UTC and UTCr algorithms

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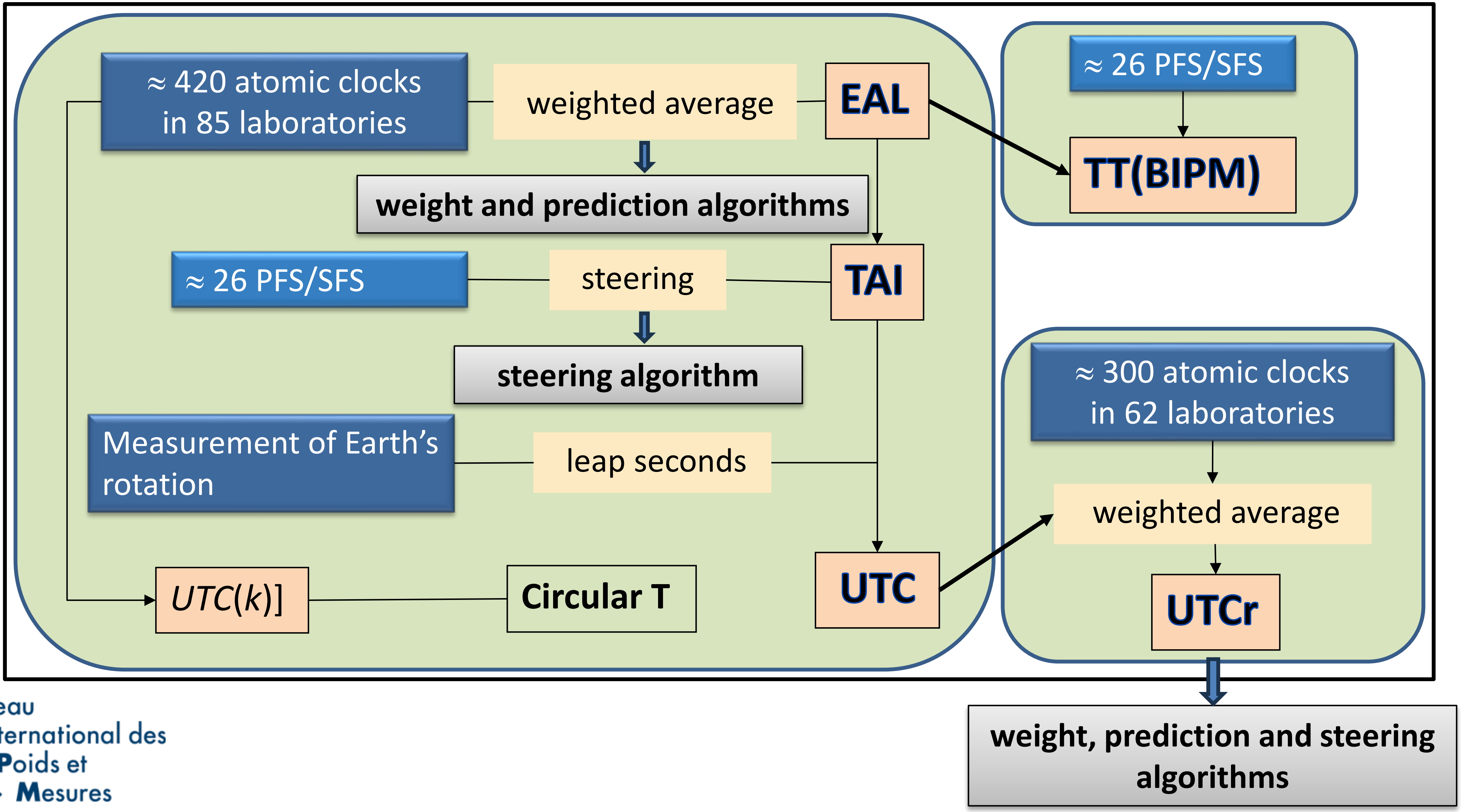
Presentation Plan

- Status of UTC:
  - Atomic clocks
  - Time transfer
  - Primary and Secondary Frequency Standard (PSFS)

- Computation of UTC:
  - Stability algorithms
    - Weight and prediction
    - Clock analysis
  - Accuracy
    - TT(BIPM) - Primary and Secondary Frequency Standard

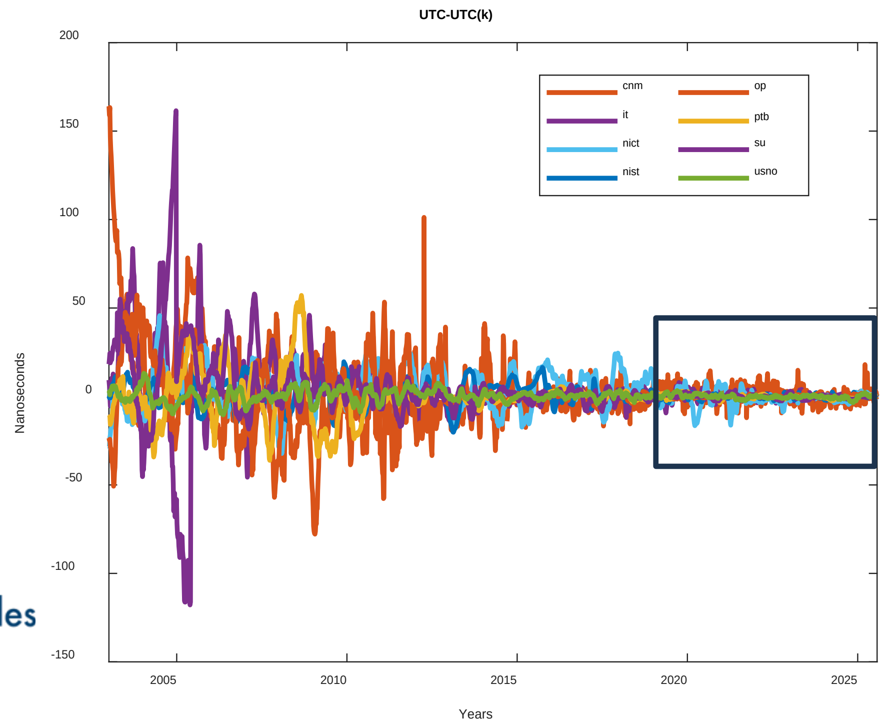
- UTCr, the rapid UTC:
  - Stability algorithm
    - Atomic clocks, time transfer
  - Accuracy
    - Steering to UTC

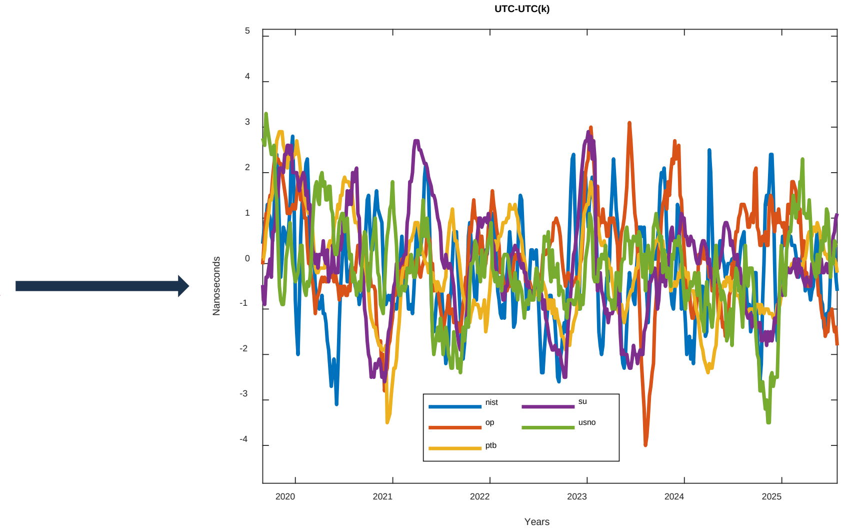
UTC, UTCr and TT(BIPM)



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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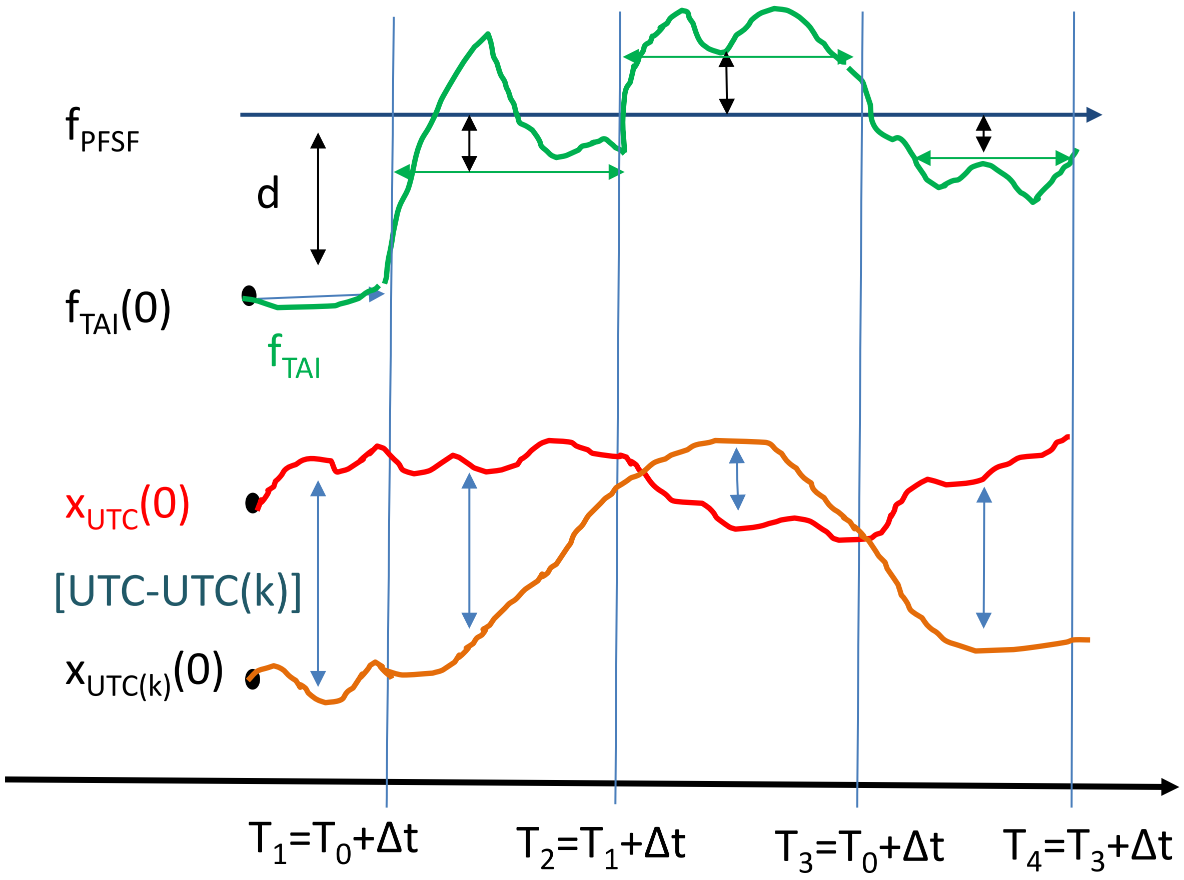
Difference between UTC and UTC(*k*)



- 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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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.

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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_v0.8.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 2025 0h UTC	JUN 28	JUL 3	JUL 8	JUL 13	JUL 18	JUL 23	JUL 28	Uncertainty/ns uA	uB	u	Notes
MJD	60854	60859	60864	60869	60874	60879	60884				
Laboratory k				[UTC-UTC(k)]/ns							
AGGO (La Plata)	339.3	337.5	328.4	316.5	301.3	290.3	-	0.7	3.0	3.1	
AOS (Borowiec)	-6.4	-6.1	-5.8	-5.5	-4.9	-4.3	-4.0	0.2	2.7	2.7	
APL (Laurel)	1.4	1.8	1.6	0.9	0.7	0.8	0.4	0.2	NC	-	
AUS (Sydney)	0.9	-1.7	3.4	3.2	15.9	4.2	-14.0	0.2	3.0	3.0	
BEV (Wien)	-6.1	-5.3	-17.0	-16.2	-22.6	-30.1	-28.0	0.2	3.0	3.0	
BFKH (Budapest)	2793.2	2834.1	2880.5	2930.7	2984.1	3033.3	3078.8	1.5	7.2	7.4	
BIM (Sofiya)	4493.9	4539.7	4587.4	4634.9	4687.1	4738.5	4782.5	0.2	2.7	2.7	
BIRM (Beijing)	0.5	-1.3	0.6	2.9	-1.5	-1.8	1.9	0.2	3.5	3.5	
BSJ (Kingston)	17.8	29.7	23.5	25.0	14.3	26.9	17.6	7.0	7.1	10.0	
BY (Minsk)	0.8	0.7	0.1	0.8	0.7	0.9	0.9	1.5	3.2	3.5	
CAO (Cagliari)	-22720.9	-22792.7	-22905.6	-23078.3	-23166.5	-23289.1	-23435.3	0.7	NC	-	
CH (Bern-Wabern)	-0.3	-0.5	-0.7	-0.7	-0.5	0.4	0.2	0.2	1.1	1.1	
CNES (Toulouse)	2.2	0.9	-0.3	-0.4	0.9	3.7	1.2	0.2	3.1	3.1	
CNM (Queretaro)	-2.7	-1.3	3.5	2.3	2.5	0.7	1.5	3.0	4.4	5.3	
CNMP (Panama)	-2.6	-1.5	11.2	-8.2	4.0	4.0	6.1	0.2	5.6	5.6	
DFM (Horsholm)	-5.4	-5.8	-6.6	-7.4	-3.5	-5.1	-5.1	0.2	2.8	2.8	
DFNT (Tunis)	-454.8	-504.1	-563.4	-611.8	-662.3	-736.5	-806.8	0.7	2.7	2.8	
DLR (Oberpfaffenhofen)	-1.5	-0.4	0.3	-0.4	-0.7	-0.0	-1.0	0.2	2.7	2.7	
DMDM (Belgrade)	-29.2	-35.3	-56.9	-36.0	-28.5	-4.7	-16.6	0.2	7.5	7.5	
DTAG (Frankfurt/M)	94.3	95.2	93.8	79.8	71.7	66.2	51.9	0.2	3.5	3.5	
ESA (Noordwijk)	0.8	0.1	1.8	1.0	0.9	1.1	1.1	0.2	2.7	2.7	
HKO (Hong Kong)	217.6	224.3	238.7	247.6	257.4	268.1	287.8	0.2	3.7	3.7	
IBM (La Paz)	-	-	301.9	290.5	288.1	266.4	261.4	4.0	7.6	8.6	
ICE (San Jose)	-15.5	-10.5	-14.7	-7.5	3.6	4.2	-7.2	0.2	7.1	7.1	
IDN (Serpong-Tangerang)	-876.7	-866.0	-873.7	-879.9	-883.9	-870.4	105.0	0.2	NC	-	(1)
IFAG (Wettzell)	-738.5	-734.3	-731.6	-728.8	-712.8	-722.8	-721.6	0.2	2.7	2.7	
IFZG (Zagreb)	253.5	258.4	273.6	277.2	281.1	289.7	289.0	0.2	2.7	2.7	
IGNA (Buenos Aires)	-	-	-	-	-	-	-				
IMBH (Sarajevo)	-1.6	0.2	4.0	1.6	1.2	3.6	3.6	0.2	2.9	2.9	
INCP (Lima)	-56.6	-58.1	-66.0	-74.4	-77.5	-64.0	-72.5	5.0	NC	-	

