Report from BIPM on UTC, UTCr and update on Circular T

Patrizia Tavella
Director of the BIPM Time Department

Bureau International des Poids et Mesures

WG-D Recommendations

- Rec #16-A « **Information on the works related to the proposed redefinition of UTC** »
- Rec #19 « **Official provision of a rapid UTC (UTCr) by the BIPM** »
- Rec #20 « **BIPM publication of [*UTC – GNSS times*] and [*UTC – UTC (k)*$_{\text{GNSS}}$]** »

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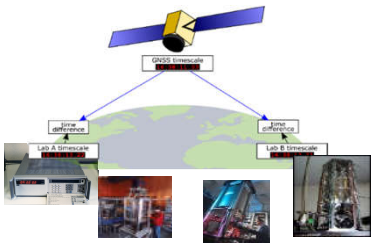
Construction of the Coordinated Universal Time



National time laboratories realize real-time approximations **UTC(k)**

≈ 450 atomic clocks
≈ 10 primary frequency standards

in ~ 85 laboratories

TAI

International Atomic Time

Measurement of Earth's rotation UT1 (IERS)

leap seconds

UTC

Coordinated Universal Time
|UT1 – UTC| < 1 s

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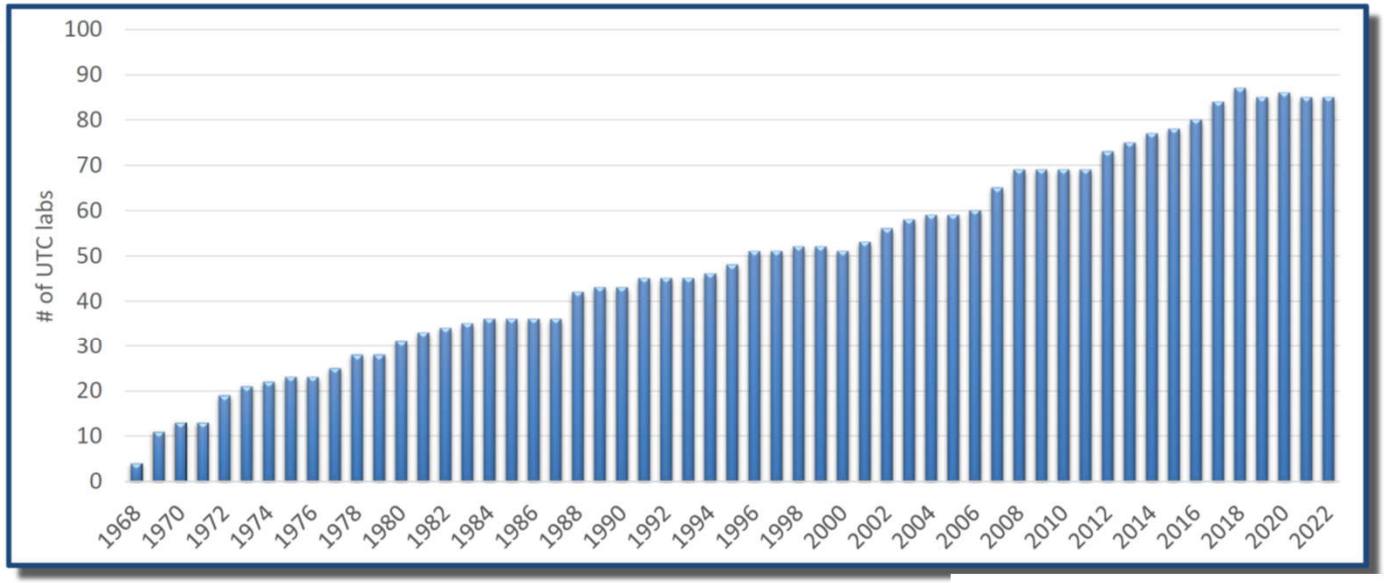
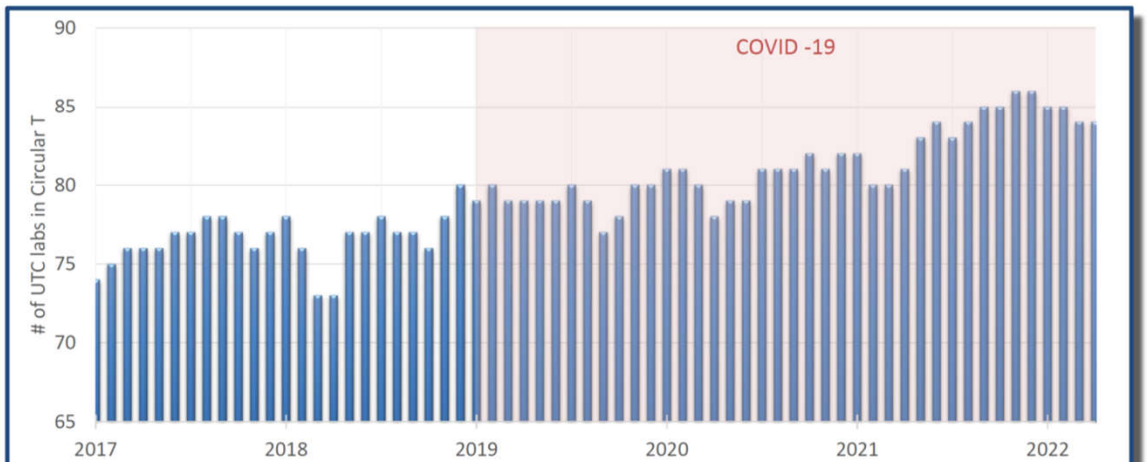
The offset [***UTC*** - ***UTC(k)***] is published in **BIPM *Circular T***

