs equipped with GNSS receivers periodically compare their clocks to the broadcasted time and send the result to the BIPM. Typical algorithms are All in View, Common View, and Precise Point Positioning



Two-Way Satellite Time & Freq. Transfer (TWSTFT)
dedicated ground terminals simultaneously receive and transmit time transfer signals (two-way time transfer) on geostationary telecom satellites. Two-way method cancels out (at first order) the propagation time of the signal.



Progress in GNSS measures

GPS+ GLONASS + Beidou + Galileo
IPPP : Precise Point Positioning with integer ambiguity resolution

Progress in TWSTFT

Software Designed Radio and TWSTFT Carrier Phase

In development : Optical Fiber links

A growing number of UTC laboratories are gaining access to fiber links dedicated to time and frequency. Although few of them are currently interconnected by operational, high-duty cycle links, this number is expected to grow quickly during the next decade.

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Time Links used for UTC calculation

5 - Time links used for the computation of TAI, calibrations information and corresponding uncertainties.

Link	Type	Equipment	Cal_ID1/Cal_ID2	uStb/ns	uCal/ns	uAg/ns	A1/ns	YYMM
ESA /PTB	GPSPPP	ES07 /PT13	1014-2022/1001-2020	0.3	2.6	0.9		
HKO /PTB	GPSPPP	HKO1 /PT13	1011-2018/1001-2020	0.4	3.2	2.0		
ICE /PTB	GPS MC	CE1_ /PT13	NA_A1 /1001-2020	3.5	7.3	1.6	-16.5	2111
IDN /PTB	GPSPPP	KI01 /PT13	1017-2018/1001-2020	0.3	3.1	1.8		
IFAG/PTB	GPSPPP	IF20 /PT13	1014-2020/1001-2020	0.3	2.7	1.1		
IGNA/PTB	GPSPPP	IG02 /PT13	NC_A1 /1001-2020	0.3	20.0		-7.0	2106
IMBH/PTB	GPSPPP	BH02 /PT13	1013-2022/1001-2020	0.3	2.6	0.9		
INCP/PTB	GPS MC	CP__ /PT13	NC /1001-2020	5.0	20.0			
INM /PTB	GPS MC	IC__ /PT13	NC /1001-2020	1.5	20.0			
INPL/PTB	GPSPPP	IL06 /PT13	2003-2016/1001-2020	0.3	7.4	2.5		
INTI/PTB	GPSPPP	INTI /PT13	1014-2021/1001-2020	0.3	3.0	0.9		
INXE/PTB	GPSPPP	NXRA /PT13	1012-2020/1001-2020	0.3	2.8	1.3		
IPQ /PTB	GPSPPP	IP05 /PT13	1017-2021/1001-2020	0.3	2.6	0.9		
JATC/PTB	GPSPPP	JA01 /PT13	1201-2018/1001-2020	0.3	3.1	1.9		
JV /PTB	GPSPPP	JV02 /PT13	1101-2017/1001-2020	0.3	4.5	2.1		
KRIS/PTB	GPSPPP	KRG1 /PT13	1017-2017/1001-2020	0.3	3.4	2.3		
KZ /PTB	GPS P3	KZ04 /PT13	1202-2021/1001-2020	0.7	4.1	0.9		
LRTE/PTB	GPS P3	LRRC /PT13	NC /1001-2020	0.7	20.0			
CH /PTB	TWSTFT	CH01 /PTB05	0543-2021	0.5	1.5	0.9		
IT /PTB	TWGPPP	IT01 /PTB05	0584-2022	0.3	1.7	1.0		
NIST/PTB	TWGPPP	NIST01/PTB05	0533-2021	0.3	2.5	1.9		

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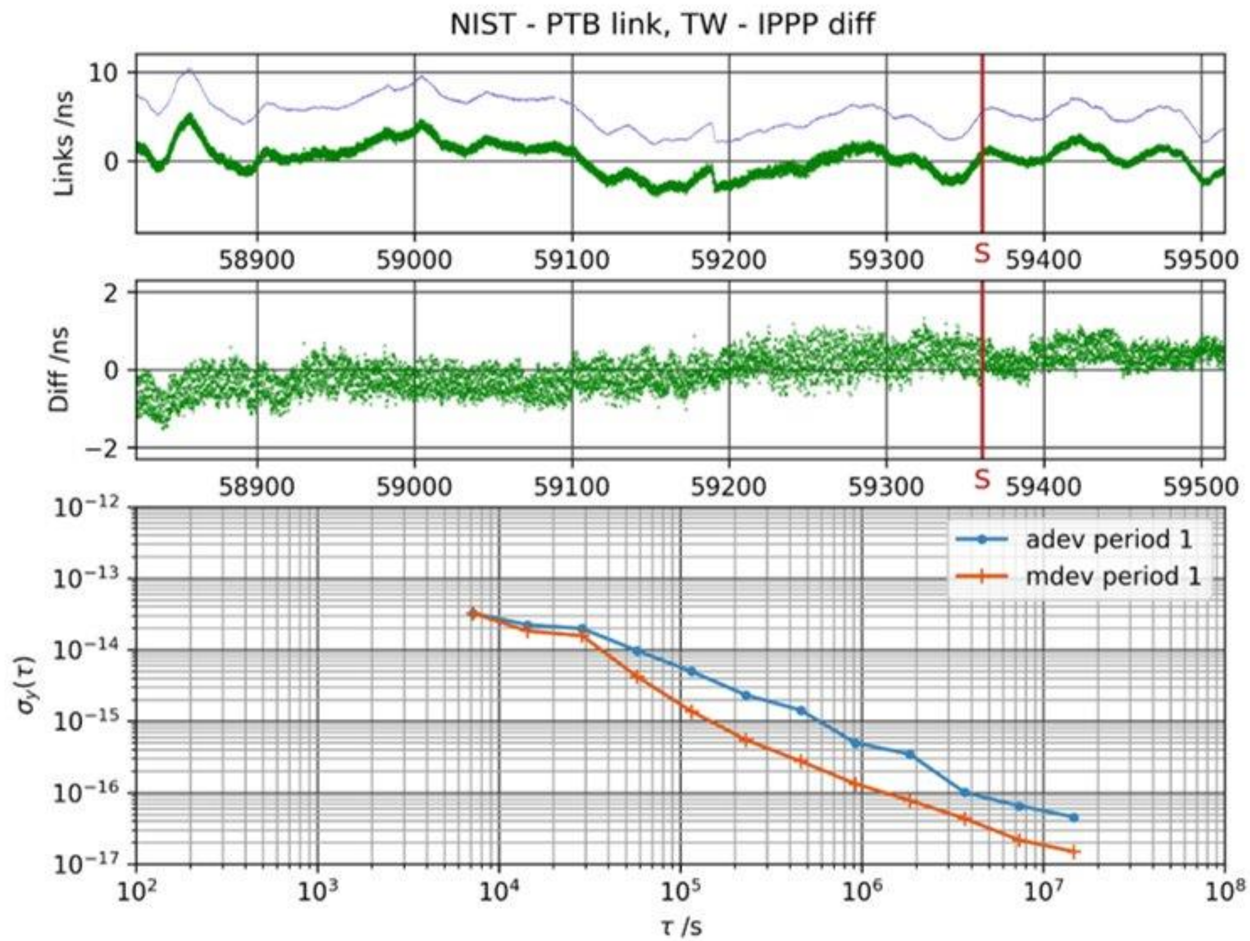
The calibration is a key issue to ensure the quality of UTC.

Future development: Regular computation of continuous IPPP links

Example:
NIST-PTB
TW and IPPP



•Significant diurnal in TW data
•Small but clear long-term drift-like instability.

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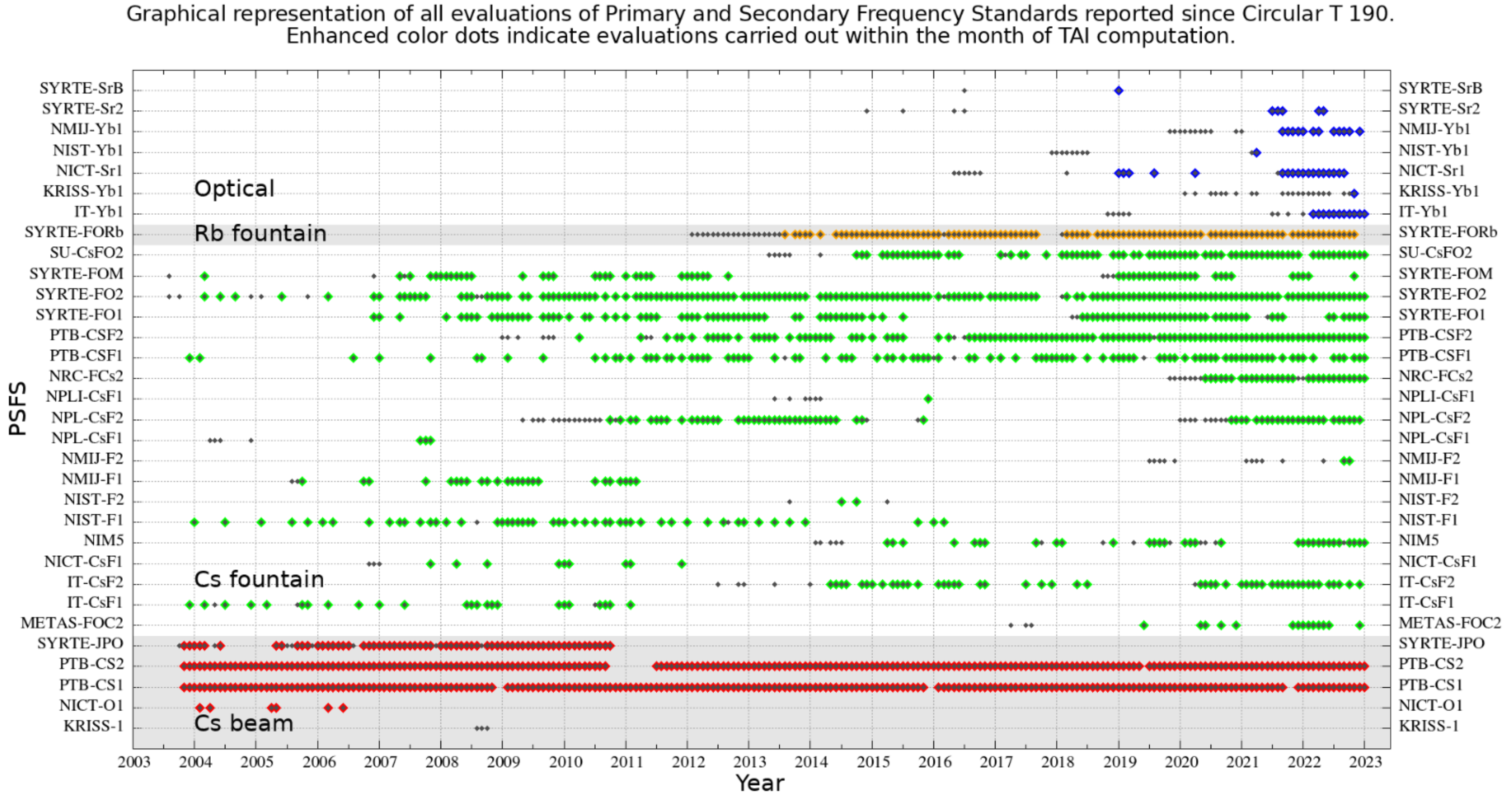
TAI calculation

