The CCTF and the BIPM Time Department activities

Patrizia Tavella
BIPM Time Department

Bureau International des Poids et Mesures

Time Department group

Gerard PETIT
Gianna PANFILO
Frédéric MEYNADIER

Aurélie HARMEGNIES
Camille PARRA
Laurent TISSERAND

Patrizia TAVELLA

CCTF HOT TOPICS

The **Consultative Committee on Time and Frequency** is concentrating on 4 hot topics
for which task groups have been created in 2020 under the CCTF Strategic Planning WG coordination

1. **Task Force on *Updating the Roadmap for the redefinition of second:***
   A. *Request from user communities, NMIs and Liaisons* (M. Gertsvolf, NRC; G. Mileti, Uni Neuchatel)
   B. *Atomic frequency standards, and possible redefinition approaches* (S. Bize, SYRTE; E. Peik, PTB; C. Oates, NIST)
   C. *TF Dissemination and time scales* (D Calonico, INRIM; T. Ido NICT)
2. **Leap seconds in UTC and building a consensus for a continuous timescale** (J. Levine, NIST; P. Tavella, BIPM)
3. **Promoting the mutual benefit of UTC and GNSS, subgroup on Traceability to UTC from GNSS measurement** (P. Defraigne, ORB; A. Bauch, PTB)
4. **Sharing Resources to Improve the International Timekeeping** (M. Gertsvolf NRC, Y. Hanado, NICT)

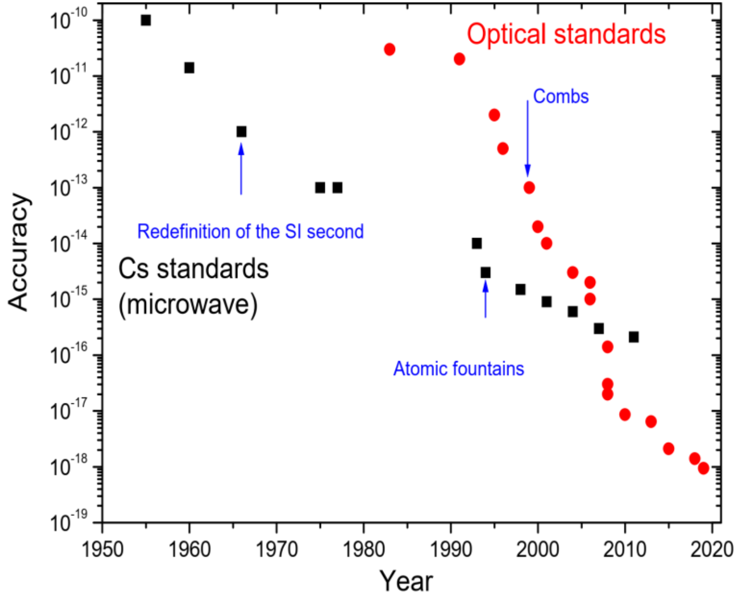
CCTF work in progress:

- CCTF Session 1 in October 2020: introduction of the topics, main issues, opening of a questionnaire to NMIs, UTC labs, Liaisons, Stakeholders (4 sets of questions)
- From Nov 2020 to Feb 2021, online questionnaire with > 200 answers
- CCTF session 2 in March 2021 to discuss main expectations/constraints/possible schedule and way forward
- Work in progress:
  - finalize way forward within CCTF by Sept 2021,
  - input to CIPM in Oct 2021,
  - contribution to CGPM in 2022

All next slides are taken from the CCTF working group presentations and the different CCTF members contributions

Updating the roadmap for the redefinition of the second

A CCTF Task Force is working to prepare a detailed roadmap by identifying the intermediate objectives and open issues, based on collect of information and critical assessment.



Task force

Co chairs: N. Dimarcq and P. Tavella

3 subgroups

A – Request from user communities, NMIs, and Liaisons

- **Chair : Marina Gertsvolf, Gaetano Mileti**

B – Atomic frequency standards, and possible redefinition approaches

- **Chair : Sebastien Bize, Ekkehart Peik, Chris Oates**

C – TF Dissemination and time scales

- **Chair : D Calonico, Tetsuya Ido**

More than 40 people from all RMOs, from all CCTF members, from all CCTF WGs, working together to assesse the possible roadmap for rdefning the second

Redefinition criteria / conditions

Mandatory criteria
To be achieved
before changing the
definition

Achieved

- **Validation that Optical Frequency Standards are at a level 100 times better than Cs (I.1, I.2)**
- **Continuity with the definition based on Cs (I.3)**
- **Regular contributions of OFS to TAI as secondary representations of the second (I.4)**
- **Availability of sustainable techniques for OFS comparisons (II.1)**
- **Knowledge of the local geopotential with a sufficient uncertainty level (II.2)**
- **Definition allowing future more accurate realizations (III.1)**
- **Access for NMIs to primary or secondary realizations of the new definition (III.2)**

Mandatory achievements frontier

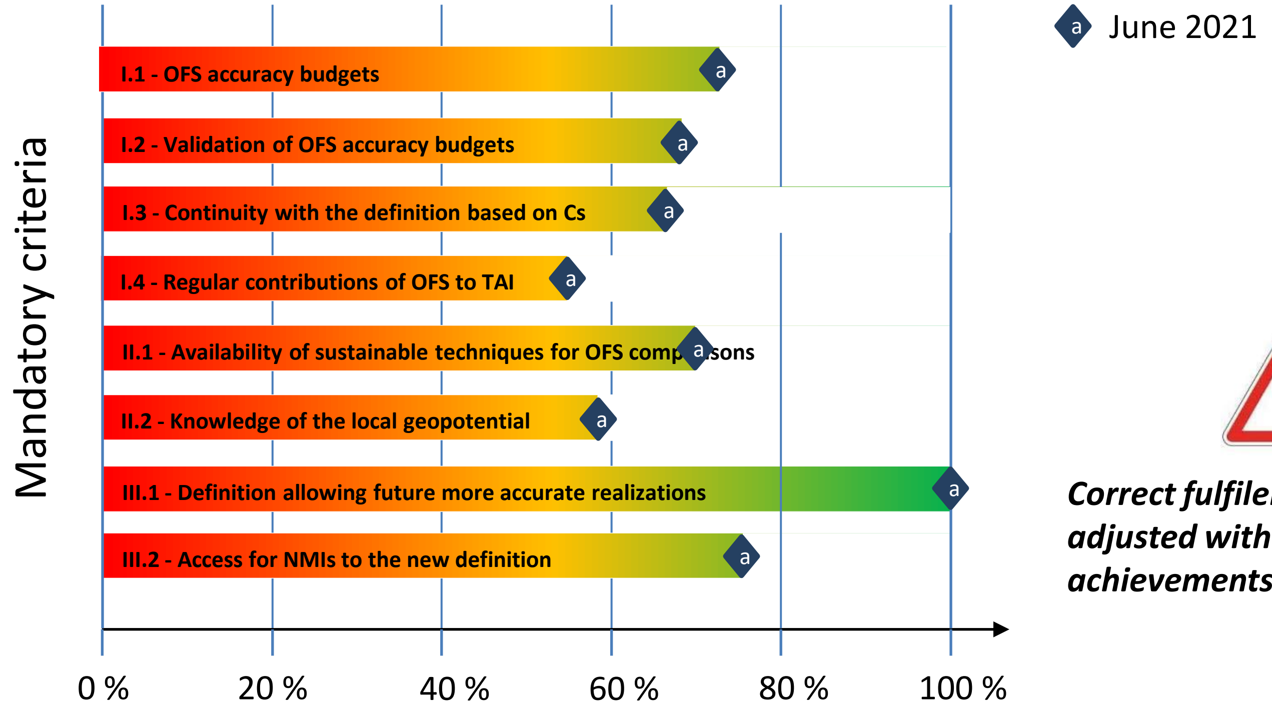
Conditions corresponding to essential **Work still in progress** when the definition is changed

In progress

- **High reliability of optical frequency standards (I.5)**
- **High reliability of ultra high stability T/F links (II.3)**
- **Continuous improvement of the realization and time scales after redefinition (III.3)**
- **Regular contributions of optical clocks to UTC(k) (I.6)**
- **Availability of commercial optical clocks (III.4)**
- **Improved quality of the dissemination towards users (III.5)**