UTC community is increasing





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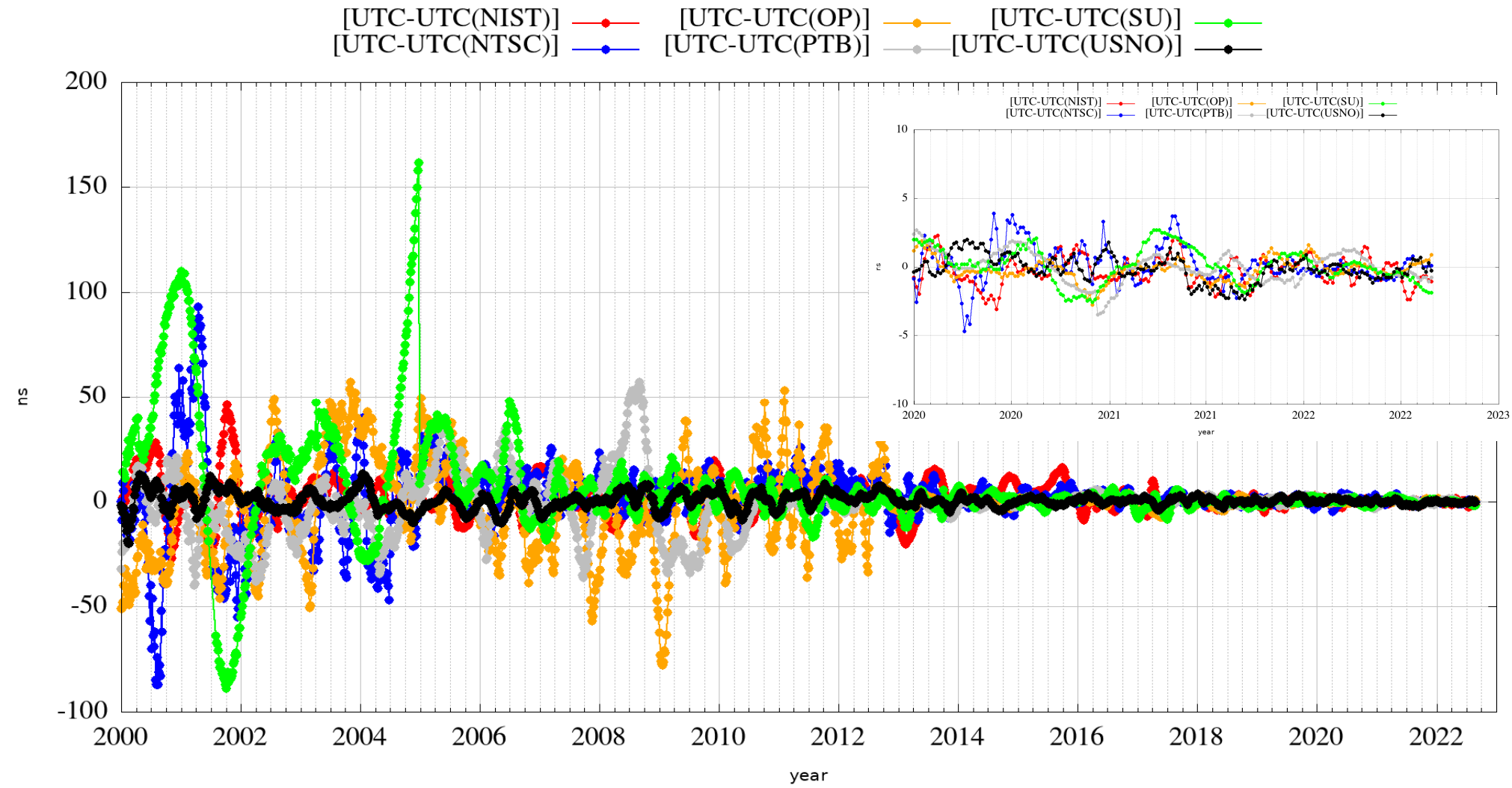
[UTC-UTC(NIST)]
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[UTC-UTC(SU)]
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5
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2020
2021
2021
2022
2022
2023

Recommendation 19 for Committee Decision
Prepared by: Working Group D
Date of Submission: 12 November 2013
Issue Title: Official provision of a rapid UTC (UTCr) by the BIPM

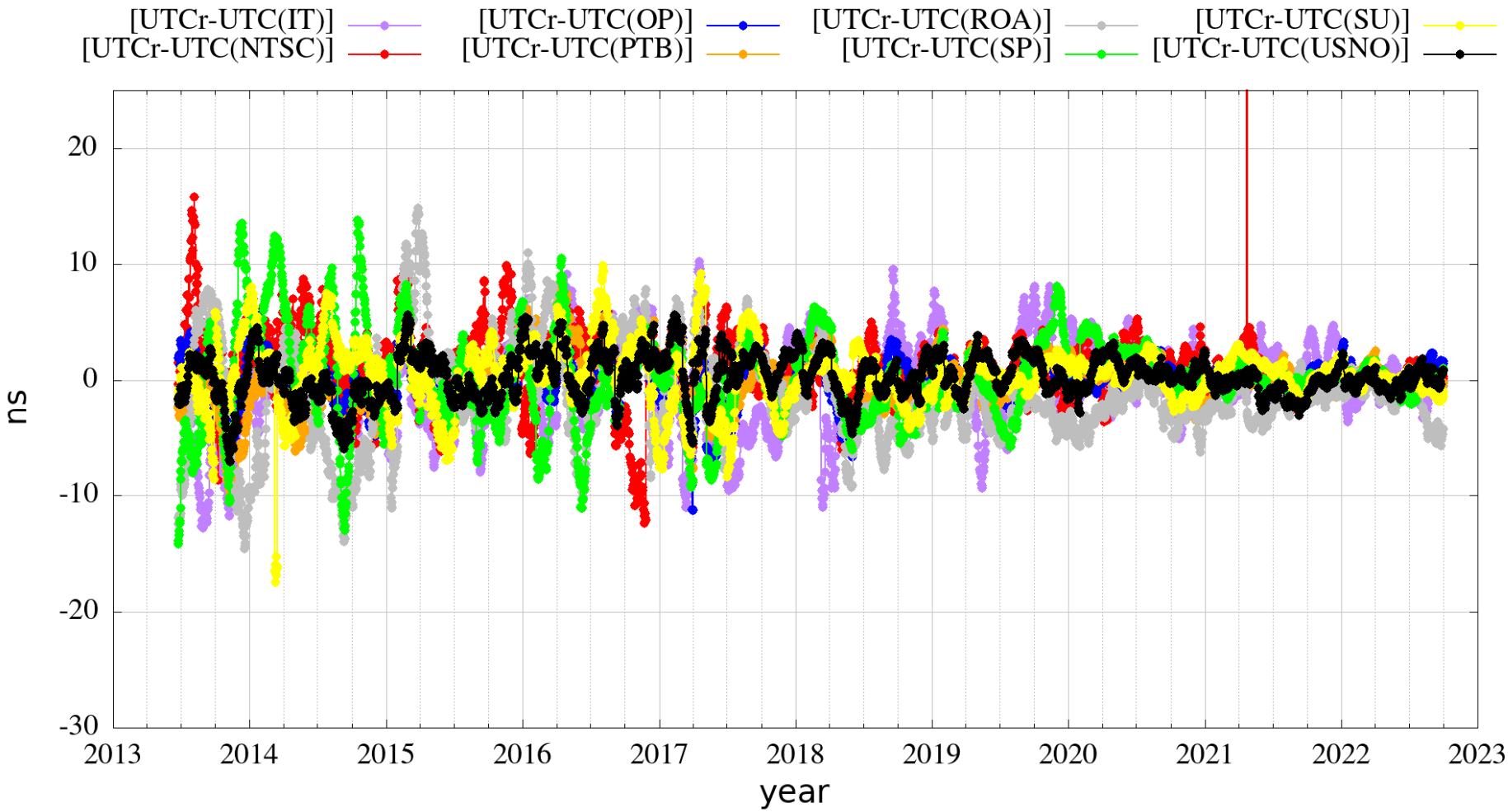
Background/Brief Description of the Issue:
In November 2012 the ICG recognized that a rapid computation of UTC at the BIPM was an important service benefiting interoperability of navigation systems.

Considering that:
- after a successful pilot experiment started in January 2012, UTCr has attained the expected stability and accuracy, at the issue of the validation process, UTCr become an official BIPM product in July 2013, and is regularly published on the BIPM website every Wednesday at 18 h UTC at latest,
- the weekly provision of the offsets between local realizations UTC(k) in national institutes with respect to UTCr enhances the traceability of these local realizations to the ultimate reference UTC,
- the UTC(k) serving for synchronizing the GNSS times to UTC participate to the weekly UTCr solution, and that predictions of these UTC(k) are broadcast by GNSS,
- users of GNSS get a better synchronization of GNSS times to UTC, through improved UTC and UTC(k) predictions.

Recommendation of Committee Action:

WG-D recommends that GNSS Providers consider the use of UTCr for
- getting a better synchronization of GNSS times to UTC,
- improving the quality of the predictions of UTC(k) broadcast by GNSS, and further recommends studying the possibility of using UTCr as a common time reference for interrelationship between GNSS times.

