LNE-SYRTE
GNSS station relative calibration report

G1/G2 #1017-2023

ORB
GNSS stations relative calibration.

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Content

1. Introduction.

This calibration report released by LNE-SYRTE is about the G1/G2 relative calibration campaign of GNSS stations located in ORB. This campaign took place in ORB site from 6 May 2023 (MJD 60070) to 14 May 2023 (MJD 60078).

The report is built according to the Annex 4 of the document "BIPM guidelines for GNSS equipment calibration", V4.0 05/08/2021 [2], and contains all the required informations, data, plots and results either required by BIPM in the frame of the CCTF Working Group on GNSS, or by BIPM and EURAMET in the frame of the Group1/Group2 calibration scheme. It also contains the uncertainty budget computation according to the Guidelines, which is showing whether the calibrated links used in the frame of the TAI computation would be in line with the conventional values.

This document contains first a summary of the results, followed by a Section devoted to the list of the acronyms used in the document and of the reference documents. Section 4 describes the equipment and operations during the calibration campaign. Section 5 provides all informations about data handling and calibration processing. Section 6 is about the calibration results between stations, and Section 7 is devoted to the uncertainty budgets computation. After an assessment of the stability of the GNSS reference station and of the traveling ones during this campaign in Section 8, the resulting delays and related uncertainties of the calibrated stations are provided in Section 9.

Annex A provides the required BIPM information sheets for all GNSS stations involved, Annex B shows the plots of the raw data together with the related TDEV. Annex C describes all the terms appearing in the uncertainty budgets.

This is Issue 0 of this calibration report.

The LNE-SYRTE acknowledges the support of all the colleagues in ORB.

This report is consistent with the capabilities that are included in Appendix C of the CIPM MRA drawn up by the CIPM. Under the CIPM MRA, all participating institutes recognize the validity of each other's calibration and measurement certificates for the quantities, ranges and measurement uncertainties specified in the KCDB (for details see https://www.bipm.org/kcdb/).

2. Summary of the results.

This Section is a summary of the ORB GNSS stations relative calibration results. Table 1 provides the GPS P1-code and P2-code calibrated delays for all stations, from where P3 delays are computed, together with their related uncertainties. The deviation from closure having been very small (see Section 7), the combined uncertainties of the GPS P3 delays remain below the 2.5 ns conventional value. As a consequence, Table 1 shows the conventional value from a G1/G2 relative calibration to be considered for all GPS P3 time transfer when using any of the listed stations in the TAI network. These results are fully valid for the period of the calibration campaign.

Table 1. Summary of the ORB stations GPS delays (all values in ns).

Station	IGS name	Measurement period	P1-code Delays	Combined uncertainty	P2-code Delays	Combined uncertainty	P3 Delays	Combined uncertainty [*]
OR5Z	BRUX	60070-60078	27.9	0.7	23.9	0.7	34.1	2.5
OR20	GRCB	60070-60078	32.7	0.7	28.3	0.7	39.7	2.5
OR4Z	ORBA	60070-60078	54.6	0.7	55.5	0.7	53.3	2.5
ZTB5	ZTB5	60070-60078	170.3	0.7	168.4	0.7	173.3	2.5

[*] Conventional combined uncertainty value for G1/G2 calibration in the frame of the TAI network.

Table 2 provides the Galileo E1-code and E5a-code calibrated delays for all stations, from where E3 delays are computed, together with their related uncertainties. The deviation from closure having been very small (see Section 7), the combined uncertainties of the Galileo E3 delays remain below the 2.5 ns conventional value. As a consequence, Table 2 shows the conventional value from a G1/G2 relative calibration to be considered for all Galileo E3 time transfer when using any of the listed stations in the TAI network. These results are fully valid for the period of the calibration campaign.

Table 2. Summary of the ORB stations Galileo delays (all values in ns).