Primary and Secondary standards contributing to UTC



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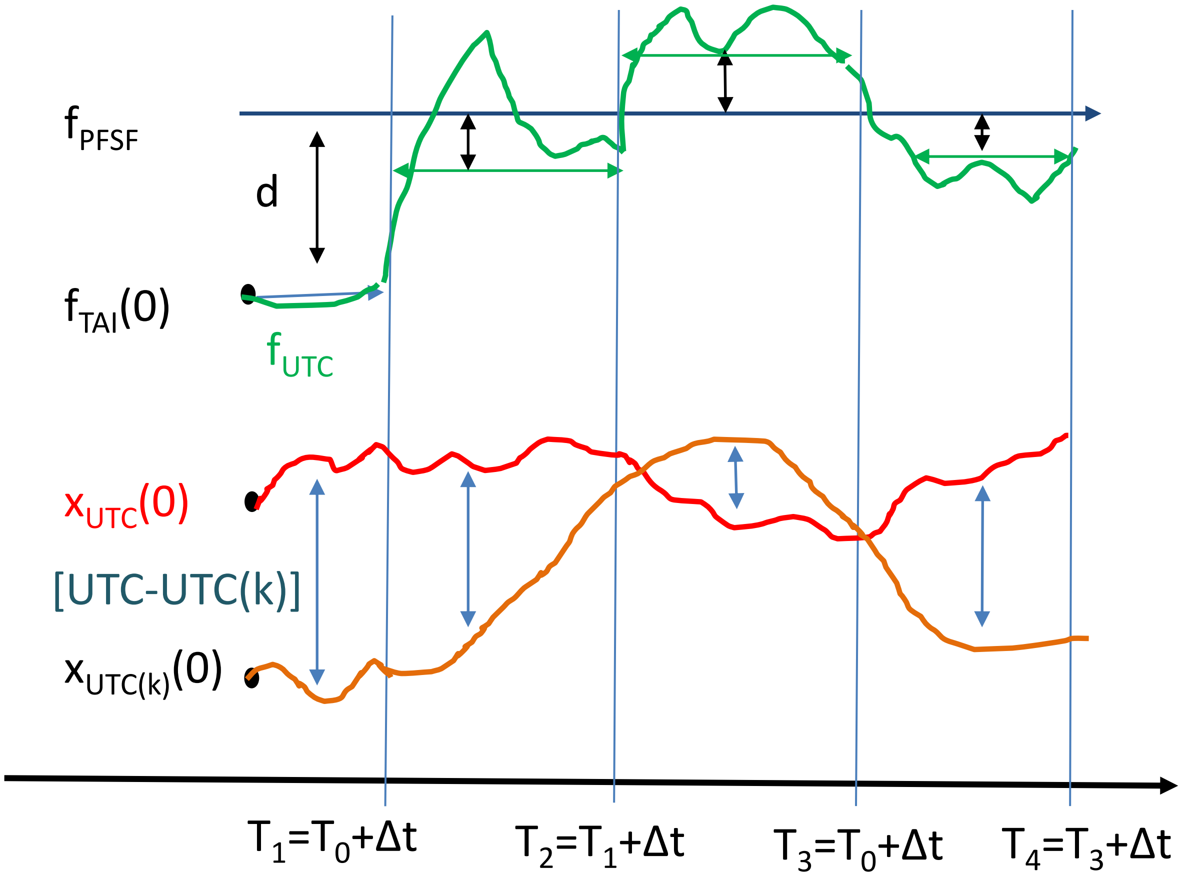
UTC, UTC(*k*) and [UTC-UTC(*k*)]



- UTC a time scale optimized to be stable in frequency at very long term. EAL provides the stability
- UTC unit is the SI second
- UTC is steered in **FREQUENCY** to be close to the frequency of PFSF (d published monthly in CirT)
- UTC(k) is generally steered in **FREQUENCY** and in **TIME** to be close to UTC

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Accuracy of UTC – Calculation of *d*

- Several laboratories in the world contribute to the accuracy of UTC providing the evaluations of PSFS to the BIPM.
- In Sec. 3 of Circular T:
  - The PSFS are evaluated singularly with respect to TAI
  - The algorithm used to calculate the Terrestrial Time (TT) is used to evaluate the frequency deviation of TAI (d = -y(TAI)) with respect to the ensemble of PSFS.

BIPM calculation — Laboratory contribution

$$f(TAI - PSFS) = \boxed{f(EAL - clock) - f(EAL - TAI)} - \boxed{f(SFS - clock)}$$

Labo	SFS	SfsCode	FreqRef	MJD1	MJD2	[Ref-SFS] 10E-15	uA 10E-15	uB 10E-15	uA/Lab 10E-15	uB/Lab 10E-15	Uptime %	Ref(uB)	uB(Ref) 10E-15	Ref_Freq
xxxx	xxxxxxxxxx	xxxxxxx	xxxxxxx	xxxxx	xxxxx	xxxxxxxxxxxx	xxxxxx	xxxxxx	xxxxxx	xxxxxx	xxxxxx	xxxxxx	xxxxxx	xxxx
KRIS	KRISS-Yb1	1885601	1405628	59849	59854	-693.46	0.01	0.04	0.41	0.07	12.1	T405	0.03	2021

ADDITIONAL INFORMATION :
Reported by : KRISS
Date of report : 09 11 2022
Name of the reporter : Myoung-Sun Heo

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Section 3 of Circular T

	Interval of validity	f(EAL)-f(TAI)	
Steering correction	59849 - 59879	6.501x10**-13	(2022 SEP 27 - 2022 OCT 27)
New correction	59879 - 59909	6.500x10**-13	(2022 OCT 27 - 2022 NOV 26)
New correction foreseen	59909 - 59944	6.498x10**-13	(2022 NOV 26 - 2022 DEC 31)

Applied and foreseen steering

3 - Duration of the TAI scale interval d.

Table 1: Estimate of d by individual PSFS measurements and corresponding uncertainty.
All values are expressed in 10**-15 and are valid only for the stated period of estimation.

Standard	Period of Estimation	d	uA	uB	uA/Lab	uB/Lab	ul/Tai	u	uSrep	Ref(uS)	Ref(uB)	uB(Ref)	Uptime %	LastRep	Nrep3y	Steer	Note
PTB-CS1	59849 59879	4.79	8.00	8.00	0.00	0.00	0.07	11.31	PFS/NA		T148	8.00	100.0	T417	34	Y	(1)
PTB-CS2	59849 59879	3.17	5.00	12.00	0.00	0.00	0.07	13.00	PFS/NA		T148	12.00	100.0	T417	36	Y	(1)
IT-Yb1	59849 59879	0.16	0.00	0.03	0.21	0.02	0.20	0.29	0.19	[1]	T383	0.03	12.1	T417	18	Y	(2)
KRISS-Yb1	59849 59854	0.50	0.01	0.04	0.41	0.07	0.98	1.07	0.19	[1]	T405	0.03	12.1	T417	21	Y	(3)
NIM5	59849 59879	-0.02	0.33	0.90	0.10	0.01	0.20	0.98	PFS/NA		T340	1.40	98.6	T417	20	Y	(4)
NPL-CsF2	59849 59879	0.16	0.08	0.21	0.10	0.03	0.20	0.32	PFS/NA		T284	0.23	92.3	T417	31	Y	(5)
NRC-FCs2	59849 59879	0.95	0.15	0.55	0.17	0.00	0.20	0.63	PFS/NA		T389	0.23	62.7	T417	37	Y	(6)
SYRTE-FO1	59849 59879	0.72	0.20	0.38	0.07	0.00	0.20	0.48	PFS/NA		T301	0.37	85.8	T417	24	Y	(7)
SYRTE-FO2	59849 59879	0.39	0.20	0.33	0.07	0.00	0.20	0.44	PFS/NA		T301	0.23	82.4	T417	35	Y	(7)
SYRTE-FOM	59849 59879	0.76	0.25	0.53	0.06	0.00	0.20	0.62	PFS/NA		T372	0.70	83.0	T409	15	Y	(7)
SYRTE-FORb	59849 59879	0.69	0.20	0.33	0.06	0.00	0.20	0.44	0.34	[1]	T328	0.34	84.1	T417	35	Y	(7)
PTB-CSF1	59849 59879	0.35	0.07	0.31	0.01	0.00	0.07	0.32	PFS/NA		T371	0.27	97.7	T416	27	Y	(8)
PTB-CSF2	59849 59879	0.18	0.10	0.17	0.01	0.00	0.07	0.21	PFS/NA		T370	0.17	98.0	T417	40	Y	(8)
SU-CsFO2	59849 59879	0.51	0.23	0.22	0.11	0.00	0.20	0.39	PFS/NA		T315	0.50	89.0	T417	33	Y	(9)

Notes:
(1) Continuously operating as a clock participating to TAI
(2) Report dated 31 OCT. 2022 by INRIM
(3) Report dated 09 NOV. 2022 by KRISS (new height evaluation)
(4) Report dated 02 NOV. 2022 by NIM
(5) Report dated 31 OCT. 2022 by NPL
(6) Report dated 28 OCT. 2022 by NRC
(7) Report dated 03 NOV. 2022 by LNE-SYRTE
(8) Report dated 01 NOV. 2022 by PTB
(9) Report dated 31 OCT. 2022 by SU
[1] CCTF Recommendation PSFS-2 (2021),22nd meeting (session II online),
available at https://www.bipm.org/en/committees/cc/cctf/22-_2-2021