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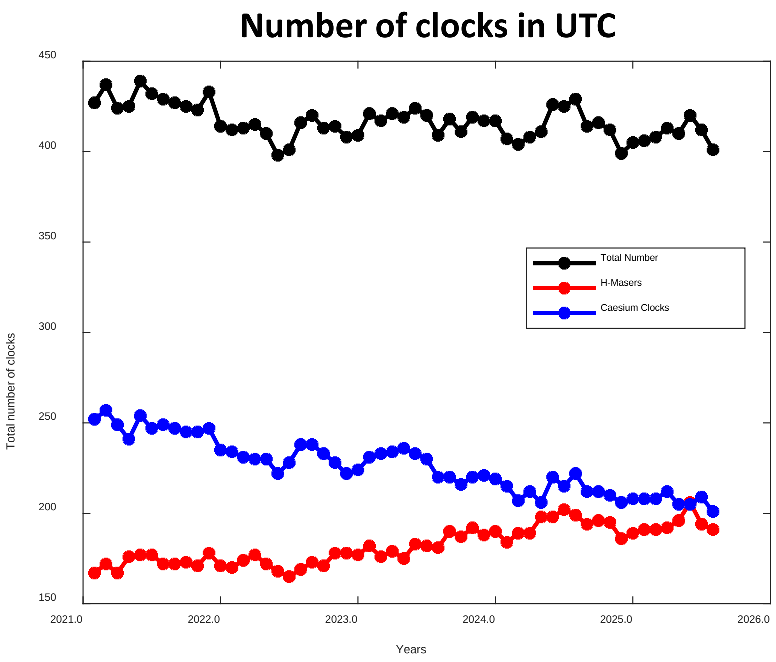
UTC algorithms

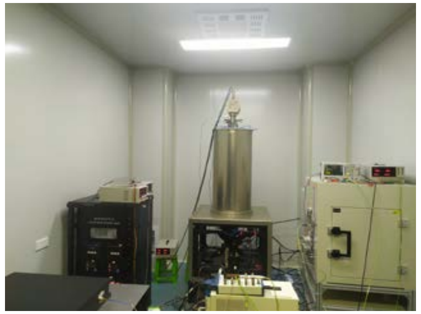
Status of Atomic clocks in UTC - 2025

400 atomic clocks contributing to UTC of which:

- ~200 H-Masers (from 160 to 200 in 5 years)
- ~200 Cs-clocks (from 250 to 200 in 5 years)
- 5 Rubidium Fountains in UTC



NTSC Rubidium Fountain



Credit: NTSC

Caesium Clock

Hydrogen Masers

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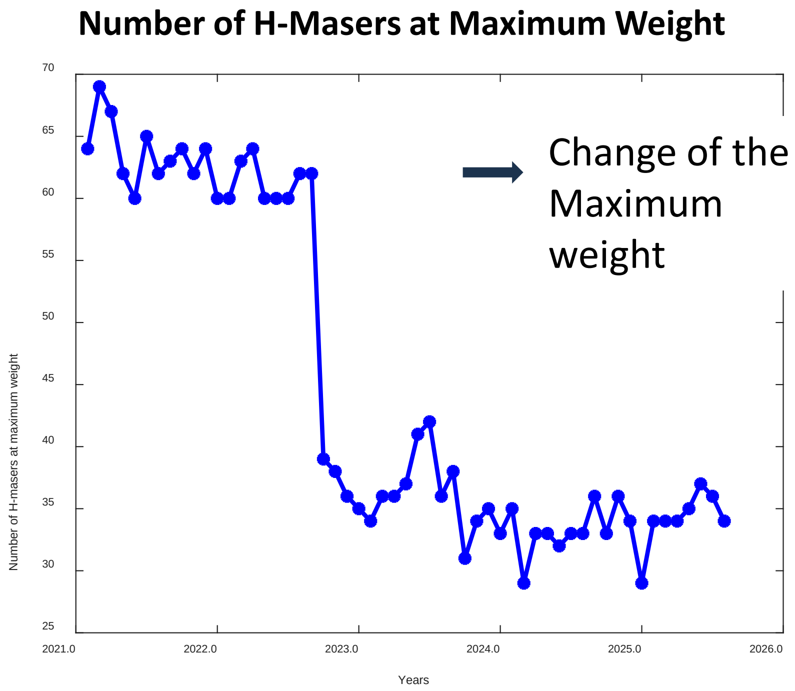
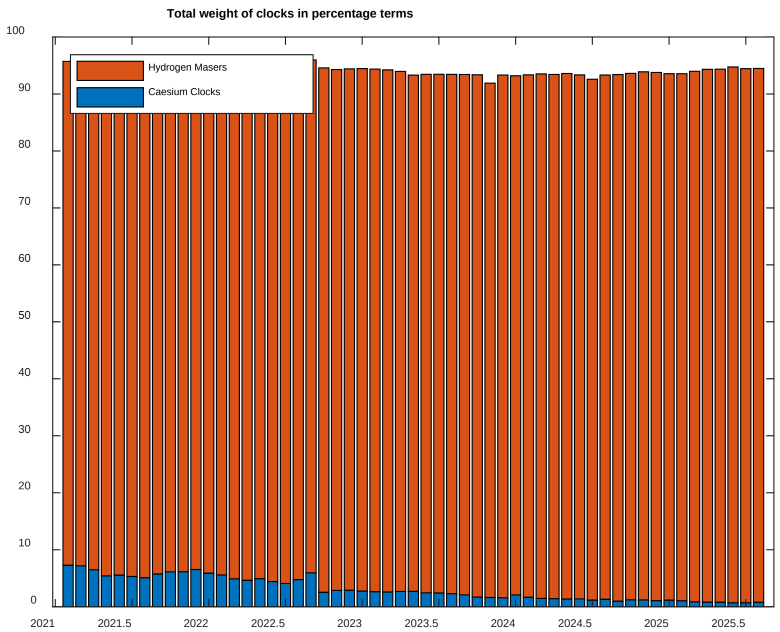
Status of Atomic clocks in UTC - 2025





The total weight of the contributing clocks to UTC:

- ~ 94 % is assigned to H-masers
- ~ 1 % to Cs-clocks
- ~ 5 % to Rubidium Fountains

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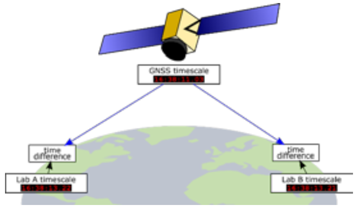
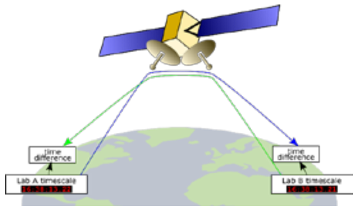
Time links in UTC

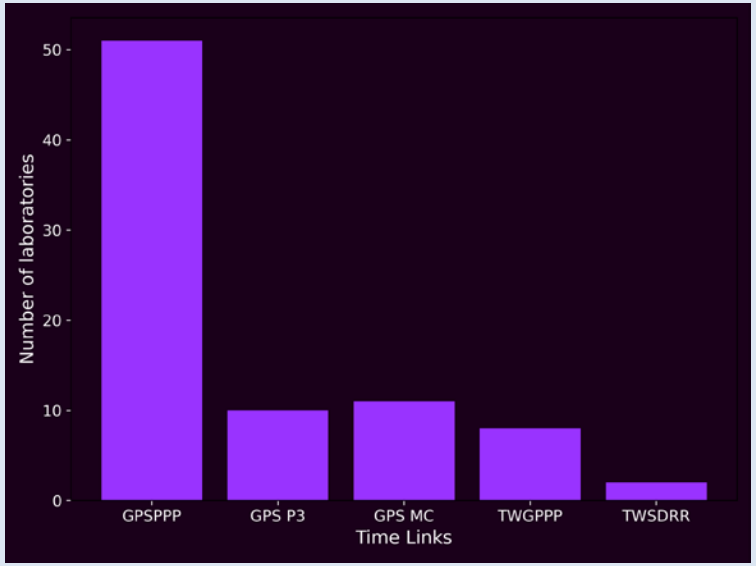
- The time links in UTC are :
  - Global Navigation Satellite Systems (GNSS)
    - GPSPPP, GPSP3, GPSMC
  - Two-Way Satellite Time & Freq. Transfer (TWSTFT)
    - TWSTFT, TWSDRR, TWGPPP (combination)





In the last Circular T

July 2025



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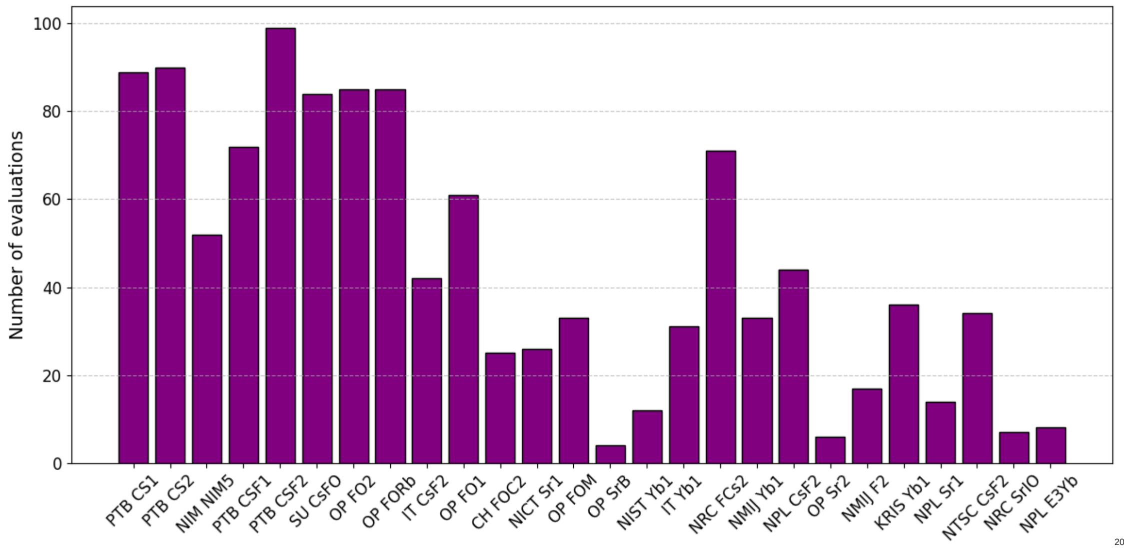
The role of PSFS in UTC

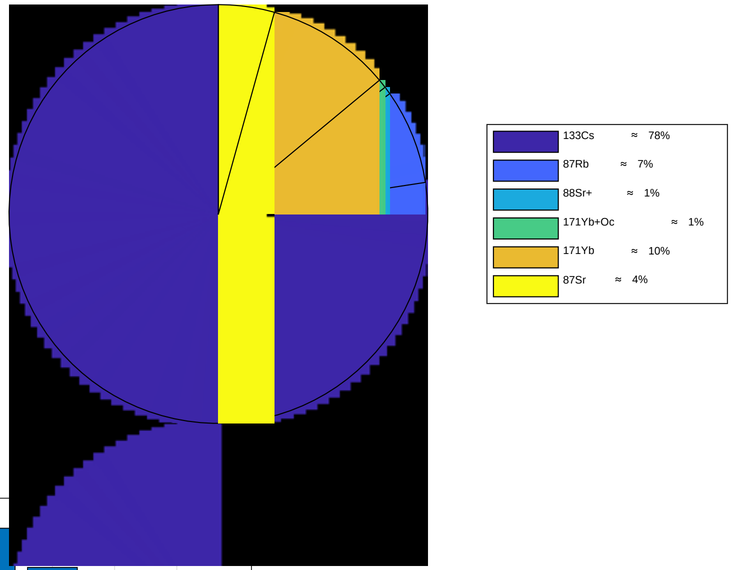
- The PSFS are used for UTC in:
  - the algorithm used to evaluate EAL (prediction and weight) (stability).
  - the algorithm to calculate TT(BIPM).
  - the algorithm to evaluate the difference between TAI and PSFS (accuracy).

Primary and Secondary Frequency Standards (PSFS)

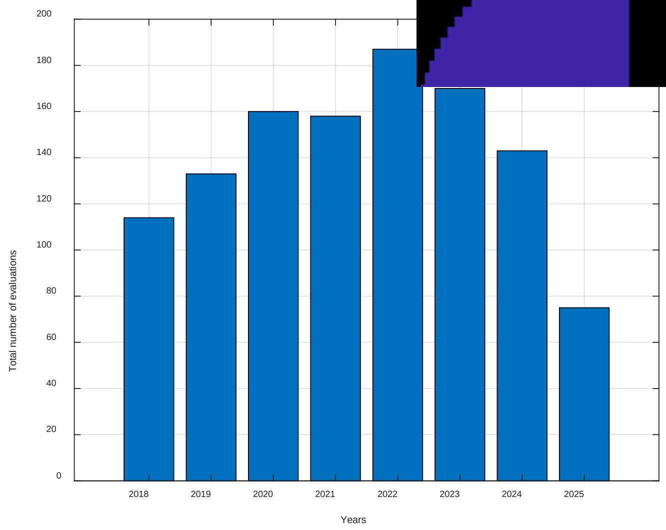
Number of evaluations from 2018 to 2025



Repartition of the PSFSs (lattice and Ions clocks)



The accuracy of TAI is based on the availability of PSFSs



Number of evaluations par years

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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: $\sum_{i=1}^{N} w_i = 1$

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:

$$\boxed{x_j(t) = EAL - h_j = \sum_{i=1}^{N} \overbrace{w_i}^{\text{Weigth}} \underbrace{\left[h_i'(t) - x_{i,j}(t)\right]}_{\text{Prediction}}}$$

The main algorithms used are:

- the **prediction algorithm** (quadratic model)
- the **weighting algorithm** (each clock is weighted wrt to their stability/predictability)

EAL – practical implementation

- 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
             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(k)-UTC(PTB)), we obtain:
  - EAL-1351135
  - EAL-1405628 etc.
  - but also, EAL-UTC(k)

EAL – practical implementation

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

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

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.