Criteria for Redefinition – Fulfilment indexes

3 possible scenarios with redefinion in 2026, 2030, 2034



Correct fulfilement levels to be adjusted with real achievements

Bureau International des Poids et Mesures

CCTF

Leap seconds in UTC and building a consensus for a continuous timescale

Bureau International des Poids et Mesures

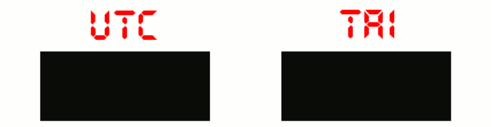
Coordinated Universal Time UTC is kept in agreement with the rotational angle of the Earth UT1 by the insertion of leap seconds

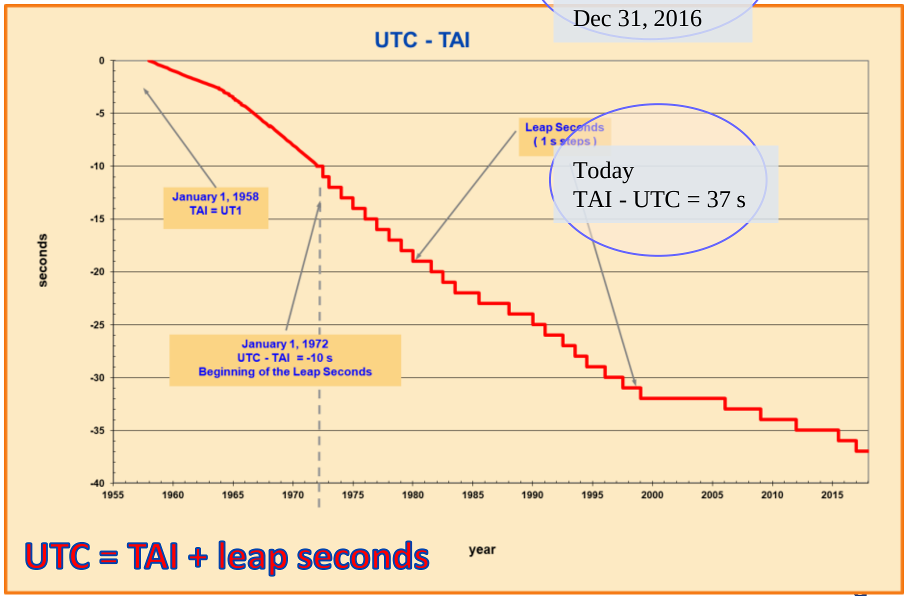
UTC is obtained from the International Atomic Time (TAI) plus leap seconds.

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

|UTC - UT1| < 1 second

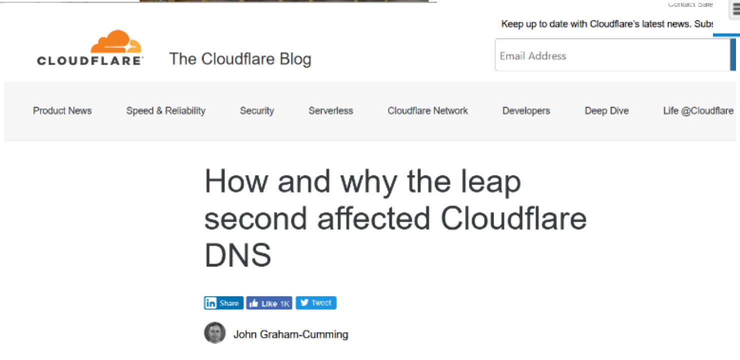
23:59:59
23:59:60
00:00:00





Bureau International des Poids et Mesures

The digital networks cannot cope with the leap second



Time travels on the network

Computer operating systems are not easily able to handle a minute with 61 seconds

Different “solutions” have been adopted

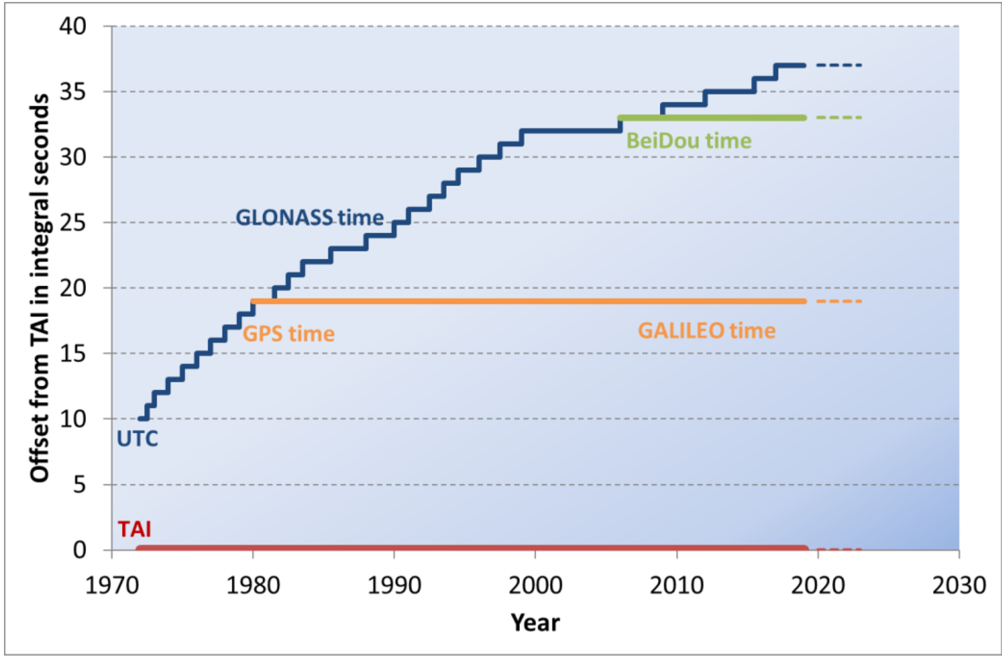
- Ignore leap seconds after an initial synchronization
    - GPS, Galileo, BeiDou system times.
    - Most current versions of Windows
- Stop clock for 2 seconds at 23:59:59 or 00:00:00
    - Network Time Protocol, Posix time on many computers
    - Two seconds have same name
    - Problems with causality, time ordering, time intervals
    - Leap second has no indicator
- Reduce frequency of clock over some interval
    - Google (24 h before), Microsoft, Facebook (18 h after), Alibaba (12 h before – 12 h after) …

All of these solutions are not in agreement with UTC on the leap second day, and many disagree with each other

Users cannot tell which method is used by a time source, especially a posteriori

Different solutions: Time in GNSS

Navigation using GNSS signals prefers a continuous time scale, and the GNSS system time does not use leap seconds (except GLONASS which applies leap seconds). These time scales are easily available all over the world, are commonly used as time and frequency references, and differ from each other and from UTC by several seconds

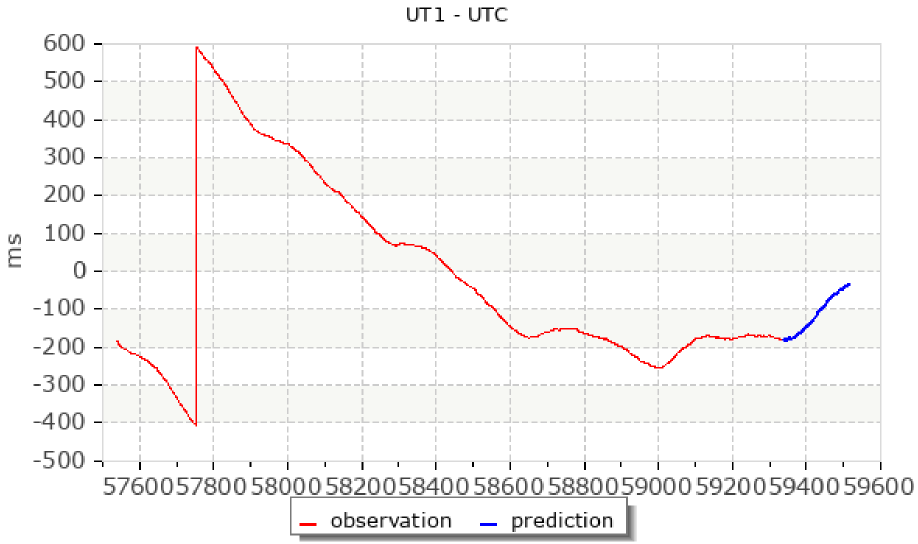


Bureau International des Poids et Mesures

The outcome

- UTC with leap seconds does not satisfy requirements of many applications
- Several different solutions have been implemented
- Solutions are not universal and different methods are not compatible with UTC or with each other
- UTC is becoming less relevant and less useful