Station	IGS name	Measurement period	E1-code Delays	Combined uncertainty	E5a-code Delays	Combined uncertainty	E3 delays	Combined uncertainty [*]
OR5Z	BRUX	60070-60078	30.1	0.7	30.1	0.7	30.2	2.5
OR20	GRCB	60070-60078	35.4	0.7	33.8	0.7	37.4	2.5
OR4Z	ORBA	60070-60078	55.7	0.7	65.6	0.7	43.2	2.5
ZTB5	ZTB5	60070-60078	173.1	0.7	171.6	0.7	174.9	2.5

[*] Conventional combined uncertainty value for G1/G2 calibration in the frame of the TAI network.

3. Acronym list and Reference Document.

3.1. Acronym list:

ADEV :	Allan deviation, square root of AVAR.
AVAR :	Allan variance or two-sample variance.
BIPM:	Bureau International des Poids et Mesures, Sèvres, France.
BRDC :	IGS harmonized GNSS broadcast ephemeris.
CCTF:	Consultative Committee on Time and Frequency.
CGGTTS:	CCTF Global GNSS Time Transfer Standard format.
CIPM:	Comité International des Poids et Mesures.
CV :	Common-View.
DI :	Designated Institute.
EURAMET :	European association of metrology laboratories.
G1:	Group 1 laboratory in the frame of the TAI network.
G2:	Group 2 laboratory in any given Regional Metrology Area.
GLONASS:	Russian GNSS.
GNSS:	Global Navigation Satellite System.
GPS:	United States of America GNSS.
GST:	Galileo System Time.
IGS:	International GNSS Service.
LNE:	Laboratoire National de Métrologie et d'Essais, French NMI.
LNE-SYRTE:	French designated laboratory in charge of Time and Frequency units.
MDEV:	Modified Allan deviation, square root of MVAR.
MVAR:	Modified Allan variance.
na:	Not available.
nc:	Not computed.
NMI:	National Metrology Institute.
NRCan :	National Ressources Canada, Canadian NMI.
OP:	Observatoire de Paris, France.
ORB :	Observatoire Royal de Belgique, Brussels, Belgium DI.
PPP :	Precise Point Positioning.
PPS:	Pulse per second.
PTB:	Physikalisch Technische Bundesanstalt, German NMI.
PTF:	Precise Time Facility.
RINEX:	GNSS Receiver International Exchange format for Geodesy.
SYRTE:	Systèmes de Référence Temps-Espace, OP laboratory where LNE-SYRTE is located.
TAI:	Temps Atomique International.
TDEV:	Time Allan deviation, square root of TVAR.
TIC:	Time Interval Counter.
TSP:	Time Service Provider.
TVAR:	Time Allan variance, derived from AVAR and MVAR.
UTC:	Coordinated Universal Time.

3.2. References.

[1] Pierre Uhrich and David Valat, "*GPS receiver relative calibration campaign preparation for Galileo In-Orbit Validation*", Proc. of the 24th European Frequency and Time Forum (EFTF), Noordwijk, The Netherlands, April 2010 (CD-Rom).

[2] BIPM Guidelines for GNSS equipment calibration, v4.0, 05/08/2021.

[3] G.D. Rovera, J-M. Torre, R. Sherwood, M. Abgrall, C. Courde, M. Laas-Bourez and P. Uhrich, "*Link calibration against receiver calibration: an assessment of GPS time transfer uncertainties*", Metrologia 51 (2014) 476-490.

[4] Daniele Rovera, Michel Abgrall, Pierre Uhrich and Marco Siccardi, "*Techniques of antenna cable delay measurement for GPS time transfer*", Proc. of the 5th International Colloquium on Scientific and Fundamental Aspects of the Galileo Programme, 27-29 October 2015, Braunschweig, Germany.

4. Description of equipment and operations.

4.1. OP GNSS equipment.

The OP GNSS reference station for this campaign is made of one multi-GNSS Septentrio PolaRx5TR main unit called OP73, connected by a 30 m long antenna cable to a SepChoke B3/E6 multi-GNSS antenna. This station was part of the last G1 calibration campaign (#1001-2020), its delays having been computed by BIPM.

The OP GNSS traveling equipment is made of two multi-GNSS Septentrio PolaRx5TR main units called OP72 and OP74, connected to one single 50 m long antenna cable thanks to a power splitter, and to one single multi-GNSS Veraphase VP6000 antenna.