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The prediction algorithm

- The prediction algorithm has the scope to avoid/minimize any time and frequency steps to UTC when a clock is added or eliminated from the ensemble.
- Any deterministic signatures (x_0, y_0 and frequency drift) are estimated and eliminated by the clocks to avoid affecting UTC.
- The quadratic prediction for the interval (t_k, t_{k+1}) is used:

$$\widehat{h_i'}(t) = \widehat{x_0}(t_k) + \widehat{y_0}(t - t_k) + \frac{1}{2}\hat{d}(t - t_k)^2$$

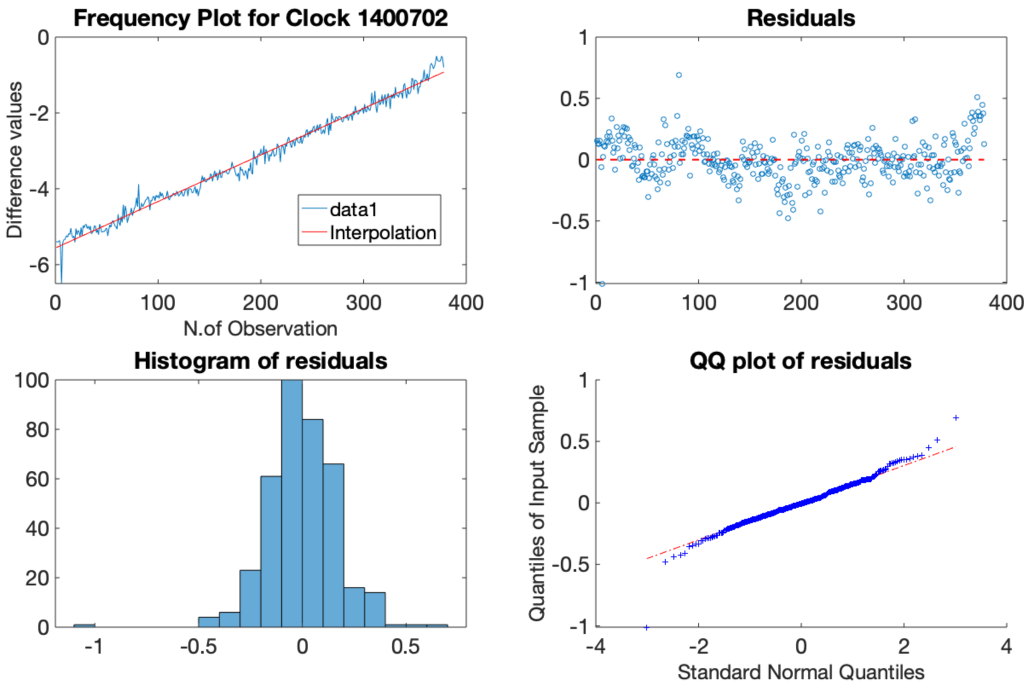
EAL-h_i at date t_k

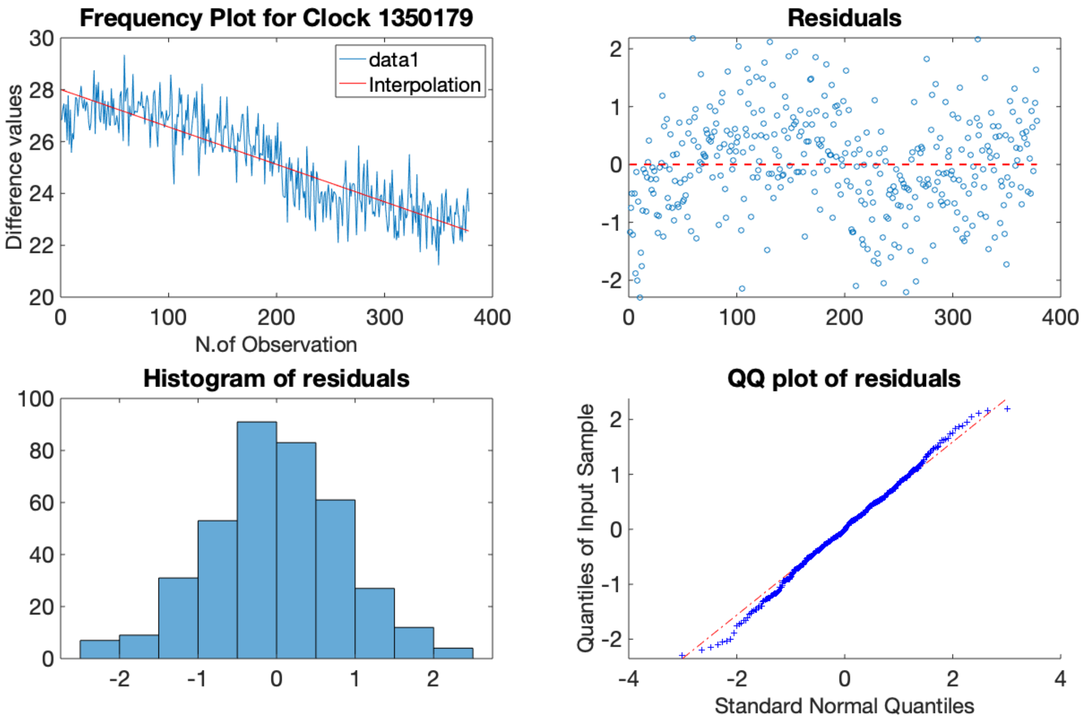
Frequency of h_i relative to **EAL** predicted over the period [t_k ,t]

Frequency drift of h_i relative to a **frequency reference** predicted over the period [t_k ,t]; the data used are y(TT-h_k)

Parameters estimation

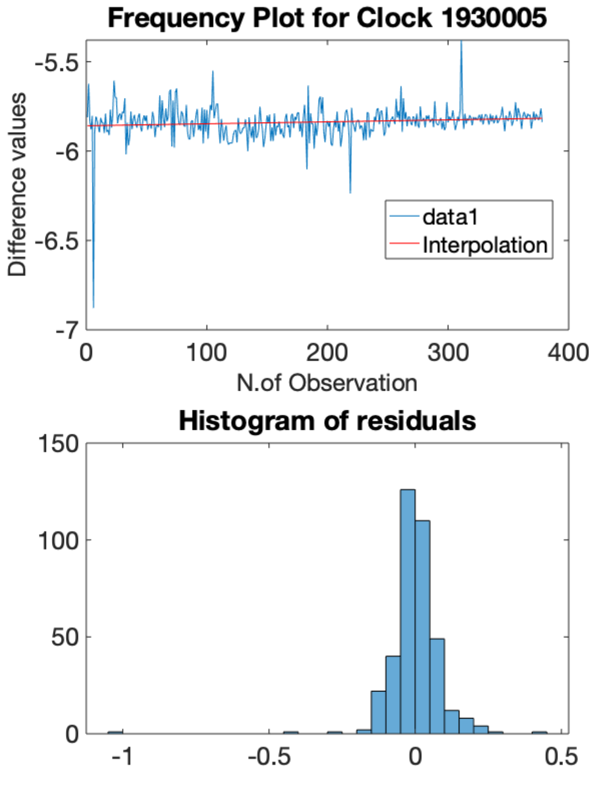
Five Years frequency analysis (2018-2022)



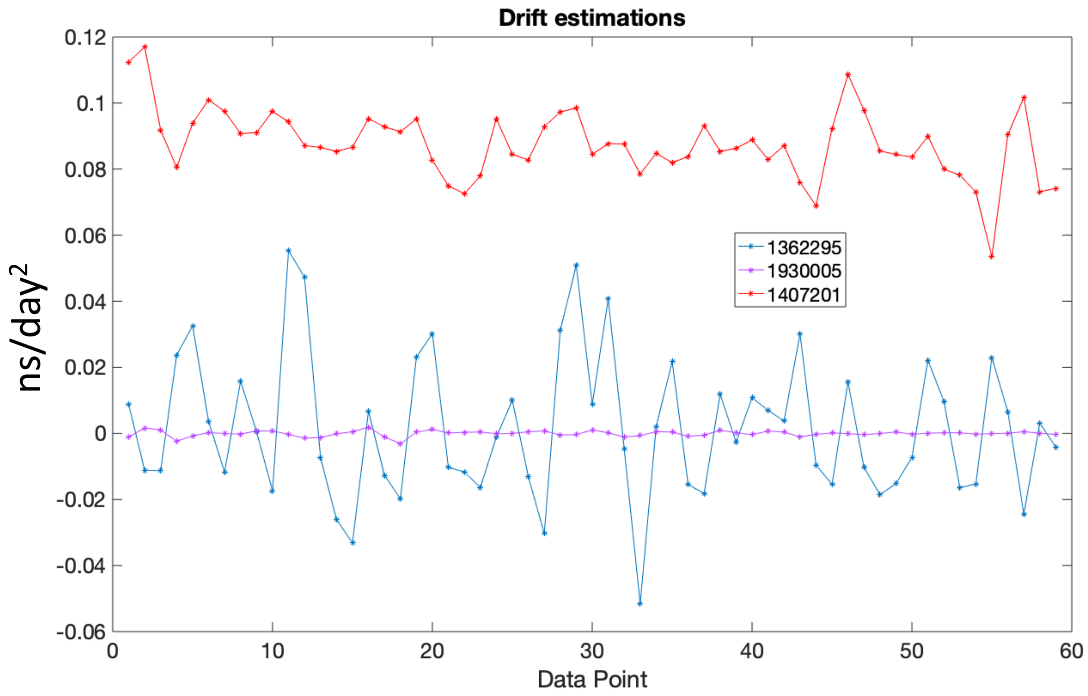


Parameters estimation

Five Years frequency analysis (2018-2022)



Drift analysis over the same period



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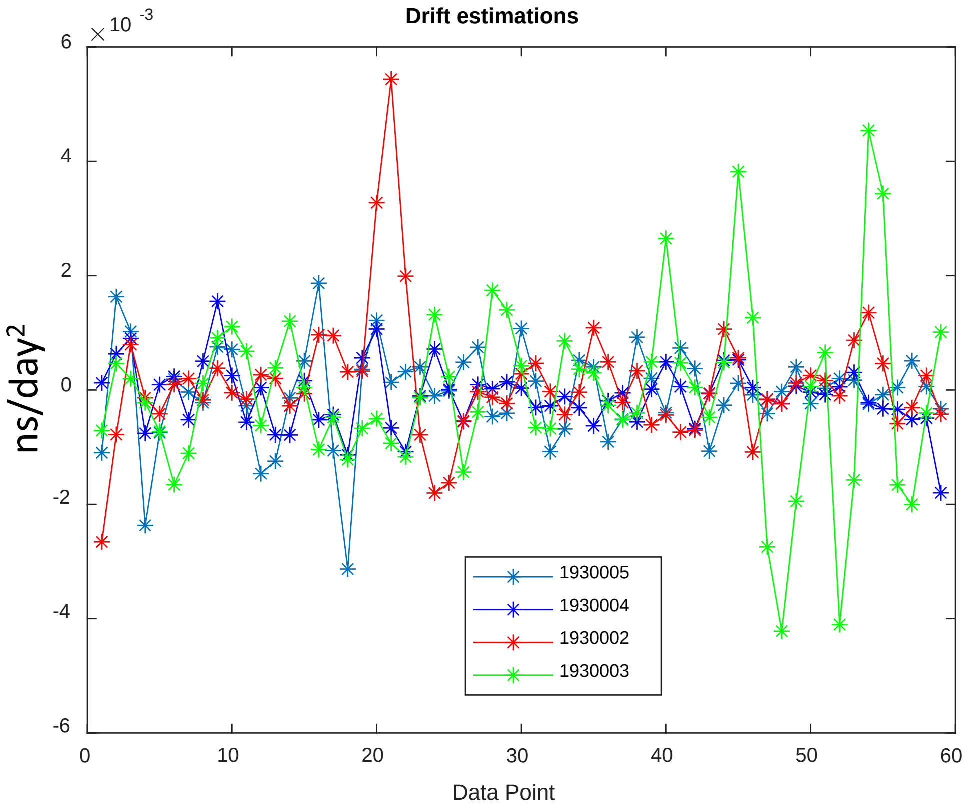
The estimation of the frequency drift

- It is a key issue for using at the best the hydrogen masers
- The reference used to estimate the frequency drift is the most important point; EAL and TAI are not enough stable to estimate the drift.
- The BIPM realization of TT, called TT(BIPM) is used to evaluate monthly the frequency drift of the hydrogen masers.
- The main components of TT(BIPM) are EAL and the PSFS.

Drift estimation – Rb Fountain



T-test on over the 5 years monthly frequency – returns a test decision for the null hypothesis that the data comes from a normal distribution with mean equal to zero (drift zero) and unknown variance.

The alternative hypothesis is that the population distribution does not have a mean equal to zero.

The result is always drift equal to 0: the test accept the null hypothesis at the 99% significance level.