The recent acceleration of the Earth rotation may lead to a negative leap second, for the first time, never happened, never tested



https://eoc.obspm.fr/index.php?index=realtime&lang=en

Bureau International des Poids et Mesures

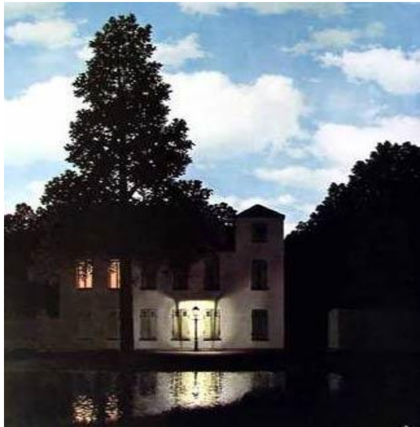
A Possible Solution discussed at CCTF

Increase tolerance of |UT1 - UTC|

- If limit of DUT1= |UT1 - UTC| < 100 or XXX seconds
  - No leap seconds for a century or more at current rate of increase
  - Tolerance could be one hour (change of time zone)
- UTC remains linked to UT1, the Earth's rotation angle, the origin is the reference meridian of Greenwich
- UTC is approximately UT1 within the 15 min of seasonal day variation for centuries. For the general public this is a "no event"

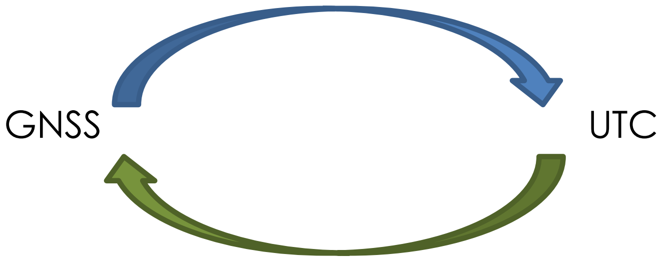
Users of UT1 can find precise information

- IERS and NASA web sites with microsecond uncertainty
- GNSSs, with some update, will still disseminate UT1-UTC
- Radio stations may stop the transmission of DUT1 (as DCF 77 did)



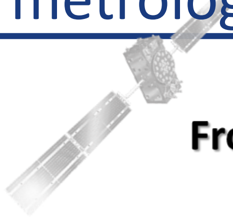
Promoting the mutual benefit of UTC and GNSS

1. Current use of GNSS for UTC
2. Calibration for GNSS hardware delays



1. UTC is disseminated by GNSS with the contribution of national metrological laboratories
2. Users may need traceability to UTC from GNSS measurements
3. UTC can help Interoperability (discussion at the International Committee on GNSS)

UTC is disseminated by GNSS with the contribution of national metrological laboratories



From GNSS : position + ($t_{receiver} - t_{GNSS}$)

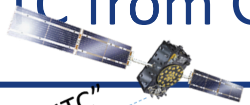
t_{GNSS} – "UTC"

($t_{receiver}$ – "UTC")

- The user clock offset versus the GNSS time is estimated by the receiver.
- The GNSS is also broadcasting a prediction of t_{GNSS} versus UTC
- The offset of the user clock versus a prediction of UTC can be estimated

- "UTC" is the prediction of UTC provided by the GNSS
- It allows the user to synchronize a clock on "UTC"
- Each GNSS constellation broadcasts a different prediction, based on different UTC(k)s
- The BIPM currently provides in Circular T (Section 4) :
  [UTC–UTC(USNO)_GPS] = C0',
  [UTC–UTC(SU)_GLONASS]= C1',
- The Circular T Section 4 will be upgraded to include Galileo and BeiDou, with new naming convention: [UTC–Broadcast_UTCxxx] (xxx for GPS, BDS, GAL, GLO). Absolutely calibrated G1 receivers will be used

Users may need traceability to UTC from GNSS measurements



From GNSS : position + ($t_{receiver} - t_{GNSS}$)

t_{GNSS} – "UTC"

+

($t_{receiver}$ – "UTC")

- The offset of the user clock versus a prediction of UTC can be estimated.
- Is this traceable to the international UTC, i.e. is the meaurement chain uninterrupted and is the uncertainty of each step known?

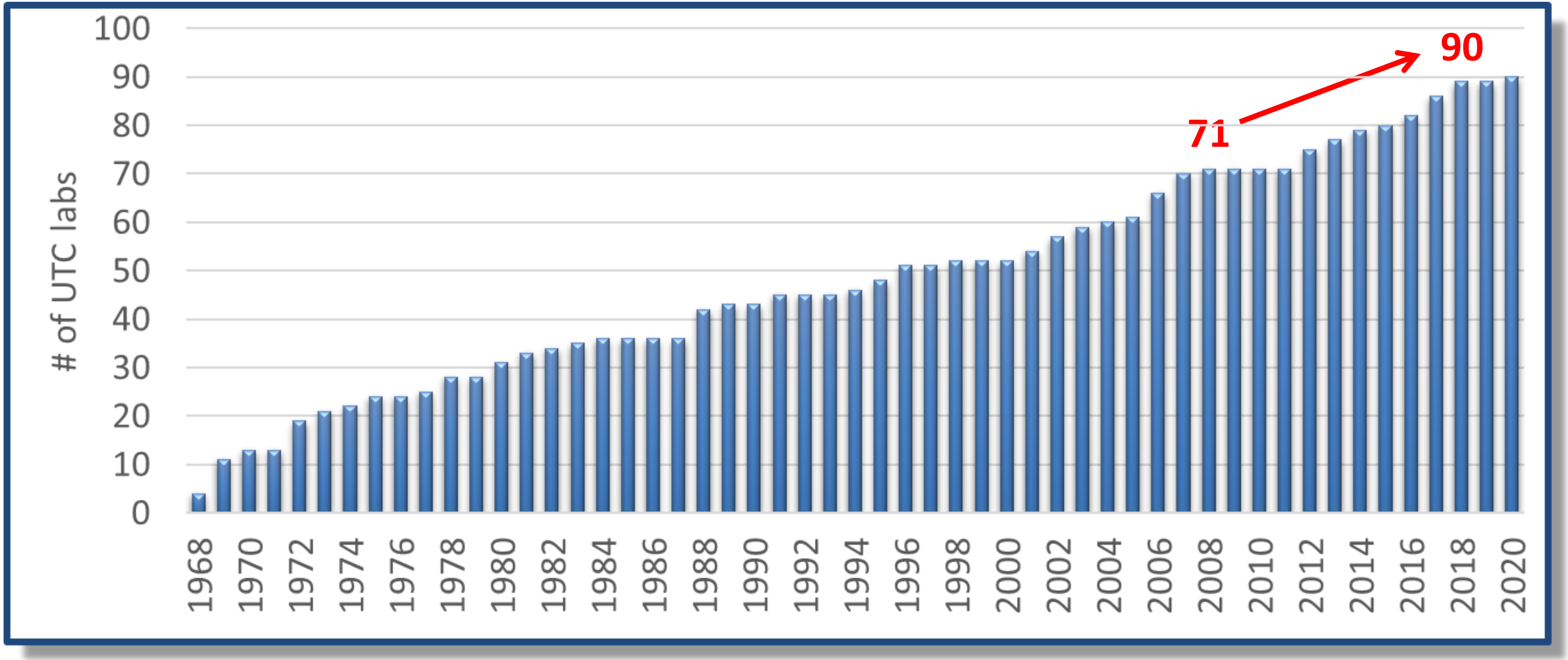
Increasing use of GNSS for synchronization & increasing demand for traceability

Need for guidelines on
- how the user can get UTC from GNSS (including equipment and calibration)
- and how traceability can be obtained when using GNSS for synchronization to UTC (UTC from Signal in Space or UTC from UTC(k))