The firmware of all PolaRx5TR was 5.4.0.

4.2. UTC(k) GNSS equipment.

The UTC(k) GNSS equipment to calibrate was based on three Septentrio PolaRx5TR and one Septentrio PolaRx4TR main units. Annex A contains the details about the local implementations in the visited stations.

These stations were calibrated as G2 GNSS stations according to the BIPM Guidelines for the delays computations including the related combined uncertainties. But the resulting uncertainties will also be provided within the 95 % uncertainty level as recommended by EURAMET.

4.3. Summary of the involved equipment and planning.

Table 3 summarizes the equipment involved in the GNSS relative calibration campaign of UTC(k) laboratories with highlighted traveling station measurement periods on each site.

Table 3. Summary of equipment and planning.

Institute	Station	Equipment status	MJD of measurement	Receiver type	BIPM code	RINEX name
OP	OP72	Traveling	60052-60130	Septentrio PolaRx5TR	OP72	OP72
OP	OP74	Traveling	60052-60130	Septentrio PolaRx5TR	OP74	OP74
OP	OP73	G1 reference	60052-60130	Septentrio PolaRx5TR	OP73	OP7300FRA
ORB	BRUX	G2	60070-60078	Septentrio PolaRx5TR	OR5Z	BRUX00BEL
ORB	GRCB	G2	60070-60078	Septentrio PolaRx5TR	OR20	GRCB00BEL
ORB	ORBA	G2	60070-60078	Septentrio PolaRx4TR	OR4Z	ORBA00BEL
ORB	ZTB5	G2	60070-60078	Septentrio PolaRx5TR	ZTB5	ZTB500BEL

5. Data and processing.

All OP collected raw Septentrio binary files (SBF) data are transformed into GNSS RINEX 3 format by using the Septentrio proprietary SBF2RIN software. Local receivers SBF and/or RINEX 3 and/or RINEX 2 data, together with CGGTTS files when they exist, are provided by the visited institution/laboratory. The calibration is consisting in building differential 30 s sampled CGGTTS data for each P1- and P2-codes for GPS and for each E1- and E5a-codes for Galileo between pairs of receivers, for which we partly use the R2CGGTTS software developed by P. Defraigne (ORB). Another part of the calibration software is an original development by LNE-SYRTE. These CGGTTS differences are corrected by the known reference delay (REFDLY) and antenna cable delay (CABDLY) when available. In this case, the calibrated delays are for the ensemble receiver main unit plus antenna.

For each location, the coordinates of the antenna phase centers are especially computed for the calibration period from RINEX files by using the NRCan PPP software. Unfortunately, this computation is limited to GPS phase center for L1 and L2 carrier frequencies. Galileo E1 carrier being equal to L1, we assume the phase center is identical. But it is not the case for Galileo E5a compared to L2, and we can only approximate the Galileo E5a phase center by using L2 one. The geometric correction between pairs of antenna phase centers for receivers in common-clock set-up is computed by using Rapid BRDC files provided by IGS.

Reference delays are measured against either the local UTC(k) physical reference point or the local time scale reference point at the trigger level currently used in the involved laboratories. The trigger level in LNE-SYRTE is 1.0 V. Antenna cable delay is either obtained from dedicated measurements or included in the P1 and P2 delays and in the E1 and E5a delays when no value is available for this parameter. In this latter case, the CABDLY value is set to 0 in the parameter file, and the calibrated delays are for the ensemble receiver main unit plus antenna cable plus antenna.

For validation purposes, ionosphere-free linear combinations P3 and E3 CGGTTS files are computed by using the R2CGGTTS software provided by P. Defraigne (ORB), and CV are built between pairs of receivers. This is more especially the case when we are using two traveling receivers in a visited location, in order to better assess the stability of this traveling ensemble all over the calibration campaign. But this usual validation process cannot be applied when both traveling receivers are not connected to the same local time scale. The conservative estimated value for the traveling equipment stability during such a campaign is typically chosen for each code as the maximum between the misclosure between the start and the end of the campaign and the average offset between both traveling receivers as measured in each location.