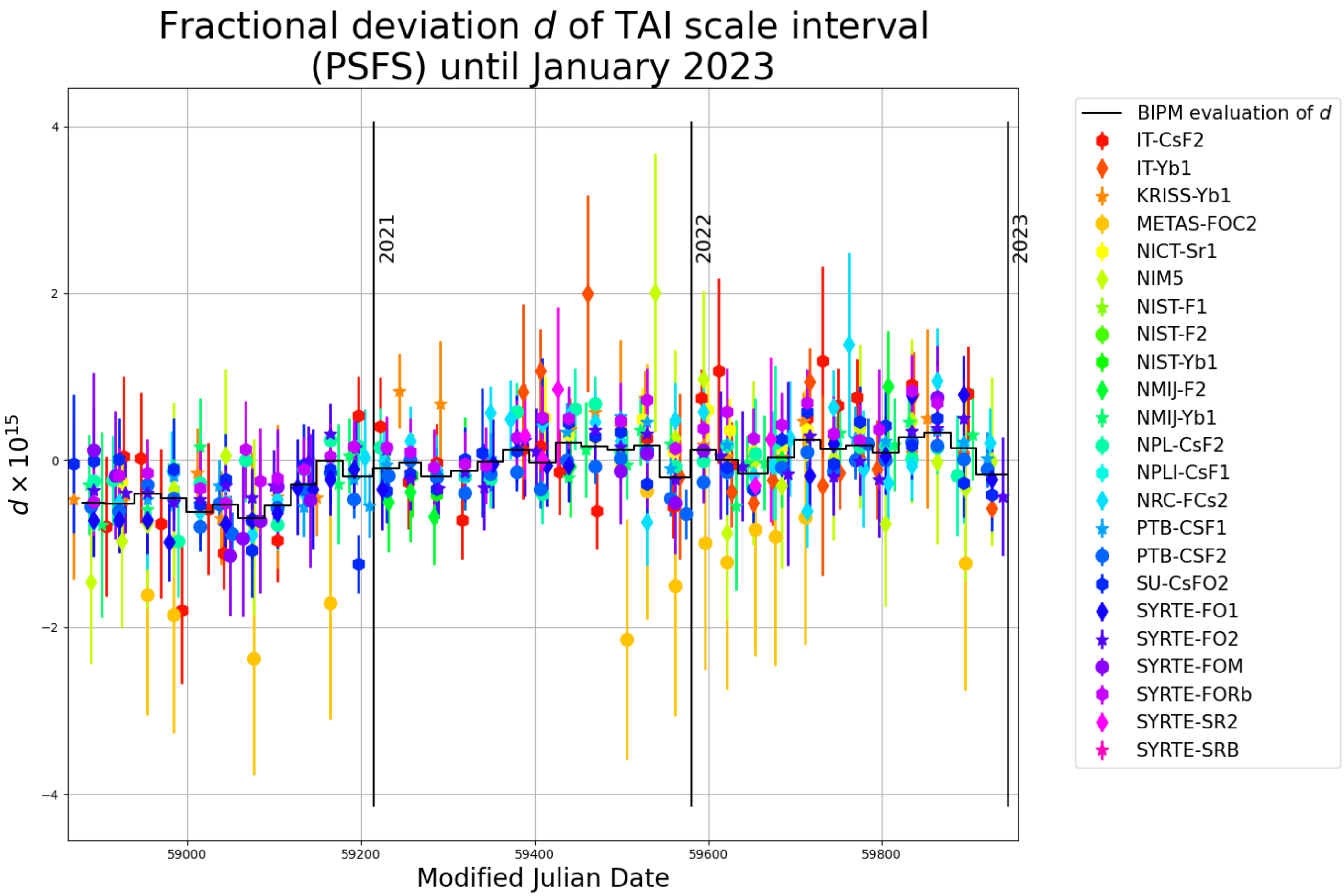
Table 2: Estimate of d by the BIPM based on all PSFS measurements identified to be used for TAI steering over the period MJD 59489-59879, and corresponding uncertainties.

Period of estimation	d	u	
59849-59879	0.33x10**-15	0.11x10**-15	(2022 SEP 27 - 2022 OCT 27)

-y(TAI) and uncertainty

If |d|>= 1 x 10^{-15} a correction of about 0.2 x 10^{-15} is applied two months later.

d values



https://webtai.bipm.org/database/d_plot.html

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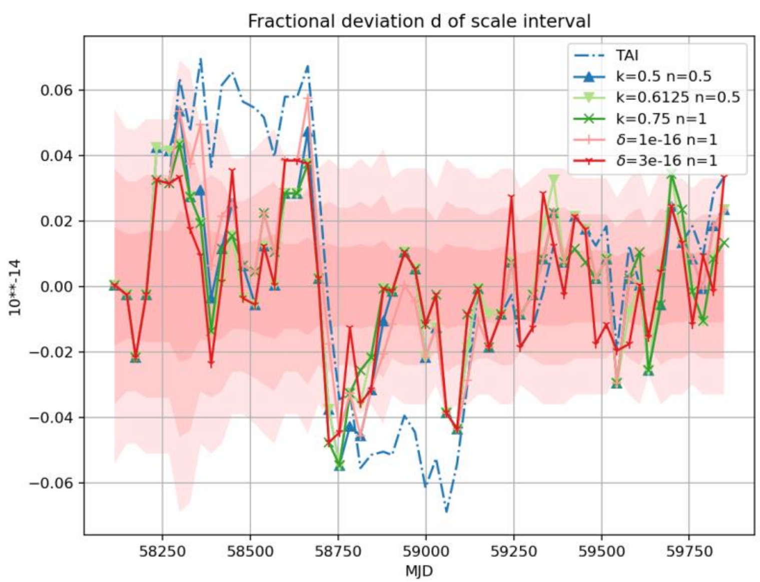
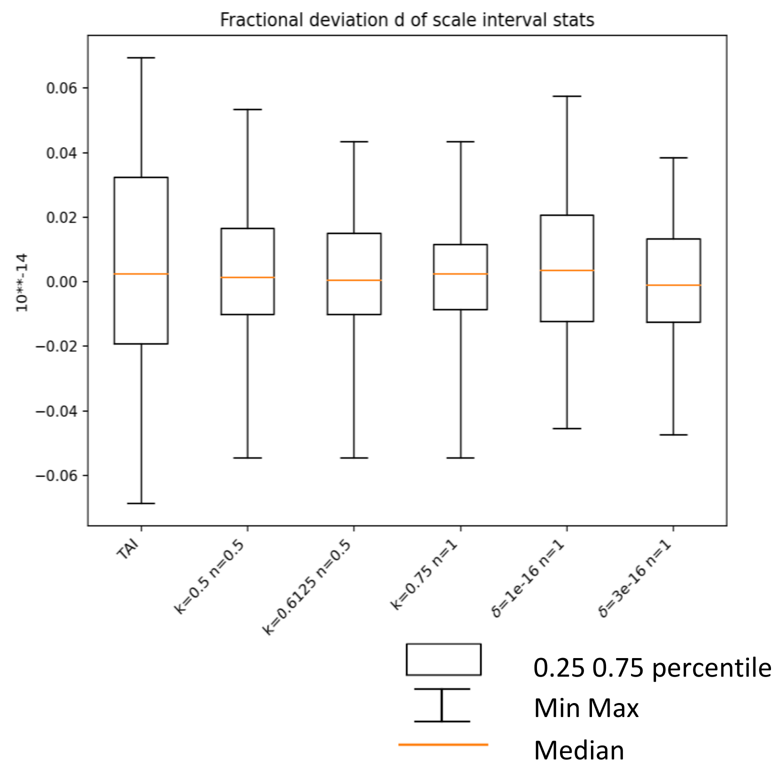
New development – new steering strategies

- The scope of this study is to evaluate different steering strategies to achieve:
  - Improvement of long-term stability/accuracy of UTC/TAI
  - a value *d* as small as possible over the different months
- In doing so it is important to avoid a degradation of the middle term stability (EAL contribution) due to steering procedures.





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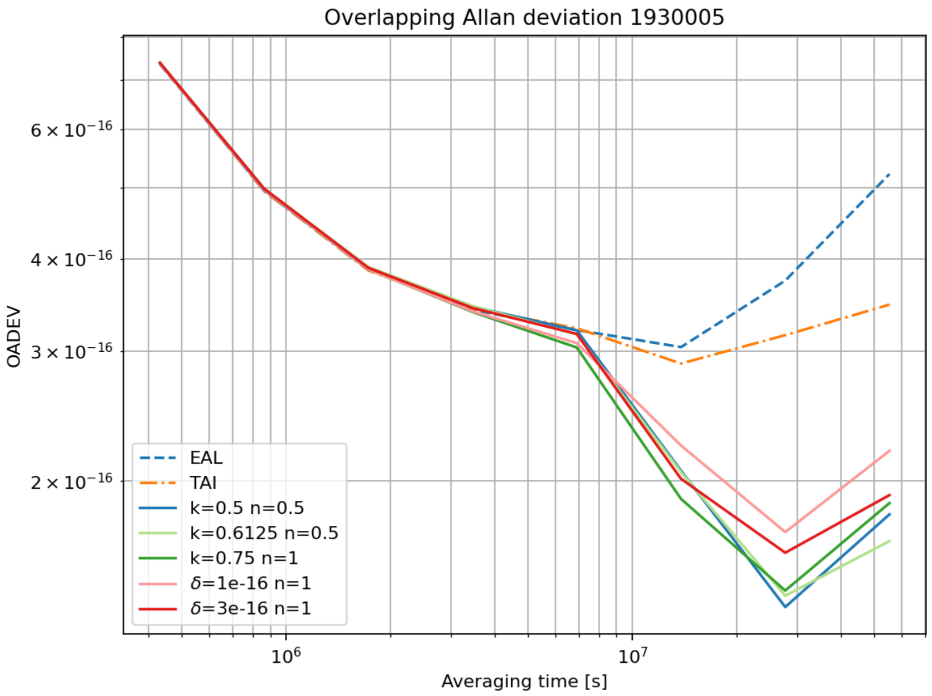
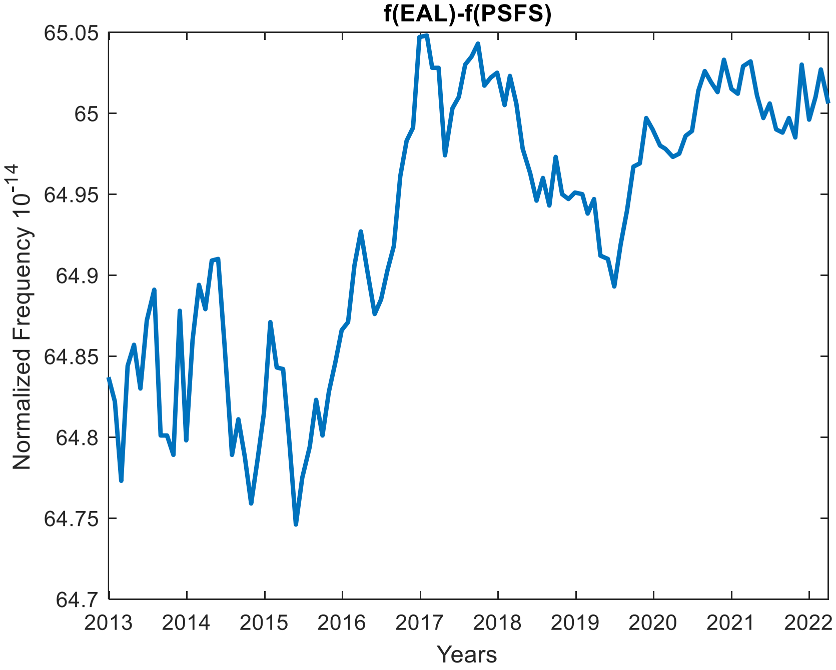
Preliminary results of new strategies