UTCrapid is based on an increasing number of laboratories



Recommendation 16-A for Committee Decision
Prepared by: Working Group D
Date of Submission: 12 November 2013
Issue Title: Information on the works related to the proposed redefinition of UTC (revision of Recommendation 16 (2012))

Background/Brief Description of the Issue:
Considering that:

- the navigation systems have unique timing and geodetic references for operational necessity. Interoperability of the GNSS requires interrelationship of the timing and geodetic references to reduce ambiguities for users with regard to the interpretation of navigation and timing solutions.
- discussion on redefinition of UTC started in 2000 at the ITU-R, SG7 Science Services WP7A Time Signals and Frequency Standard Emissions, during 2000-2010 WP7A studied the issue, considered different options, organized an open meeting (Torino, 2003), and worked on a proposal for an amended ITU recommendation,
- in 2010 the Draft Revision of Recommendation ITU-R TF.460-6 (new proposed version) was submitted by ITU-R WP7A to ITU-R SG7; while considering this issue at SG7 no consensus on the Draft Revision of Recommendation ITU-R TF.460-6 was achieved,
- the SG7 sent the Draft Revision of Recommendation ITU-R TF.460-6 to the Radiocommunication Assembly 2012 (RA -12) for « final decision »,
- at RA-12 after several statements of Administrations and Sector members supporting different views the Chairman stated that there are almost even balance between those administrations that are in favour of the draft revision of the Recommendation, those that are opposing it, and a third group of administrations who indicated that as they had not participated actively at SG7 and WP7A meetings, more information is required to enable them to form an opinion,
- as a result RA-12 decided to address this issue in the RA-12 Report for World Radiocommunication Conference 2012 (WRC-12) to develop a new WRC-15 Agenda item.
- WRC-12 started a new study question on WRC-15 Agenda item 1.14 in accordance with Resolution 653 (WRC-12) and put back the Draft Revision of Recommendation ITU-R TF.460-6 to SG7-WP7A for a final decision at WRC-15,
- WRC-12 Resolution 653 on the feasibility of a continuous UTC involves the BIPM, CCTF, CGPM, IAU, IUGG, URSI, ICAO, IMO, WMO, ISO, and invites to consider the feasibility of achieving a continuous reference time-scale, whether by the modification of UTC or some other method, and take appropriate action, taking into account ITU-R studies.

Recommendation of Committee Action:

- It is recommended that the ICG monitors the ongoing development of the proposed redefinition of UTC and that reports be presented until a decision is made at WRC-15.

BIPM and ITU working together (1)

- ITU-R TF.460-6 (2002): *Standard-frequency and time-signal emissions* from 1972

Recommends

- that all standard-frequency and time-signal emissions conform as closely as possible to coordinated universal time (UTC)
- that standard-frequency and time-signal emissions… contain information on DUT1 = UT1 – UTC

Annex

- UTC is maintaned by the BIPM, DUT1 is given by IERS in multiples of 0.1 s.
- The departure of UTC from UT1 should not exceed ± 0.9 s
- the UTC scale is adjusted by the insertion or deletion of seconds (positive or negative leap seconds) to ensure approximate agreement with UT1.
- a code for the transmission of DUT1 is established

- In 2000, users starts the discussion. Several groups are created, BIPM and some time experts take part to the ITU-R WP 7A, ITU is a liaison to the CCTF, BIPM is a sector member of ITU-R. …..
- World Radiocommunication Conference 2015: *Resolution 655*

Resolution 655 – 2015:

- To strengthen the cooperation between ITU-R and BIPM, the International Committee for Weights and Measures (CIPM), CGPM, as well as other relevant organizations, and to carry out a dialogue concerning the expertise of each organization;
- To further and more widely study in cooperation with the relevant international organizations, concerned industries and user groups, through the participation of membership, the various aspects of current and potential future reference time scales, introducing their impacts and applications;
- To provide advice on the content and structure of time signals to be disseminated by radiocommunication systems, using the combined expertise of the relevant organizations;
- To prepare one or more reports containing the results of studies that should include one or more proposals to determine the reference time scale and address other issues mentioned in 1,2 and 3 above

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BIPM and ITU working together (2)

✓ 2018 26th CGPM Resolution 2

« On the definition of time scales »

• **confirms** that
Coordinated Universal Time (UTC) is a time scale produced by the BIPM with the same rate as TAI, but differing from TAI only by an integral number of seconds,

recommends that

- all relevant unions and organizations consider these definitions and work together to develop a common understanding on reference time scales, their realization and dissemination with a view to consider the present limitation on the maximum magnitude of UT1 - UTC so as to meet the needs of the current and future user communities,
- all relevant unions and organizations work together to improve further the accuracy of the prediction of UT1 - UTC and the method for its dissemination to satisfy the future requirements of users.

✓ 2020 MoU BIPM-ITU

Article II
Scope of mutual cooperation

- Assistance to the ITU-R in its role to set standards concerning time signals and frequency standard emissions, protocols, and dissemination procedure, related studies and other issues by the BIPM to ensure compatibility and adherence to the International System of Units (Système International d'Unités, the SI), metrological traceability and measurement uncertainty;
- Assistance to the BIPM in its role of defining and realizing measurement standards and reference time-scales taking into account the needs of radio communication users and regulations by ITU

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BIPM and ITU working together (3)

ITU R working party 7A delivered on Oct 6 , 2022

- A report on UTC and the impact of a continuous time scale,
- A Note to the Director of ITU – R in preparation to the World Radio Conference in 2023

Conclusion and Recommendation

In conclusion of this Note to the Director of the BR the following facts shall be emphasized:

(1) the current definition of UTC was adopted in Resolution 2 of the 26th General Conference on Weights and Measures (CGPM) in 2018;

(2) the role of the BIPM in the realisation and publication of the universal time reference UTC is defined by the CGPM, while the dissemination of time signals and adequate implementation of those signals in radiocommunication services remains core responsibility of the ITU-R;

(3) the establishment of UTC is not a spectrum regulation task; and

*(4) UTC is addressed in the provision No. **1.14** of the Radio Regulations, in the Resolution **655 (WRC-15)** and in Recommendation ITU-R TF.460-6.*

It can be concluded that if the decision on a continuous reference time scale will be taken, remaining work, e. g. cooperation between ITU-R and international organisations, and necessary updates of Recommendation ITU-R TF.460-6, falls as general task under the responsibility of the relevant ITU-R working groups.

BIPM and ITU working together – next steps

November 2022 – The 27th meeting of the CGPM will consider a draft resolution

« On the use and future development of UTC »

recognizing *that the use of UTC* ***as the unique reference time scale for all applications****, including advanced digital networks and satellite systems, calls for its clear and unambiguous specification as* ***a continuous time scale****, with a well-understood traceability chain,*

decides *that the maximum value for the difference (UT1-UTC) will be increased in, or before, 2035,*

requests *that the CIPM consult with the ITU, and other organizations that may be impacted by this decision in order to*

- *propose a new maximum value for the difference (UT1-UTC) that will ensure the continuity of UTC for at least a century,*
- *prepare a plan to implement by, or before, 2035 the proposed new maximum value for the difference (UT1-UTC),*
- *propose a time period for the review by the CGPM of the new maximum value following its implementation, so that it can maintain control on the applicability and acceptability of the value implemented,*
- *draft a resolution including these proposals for agreement at the 28th meeting of the CGPM (2026),*

encourages *the BIPM to work with relevant organizations to identify the need for updates in the different services that disseminate the value of the difference (UT1-UTC) and to ensure the correct understanding and use of the new maximum value.*

Next step – develop a common way forward towards WRC 2023 so that both organisations continue to address the needs for internationally-recognised timing and synchronisation.