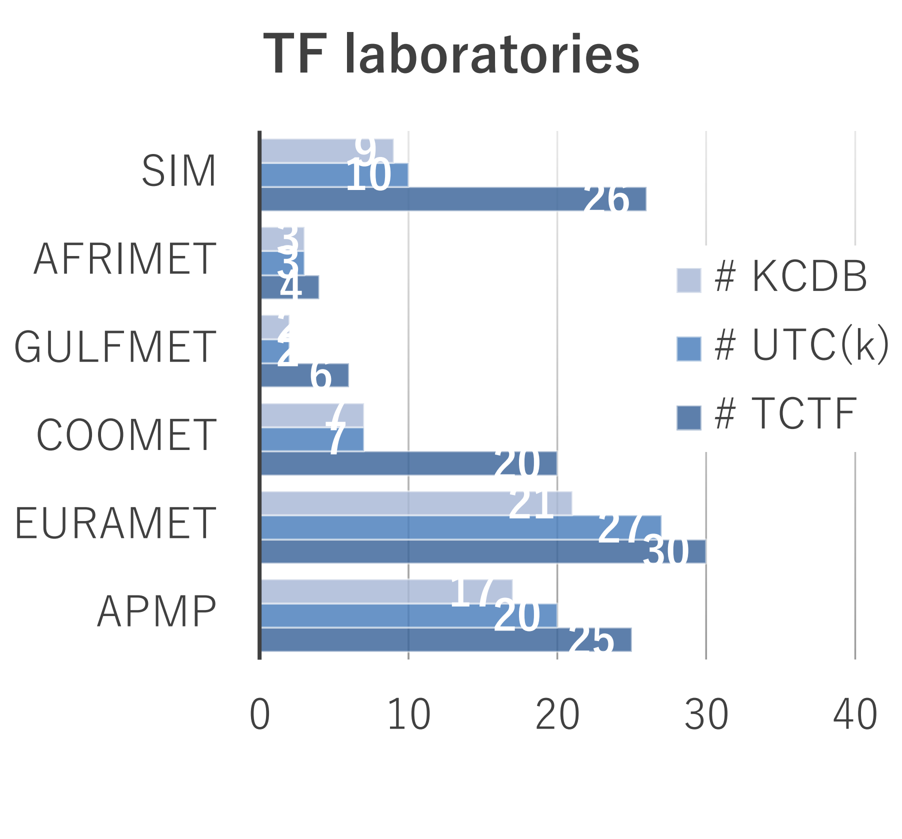
CCTF Task group is working on that in collaboration with metrology institutions

Sharing Resources to Improve the International Timekeeping

UTC(k) community is growing:



Time Labs



New labs are coming on board that will benefit from learning more about the best practices in setting up UTC(k)

more Training and Resources are required:

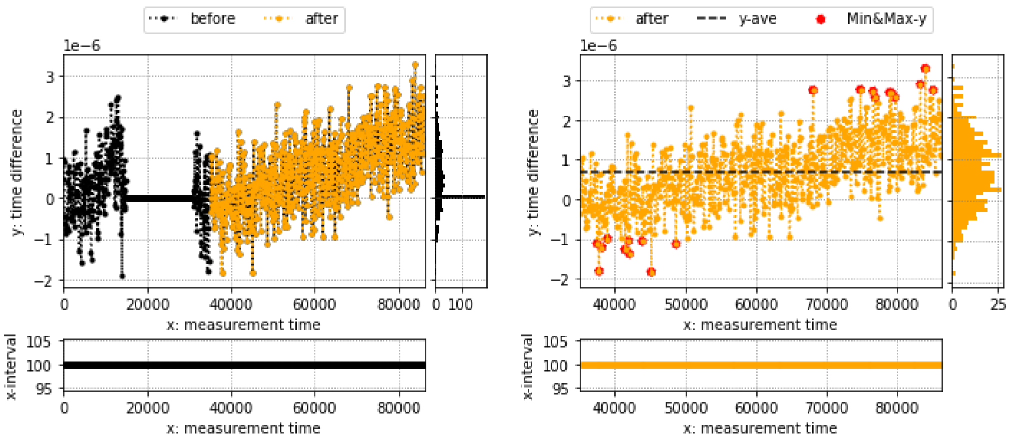
- automatic UTC computation algorithms check for anomalies in submitted data (labs are contacted when problem investigation is required)
  - outliers
  - jumps / step direction
  - consistency with previous submission
  - gaps

Goal: Support labs in developing methods for fast and efficient data diagnosis and problems identification

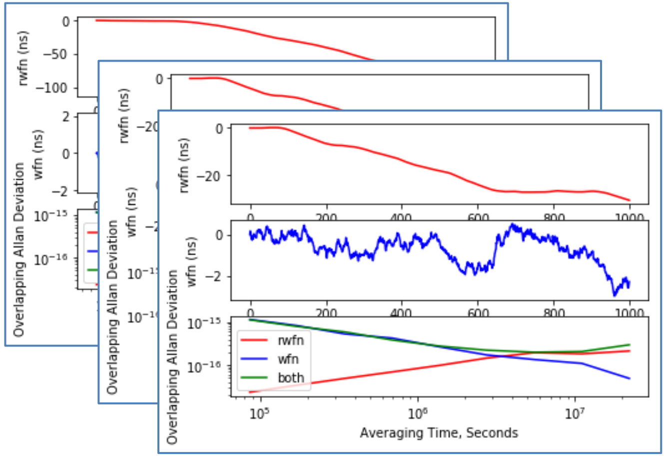
The CCTF is aiming to “sharing resources” to allow synergies among laboratories

We are working on open software development

- Practical exercise for generating a timescale is going to be prepared.
  Data processing tool & time scale simulator by Python code
- This software is open source



Data processing tool (bad data elimination, linear fitting etc.)



Time scale simulator by using the virtual clock

CCTF proposal on enhancing resource sharing opportunities at BIPM

knowing that

•Individual laboratory realisations of UTC(k) and atomic clocks ensemble and time link measurements and data quality affect the quality and accuracy of TAI and UTC,

Considering that

•The clock ensemble and links data collection and submission have become highly automated to support daily data submission to BIPM for UTCr calculation,

•There are common techniques, equipment and analysis tools that are used by UTC(k) laboratories to maintain and monitor their clock ensemble,

•That the BIPM has a Capacity Building and Knowledge Transfer (CBKT) program to support the efficient realization of national and international standards, and this program could be extended to further support the UTC laboratories to efficiently realize UTC(k) and contribute to UTC.

•That NMIs and UTC laboratories have expressed their availability to support a cooperative initiative by sharing resources, tools, and personnel,

•That the CCTF considers of strategic importance the capacity building in all the time laboratories

CCTF proposes to build up a "secondee-based" program at the BIPM to extend the capacity building and resource sharing for the improvement of UTC(k) and UTC, where

The BIPM

•Continues and extends the CBKT initiative toward the improvement of UTC and UTC(k) realization

•Creates and maintains a website for resources sharing that could contain technical and training material in the form of presentations, tutorials, training videos, software tools, and guideline documents.

•Establishes an ongoing secondment program to support and develop resource sharing activities and tools for UTC laboratories with the capacity to host at least one secondee at a time.

The NMIs

•Support this initiative by

- •contributing to the collection and development of training tools,
- •funding an expert from their institution as secondees to BIPM to develop the training materials and tools, and to promote and support their use.