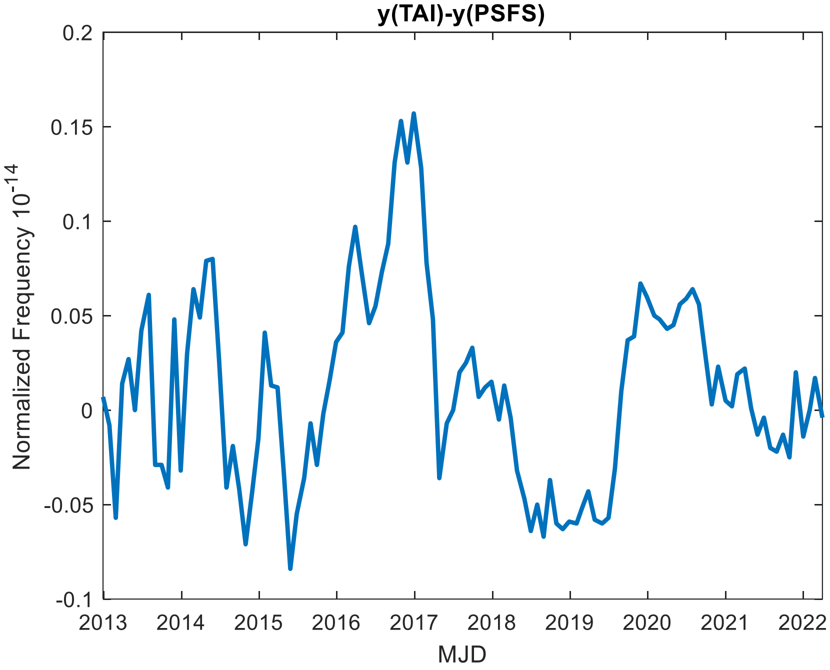
- Applying a regular steering improves the long-term stability of UTC.
- From the stats (previous slide) better results are obtained with proportional steering technique
- In the most recent period, particularly quiet for TAI, there is almost no need of steering.



EAL and TAI versus PSFS

The Primary and secondary frequency standards (PFSF) are also used to evaluate the behaviour of EAL and TAI. After each calculation month the we evaluate the plot the f(EAL-PSFS) and f(TAI-PSFS) to check and verify them.





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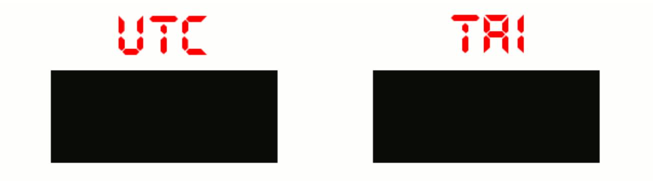
UTC calculation

Since 1975, UTC is obtained from the International Atomic Time (TAI) plus leap seconds.

When the difference between the Earth rotational angle UT1 time scale and UTC reaches 0.9 second, an integer second is inserted to UTC to keep it within 1 s of UT1.

UTC = TAI + leap seconds



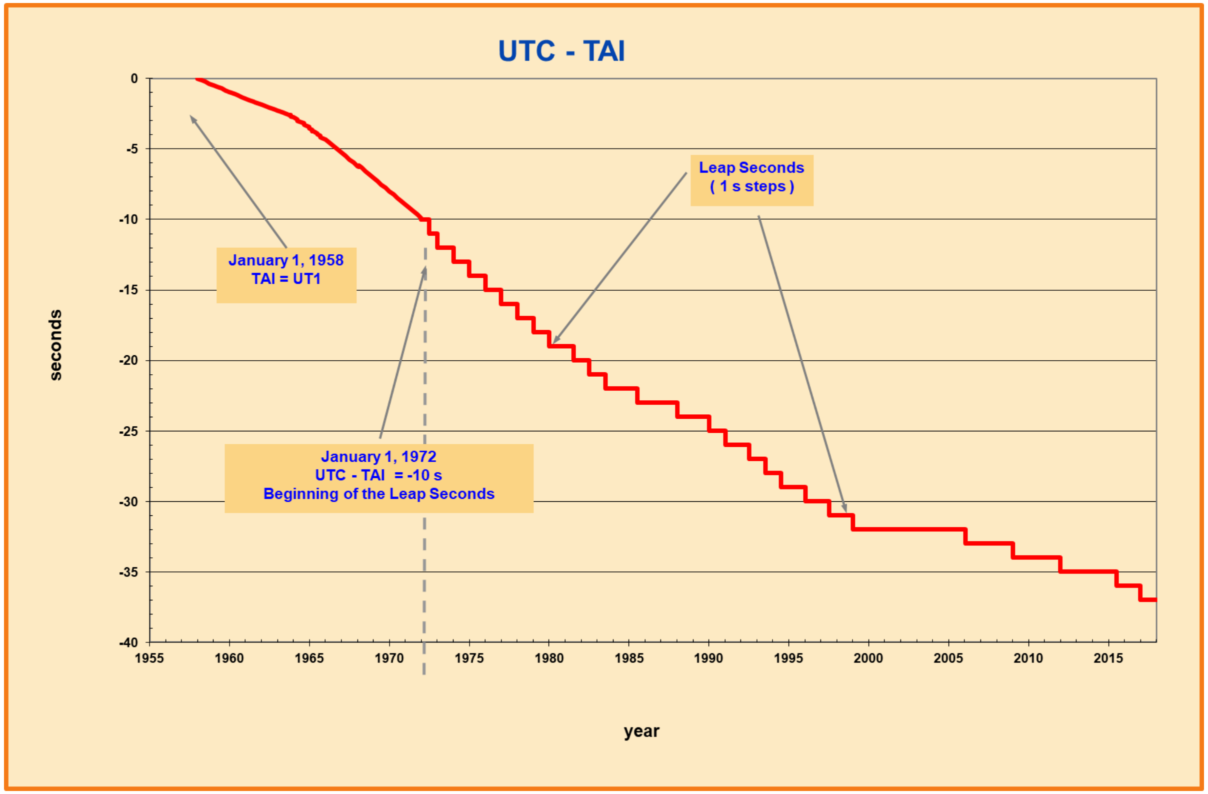
UTC = TAI + n seconds

|UTC - UT1| < 1 second

23:59:59
23:59:60
00:00:00

Can be negative (never happened until now)

23:59:58
00:00:00



Circular T – [UTC-UTC(k)]

The laboratories have direct access to UTC through your local realization of UTC, so called ‘UTC(k)’, via the **BIPM** ***CircularT*** monthly publication: differences [*UTC-UTC(k)*] are published, with time spacing of 5 days.

Bureau International des Poids et Mesures

CIRCULAR T 420

2023 JANUARY 13, 15h UTC

ISSN 1143-1393

BUREAU INTERNATIONAL DES POIDS ET MESURES
THE INTERGOVERNMENTAL ORGANIZATION ESTABLISHED BY THE METRE CONVENTION
PAVILLON DE BRETEUIL F-92312 SEVRES CEDEX TEL. +33 1 45 07 70 70 tai@bipm.org

The contents of the sections of BIPM *Circular T* are fully described in the document " Explanatory supplement to BIPM Circular T " available at https://webtai.bipm.org/ftp/pub/tai/other-products/notes/explanatory_supplement_v0.6.pdf

1 - Difference between UTC and its local realizations UTC(k) and corresponding uncertainties. From 2017 January 1, 0h UTC, *TAI-UTC* = 37 s.

Date 2022 0h UTC		NOV 26	DEC 1	DEC 6	DEC 11	DEC 16	DEC 21	DEC 26	DEC 31	Uncertainty/ns			Notes
	MJD	59909	59914	59919	59924	59929	59934	59939	59944	u_A	u_B	u	
Laboratory *k*		[*UTC-UTC(k)*]/ns											
AGGO	(La Plata)	1011.8	1030.6	1033.1	1031.2	1036.6	1058.3	1079.7	1087.1	0.7	2.8	2.9	
AOS	(Borowiec)	-4.5	-3.5	-2.7	-1.2	0.0	0.8	2.3	3.1	0.3	3.3	3.3	
APL	(Laurel)	-0.7	-0.7	-0.5	-0.6	3.2	-1.0	-1.6	-0.3	0.3	19.3	19.3	
AUS	(Sydney)	-554.5	-552.1	-545.3	-550.3	-566.6	-562.0	-546.7	-553.2	0.3	11.2	11.2	
BEV	(Wien)	48.6	35.5	32.7	22.8	21.4	24.8	22.1	13.1	0.3	2.8	2.8	
BFKH	(Budapest)	6218.9	6250.7	6283.3	6312.6	6353.0	6381.0	6410.1	6438.3	1.5	20.0	20.1	
BIM	(Sofiya)	17002.2	17024.4	17010.2	17037.4	17048.1	17069.1	17104.7	17123.7	0.3	7.3	7.3	
BIRM	(Beijing)	6.9	5.6	4.6	4.1	4.0	3.7	4.2	6.6	0.3	3.2	3.2	
BOM	(Skopje)	-	-	-	-	-	-	-	-				
BY	(Minsk)	-0.1	0.1	0.9	-0.2	-0.7	-0.5	-0.3	-0.2	1.5	3.0	3.3	
CAO	(Cagliari)	-639.2	-759.6	-874.9	-994.0	-1110.7	-1230.7	-1350.5	-1472.1	1.5	20.0	20.1	
CH	(Bern-Wabern)	-2.0	-3.0	-2.9	-2.8	-2.9	-1.6	-0.9	-0.2	0.5	1.8	1.9	
CNES	(Toulouse)	-18.1	-19.0	-7.7	-3.3	-3.5	-3.5	-4.3	-3.4	0.3	2.8	2.8	
CNM	(Queretaro)	-0.2	2.8	2.9	1.3	-0.5	-0.7	-3.2	-2.1	1.5	4.1	4.4	
CNMP	(Panama)	-3.5	1.6	-4.9	-14.3	2.8	2.0	6.6	2.3	0.3	5.3	5.3	
DFM	(Horsholm)	-5.7	-5.1	-7.4	-10.1	-13.3	-5.4	-6.4	-7.9	0.3	2.8	2.8	
DFNT	(Tunis)	6423.4	6526.7	6635.2	6732.9	6837.4	6951.1	7047.0	7143.7	0.7	20.0	20.0	
DLR	(Oberpfaffenhofen)	15.8	12.3	9.3	6.1	2.1	-0.5	-2.6	-3.8	0.7	2.8	2.9	
DMDM	(Belgrade)	-	-	-	-14.2	-9.3	-4.2	-0.9	-2.9	0.3	3.7	3.7	
DTAG	(Frankfurt/M)	53.5	53.6	39.5	29.0	26.7	18.9	13.8	15.5	0.3	3.2	3.2	
EIM	(Thessaloniki)	-	-	-	-	-	-	-	-				
ESA	(Noordwijk)	-0.1	1.0	2.1	3.1	3.3	3.3	2.4	1.5	0.3	2.7	2.8	
HKO	(Hong Kong)	724.7	743.2	760.3	785.0	803.0	815.8	839.8	861.4	0.4	3.3	3.4	
ICE	(San Jose)	31.2	56.6	29.0	35.7	39.6	15.2	-6.1	-19.4	3.5	7.4	8.2	
IDN	(Serpong-Tangerang)	669.8	664.4	683.5	731.3	774.4	793.1	803.7	833.5	0.3	3.3	3.3	
IFAG	(Wettzell)	-856.3	-	-	-855.0	-853.6	-851.8	-848.9	-842.2	0.3	2.9	2.9	
IGNA	(Buenos Aires)	-102.7	-177.7	-248.4	-319.1	-389.8	-463.6	-546.3	-620.3	0.3	20.0	20.0	
IMBH	(Sarajevo)	0.7	0.3	-0.8	-0.5	-2.2	-3.0	0.5	4.6	0.3	2.8	2.8	
INCP	(Lima)	-68.3	-	-	-	-	-	-	-	5.0	20.0	20.6	
INM	(Bogota D.C.)	178.0	175.0	174.1	160.6	169.3	158.6	135.0	115.8	1.5	20.0	20.1	
INPL	(Jerusalem)	-8.2	-8.5	-12.3	-5.5	-12.4	-19.0	-16.0	-11.3	0.3	7.5	7.5	
INTI	(Buenos Aires)	232.4	244.3	237.1	237.3	236.7	247.1	239.2	234.5	0.3	3.2	3.2	
INXE	(Rio de Janeiro)	-24.5	-20.4	-5.5	13.2	20.3	34.3	47.0	49.3	0.3	3.0	3.0	
IPQ	(Caparica)	705.5	707.2	705.2	700.2	694.1	695.7	704.7	705.3	0.3	2.8	2.8	
IT	(Torino)	0.6	0.5	0.7	1.2	0.8	0.2	-0.2	0.2	0.3	1.9	2.0	
JATC	(Lintong)	-0.2	-0.5	0.2	0.3	0.6	1.0	1.1	1.2	0.3	3.3	3.3	
JV	(Kjeller)	5.7	5.7	6.4	7.5	7.6	6.9	5.9	5.6	0.3	4.6	4.6	
KRIS	(Daejeon)	0.0	1.1	1.8	2.1	2.8	3.5	3.9	4.9	0.3	3.5	3.5	