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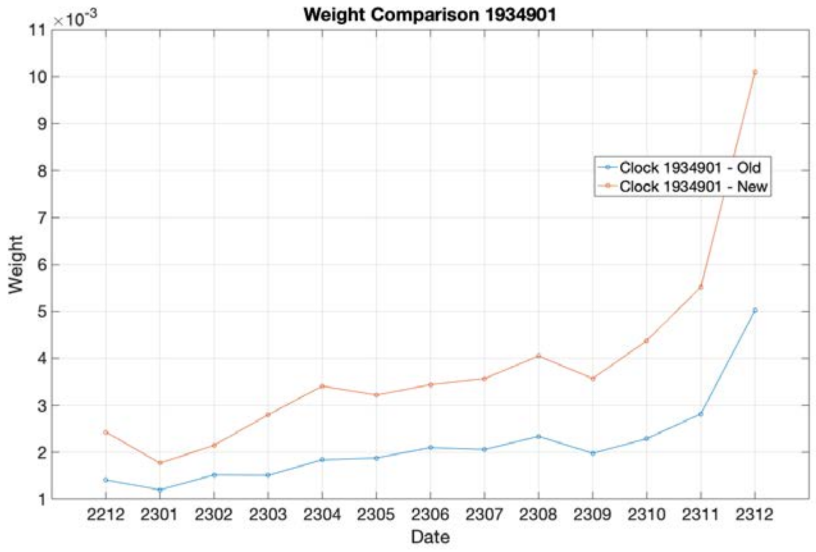
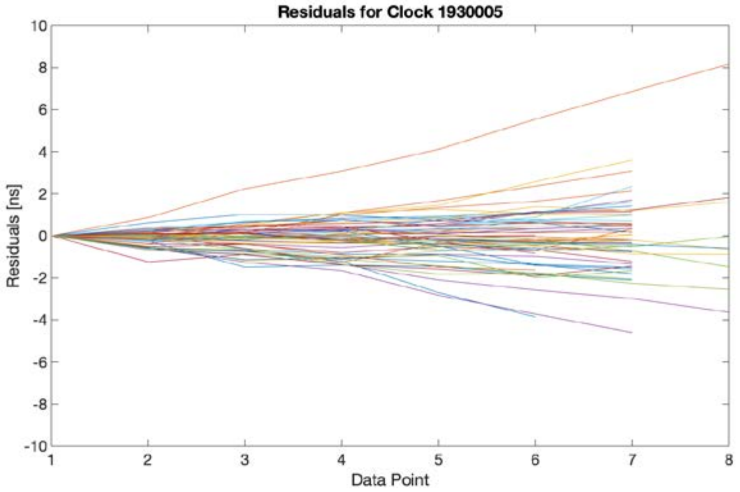
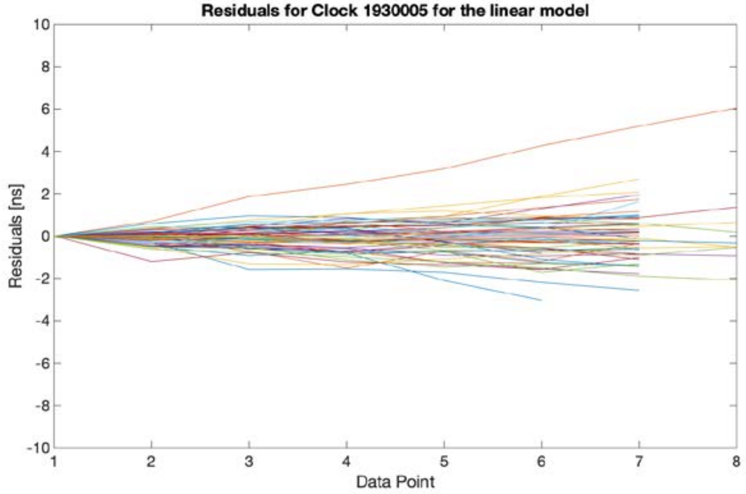
Linear model vs quadratic model Rb Fountains

The weights of the Rb fountains are calculate with and without the frequency drift (quadratic and linear model).







The residuals

$$\varepsilon_i = y(EAL - h_i) - \hat{y}(EAL - h_i)$$

The dispersion of the residuals is very reduced in case of linear model for the prediction.

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Long-term stability of EAL

- EAL is currently free from frequency drifts affecting H-Masers even if they are contributing with a global weight of 90%.
- This result is obtained because of the availability of PSFS allowing us to generate TT(BIPM) each month.
- We can conclude, as some extent, that PSFS allow to the BIPM:
  - To use at the best the Hydrogen Masers
  - To ensure a long-term stability to EAL

Weighting algorithm

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).

x_i = EAL- h_i is obtained with the weights ω_i calculated in the previous interval.

The residuals
$$\varepsilon_i = y(EAL - h_i) - \hat{y}(EAL - h_i)$$
are calculated

Weighted mean of ${\varepsilon_i}^2$ over M months
$$\sigma_i^2 = \frac{\sum_{i=1}^{M}({\varepsilon_i}^2/(M-i+1))}{\sum_{i=1}^{M}(1/(M-i+1))}$$

The relative weight ω_{iTEMP} of each clock is obtained
$$\omega_{i\,TEMP} = \frac{1/\sigma_i^2}{\sum_{i=1}^{N} 1/\sigma_i^2}$$

1) The weight is bigger than the upper limit : $\omega_i = \omega_{max}$
2) Abnormal behaviour : $\omega_i = 0$

$$|y(EAL - hi) - \hat{y}(EAL - hi)| > 5\ ns/day$$

4 iterations

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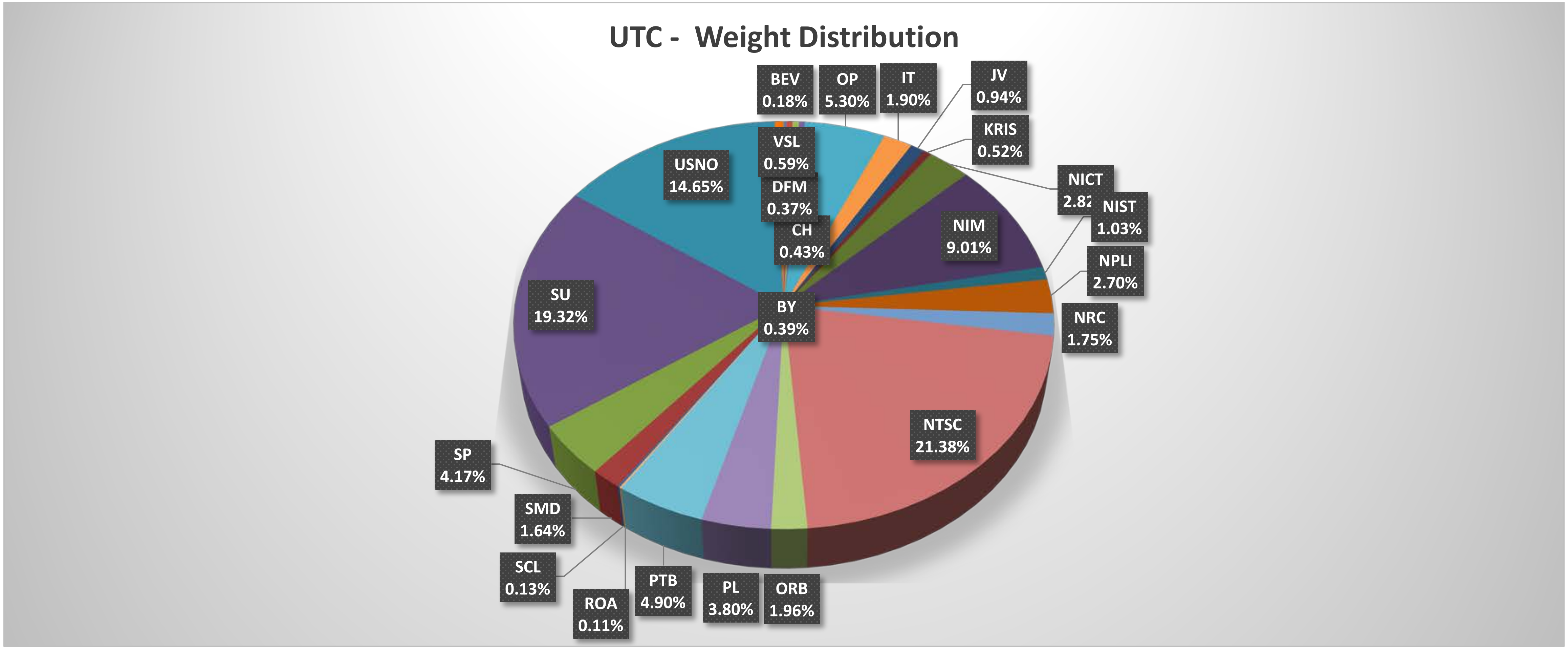
UTC – Weight Distribution – July 2025



Only laboratories with a total weight exceeding 0.1% are reported.

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TT(BIPM)

- As TAI is computed in almost real time and never corrected in retrospect, it is not optimal. Therefore, the BIPM computes a post-processed time scale TT(BIPM).
- Each new version TT(BIPM) updates and replaces the previous one.
- TT(BIPM) calculation
  - Post-processed using all available PFS data, as of year 20xx.
  - f(EAL) is estimated each month using available PFS. Monthly estimates are smoothed and integrated to obtain TT(BIPMxx).
  - Last realization: TT(BIPM24), released in February 2025.

Algorithm used for estimating f(EAL)

- We want to estimate the frequency of EAL, over an estimation interval T from N PFS evaluations,

$$y = \sum_{j=1}^{N} a_j \, W_j$$

where:

– W_j is the rate difference between EAL and a PFS on a given interval T_j

– The filter coefficients a_j, are normalized and depend on

  - The uncertainty of the evaluation *j*. It is fully characterized by its components u_A, u_B. u_A is the combined uncertainty from that originated in the instability of the PFS, that of the link between the PFS and the clock participating to TAI (dead time included), and that of the link to EAL. u_B is the combined uncertainty from systematic effects
  - The distance between T_j and T
  - The instability of EAL, which transfers the evaluation fromT_j to T

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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.

$$f(TAI - PSFS) = \underbrace{\boxed{f(EAL - clock) - f(EAL - TAI)}}_{\text{BIPM calculation}} - \underbrace{\boxed{f(PSFS - clock)}}_{\text{Laboratory contribution}}$$

Labo	PFS	PfsCode	FreqRef	MJD1	MJD2	[Ref-PFS]	uA	uB	uA_Lab	uB_Lab	Uptime	Ref(uB)	uB(Ref)
						10E-15	10E-15	10E-15	10E-15	10E-15	%		10E-15
xxxx	xxxxxxxxxx	xxxxxxx	xxxxxxx	xxxxx	xxxxx	xxxxxxxxxxxx	xxxxxx	xxxxxx	xxxxxx	xxxxxx	xxxxxx	xxxxxx	xxxxxx
OP	SYRTE-FO2	1920803	1400810	60154	60184	-166.20	0.20	0.30	0.05	0.00	91.7	T301	0.23

```
ADDITIONAL INFORMATION :
Reported by          : LNE-SYRTE
Date of report       : 04 09 2023
Name of the reporter : B. Chupin
```

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Section 3 of Circular T

	Interval of validity	f(EAL)-f(TAI)	
Steering correction	60154 - 60184	6.498x10**-13	(2023 JUL 29 - 2023 AUG 28)
New correction	60184 - 60214	6.498x10**-13	(2023 AUG 28 - 2023 SEP 27)
New correction foreseen	60214 - 60244	6.498x10**-13	(2023 SEP 27 - 2023 OCT 27)

Applied and foreseen steering's

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	60154 60184	-4.46	8.00	8.00	0.00	0.00	0.07	11.31	PFS/NA		T148	8.00	100.0	T427	34	Y	(1)
PTB-CS2	60154 60184	-1.41	5.00	12.00	0.00	0.00	0.07	13.00	PFS/NA		T148	12.00	100.0	T427	36	Y	(1)
KRISS-Yb1	60154 60184	-0.37	0.00	0.04	0.11	0.07	0.20	0.24	0.19	[1]	T405	0.03	37.5	T427	27	Y	(2)
NPL-CsF2	60154 60169	0.27	0.12	0.23	0.10	0.05	0.37	0.46	PFS/NA		T284	0.23	91.1	T427	40	Y	(3)
NRC-FCs2	60154 60184	-0.65	0.13	0.22	0.11	0.00	0.20	0.34	PFS/NA		T389	0.23	89.9	T427	37	Y	(4)
SYRTE-FO2	60154 60184	0.49	0.20	0.30	0.05	0.00	0.20	0.41	PFS/NA		T301	0.23	91.7	T427	35	Y	(5)
SYRTE-FORb	60154 60184	0.11	0.20	0.31	0.05	0.00	0.20	0.42	0.34	[1]	T328	0.34	90.3	T427	34	Y	(5)
PTB-CSF1	60154 60184	0.09	0.09	0.47	0.01	0.00	0.07	0.48	PFS/NA		T371	0.27	96.9	T427	29	Y	(6)
PTB-CSF2	60134 60154	-0.47	0.14	0.17	0.01	0.00	0.09	0.24	PFS/NA		T370	0.17	98.3	T427	40	Y	(6)
PTB-CSF2	60154 60184	-0.11	0.10	0.17	0.02	0.00	0.07	0.21	PFS/NA		T370	0.17	95.9	T427	40	Y	(6)
SU-CsFO2	60154 60184	0.51	1.10	0.22	0.14	0.00	0.20	1.15	PFS/NA		T315	0.50	66.4	T427	33	Y	(7)

Notes:
(1) Continuously operating as a clock participating to TAI
(2) Report dated 08 AUG. 2023 by KRISS
(3) Report dated 30 AUG. 2023 by NPL
(4) Report dated 31 AUG. 2023 by NRC
(5) Report dated 04 SEP. 2023 by LNE-SYRTE
(6) Report dated 01 SEP. 2023 by PTB
(7) Report dated 04 SEP. 2023 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 59794-60184, and corresponding uncertainties.