The RMOs

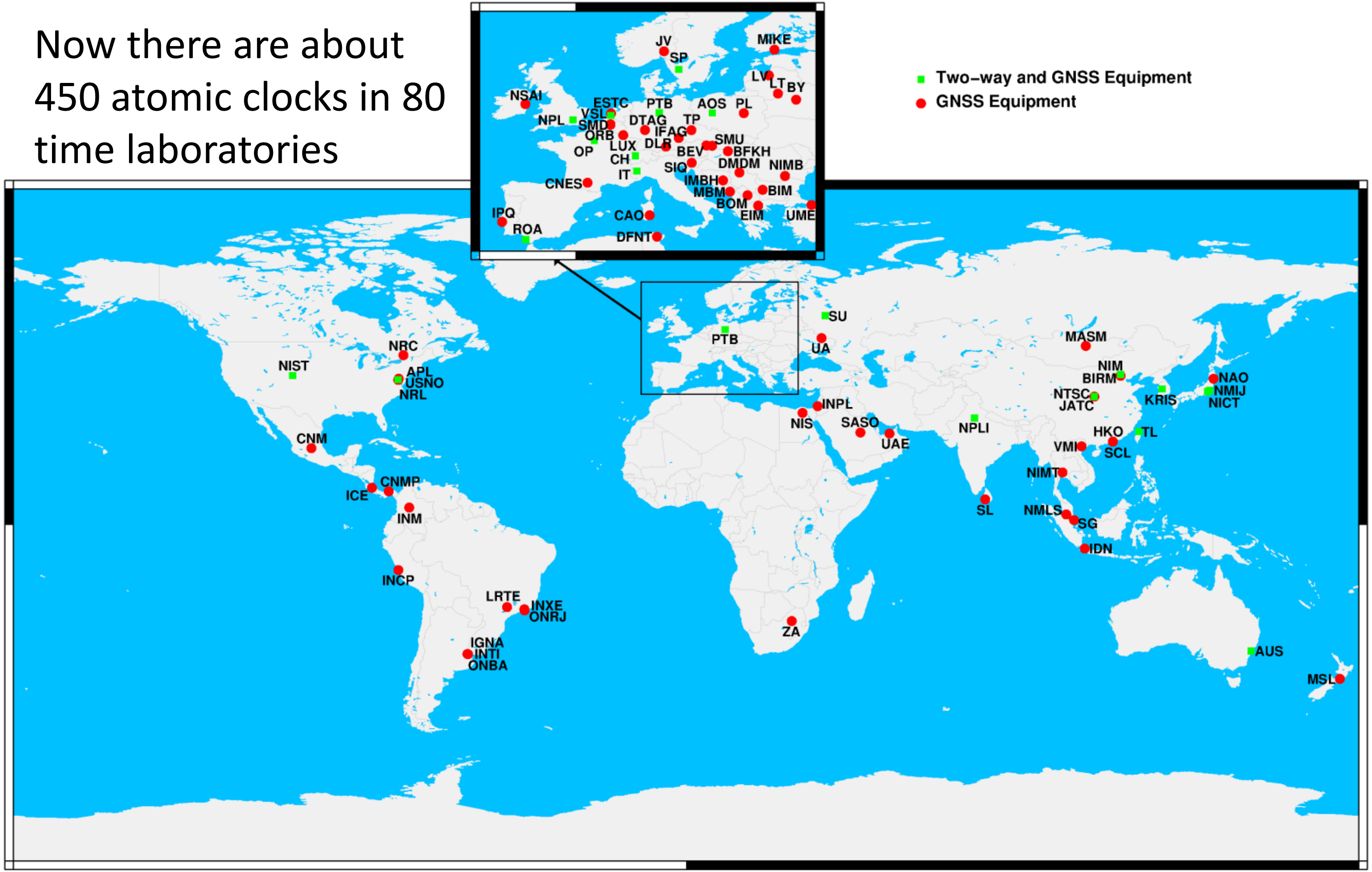
•Support this initiative by

- •contributing to the collection and development of training tools,
- •promoting the exchange of information, trainers and trainees between NMIs, DIs and BIPM.

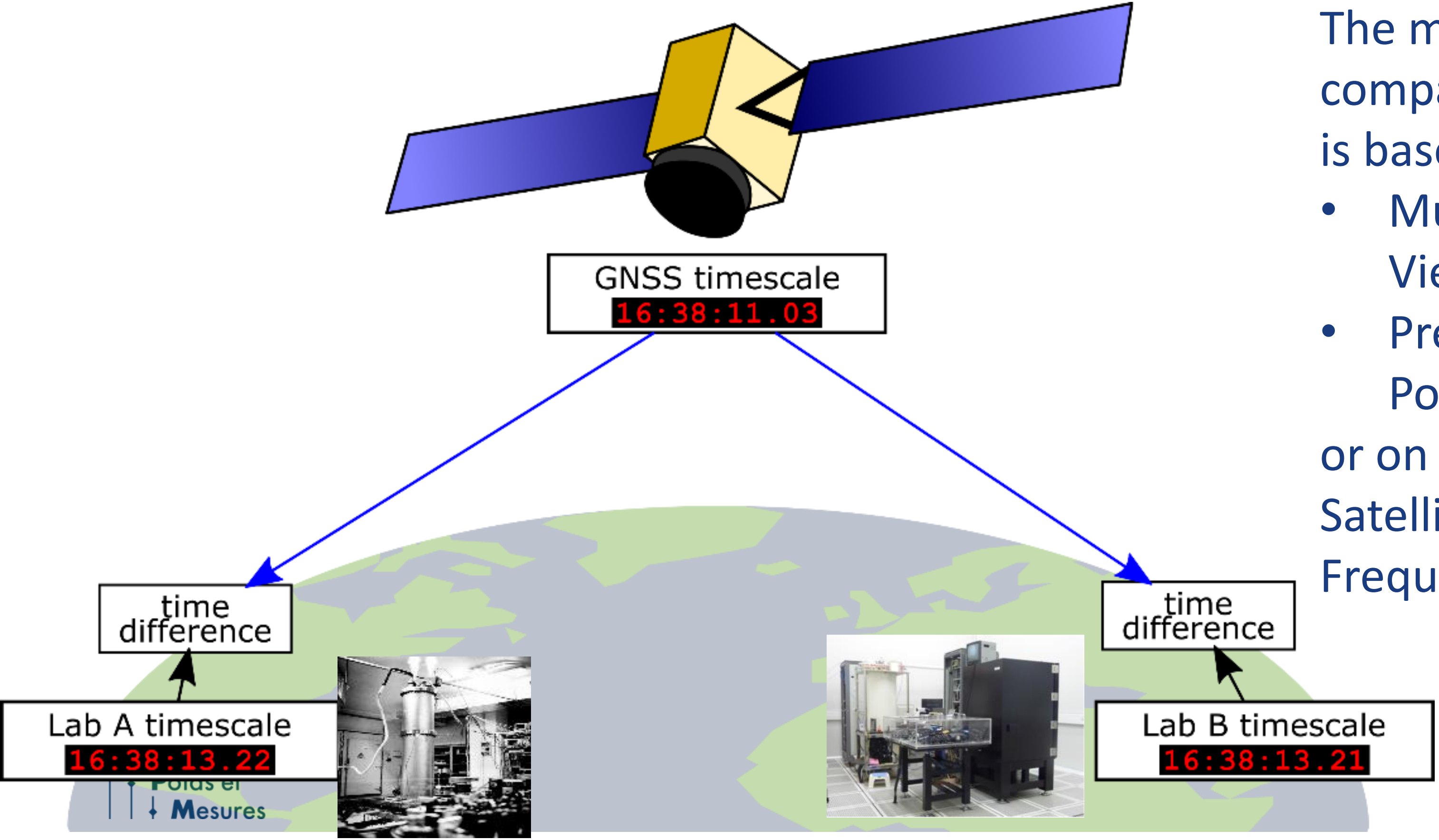
BIPM Time Dept activities to improve UTC and rapid UTC

Geographical distribution of the laboratories that contribute to TAI and time transfer equipment (2020)

Now there are about 450 atomic clocks in 80 time laboratories



Clocks need to be compared

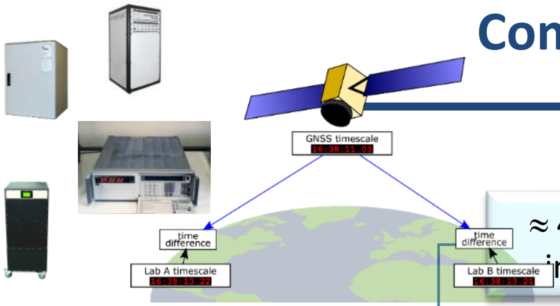


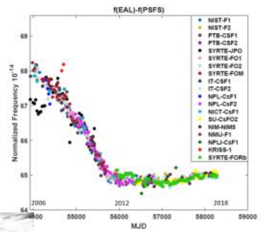
The most used clock comparison techniques is based on GNSS:

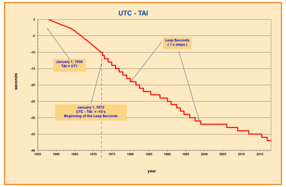
- Multichannel All in View,
- Precise Point Positioning

or on the Two Way Satellite Time and Frequency Transfer

Computation of UTC (monthly) at the BIPM







≈ 450 atomic clocks in 80 laboratories

≈ 10 primary and secondary frequency standards

Measurement of Earth's rotation (IERS)

weighted average → **EAL**

frequency steering → **TAI**

leap seconds → **UTC**

Echelle Atomique Libre
freq stability
3 x 10^{-16}
@ 30-40 days

International Atomic Time
freq accuracy ~10^{-16}

Coordinated Universal Time

[UTC - UTC(k)] **BIPM *Circular T***

Bureau International des Poids et Mesures

Improvement of the time link used in UTC

Improve UTC links aiming at sub 10^{-16} performance

- **Standard techniques for UTC links** :
  - ’Classical’ GNSS (e.g. **P3** and **PPP**) and two-way time & frequency transfer (**TWSTFT**), using code or code+phase provide time transfer. Frequency transfer performance limited to few 10^{-16} after many days of averaging.
  - TWSTFT with software defined radio receiver SDR and new digital modems expected to improve stability.