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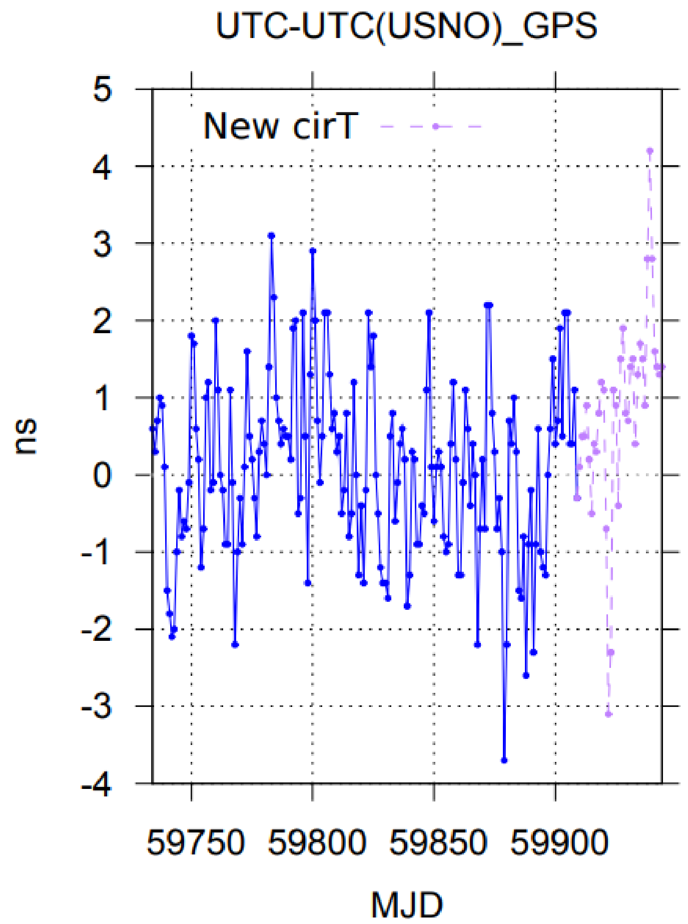
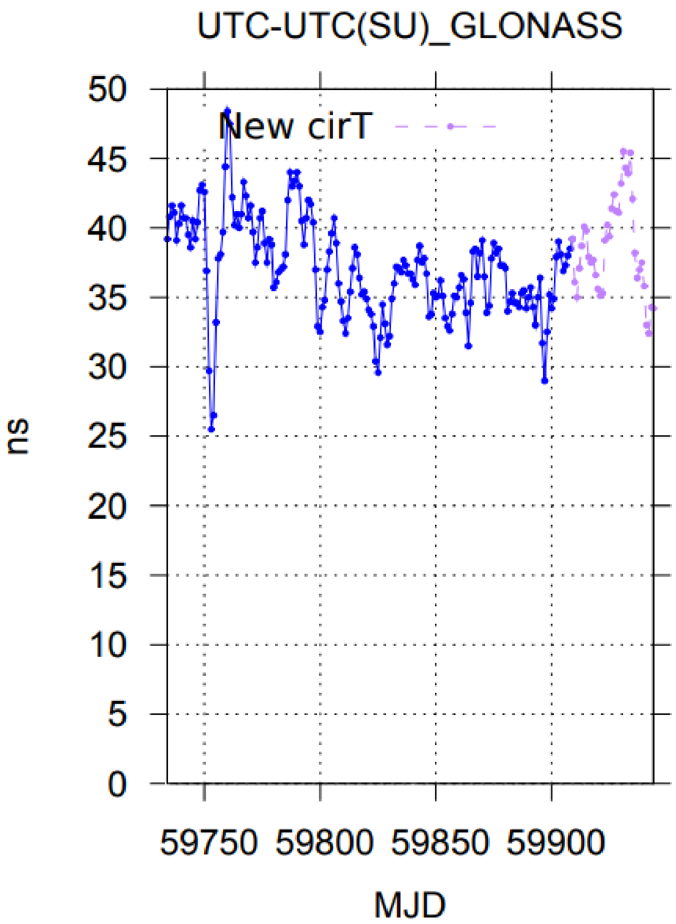
Circular T - Relations of UTC and TAI with predictions of UTC(k) disseminated by GNSS





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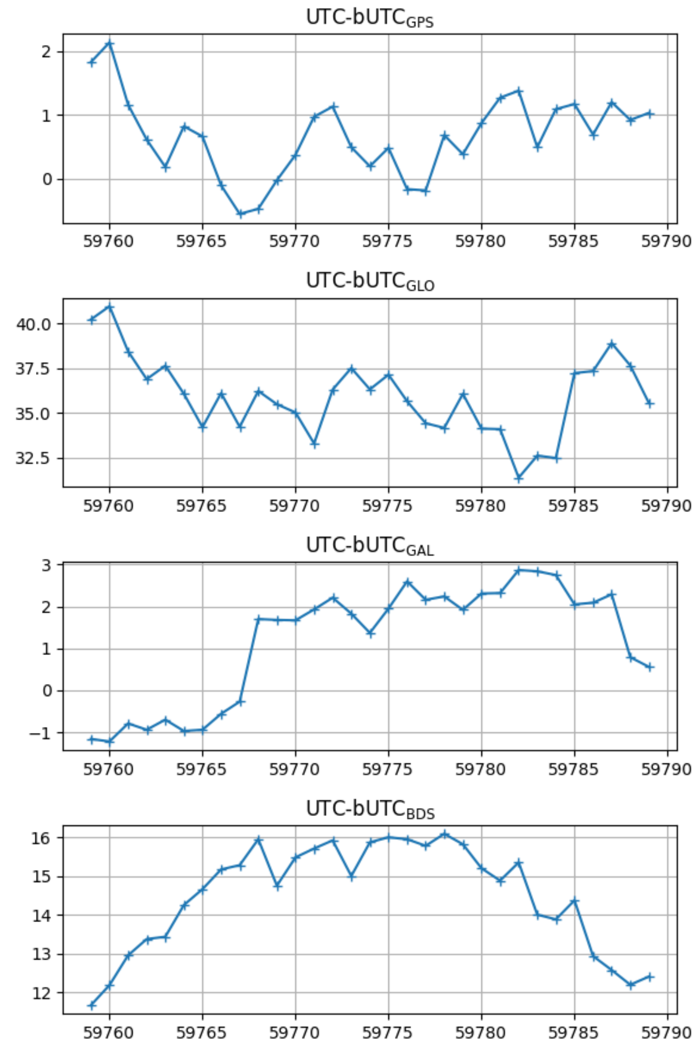
Future development GNNS Broadcast solution

Publication of GPS, GLONASS, Galileo and Beidou

Date	MJD	UTC-bUTC$_{GPS}$ /ns	UTC-bUTC$_{GLO}$ /ns	UTC-bUTC$_{GAL}$ /ns	UTC-bUTC$_{BDS}$ /ns
2022-06-29	59759	1.83	40.22	-1.16	11.66
2022-06-30	59760	2.14	40.96	-1.22	12.18
2022-07-01	59761	1.16	38.44	-0.79	12.95
2022-07-02	59762	0.61	36.89	-0.94	13.37
2022-07-03	59763	0.18	37.64	-0.70	13.43
2022-07-04	59764	0.82	36.07	-0.97	14.25
2022-07-05	59765	0.66	34.21	-0.94	14.66
2022-07-06	59766	-0.11	36.11	-0.56	15.17
2022-07-07	59767	-0.56	34.23	-0.27	15.28
2022-07-08	59768	-0.48	36.23	1.70	15.95
2022-07-09	59769	-0.03	35.49	1.68	14.75
2022-07-10	59770	0.37	35.03	1.67	15.48



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UTCr – the rapid realization of UTC

Since 2013 a rapid evaluation of UTC is available, UTCr.

The data are on daily batches and published each week, the Wednesday.

The number of participating laboratories is slightly increased in the last years.