Period of estimation	d	u	
60154-60184	-0.11x10**-15	0.12x10**-15	(2023 JUL 29 - 2023 AUG 28)

-y(TAI) and uncertainty

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

The frequency accuracy of TAI is estimated at the level of ~10^{-16}

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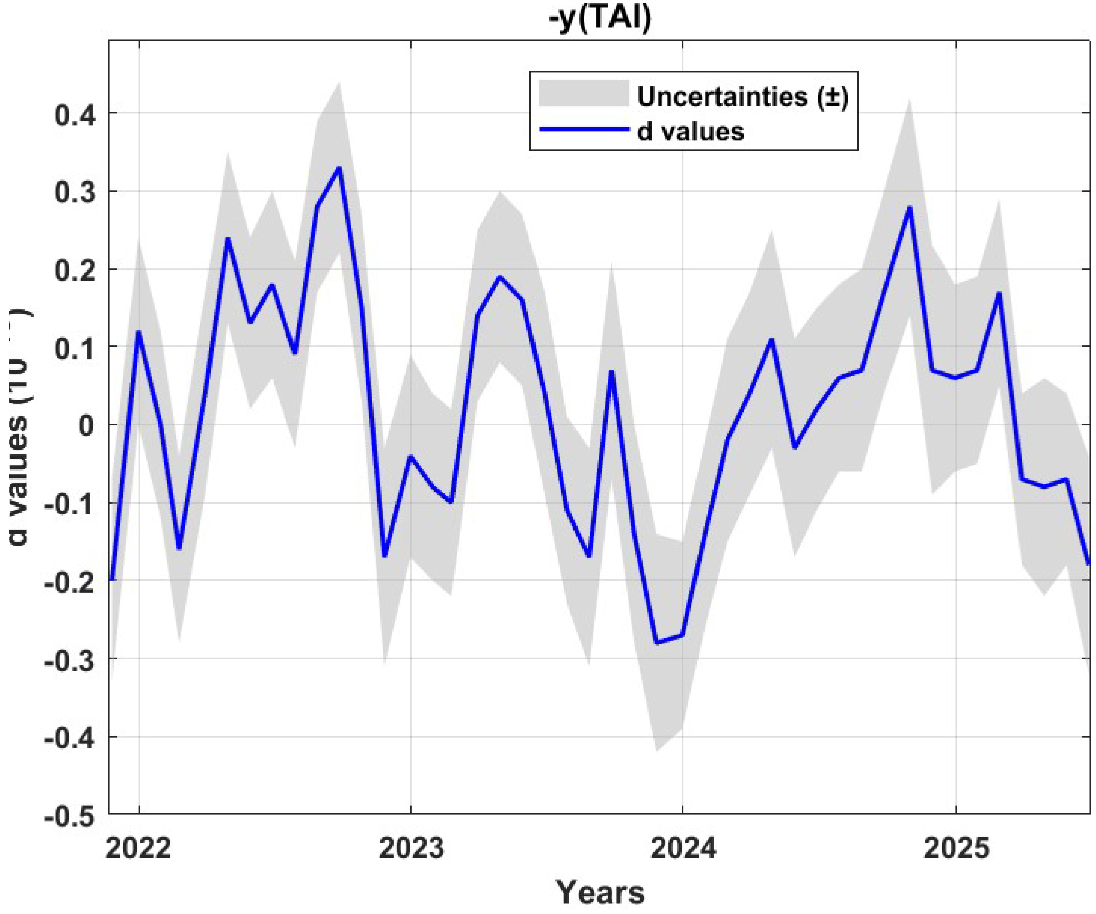
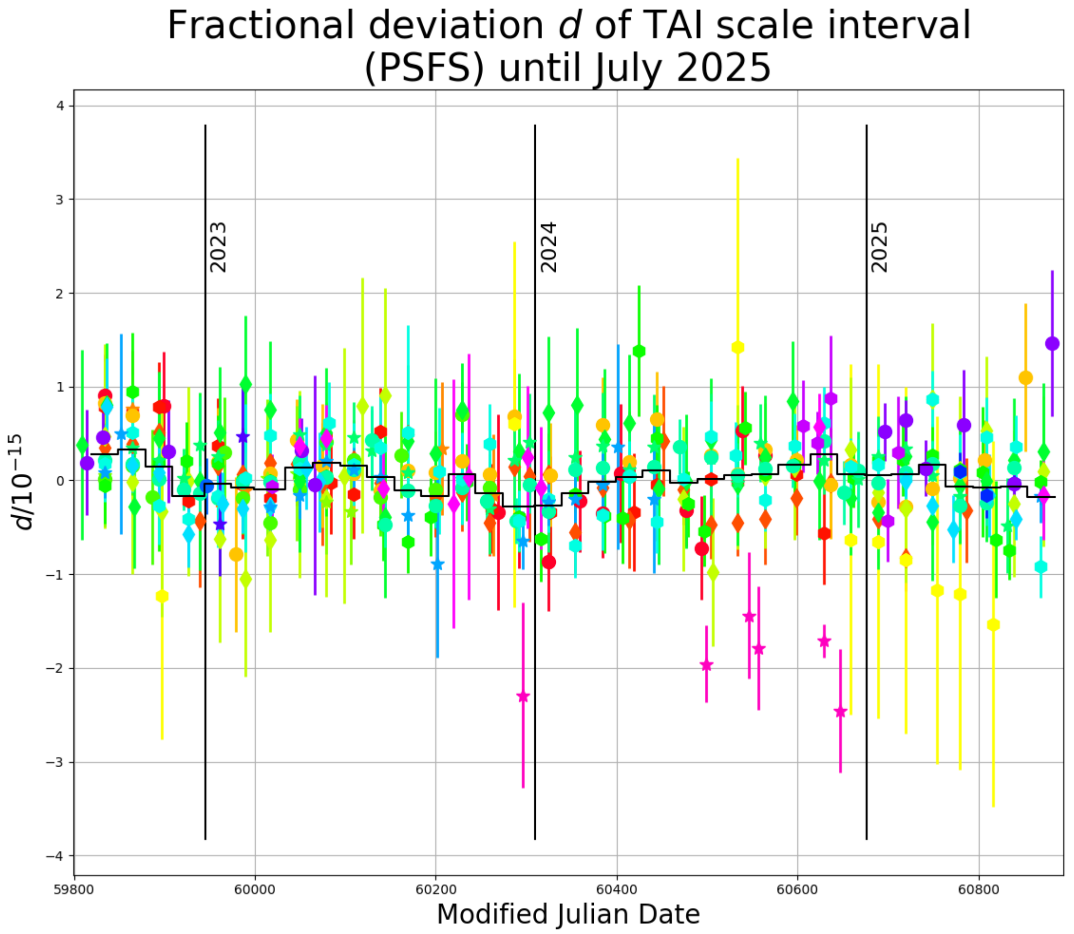
d values





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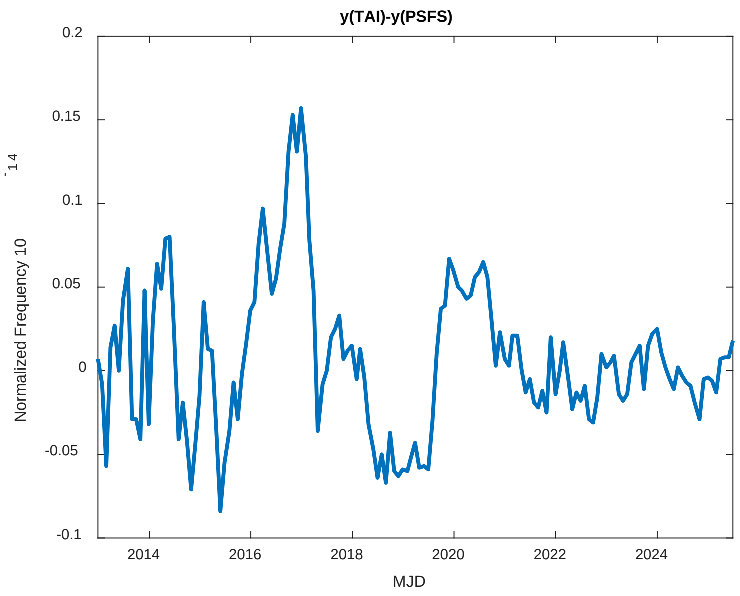
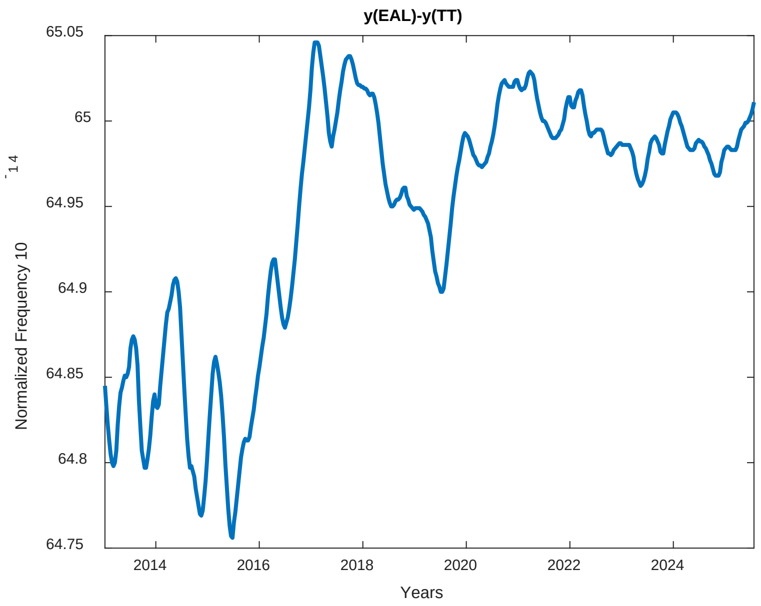
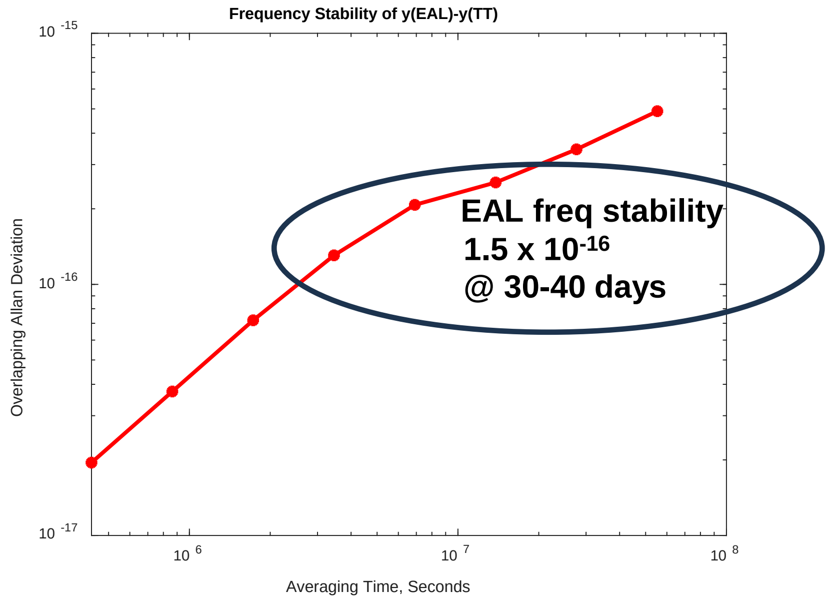
EAL and TAI wrt TT(BIPM2024)

By using TT(BIPM) we can estimate the long-term stability of EAL.







If the short term of the Allan Variance is not useful because EAL and TT are strictly correlated at the short term, we can evaluate the long-term performances of EAL by analyzing it.

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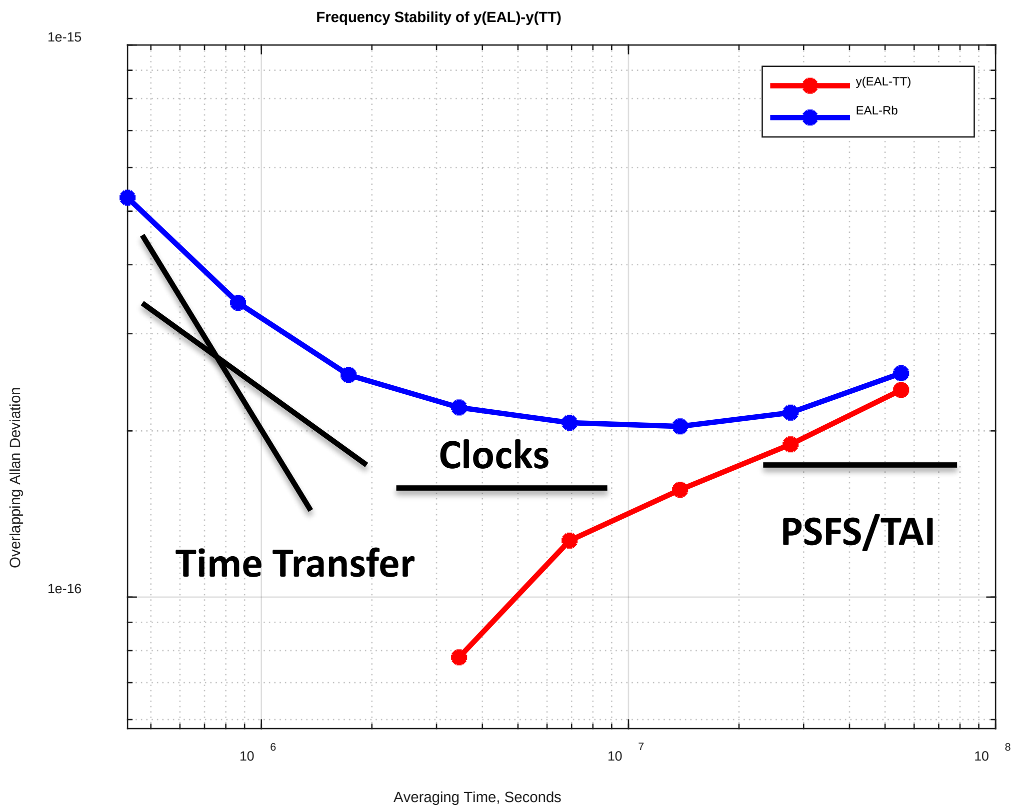
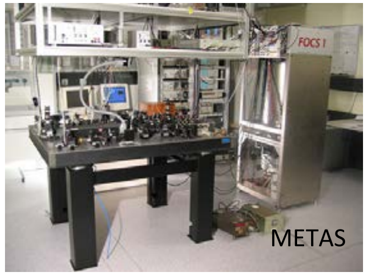
Estimation of UTC Instability