- **Advanced techniques** using only phase measurements improve time stability over classical techniques, but require phase continuity:
  - GPS Integer PPP provides ~ 1×10^{-16} at ~ 5-7 days, low 10^{-17} at 20 days.
  - Our IPPP technique is based on CNES developments, and a user-friendly post-processing software developed at BIPM.

Bureau International des Poids et Mesures

TWSTFT : Software-Defined Radio receiver

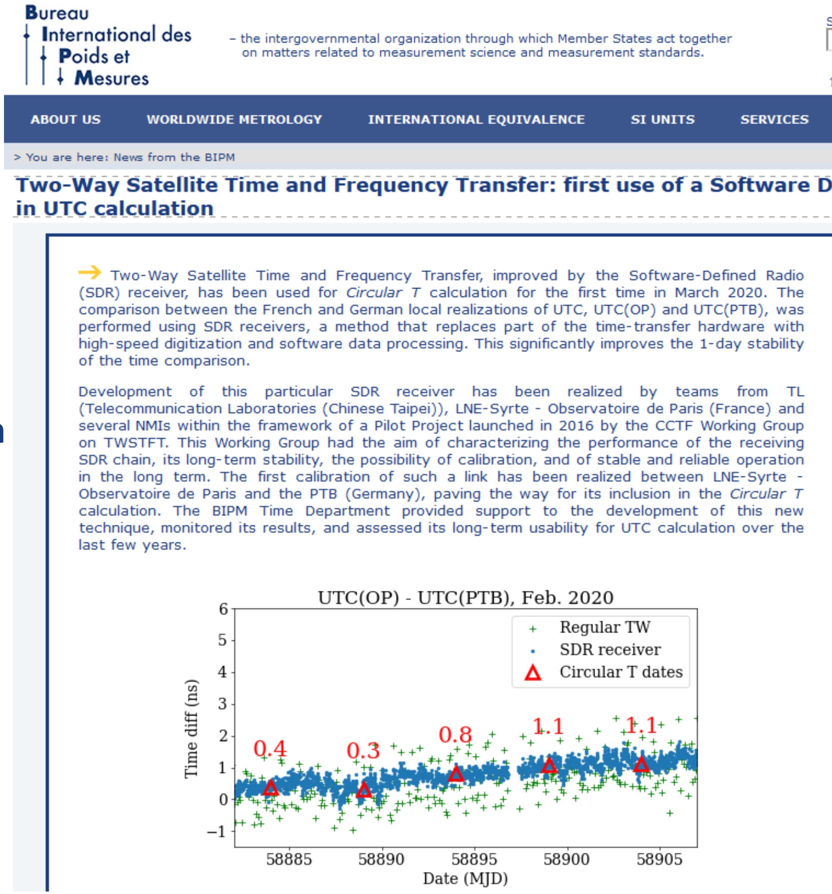
BIPM and TW WG joint Pilot study results :

- 15 TWSTFT labs took part to the study in Asia, Europe and North America
- Improves diurnals, lower overall measurement noise
- See : Z. Jiang *et al* 2018 *Metrologia* **55** 685

Pilot study successful and closed during 28th meeting of the TW WG

First inclusion of SDR receiver data in the calculation of UTC in Circular T 386 (Feb. 2020)

-> Gitlab software forge hosted by BIPM to help collaboration between institutes (https://taigit.bipm.org), access requests to be adressed to the TWSTFT WG.


Bureau International des Poids et Mesures

– the intergovernmental organization through which Member States act together on matters related to measurement science and measurement standards.

ABOUT US | WORLDWIDE METROLOGY | INTERNATIONAL EQUIVALENCE | SI UNITS | SERVICES

> You are here: News from the BIPM

Two-Way Satellite Time and Frequency Transfer: first use of a Software D in UTC calculation

Two-Way Satellite Time and Frequency Transfer, improved by the Software-Defined Radio (SDR) receiver, has been used for *Circular T* calculation for the first time in March 2020. The comparison between the French and German local realizations of UTC, UTC(OP) and UTC(PTB), was performed using SDR receivers, a method that replaces part of the time-transfer hardware with high-speed digitization and software data processing. This significantly improves the 1-day stability of the time comparison.

Development of this particular SDR receiver has been realized by teams from TL (Telecommunication Laboratories (Chinese Taipei)), LNE-Syrte - Observatoire de Paris (France) and several NMIs within the framework of a Pilot Project launched in 2016 by the CCTF Working Group on TWSTFT. This Working Group had the aim of characterizing the performance of the receiving SDR chain, its long-term stability, the possibility of calibration, and of stable and reliable operation in the long term. The first calibration of such a link has been realized between LNE-Syrte - Observatoire de Paris and the PTB (Germany), paving the way for its inclusion in the *Circular T* calculation. The BIPM Time Department provided support to the development of this new technique, monitored its results, and assessed its long-term usability for UTC calculation over the last few years.

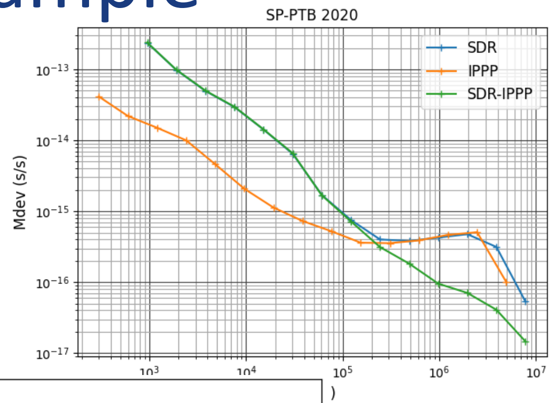
Bureau International des Poids et Mesures

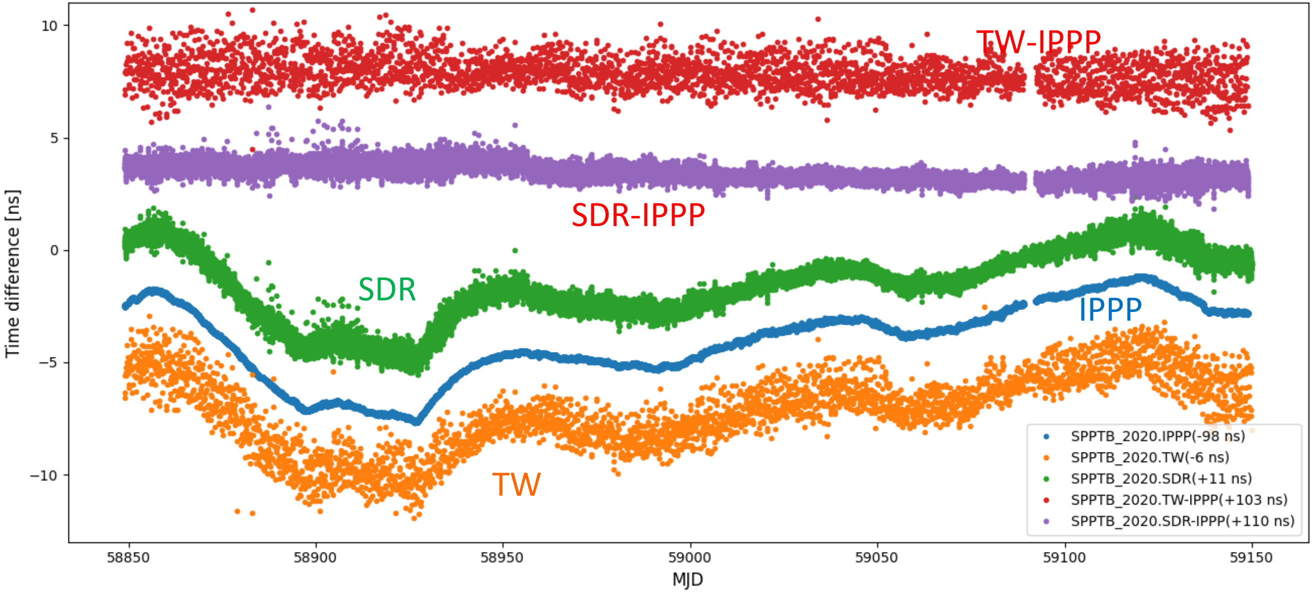
TW-SDR, TW-SATRE and IPPP: an example

SP-PTB:

- 10 months all techniques
- No significant systematic variations.