UTCr_2303
2023 JANUARY 25, 08h UTC

BUREAU INTERNATIONAL DES POIDS ET MESURES
THE INTERGOVERNMENTAL ORGANIZATION ESTABLISHED BY THE METRE CONVENTION
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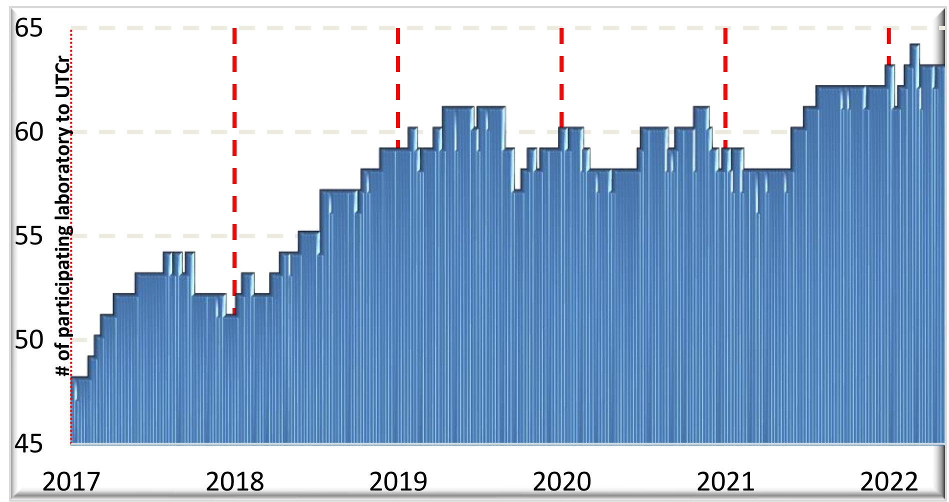
Computed values of [UTCr-UTC(k)]

Date 2023 0h UTC	JAN 16	JAN 17	JAN 18	JAN 19	JAN 20	JAN 21	JAN 22
MJD	59960	59961	59962	59963	59964	59965	59966
Laboratory k				[UTCr-UTC(k)]/ns			
AOS (Borowiec)	5.0	5.0	5.3	5.2	5.2	-	-
AUS (Sydney)	-534.5	-537.5	-532.5	-528.1	-528.2	-528.6	-532.2
BEV (Wien)	-3.7	-3.4	1.1	3.4	1.0	-2.2	1.0
BIRM (Beijing)	5.2	5.0	4.6	5.0	5.2	5.4	5.7
CH (Bern-Wabern)	0.2	-0.4	0.4	0.8	0.4	-0.0	-0.1
CNM (Queretaro)	-2.8	-4.7	-5.2	-0.3	-0.1	-3.1	-1.9
CNMP (Panama)	-5.9	-2.6	-3.8	3.1	11.5	5.6	-3.9
DLR (Oberpfaffenhofen)	-3.1	-2.6	-2.3	-2.0	-1.9	-1.8	-1.3
DMDM (Belgrade)	15.5	14.4	10.6	10.6	10.1	6.0	6.7
DTAG (Frankfurt/M)	2.3	2.9	1.8	1.3	-0.1	-1.1	0.7
ESA (Noordwijk)	2.5	2.7	2.9	3.0	2.9	2.8	3.1
HKO (Hong Kong)	921.1	924.7	927.5	932.9	938.0	945.0	946.9
ICE (San Jose)	-62.0	-64.7	-72.8	-72.9	-75.1	-62.6	-67.5
IFAG (Wettzell)	-842.4	-841.6	-840.7	-840.3	-840.5	-837.5	-835.2
IGNA (Buenos Aires)	-851.0	-865.7	-881.4	-895.5	-908.6	-917.1	-938.1
IMBH (Sarajevo)	0.6	3.2	4.3	4.8	5.0	4.2	4.4
INTI (Buenos Aires)	222.5	214.8	219.8	216.5	219.6	217.5	211.1
INXE (Rio de Janeiro)	55.9	53.1	46.4	41.6	36.3	32.8	32.5
IPQ (Caparica)	717.3	718.1	717.3	716.9	719.6	717.1	718.2
IT (Torino)	3.3	3.6	3.6	3.8	3.4	3.1	3.0
JV (Kjeller)	7.8	7.8	7.6	7.7	7.4	7.5	7.0
KRIS (Daejeon)	0.4	0.2	-0.4	-0.3	-0.8	-0.7	-1.2

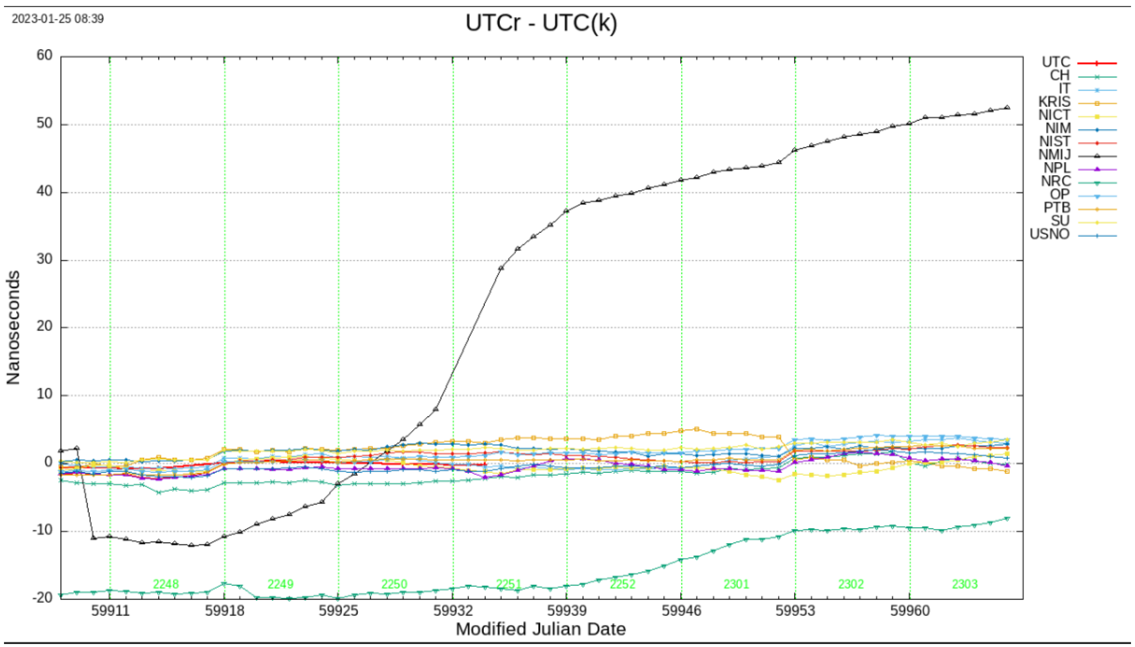


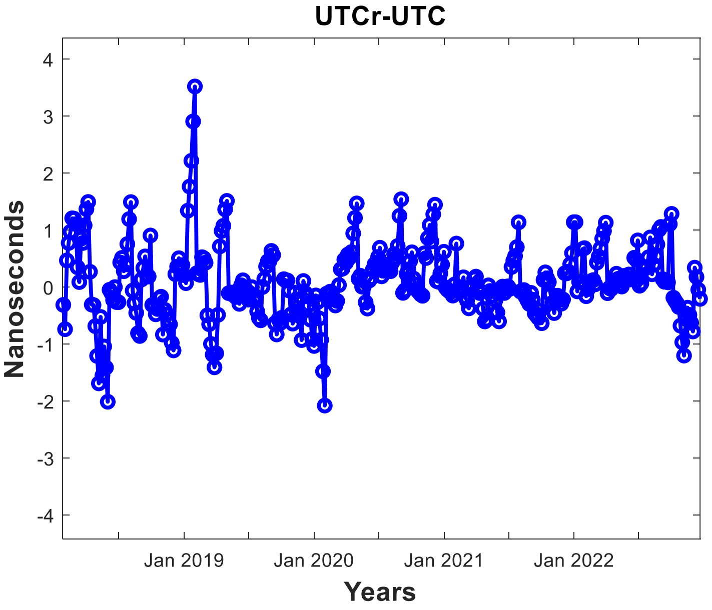
UTCr versus UTC

For the week 2303 for example we had 63 participating laboratories with 260 atomic clocks.

Concerning the time links we apply the following politics:

- if in UTC the combination of TW and GPS PPP is used ⟹ in UTCr the TW
- If in UTC we use GPS PPP ⟹ in UTCr GPS P3





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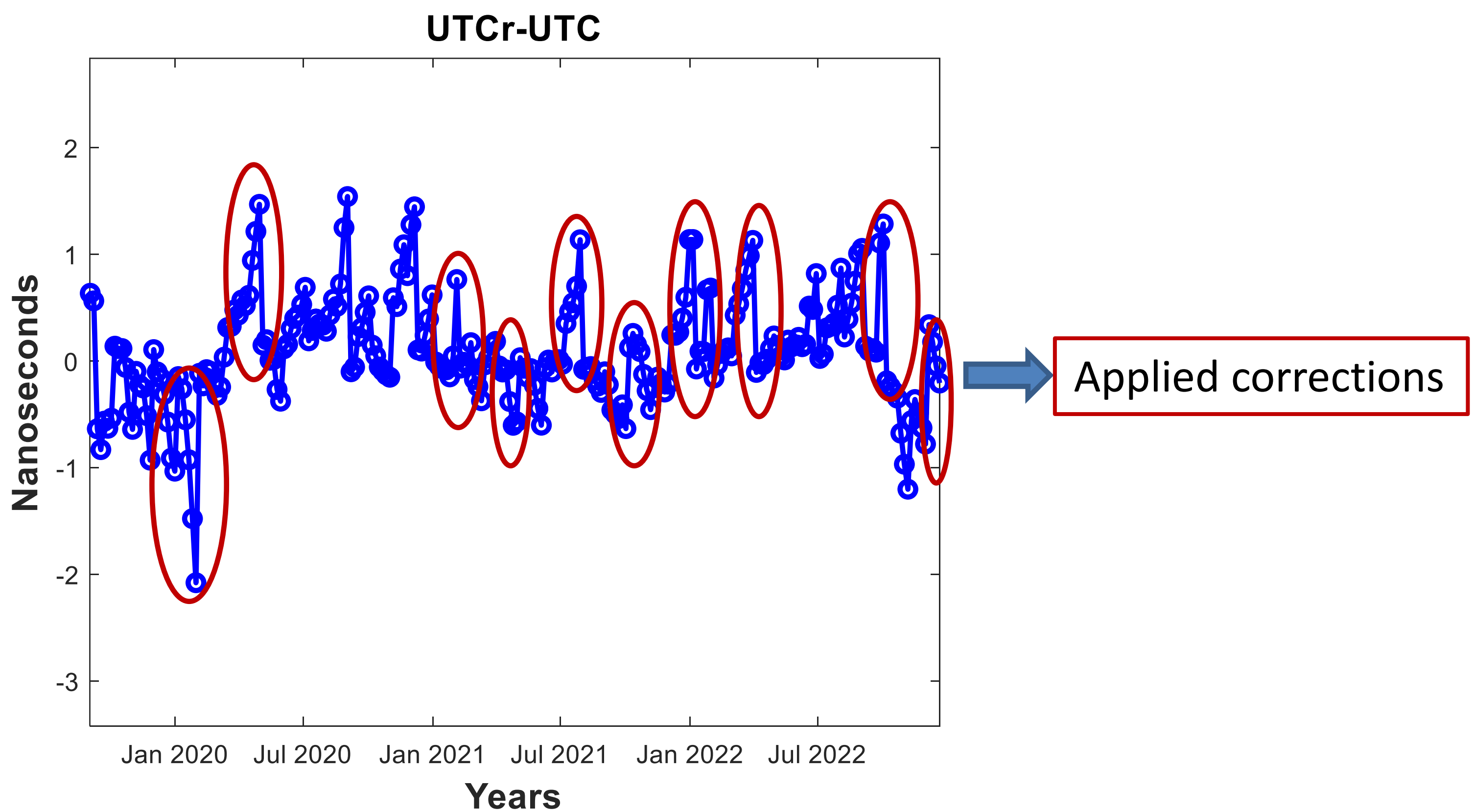
Stability of UTCr

- UTCr was not conceived to have a very good long-term stability (major difference from UTC) but to give access to UTC with a short latency to the participating laboratories .
- The goal for UTCr is to be as close as possible to UTC ($\pm 2\ ns$)
- The algorithm used for the stability is like UTC algorithm
  - quadratic prediction
  - weight algorithm attributing to the clocks a weight based on the predictability/stability

Accuracy of UTCr

- The accuracy for UTCr means that UTCr must be as close as possible to UTC.
- No frequency steering is applied
- Steering in time is applied each month after the publication of Circular T.