Ensuring a continuous UTC + efficient and used protocols for the transmission of UTC and (UT1- UTC)

Impact on GNSS and RNSS

GNSS and RNSS broadcast a time dissemination service with

- a prediction of GNSSTime – UTC (modulo 1 s)
- the number of leap second between GNSSTime and UTC,

No change

Will remain frozen

In some cases also

- a prediction of UT1 - UTC,

|UT1 – UTC| will be > 1 s

This quantity will reman < 60 s for probably 100 years

For most accurate applications:

UT1-UTC is measured and published by International Earth Rotation and Reference Systems Service (IERS), and other services, with microsecond accuracy

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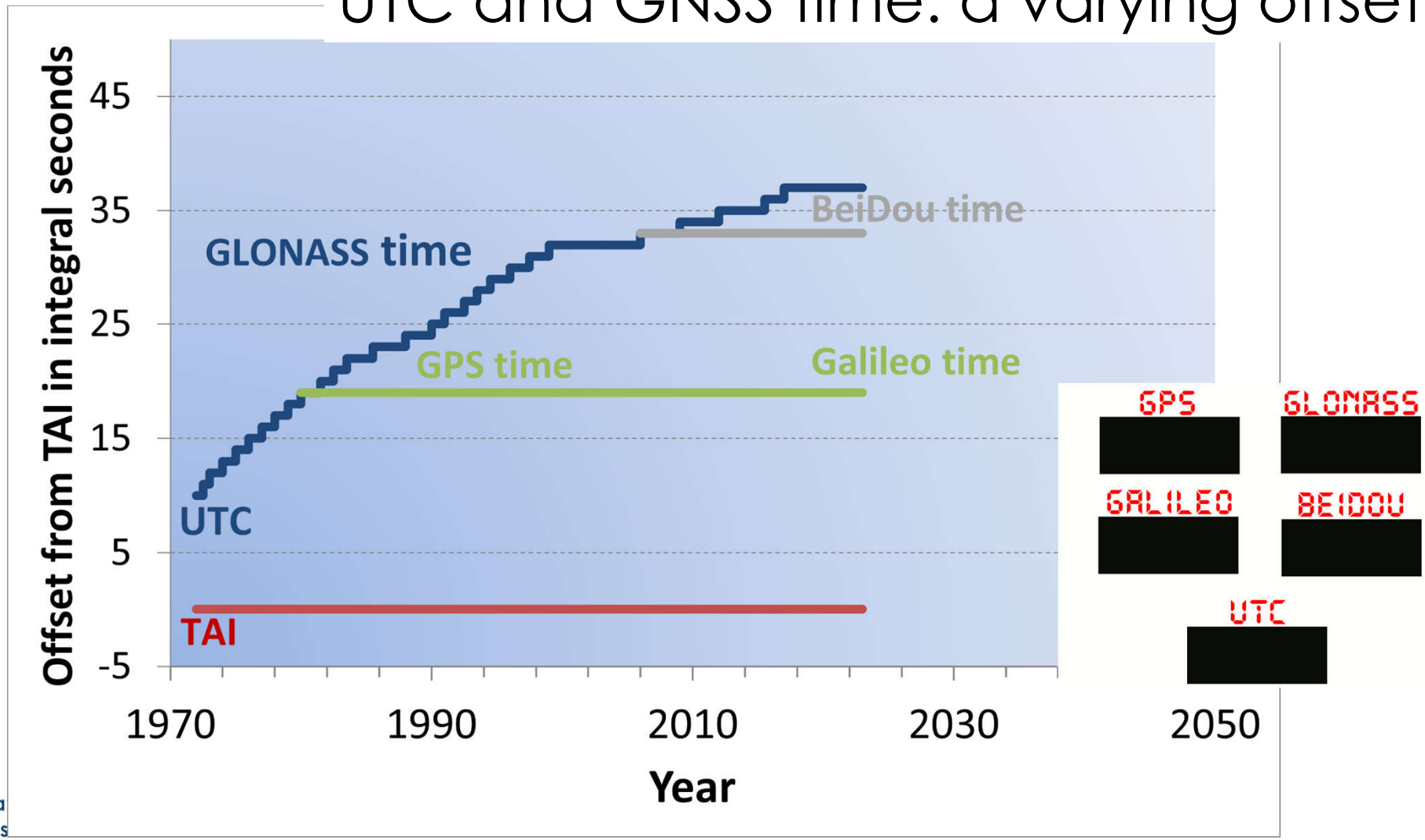
UTC and GNSS time: a varying offset



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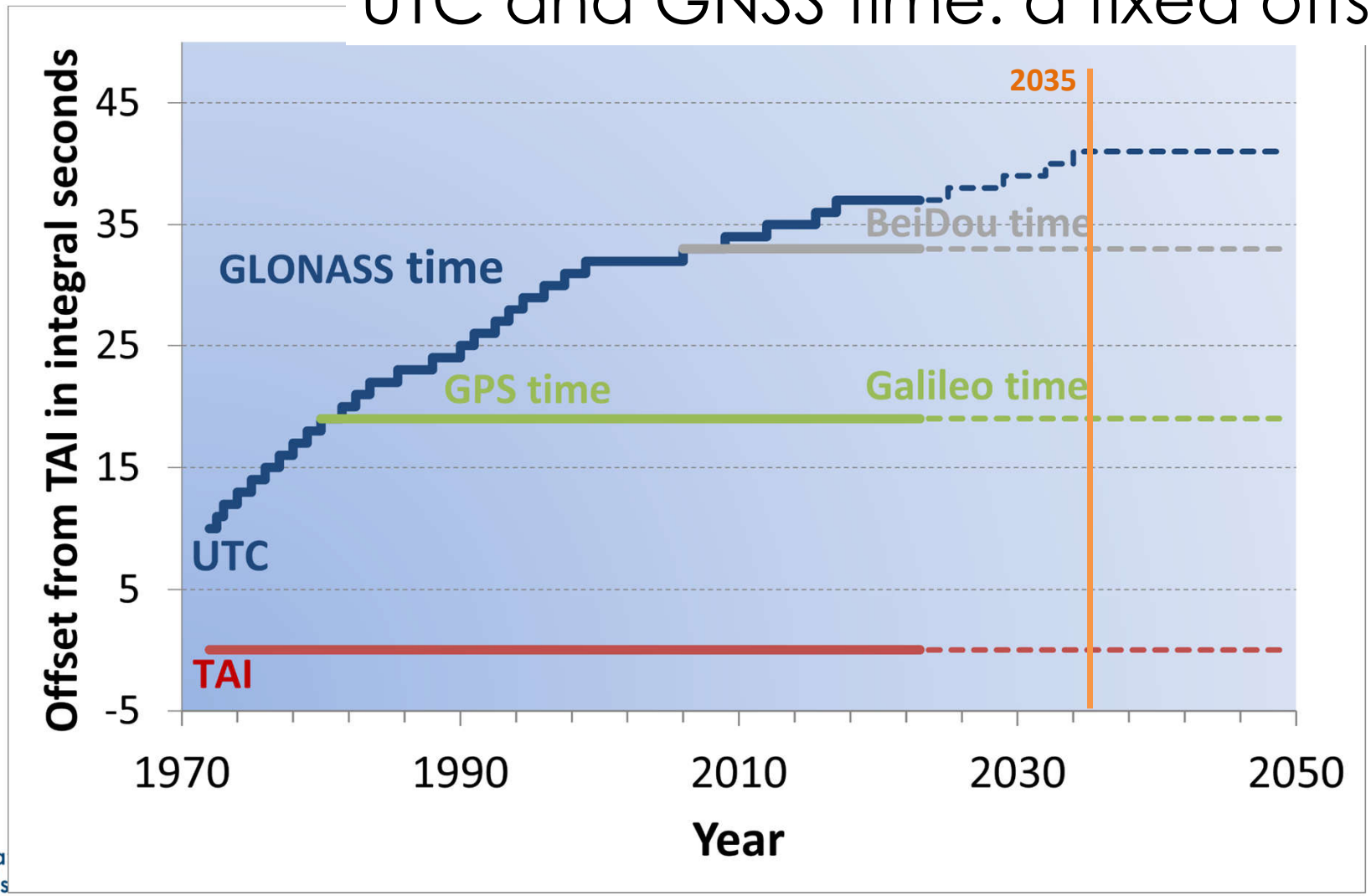
UTC and GNSS time: a fixed offset