- SDR joins IPPP at $1x10^{-16}$ level after > 10 days averaging.





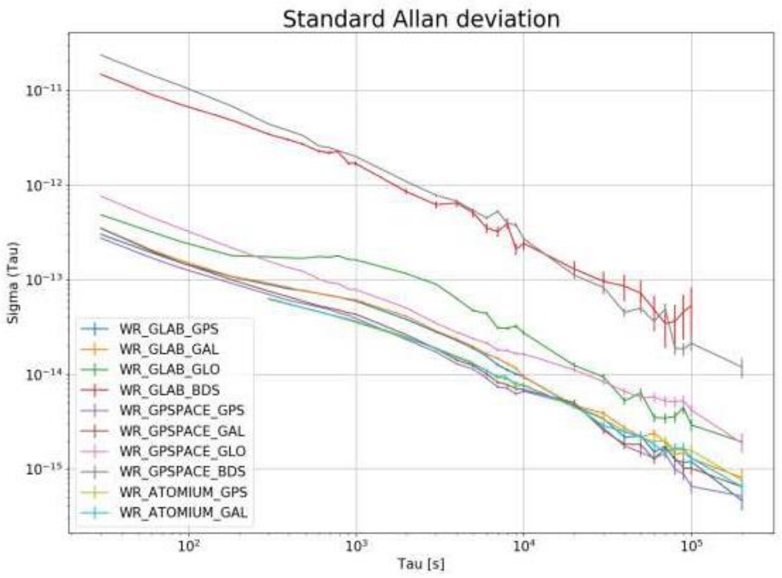
MultiGNSS time transfer by PPP techniques

Studies have been initiated to update the Precise Point Positioning technique presently used for most UTC time links.

Several different software capable of multi-GNSS processing are being tested.

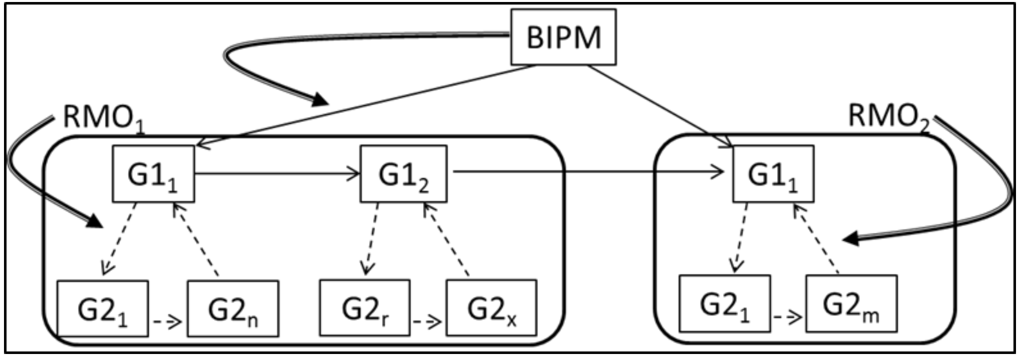
Performance of PPP solutions for GPS, GALILEO, GLONASS, BEIDOU from 3 different softwares are compared to optical fiber link

Research still on going



Bureau International des Poids et Mesures

The GNSS calibration scheme of the BIPM



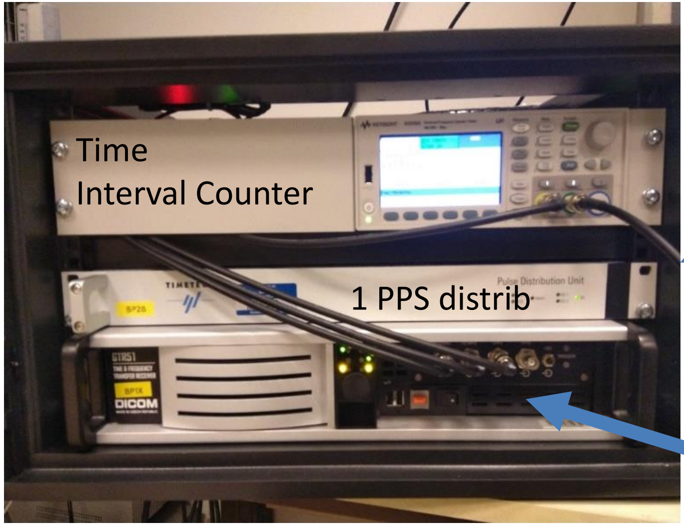
- Cooperation with RMOs has been established, and Calibration guidelines written during 2014.
- New scheme in place for GPS P1/P2 (P3) in 2015, then C1
  - BIPM calibrates the systems in laboratories G1
  - RMOs are responsible for calibrations of laboratories G2 in the regions, and for submitting reports to the BIPM.
- Scheme expanded to Galileo E1/E5a in 2019

Bureau International des Poids et Mesures

New BIPM travelling GNSS box for generic calibration purposes (TWSTFT, GNSS, …)

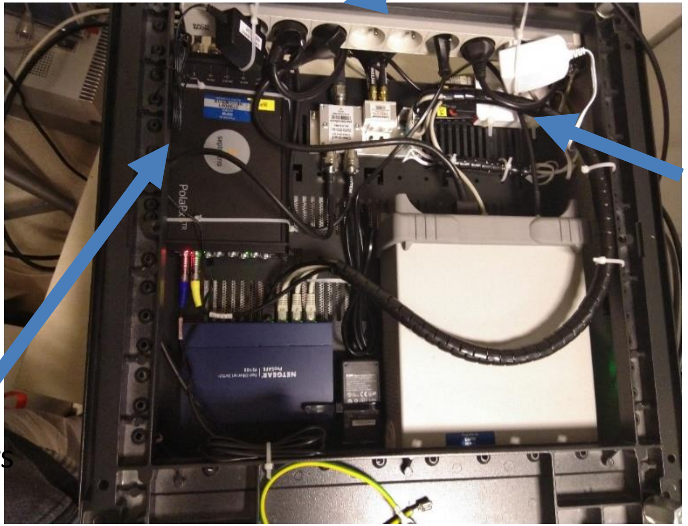
Aimed at better accuracy + easier deployment
Reduced number of operations on site, most of the connections are fixed and not demountable
The box has been tested in a calibration trip between OP, INRiM and OCA TW stations (results in process).
First calibration trip expected on TWSTFT in Asia
Developed and tested in collaboration with LNE SYRTE

Inputs : power, 1PPS,
10 MHz, antenna, Internet



Probe cable

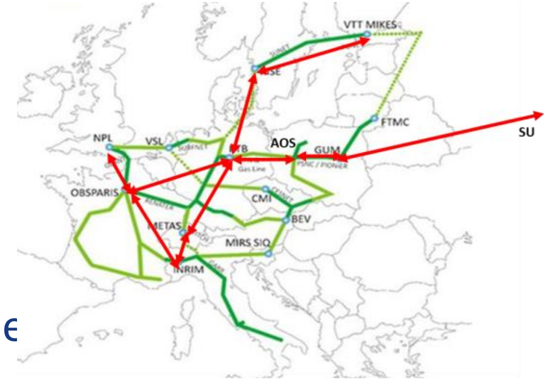
2 GNSS receivers



Embedded computer managing measures

New approach for redundant link and the uncertainty of [UTC – UTC(k)]

- The new approach
  - Can replicate the approach presently used for Circular T
  - Implements several improvements:
    - Enters GNSS measurements in their native station-based form (not links)
    - Allows correlations and **redundant** measurements
    - Correctly accounts for **systematic** uncertainties and the effect of not calibrated UTC(k)