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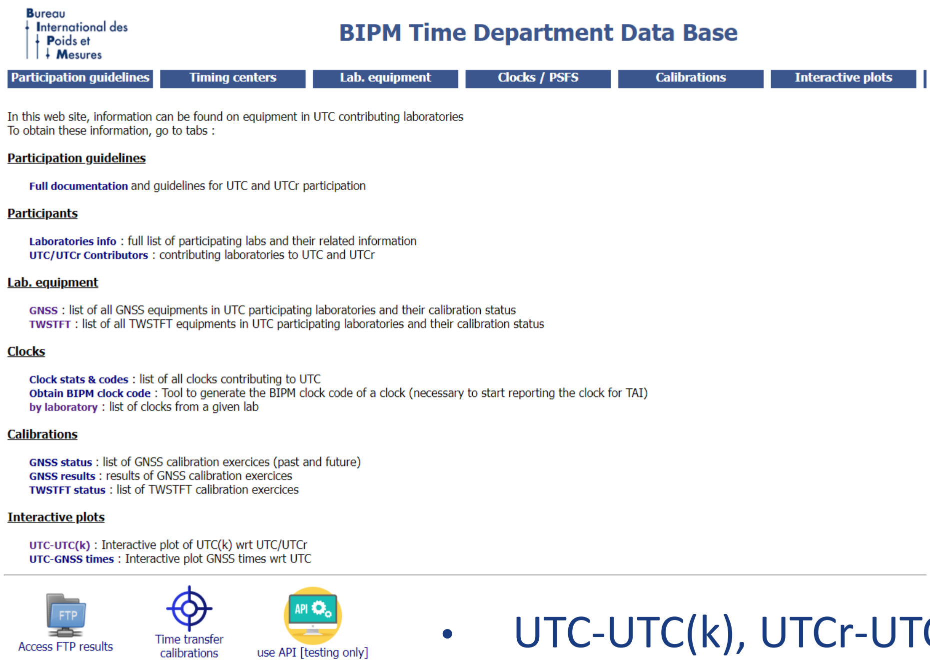
UTC data available on the BIPM web site

http://webtai.bipm.org/database/ and *https://www.bipm.org/en/time-ftp*



- UTC-UTC(k), UTCr-UTC(k)
- Several plots and data of time transfer links UTC(j)-UTC(k)
- Comparison between techniques
- Integer Precise Point Positioning (for some links), Galileo links
- UTC-GNSS Times
- Weights, frequency, frequency drifts of the clocks

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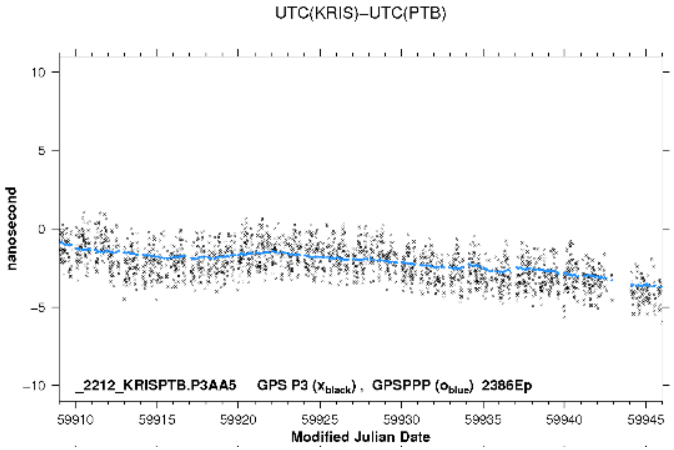
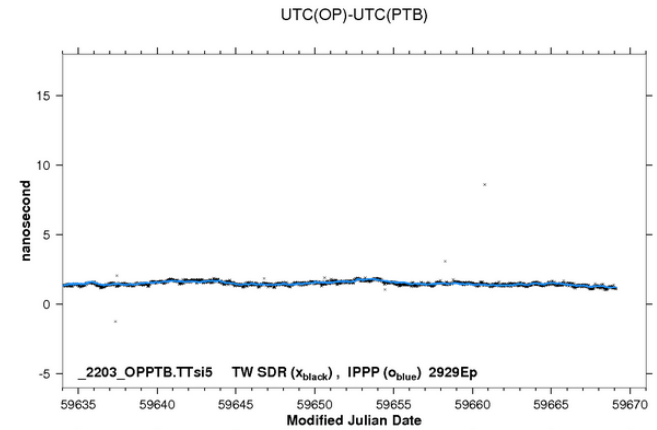
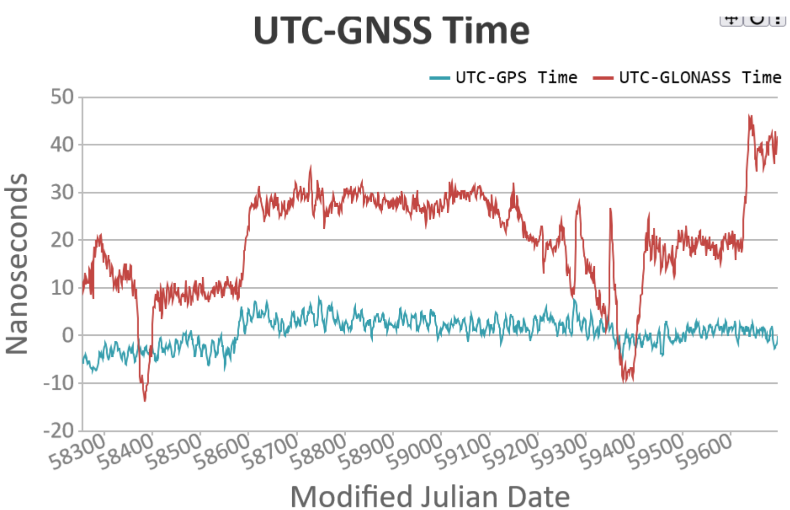
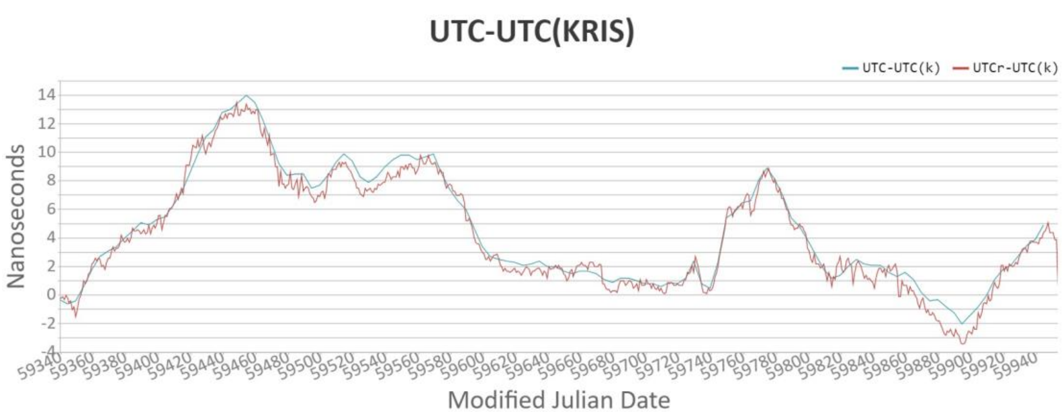
Publication examples – graphical representation



Link comparisons
- GPS P3 and GPS PPP
- TW SDR and IPPP
- UTC-UTC(k)
- UTC-UTCr(k)
- UTC-GNSS Time







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Publication exemples - Data availability - Digitalisation

- An important amount of data are published and are used by the time laboratories for internal generation of their time scale.

MJD	[UTC-UTC(NRC)]/ns	uA/ns	uB/ns	u/ns
50814	9			
50819	54			
50824	117			
50829	13			
50834	14			
50839	17			
50844	17			
50849	20			
50854	22			
50859	24			
50864	29			
50869	26			
50874	24			
50879	18			
50884	16			

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BUREAU INTERNATIONAL DES POIDS ET MESURES

INTERNATIONAL ATOMIC TIME

MONTHLY RATES OF TAI-CLOCK
FOR INTERVALS OF ONE MONTH ENDING AT THE GIVEN DATES

(UNIT IS ns/day , 0.00 DENOTES THAT THE CLOCK WAS NOT USED)

LAB.	CLOCK	59544	59579	59609	59634	59669	59699
AGGO	35 768	0.00	3.22	1.77	2.41	1.75	2.24
AGGO	40 8620	0.00	-11.47	-11.46	-11.28	-6.55	-3.03
AGGO	35 1881	0.00	-0.37	-0.34	0.19	0.96	0.59
APL	35 1264	-1.94	-1.94	-1.12	-2.59	-2.84	-2.45
APL	35 1791	1.53	1.00	1.33	1.05	1.24	2.08
APL	35 3842	1.27	1.94	1.99	2.06	2.04	3.01
APL	40 3107	57.49	57.68	58.48	58.94	59.43	59.89
APL	40 3108	684.68	687.02	689.42	690.97	692.31	693.45
APL	40 3109	20.56	20.54	20.72	20.81	20.92	20.96
AUS	36 2269	-0.43	0.22	0.56	0.69	-0.38	0.82
AUS	36 3814	0.70	0.74	0.93	1.97	0.85	2.65
AUS	36 340	6.70	7.20	6.43	7.37	8.39	6.02
AUS	36 654	-24.20	-24.40	-23.71	-24.55	-25.24	-25.12
BEV	35 3009	-1.39	-1.17	1.81	1.30	1.24	0.49
BEV	40 3452	-23.66	-20.12	-17.65	-15.29	-13.12	-10.59

- UTC-UTC(k)
- Rates and drifts of the clocks

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BUREAU INTERNATIONAL DES POIDS ET MESURES

INTERNATIONAL ATOMIC TIME

FREQUENCY DRIFTS OF THE CLOCKS USING A MONTHLY REALIZATION OF TT(BIPM)
AS REFERENCE FOR INTERVALS OF THREE MONTHS ENDING AT THE GIVEN DATE
UNIT IS ns/day/30days