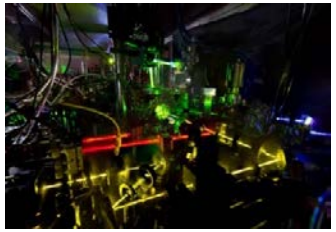


Frequency stability : UTC

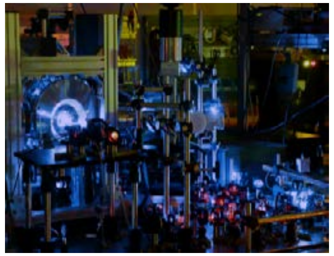
< 2 x 10^{-16} @ 30-40 days

Frequency accuracy of UTC : ~10^{-16}

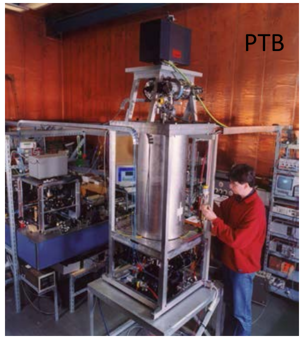


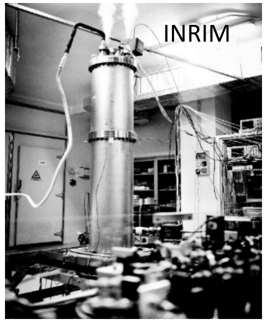


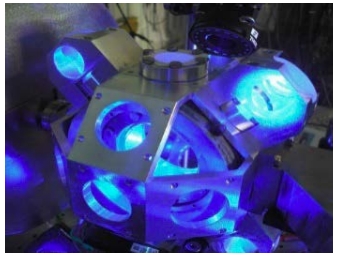
Yb Lattice Clock (NIST)



Sr lattice Clock (NICT)







Sr lattice Clock (LTE)

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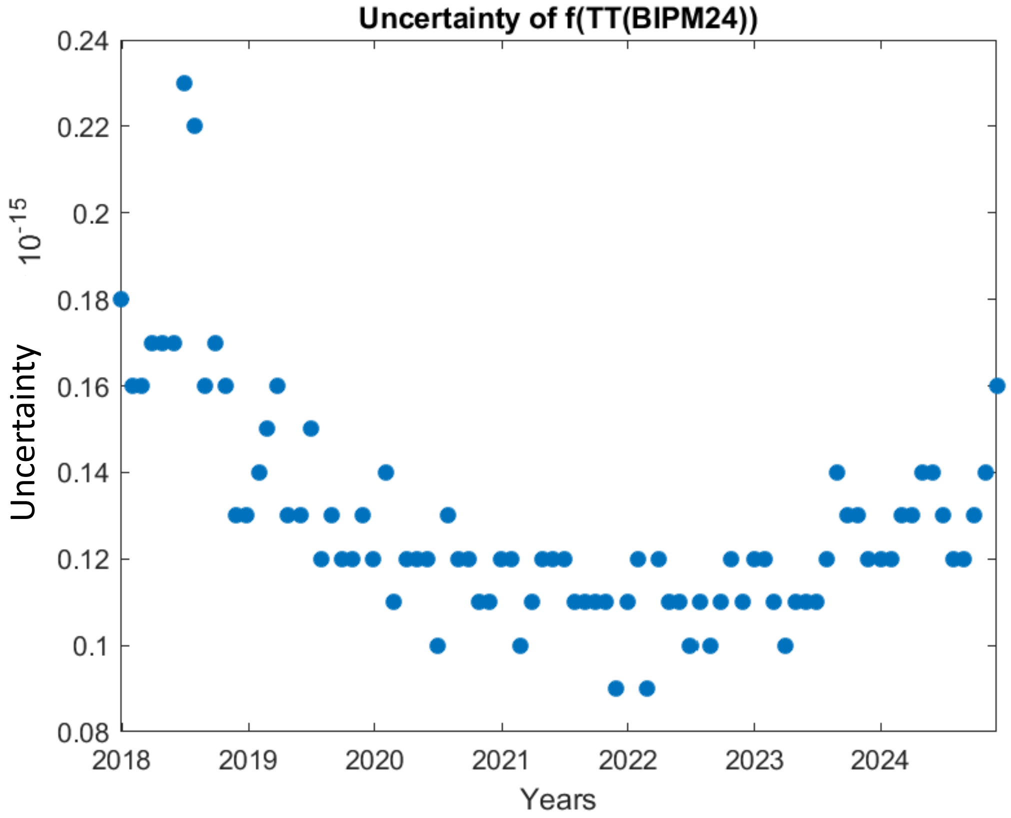
Uncertainty of f(TT(BIPM2024))

- We consider TT(BIPM) our best frequency reference to evaluate the performance of EAL, TAI and all the primary and secondary standards. Frequency accuracy improves with the standards:
  - < 1x10-15 since 2007
  - < 0.5x10-15 since 2009
  - ≤ 0.3x10-15 since 2012
  - ≤ 0.15x10-15 since 2020



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UTCr algorithms

UTCr – the rapid realization of UTC

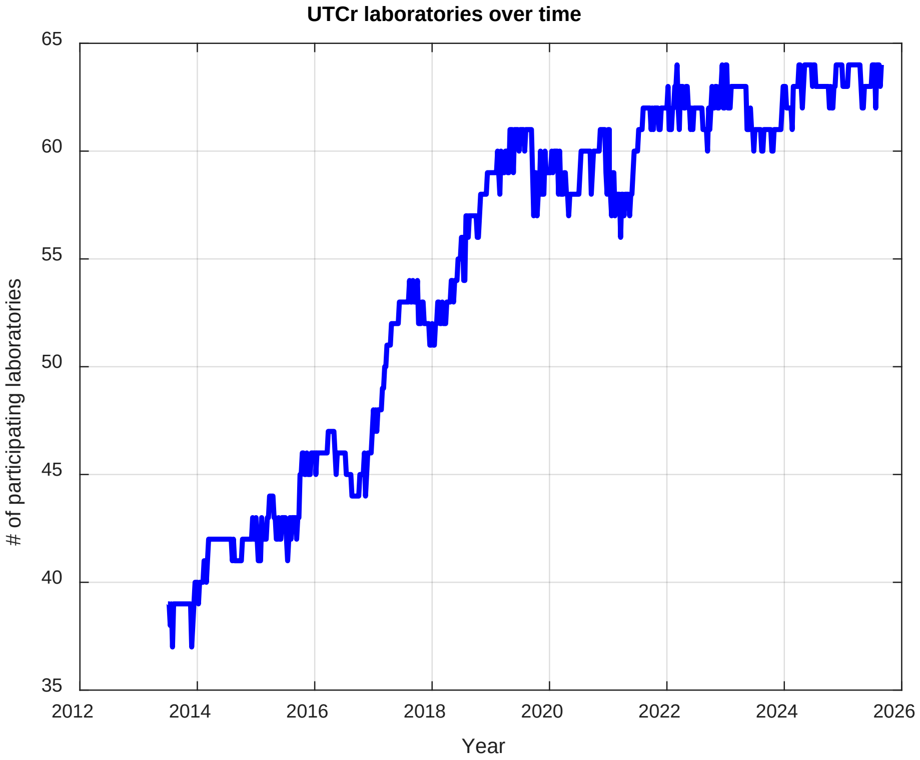
Since 2013 a rapid evaluation of UTC is available, UTCr.
The data are on daily batches and published each week, the Wednesday.
The number of participating laboratories is slightly increased in the last years.

UTCr_2534
2025 AUGUST 27, 08h UTC

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

Computed values of [UTCr-UTC(k)]

Date 2025 0h UTC	AUG 18	AUG 19	AUG 20	AUG 21	AUG 22	AUG 23	AUG 24
MJD	60905	60906	60907	60908	60909	60910	60911
Laboratory k			[UTCr-UTC(k)]/ns				
AOS (Borowiec)	-2.8	-2.7	-2.5	-2.3	-2.3	-2.2	-2.1
APL (Laurel)	-1.7	-1.9	-1.9	-2.3	-1.9	-1.3	-1.2
AUS (Sydney)	21.2	20.3	24.8	22.7	21.1	20.1	27.2
BEV (Wien)	-22.4	-20.1	-18.7	-19.9	-22.0	-21.6	-22.7
BIRM (Beijing)	-0.9	-1.5	-1.2	-1.4	-0.4	-0.6	-0.6
BSJ (Kingston)	17.1	19.0	26.8	19.4	26.0	16.9	12.2
CH (Bern-Wabern)	-0.3	-0.4	-0.2	-0.1	-0.3	-0.4	-0.3
CNM (Queretaro)	-0.8	-1.4	-1.1	0.6	1.4	0.7	-0.5
CNMP (Panama)	-16.9	-12.6	-0.3	0.2	0.1	4.2	3.7
DLR (Oberpfaffenhofen)	0.1	0.0	-0.3	-1.0	-1.2	-0.8	-1.3
DMDM (Belgrade)	11.9	14.3	16.5	18.2	21.6	25.7	28.3
DTAG (Frankfurt/M)	61.0	61.3	65.6	68.0	73.7	74.4	80.7
ESA (Noordwijk)	-0.4	-0.4	-0.4	-0.2	-0.4	-0.7	-0.5
HKO (Hong Kong)	321.8	324.6	330.9	332.8	329.5	333.0	334.9
ICE (San Jose)	0.8	7.6	-	-19.3	-25.9	-35.6	-50.9
IFAG (Wettzell)	-715.8	-717.0	-714.8	-713.9	-717.2	-714.7	-710.4
IFZG (Zagreb)	286.3	283.1	281.3	280.1	282.3	279.5	278.8
IMBH (Sarajevo)	-3.5	-3.3	-0.7	2.0	1.0	1.1	2.5
INM (Bogota D.C.)	-36.2	-31.2	-40.8	-42.6	-56.2	-55.6	-68.5
INTI (Buenos Aires)	-52.5	-51.4	-48.0	-49.3	-54.6	-55.1	-54.4
INXE (Rio de Janeiro)	1.3	0.5	-0.3	-1.7	-3.1	-1.8	-2.9
IPQ (Caparica)	-	-	1768.0	1763.3	1759.1	-	-
IT (Torino)	0.6	0.6	0.6	0.6	0.5	0.5	0.5
JV (Kjeller)	-0.2	0.0	0.6	0.3	0.6	1.3	1.4
KRIS (Daejeon)	1.3	1.4	1.1	1.0	1.0	1.2	1.1



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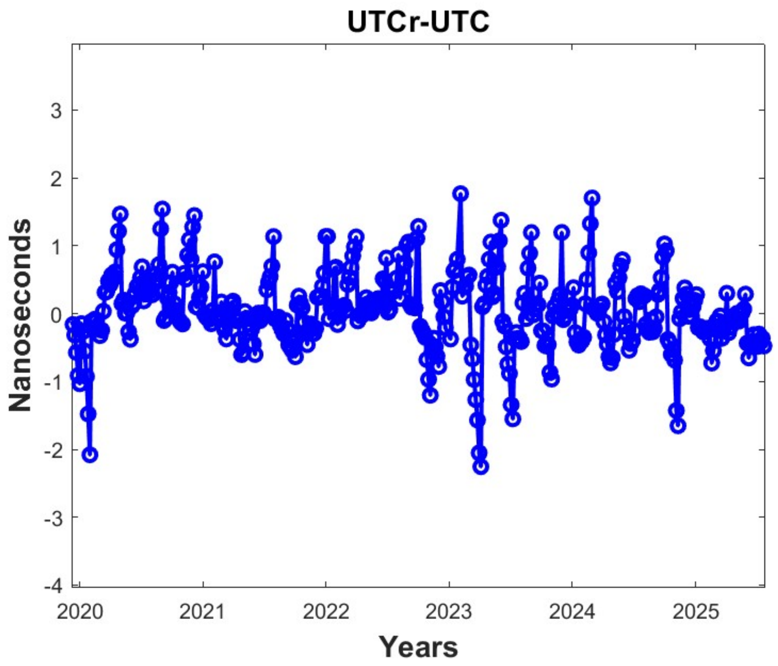
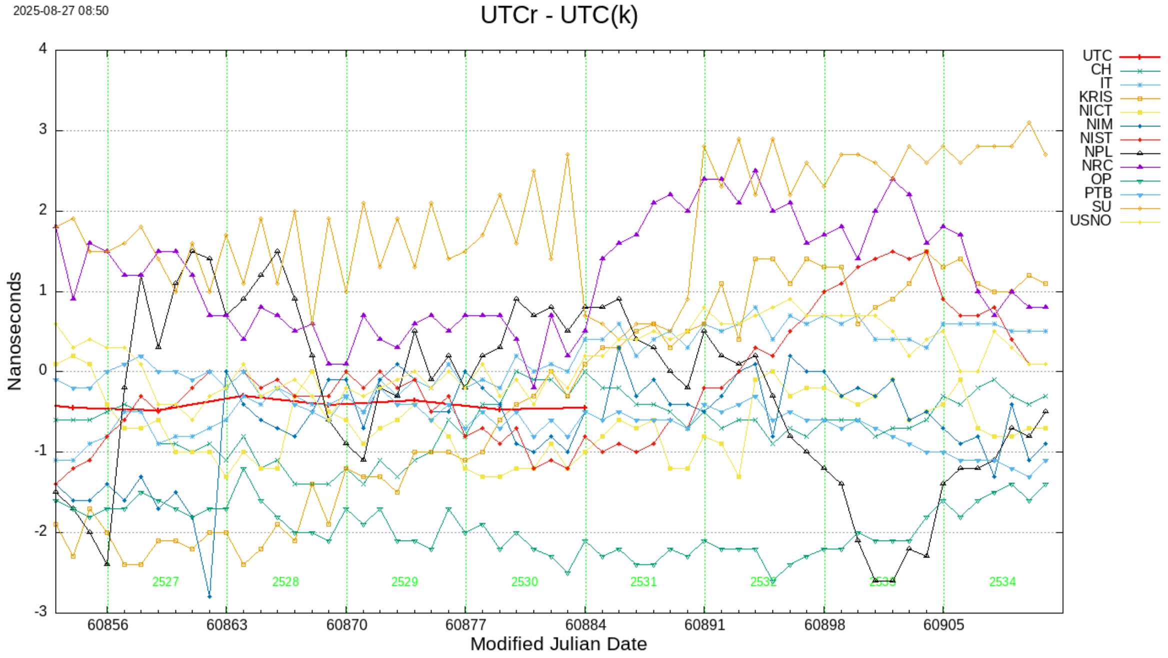
UTCr versus UTC

For the week 2534 for example we had 62 participating laboratories with 271 atomic clocks.

Concerning the time links, we apply the following rules:

- 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 and Accuracy 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 $(\pm 1\ ns)$

- 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
- **Steering algorithm** to prevent large adjustments to UTCr when UTC data are available. The correction to get UTCr=UTC is introduced gradually.