From Vojtech et al 2020

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

Date 2021 0h UTC		JAN 30	FEB 4	FEB 9	FEB 14	FEB 19	FEB 24	Uncertainty/ns		
	MJD	59244	59249	59254	59259	59264	59269	u_A	u_B	u
Laboratory *k*		[*UTC-UTC*(*k*)]/ns								
AOS	(Borowiec)	-0.4	-0.2	-0.6	-1.0	-0.5	-0.3	0.3	2.9	2.9
APL	(Laurel)	-0.8	-0.3	-0.8	-0.6	-0.2	0.1	0.3	19.6	19.6
AUS	(Sydney)	-450.0	-449.1	-442.6	-458.9	-470.1	-473.3	0.3	11.2	11.2
BEV	(Wien)	-21.2	-21.5	-31.0	-28.1	-39.8	-44.0	0.3	3.3	3.3
BFKH	(Budapest)	2008.0	2041.6	2070.7	2099.2	2121.3	2145.2	1.5	20.0	20.1
BIM	(Sofiya)	14178.6	14194.3	14235.7	14276.3	14278.8	14320.7	0.7	7.1	7.2
BIRM	(Beijing)	-0.1	-3.0	-6.4	-9.4	-10.5	-10.9	0.7	2.8	2.9
BOM	(Skopje)	-4267.1	-4296.6	-4317.0	-4315.1	-4331.8	-4336.6	5.0	7.5	9.0
BY	(Minsk)	1.5	2.3	2.8	3.1	3.1	3.3	1.5	12.2	12.3
CAO	(Cagliari)	-25237.2	-25341.8	-25448.1	-25557.7	-25668.4	-25770.5	1.5	20.0	20.1

Panfilo et al. Metrologia 57, 2020

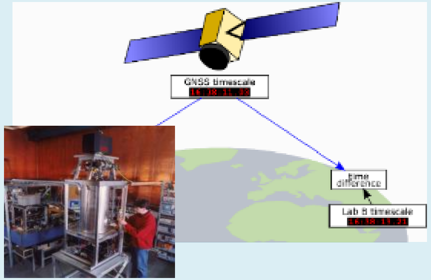
CIPM initiative to provide a Digital SI Framework

The CIPM has launched a **Task Group on the “Digital SI Framework”**

- To enable SI-based digital communication in industry
- To support the digital science and open-science paradigms
- To get metrological services ready for artificial intelligence

Time dept – Machine readable data

Data Inputs



≈ 450 atomic clocks,
≈ 80 UTC(k)
in 80 laboratories

≈ 15 primary and secondary frequency standards

≈ 250 GNSS time comparisons repeated every 5 minutes

1.5 TB/year

Computation of weekly and monthly data products

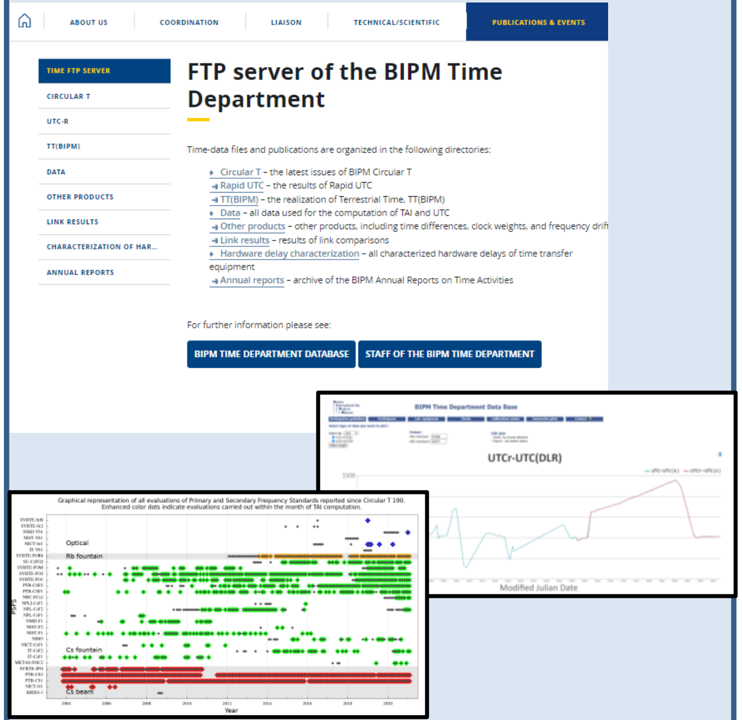
BIPM *Circular T*

[UTC – UTC (k)]

Rapid UTC

700 GB/year

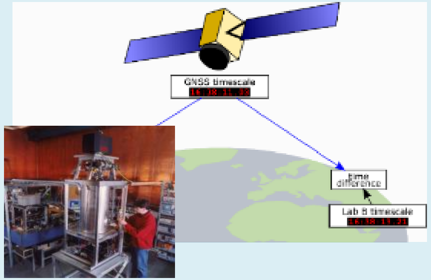
BIPM Time FTP and data base



Time dept – Machine readable data

Please volunteer to test our API
https://webtai.bipm.org/api/v0.1/

Data Inputs



≈ 450 atomic clocks,
≈ 80 UTC(k)
in 80 laboratories

≈ 15 primary and secondary frequency standards

≈ 250 GNSS time comparisons repeated every 5 minutes

1.5 TB/year

Computation of weekly and monthly data products

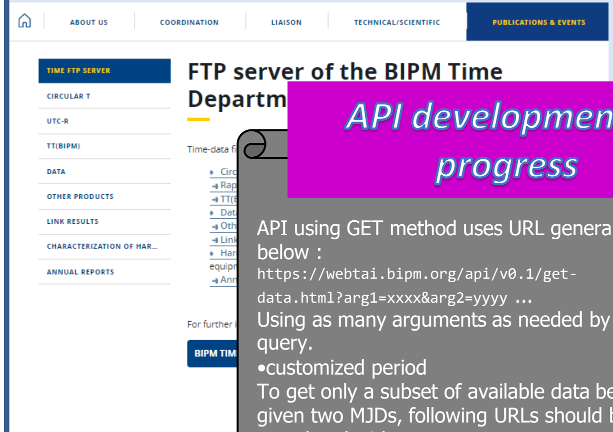
BIPM *Circular T*

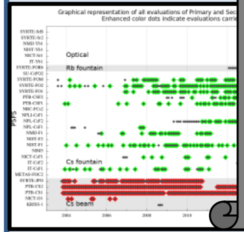
[UTC – UTC (k)]

Rapid UTC

700 GB/year

BIPM Time FTP and data base





API development in progress

API using GET method uses URL general syntax below :
`https://webtai.bipm.org/api/v0.1/get-data.html?arg1=xxxx&arg2=yyyy` ...
Using as many arguments as needed by your query.

- customized period

To get only a subset of available data between given two MJDs, following URLs should be completed with:
`&mjd1=59000&mjd2=59200` (example for request between MJD 59000 and 59200)

- customized output file format

Ouput format can be JSON (default, if not specified), Comma-Separated Values (CSV) or Text.
To define output format of the request, use following arguments in the URL:
`&outfile=json`
`&outfile=csv`
`&outfile=txt` (In fixed format : `%6d %10s %10s\r\n`

Developer in GNSS time/frequency transfer - One-year secondment

Time Department

---

https://www.bipm.org/fr/opportunities

The International Bureau of Weights and Measures (BIPM) is an intergovernmental organization whose mandate is to provide the basis for a coherent system of measurements throughout the world, traceable to the International System of Units (SI). The BIPM is based in Sèvres, in the outskirts of Paris (France), and has an international staff of about 70. Further information can be found on www.bipm.org.

The BIPM seeks a secondee to act as a Developer in GNSS time/frequency transfer:

Department:	Time Department
Deadline for applications:	20 June 2021 (midnight Paris time)
Starting date:	September/October 2021
Duration:	1 year, may be renewed for a second year
Contract:	Secondment, Fulltime basis
Location:	Sèvres, Paris suburb, France

Secondee wanted to work at the BIPM on MultiGNSS PPP and IPPP

Principal tasks

Under the supervision of Dr Gérard Petit, the successful applicant will participate in the development of operational tools and software in the field of time/frequency transfer using GNSS Precise point positioning