(********* DENOTES THAT CLOCK WAS MISSING)

LAB.	CLOCK	59544	59579	59609	59634	59669	59699
APL	35 1264	-0.1752	-0.1384	0.3015	-0.2833	-0.8140	0.0110
APL	35 1791	-0.1833	-0.0788	-0.1065	0.1010	-0.0323	0.5154
APL	35 3842	0.2303	0.3345	0.2278	-0.0148	0.0214	0.3841
APL	40 3107	0.3453	0.2380	0.4937	0.6770	0.4807	0.4640
APL	40 3108	2.0108	2.0690	2.1986	2.0262	1.4907	1.1896
APL	40 3109	-0.0388	-0.0906	0.0716	0.1333	0.0875	0.0728
AUS	36 2269	0.5353	0.3471	0.5836	0.2306	-0.5457	0.0312
AUS	36 3814	0.0325	-0.0319	0.1647	0.4176	0.0289	0.4621
AUS	36 0340	-0.4554	-0.3940	-0.1027	-0.0455	0.8141	-0.5880
AUS	36 0654	-0.1879	-0.3203	0.0678	-0.2462	-0.8862	-0.3119
BEV	35 3009	-0.2629	0.1331	1.4172	1.2959	-0.1979	-0.4485
BEV	40 3452	2.8572	3.0895	2.7549	2.3953	2.3305	2.2538
BEV	35 1793	-0.0633	-0.0165	0.2426	0.3578	0.6813	0.1187
BFKH	35 3543	*********	*********	*********	-2.2842	0.3950	0.1969
BIM	18 8058	-0.3712	0.3048	-0.4911	-0.3777	-0.3341	-0.2314
BIRM	35 3447	*********	*********	*********	*********	*********	3.7773
BIRM	35 3689	*********	*********	*********	*********	*********	6.9110
BY	40 4227	*********	*********	*********	*********	33.2125	4.2657
BY	40 4222	*********	*********	*********	*********	0.1268	-1.2629
BY	41 5105	*********	*********	*********	*********	0.0796	0.1079

API development in progress

Allow machines and applications to collect data according to custom requests :
- Customized period
- Customized output file format (JSON, CSV, Text)

Currently, only :
- [UTC-UTC(k)]
- [UTCr-UTC(k)]
- [UTC-GNSS times] are proposed.

But the service is planned to provide a larger variety of data in the future.

The API is still in testing version…

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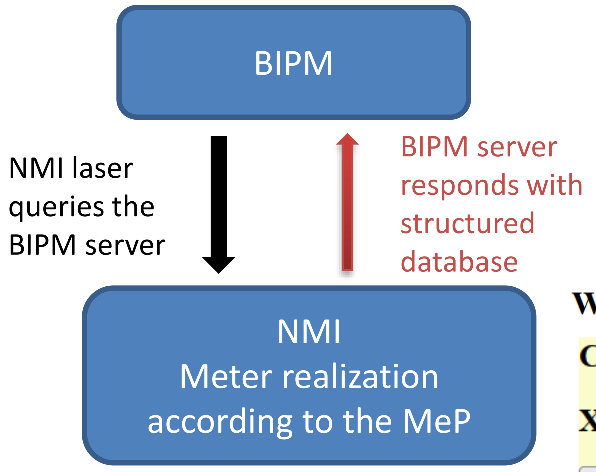
https://webtai.bipm.org/api/v0.2-beta/

New service coming soon - Digitalisation

- The MeP for the meter and the second (recommended values of standard frequencies) are published as PDF files.
- The NMIs will be able to report the traceability to SI in digital certificates.



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Approved by the CCTF in March 2021, active on April 13, 2022

RECOMMENDED VALUES OF STANDARD FREQUENCIES FOR APPLICATIONS INCLUDING THE PRACTICAL REALIZATION OF THE METRE AND SECONDARY REPRESENTATIONS OF THE DEFINITION OF THE SECOND

INDIUM 115 ION ($f \approx 1\ 267$ THz)

$^{115}In^+$, $5s^2\ {}^1S_0 - 5s5p\ {}^3P_0$ unperturbed optical transition

1. Recommended value [1] of the frequency in the CIPM List of Frequencies

$f(^{115}In^+) = 1\ 267\ 402\ 452\ 901\ 041.3$ Hz

equivalent to

$\lambda(^{115}In^+) = 236\ 540\ 853.549\ 545\ 5$ fm,

with a relative standard uncertainty of 4.3×10^{-15}.

The BIPM starting develop a database and a preliminary API (information in XML format).

Welcome on CCL-CCTF database consultation

CCL+CCTF mixed informations

XML files generator

all View (working version, under evolution ...)

Reference frequencies + source data: (by transition) [CCL&CCTF]

all View

Global content view for final XML input data check

all View


```
−<freq:stdfreq>
  <freq:label>1267 THz - 115In+</freq:label>
  <freq:freqlabel>1267 THz</freq:freqlabel>
  <freq:target>115In+</freq:target>
  <freq:validfrom>2017-06-09</freq:validfrom>
  <freq:srs>false</freq:srs>
  <freq:transitionname>5s2 1S0-5s5p 3P0</freq:transitionname>
 −<freq:value>
  −<si:real>
     <si:value>1267402452901050</si:value>
     <si:unit>\hertz</si:unit>
    −<si:expandedUnc>
       <si:uncertainty>1.6e-14</si:uncertainty>
       <si:coverageFactor>undef</si:coverageFactor>
       <si:coverageProbability>undef</si:coverageProbability>
       <si:distribution>undef</si:distribution>
     </si:expandedUnc>
   </si:real>
  </freq:value>
  <freq:numberofrules>0</freq:numberofrules>
  <freq:numberoffunccs>0</freq:numberoffunccs>
  <freq:numberoftransitions>0</freq:numberoftransitions>
  <freq:label>1267 THz - 115In+</freq:label>
  <freq:freqlabel>1267 THz</freq:freqlabel>
  <freq:target>115In+</freq:target>
  <freq:validfrom>2022-04-13</freq:validfrom>
  <freq:srs>false</freq:srs>
  <freq:transitionname>5s2 1S0-5s5p 3P0</freq:transitionname>
 −<freq:value>
  −<si:real>
     <si:value>1267402452901041.3</si:value>
     <si:unit>\hertz</si:unit>
    −<si:expandedUnc>
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       <si:coverageFactor>undef</si:coverageFactor>
       <si:coverageProbability>undef</si:coverageProbability>
       <si:distribution>undef</si:distribution>
     </si:expandedUnc>
   </si:real>
  </freq:value>
  <freq:numberofrules>0</freq:numberofrules>
  <freq:numberoffunccs>0</freq:numberoffunccs>
  <freq:numberoftransitions>0</freq:numberoftransitions>
</freq:stdfreq>
```


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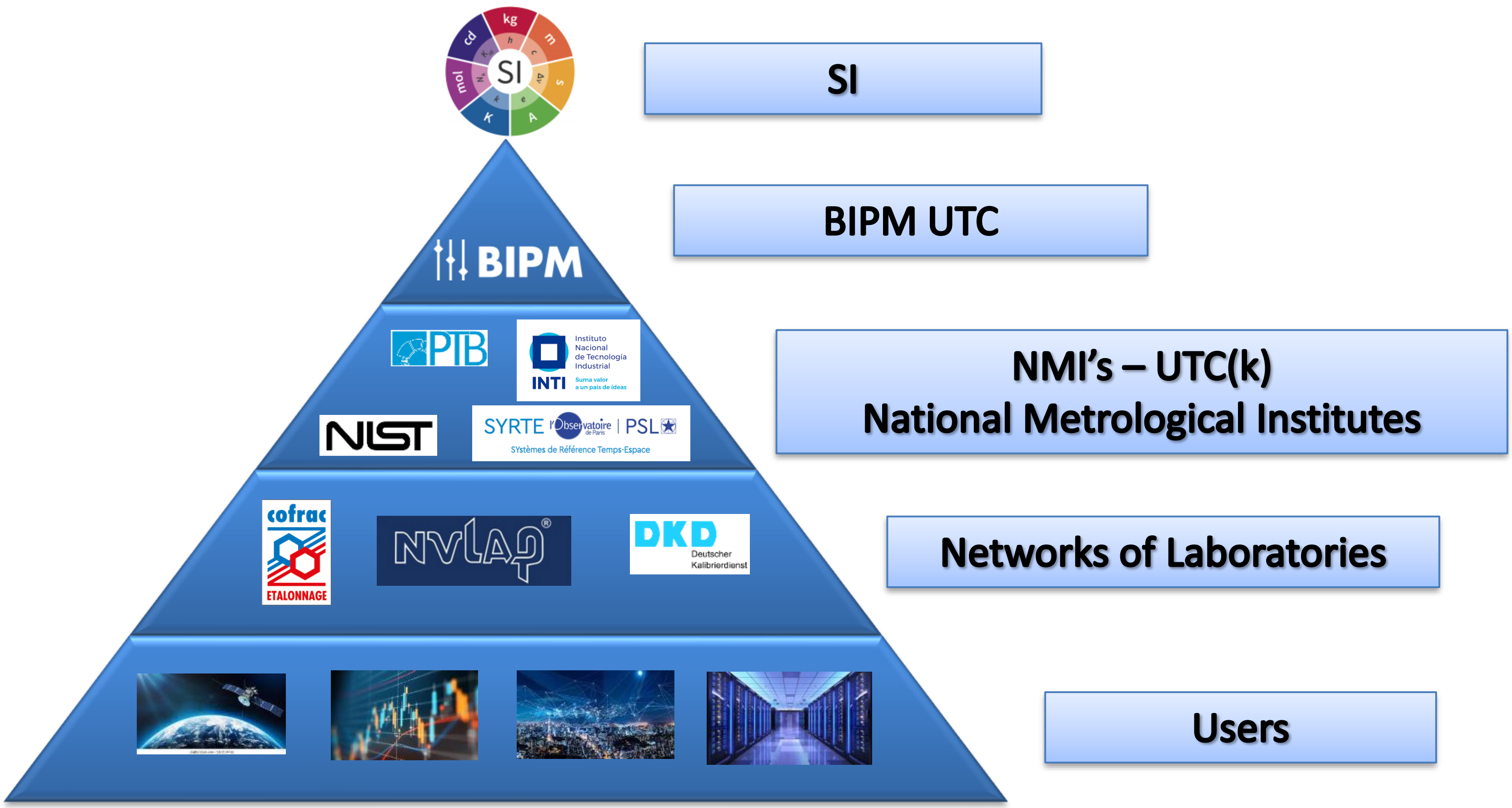
How UTC is universally used - traceability



Conclusions

Overview of the UTC and UTCr calculation.

Special attention to the actions made to ensure their long-term stability and the accuracy.

Status of clocks, PFSF, time links in UTC and in UTCr.

The current developments made in order to improve the performance of UTC in term of algorithms, time transfer and publication form.

Thank you for your attention!

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