UTCr algorithms

- The differences and interactions between the algorithms used to generate UTC and UTCr are the following:

	UTC	UTCr
Frequency drift of the clocks	Estimated over the last three month on [clock-TT] data.	The values used are the UTC values updated after each Circular T.
Maximum weight	6/N (N = number of clocks)	3.8/N1 (N1 = number of clocks)
Weight parameter	12 months of EAL-clock data are used to establish the most stable clock	4 values (1 par week) of UTCr-clock are used to establish the most stable clock
Steering algorithm	Algorithm developed based on the availability of PSFS	The values of UTC-clocks are used to steer UTCr on UTC

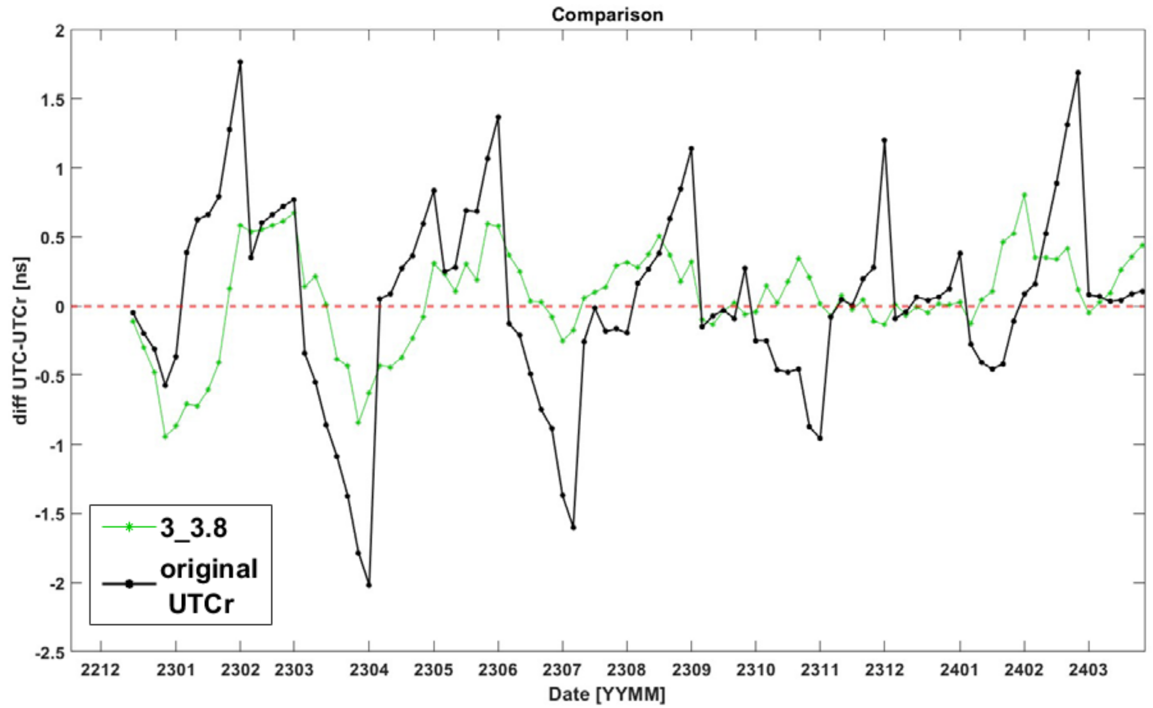
UTCr algorithm update

The algorithm generating the UTCr was updated (weighting and steering) less than a month ago:

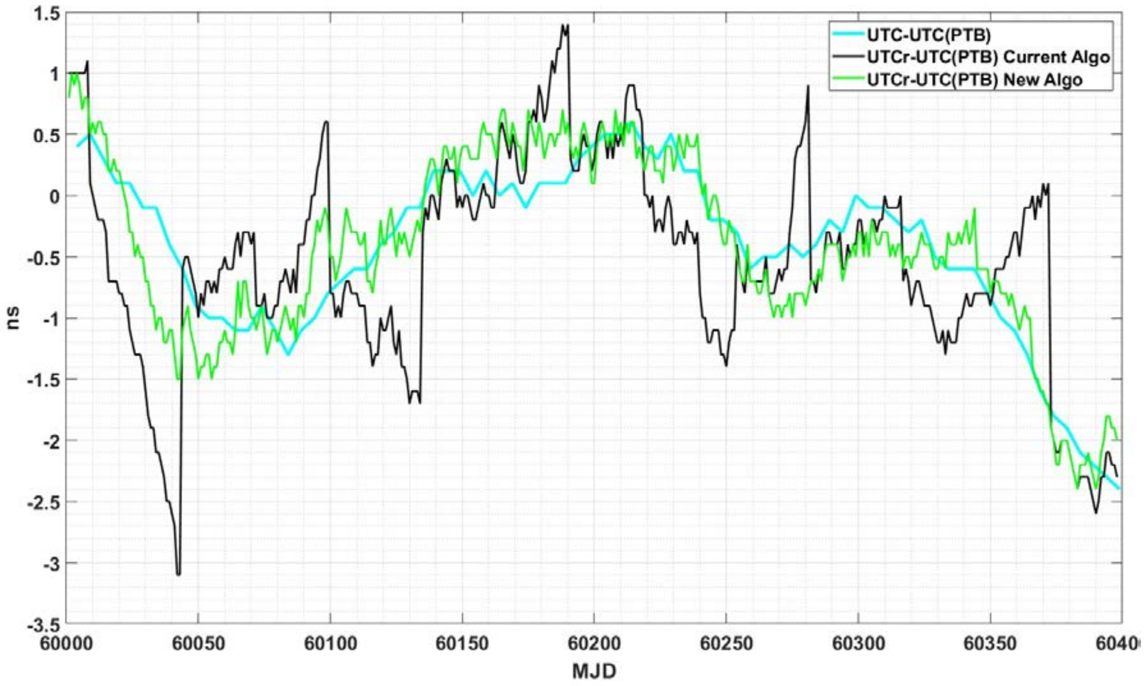
1. During the first stage, the analysis was carried out over a specific period (1 year).
   - The parameters of the new weighting and steering algorithms were optimized.
   - Different values for the maximum weighting were tested.
2. During the second stage, we tested the algorithm in real time by running it in parallel with the current algorithm.
3. Finally, the new algorithm was made official in mid-July 2025.

First step – parameters optimisation

The new algorithm succeed in maintaining UTCr close to UTC at the level of $\pm$ 1 ns.



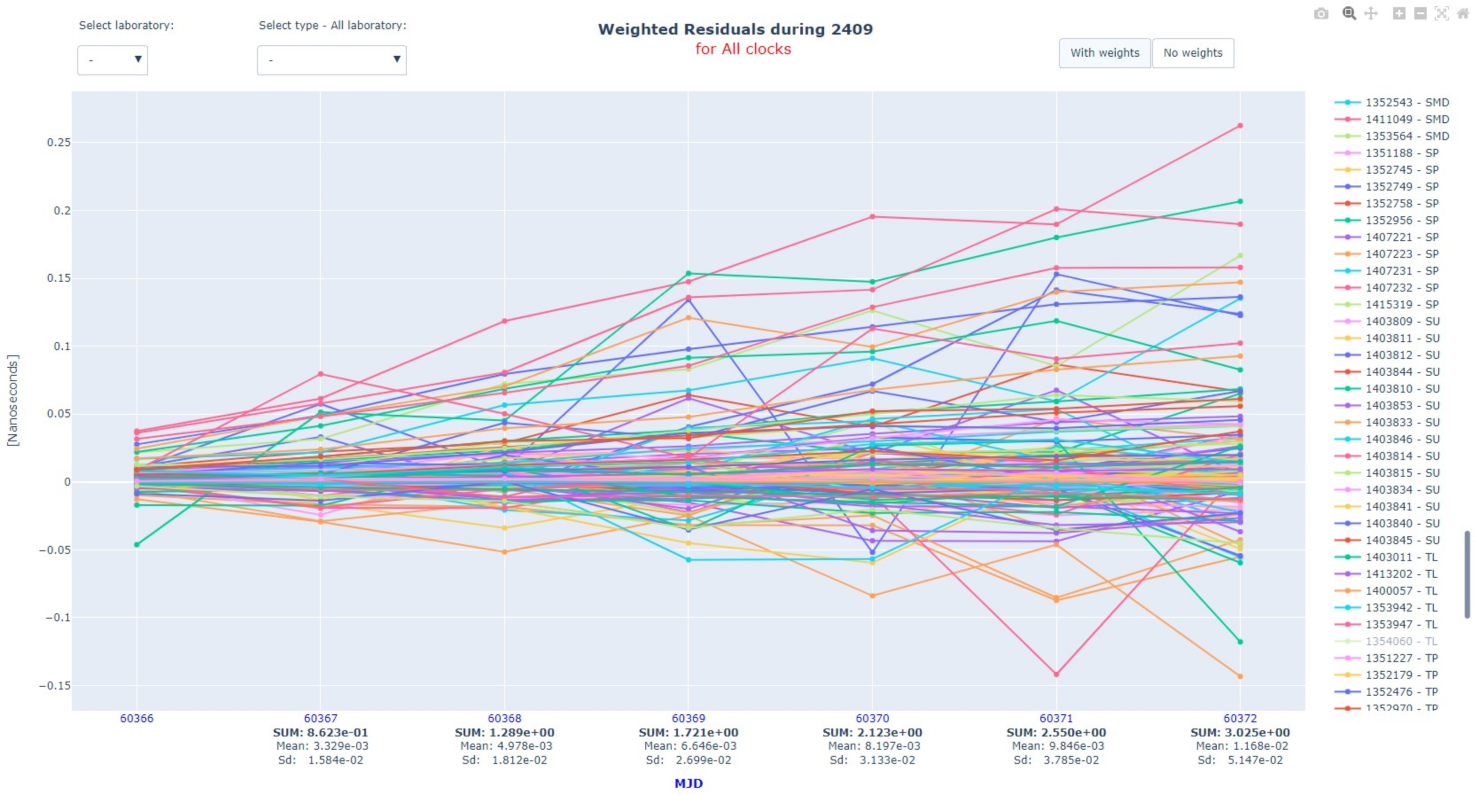
The difference between UTC and UTCr obtained with the new (green: M=3 and Wmax=3.8/N) and the old (black) algorithms.

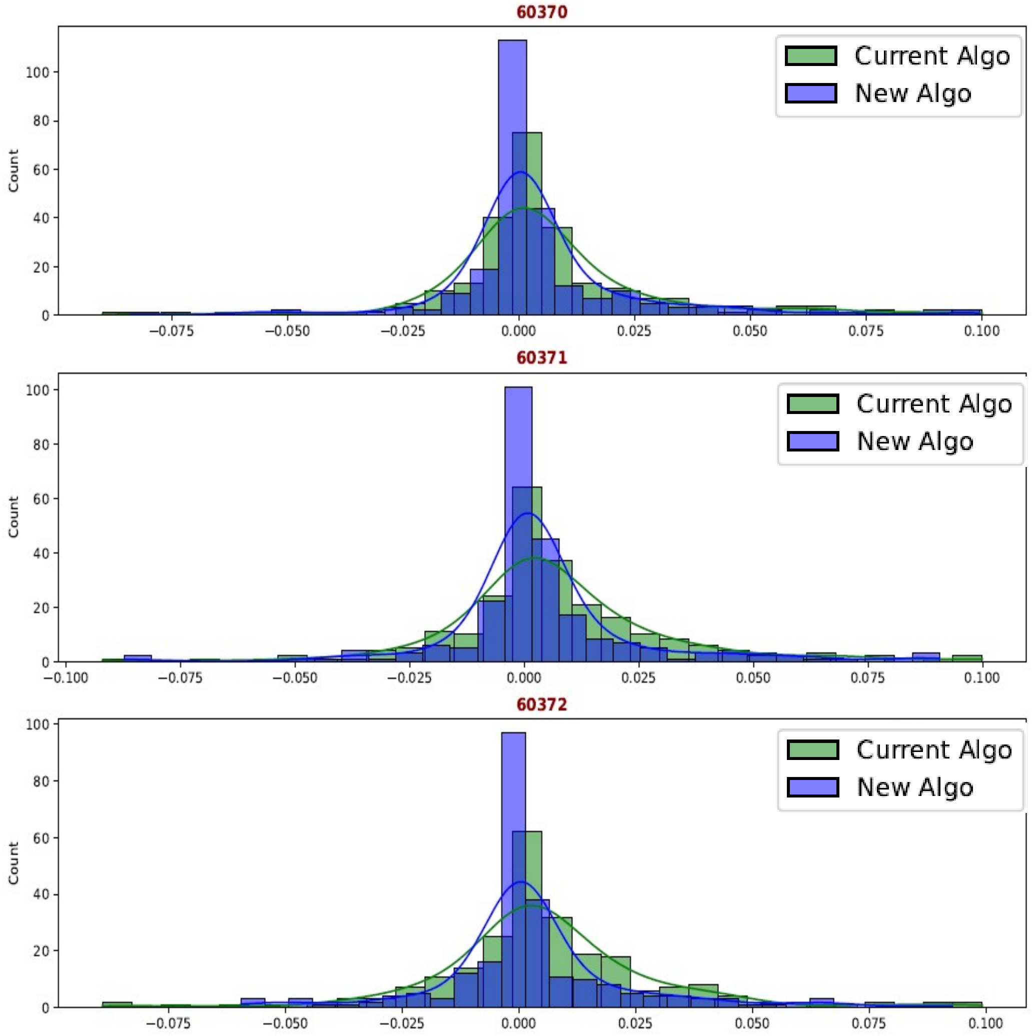


The difference between UTC and UTC(PTB) (light blue), together with UTCr - UTC(PTB) obtained with the new (green) and the old (black) algorithms.