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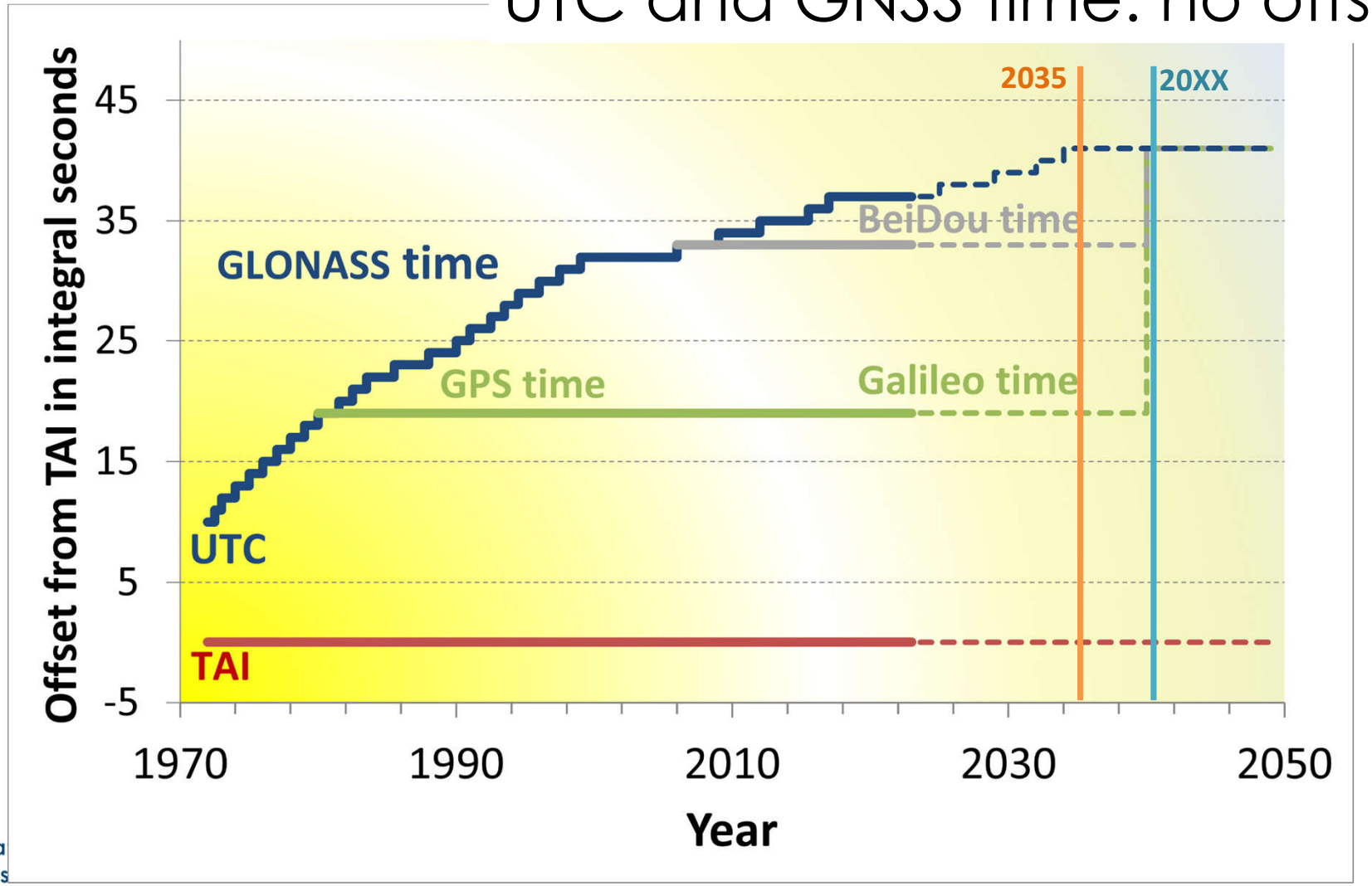
UTC and GNSS time: no offset



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Draft resolution D - On the use and future development of Universal Coordinated Time (UTC)

Overall consensus on the technical need of enlarging the tolerance: *CCTF, CIPM, ITU-T, ITU-R, IAU, IUGG, URSI, IGS, GAFA, GNSS providers, IT stakeholders, …*

Process in two steps:

1. *decision in CGPM 2022 to enlarge UT1-UTC tolerance*
2. *details for the new tolerance, its implementation and periodic review process at CGPM in 2026*

Trade-off on the implementation date between:

- *the need of updating systems*
- *the important issues that*
  - *discontinuities in UTC and different ad-hoc solutions currently implemented (Google / Facebook / Alibaba smears, NTP, Microsoft, …) cause confusion and put at risk the resilience of critical national infrastructures,*
  - *the current Earth acceleration may lead to a possible negative leap seconds in the next decade,*
  - *one of the GNSS time scales may be use de facto as the international standard*

Recommendation 20 for Committee Decision
Prepared by: Working Group D
Date of Submission: 12 November 2013
Issue Title: BIPM publication of [*UTC – GNSS times*] and [*UTC – UTC (k)_ GNSS*]

Background/Brief Description of the Issue:
Considering that
• Coordinated Universal Time UTC is the sole international reference time scale,
• That GNSS times are constraint to keep within specified offsets from UTC(k),
• That GNSS broadcast a prediction of UTC(k) namely *UTC (k)_ GNSS*.
Noting that
• the BIPM has been publishing in its monthly Circular T for over 25 years daily values of [*UTC – GNSS times*] and more recently also of [*UTC – UTC (k)_ GNSS*]
• This information is useful to users of GNSS services, but also to GNSS systems to assess the quality and interoperability of their systems.

Discussion/Analyses:
The monitoring of the values of [*UTC – GNSS times*] and [*UTC – UTC (k)_ GNSS*] serves to a better coordination of the various GNSS and to provide a better time service to users.
The procedure for calculation of these values is provided in Section 5 of BIPM Circular T, available at http://www.bipm.org/jsp/en/TimeFtp.jsp?TypePub=publication.

Recommendation of Committee Action:
The ICG WG-D recommends that the BIPM continues the regular provision of the values of [*UTC – GNSS times*] and [*UTC – UTC (k)_ GNSS*] and extends them to other GNSS, in particular Galileo and BeiDou.

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Current status of Circular T « section 4 »

Difference between
UTC
and the
prediction of UTC
broadcasted by GNSS,
$bUTC_{GNSS}$

GPS and GLONASS times, as soon BeiDou and Galileo times are intermediate parameters in the computation of UTC

4 - Relations of UTC and TAI with predictions of UTC(k) disseminated by GNSS.