Results – Effects prediction error distribution

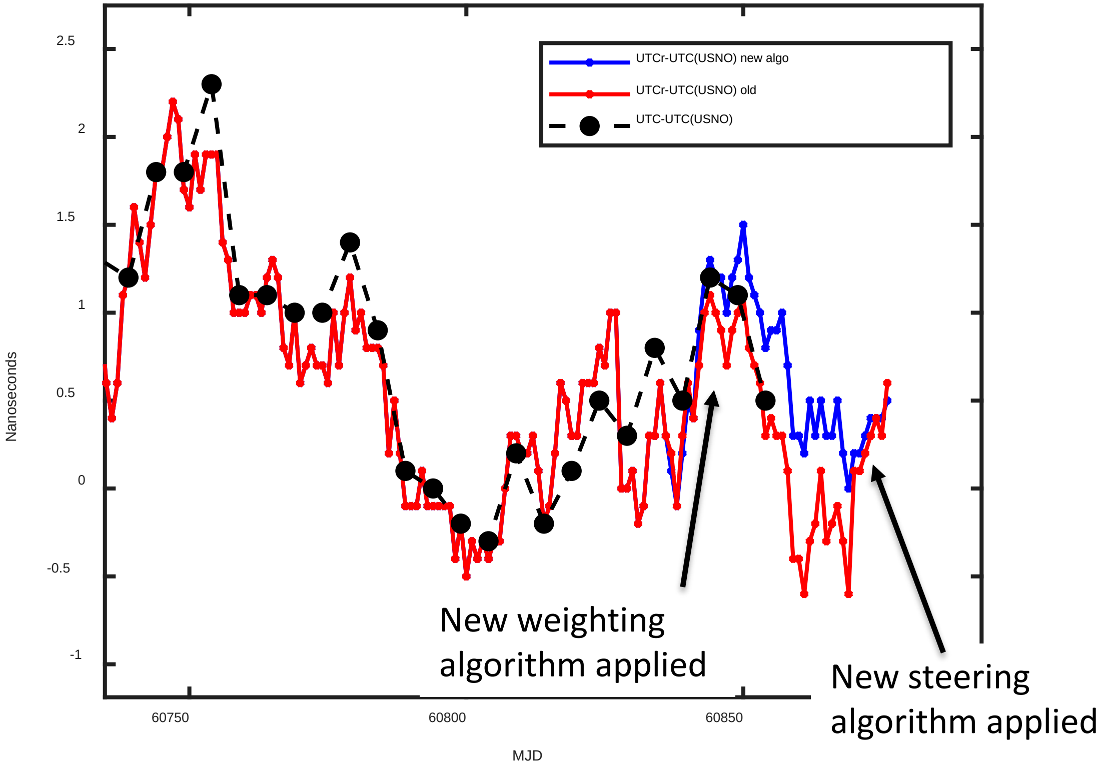
prediction error =
predicted time offset of each clock versus UTCr – its measured value

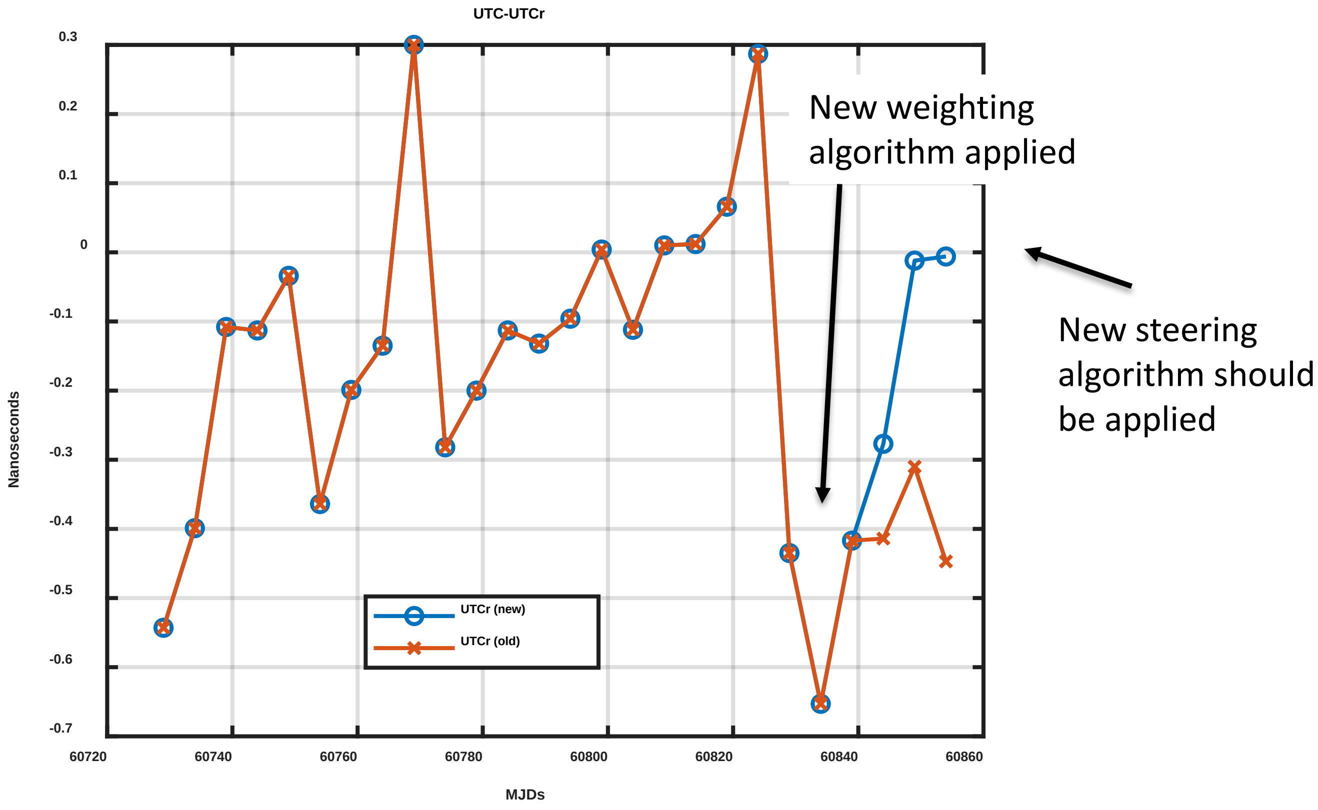




The histograms clearly show that the distribution of the weighted prediction errors obtained with the new algorithm is more centered around zero and that the approximate Gaussian distribution has a smaller variance.

Second stage – real time analysis





Applying the old algorithm a step is visible as in UTCr(USNO) as in the difference between UTC and UTCr.

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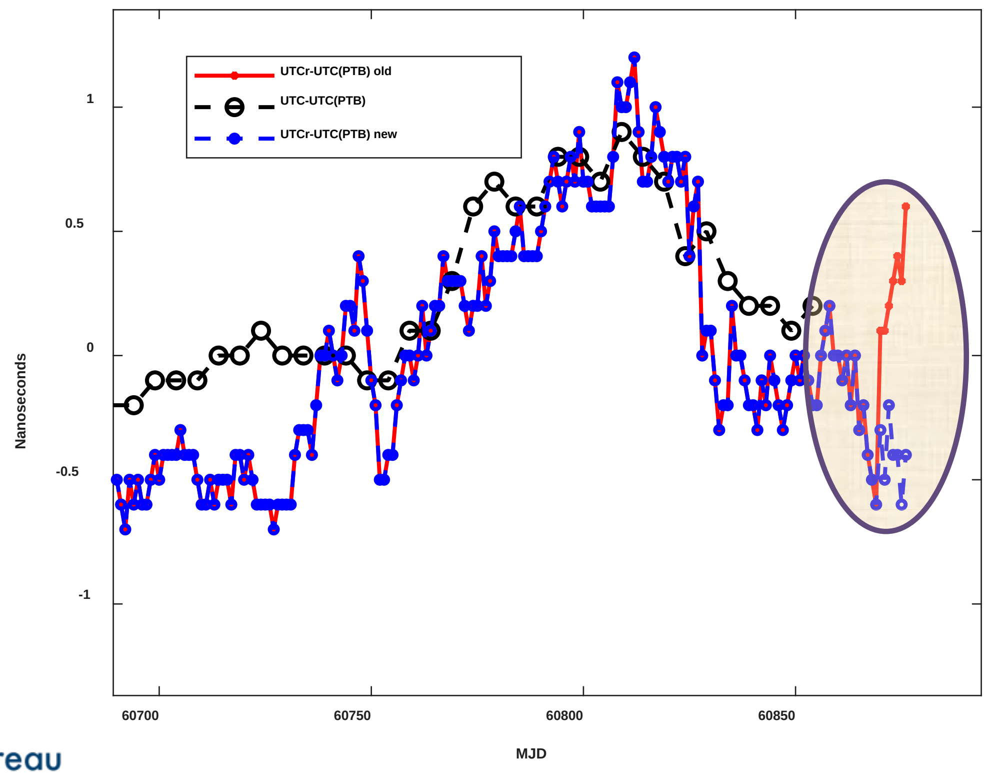
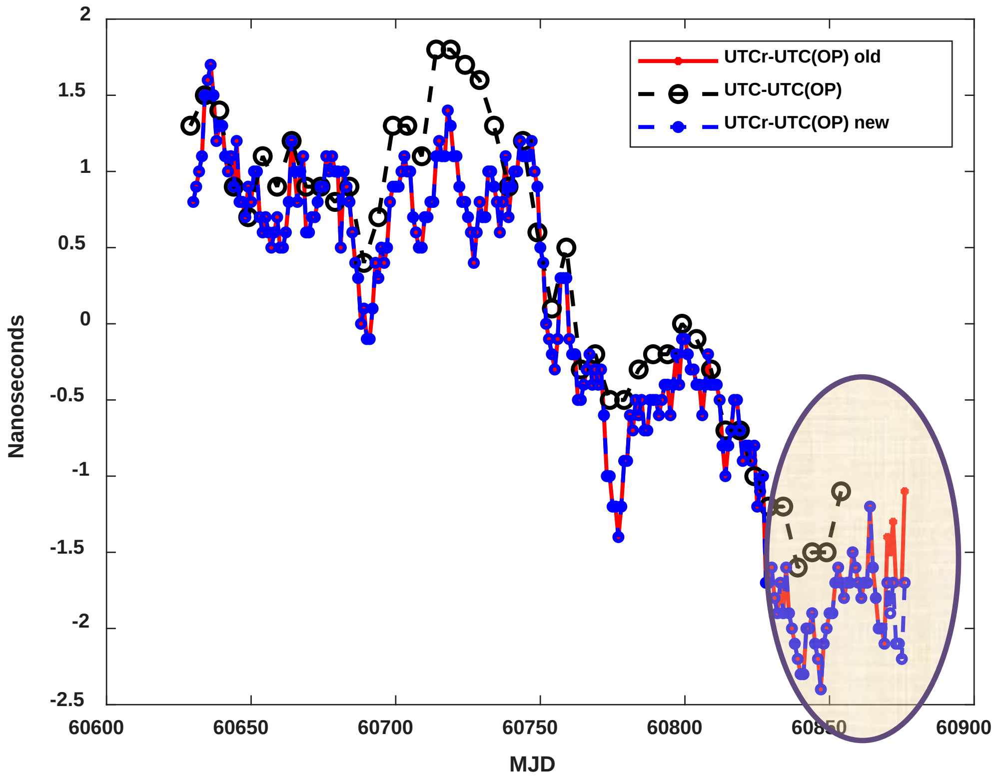
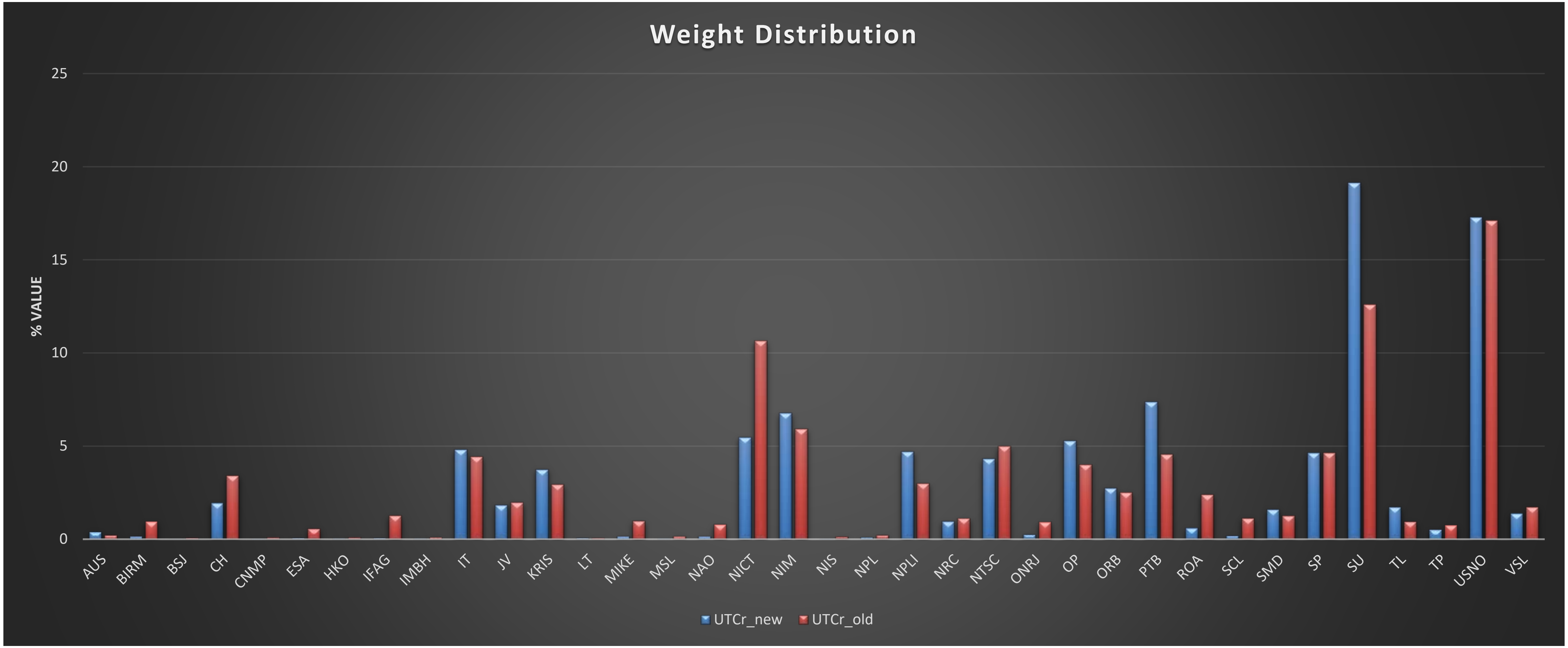
New algorithm applied

When the new algorithm has been applied the results obtained using the old and the new have been compared for different time scales, e.g. OP, PTB.





Weight distribution



Conclusions

- The algorithms used for UTC and UTCr were presented.
- The current status and performance of both were discussed.

- The development and maintenance of the algorithms used to calculate UTC and UTCr are fundamental to the BIPM in order to maintain UTC and UTCr at the best possible performance.
- Any changes to the algorithms require a significant level of analysis and study to ensure that no unexpected long-term effects occur.

Thank you very much for your attention