[UTC-UTC(USNO)_GPS] = C_0', [TAI-UTC(USNO)_GPS] = 37 s + C_0'
[UTC-UTC(SU)_GLONASS]= C_1', [TAI-UTC(SU)_GLONASS]= 37 s + C_1'

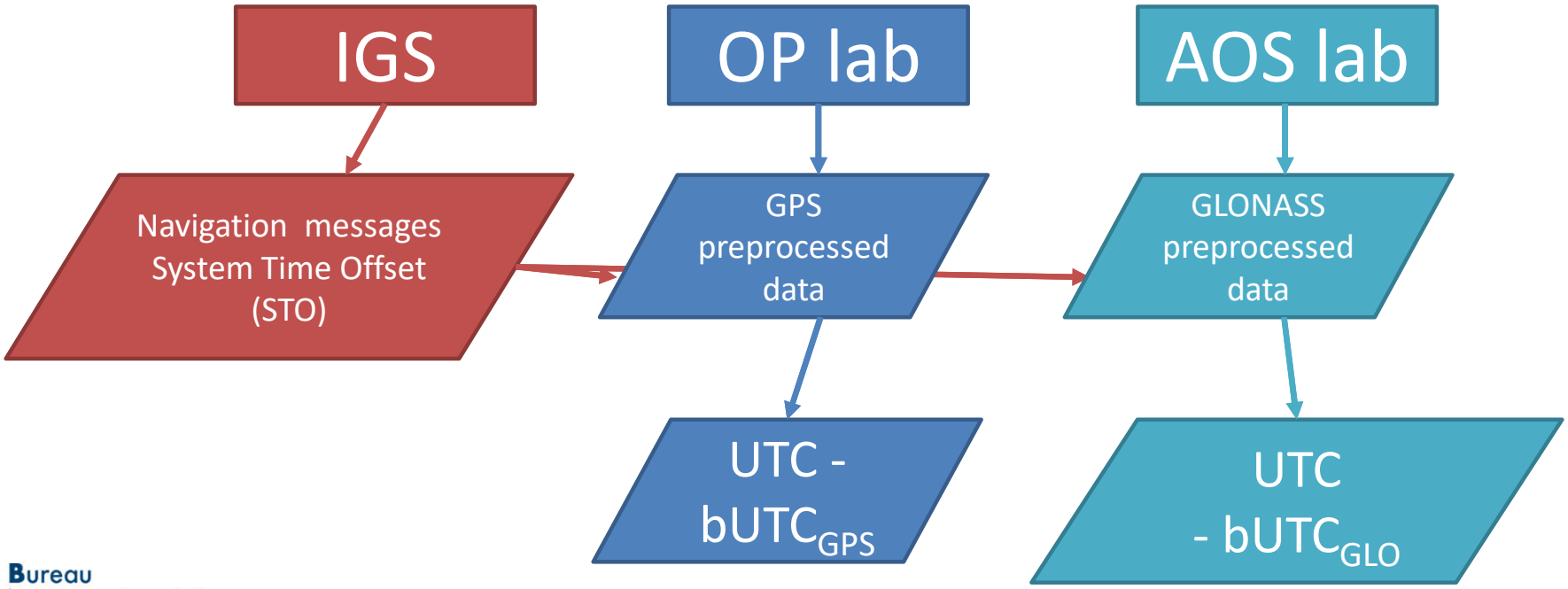
For this edition of *Circular T*, σ_0'= 0.9 ns, σ_1'= 7.1 ns

2022	0h	UTC	MJD	C_0'/ns	N_0	C_1'/ns	N_1'
	APR	30	59699	-0.4	89	40.4	87
	MAY	1	59700	-0.5	90	41.1	85
	MAY	2	59701	0.3	89	41.9	83
	MAY	3	59702	-1.3	89	41.9	85
	MAY	4	59703	-3.1	89	42.4	88
	MAY	5	59704	-1.3	89	43.5	87
	MAY	6	59705	-2.0	88	44.9	87

Date of appearance in Section 4 :
GPS in 1988 (circular T 12)
GLONASS in 1990

Current section 4 processing chain

1 lab per GNSS constellation, specific file



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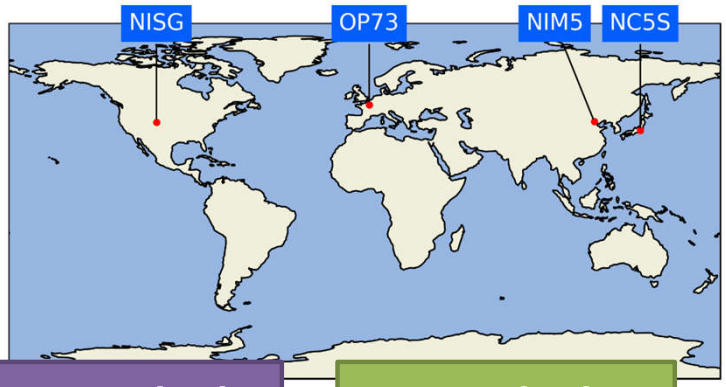
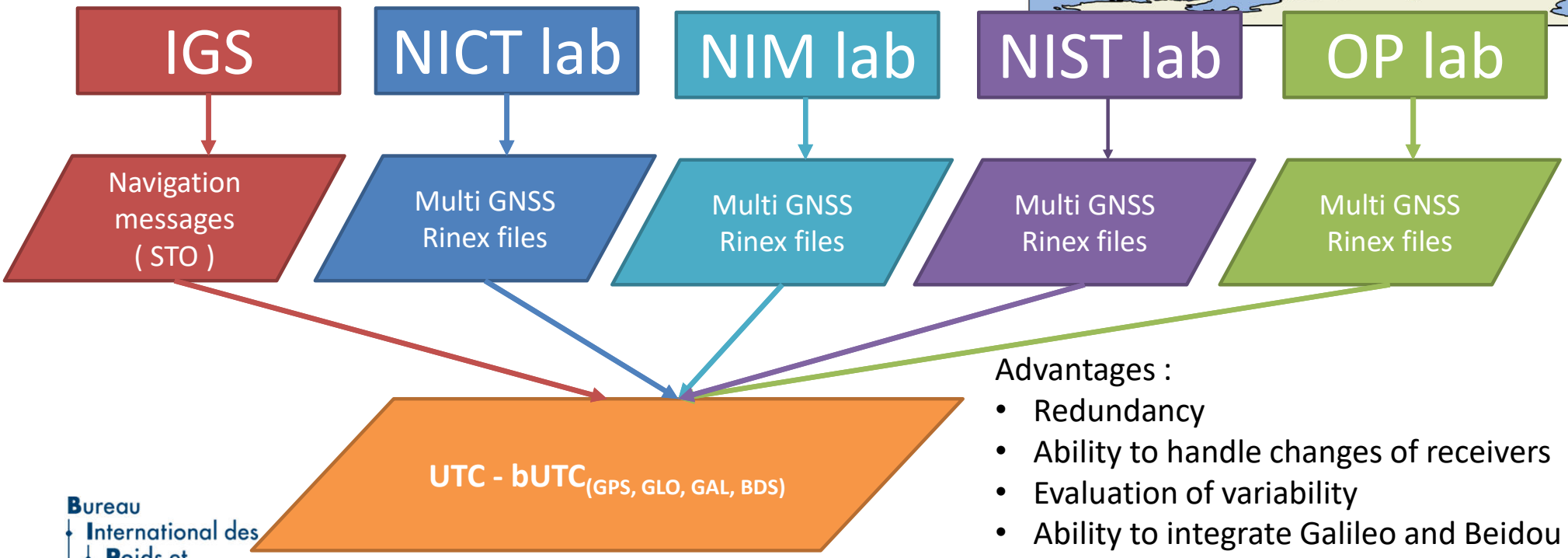
New section 4 processing chain

Pool of labs, regular rinex file, independant calculation





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Advantages :

- Redundancy
- Ability to handle changes of receivers
- Evaluation of variability
- Ability to integrate Galileo and Beidou
- New rinex parsing (accepts Rinex 4)

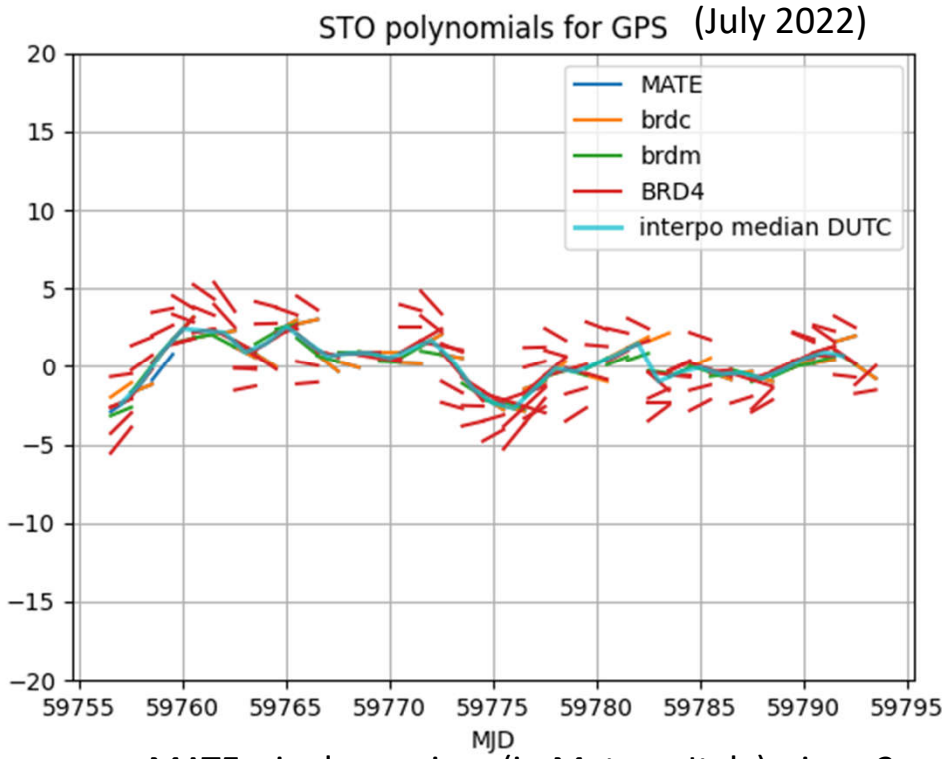
1st step : STO = GNSS time - $bUTC_{GNSS}$

STO = difference between GNSS system time and a UTC prediction realized by the system operator

New symbol: **$bUTC_{GNSS}$**
(GNSS = BDS, GAL, GLO, GPS)
= broadcasted prediction of UTC through [GNSS]

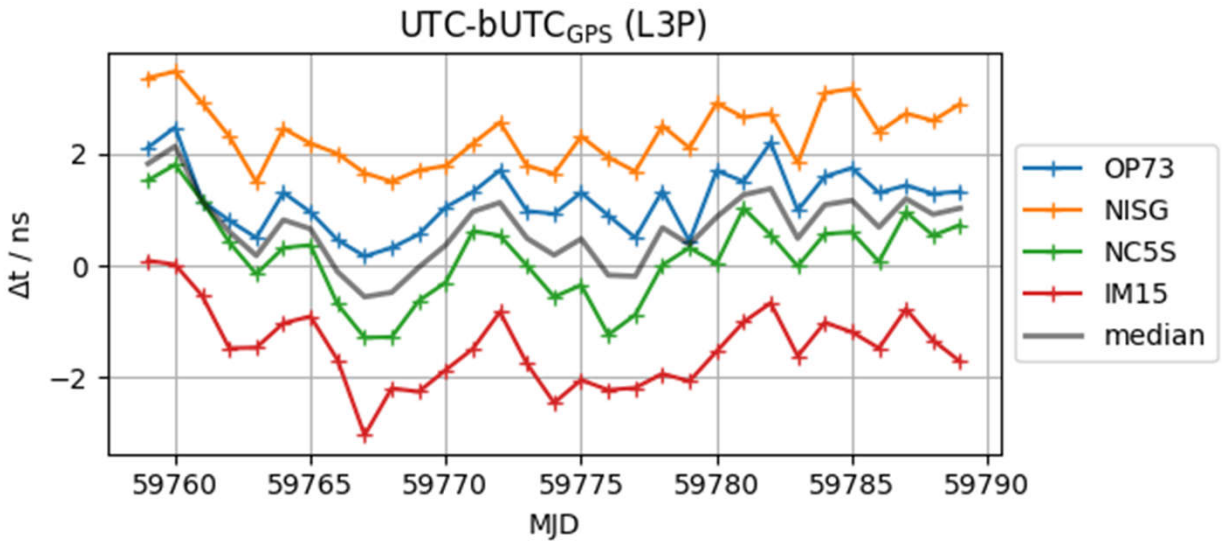
Found in Rinex3 nav headers and in Rinex4 nav data (as polynomials).

Different satellites can broadcast different polynomials, some outliers exist.



MATE: single receiver (in Matera, Italy), rinex 3
brdc: IGS /CDDIS, rinex 2
brdm: DLR/GSOC, rinex 3
BRD4: DLR/GSOC, rinex 4

2nd step: UTC - $bUTC_{GNSS}$



$$UTC - bUTC_{GNSS} = \left(UTC - UTC(k)\right)$$

Comes from Circular T, *k* is the involved time laboratory

$$+ \left(UTC(k) - GNSStime\right)$$

Comes from various absolutely calibrated receiver measurements, sent by UTC labs (previous slide)

$$+ \left(GNSStime - bUTCGNSS\right)$$

Comes from GNSS systems through navigation messages (=STO)

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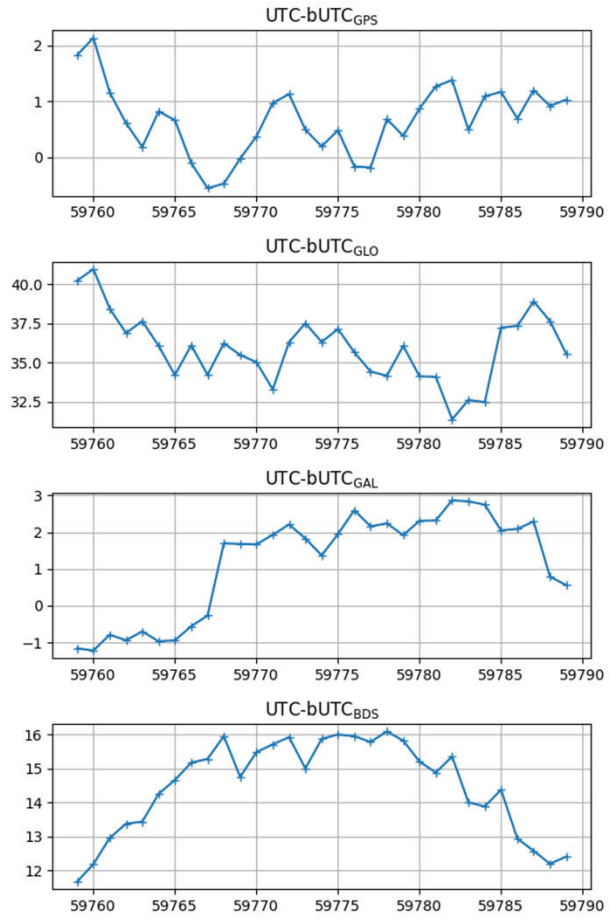
New section 4 future preview

Uncertainty estimation in progress
Absolute calibrations need to be repeated

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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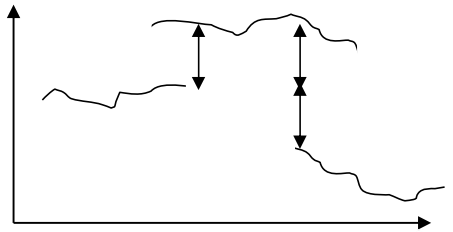
Integer PPP for UTC

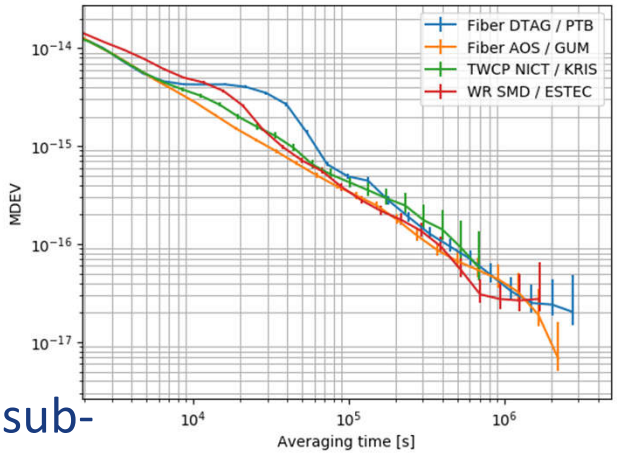
IPPP: GNSS PPP technique with integer ambiguity resolution

- Taking into account the **integer nature of the ambiguities** allows, in principle, to rigorously solve the problem of discontinuities between batches of classical PPP.



IPPP performance validated by many comparisons to optical links

Frequency transfer uncertainty
1×10^{-16} at ~ 7-10 days
low 10^{-17} at 20-30 days, with τ^{-1} behavior



This makes IPPP the technique of choice to reach sub-10^{-16} performance between any two laboratories

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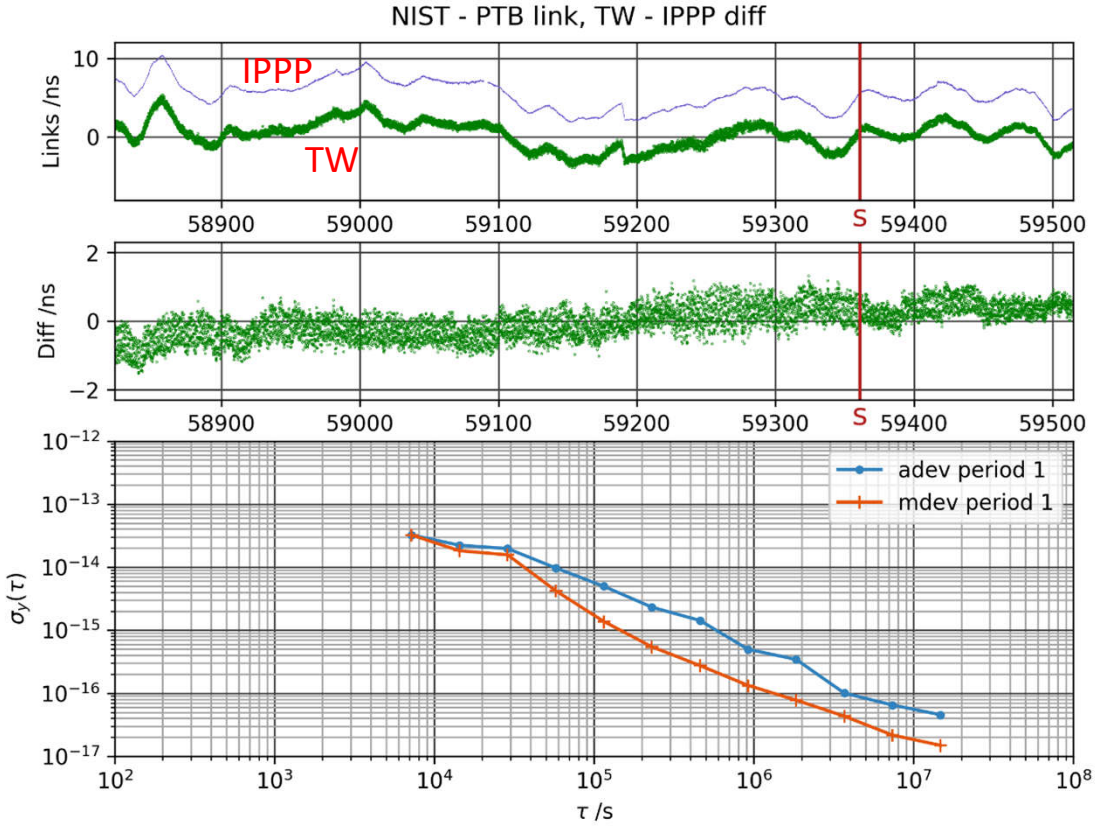
Petit G., GPS Solutions **25,** 22 (2021).
Petit et al. Metrologia 2015

Regular computation of continuous IPPP links by the BIPM

Example:
NIST-PTB TW and IPPP

No IPPP reset

22-month (and counting) continuous solution



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

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Proposed Changes in the uncertainties of Circular T and UTC computation

Calibration information in Circular T needs improvement

Details on calibration information are in Section 5, e.g. for GNSS

Not calibrated

Ageing

Link	Type	Equipment	Cal_ID1	/ Cal_ID2	u_{Stb}/ns	u_{Cal}/ns	u_{Ag}/ns	Al/ns	YYMM
AGGO/PTB	GPS P3	TC_2 /PT13	NC	/ 1001-2020	1.0	20.0			
AOS /PTB	GPSPPP	AO_4 /PT13	1014-2018	/ 1001-2020	0.3	2.9	1.5		
APL /PTB	GPSPPP	AP04 /PT13	NC	/ 1001-2020	0.4	20.0			
AUS /PTB	GPSPPP	AU04 /PT13	1002-2010	/ 1001-2020	0.3	11.2	10.0		
BEV /PTB	GPSPPP	BE1_ /PT13	1012-2016	/ 1001-2020	0.3	3.4	2.2		
BFKH/PTB	GPS MC	MK01 /PT13	NC	/ 1001-2020	1.5	20.0			
BIM /PTB	GPSPPP	BM51 /PT13	2007-2019	/ 1001-2020	0.3	7.1	1.3		
BIRM/PTB	GPSPPP	BI41 /PT13	1016-2018	/ 1001-2020	0.3	2.8	1.3		
BOM /PTB	GPS MC	MABM /PT13	NA_Al	/ 1001-2020	10.0	7.6	2.8	+4.4	2003

Aligned by BIPM

Main items under discussion:

1. Ageing and validity of old calibrations
2. Validity of temporary alignments by the BIPM
3. Status « Not Calibrated » for calibrations becoming invalid
   (also for the still numerous uncalibrated laboratories)

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Thanks you for your kind attention

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www.bipm.org