As conservative estimate, the noise of the P1 and P2 differences and of the E1 and E5a differences is obtained from the highest value of the one-sigma statistical uncertainty of the TDEV at 1 d, issued from a linear interpolation between consecutive TDEV points when required. In the case there is not enough data to compute a TDEV at 1 d, the upper limit of the last error bar available is considered as noise of the raw differences. The noise of P3 and E3 data is issued from a similar analysis on TDEV data.

6. Results of data processing.

6.1. GPS delays calibration.

The plots of the GPS codes raw data processing and the related TDEV can be found in Annex B. Table 4 to 6 provide a summary of all the delays involved in the GPS code calibrations for all stations. First, the calibration of the traveling stations OP72 and OP74 against the reference station OP73, leading to the OP72 and OP74 delay mean values between the start and the end of the campaign. Second, the calibration of the visited stations against these mean values. As typically expected, the noise estimates from the TDEVs are well below 100 ps, and are hence remaining low enough in the uncertainty budgets (see Section 7).

*Table 4. Summary of **GPS** delays for traveling stations **OP72 and OP74** (all values in ns).*

Station	Reference	MJD of Measurement	REFDLY	CABDLY	P1 DLY	TDEV	P2 DLY	TDEV
OP73	***1001-2020***	***60052-60060***	***85.2***	***129.6***	***29.500***	***NC***	***26.300***	***NC***
OP72	OP73	60052-60060	93.4	0.0	224.485	0.030	222.574	0.028
OP74	OP73	60052-60060	111.4	0.0	225.122	0.030	223.269	0.027
OP73	***1001-2020***	***60126-60130***	***85.2***	***129.6***	***29.500***	***NC***	***26.300***	***NC***
OP72	OP73	60126-60130	93.4	0.0	224.239	0.013	222.432	0.043
OP74	OP73	60126-60130	111.4	0.0	224.892	0.015	223.138	0.042

*Table 5. Summary of **GPS** delays for visited stations against **OP72 mean delays** (all values in ns).*

Station	Reference	MJD of Measurement	REFDLY	CABDLY	P1 DLY	TDEV	P2 DLY	TDEV
OP72	***OP73***	***60070-60078***	***53.6***	***0.0***	***224.362***	***NC***	***222.503***	***NC***
BRUX	OP72	60070-60078	68.7	237.5	27.896	0.014	23.882	0.016
GRCB	OP72	60070-60078	70.6	96.3	32.734	0.015	28.268	0.023
ORBA	OP72	60070-60078	158.7	149.2	54.621	0.020	5.470	0.023
ZTB5	OP72	60070-60078	79.4	0.0	170.316	0.038	168.373	0.023

*Table 6. Summary of **GPS** delays for visited stations against **OP74 mean delays** (all values in ns).*

Station	Reference	MJD of Measurement	REFDLY	CABDLY	P1 DLY	TDEV	P2 DLY	TDEV
OP74	***OP73***	***60070-60078***	***71.6***	***0.0***	***225.007***	***NC***	***223.204***	***NC***
BRUX	OP74	60070-60078	68.7	237.5	27.903	0.015	23.871	0.017
GRCB	OP74	60070-60078	70.6	96.3	32.740	0.016	28.257	0.023
ORBA	OP74	60070-60078	158.7	149.2	54.628	0.020	55.459	0.023
ZTB5	OP74	60070-60078	79.4	0.0	170.322	0.039	168.361	0.022

Table 7 provides the differential GPS delays of the visited systems with respect to the traveling system, according to BIPM Guidelines [2]. We note here that the offsets of the differences between either OP72 or OP74 and OP73 at the start and at the end of the campaign are about 0.246 ns (P1) and 0.142 ns (P2) for OP72 and 0.230 ns (P1) and 0.131 ns (P2) for OP74 respectively, which is small enough to provide excellent resulting uncertainty budgets (see Section 7). In addition, there is also an excellent consistency of the remote station delays obtained either from OP72 or from OP74 in the visited location, the maximum offset between both staying equal or below 12 ps.

Table 7. Visited systems with respect to reference system via traveling systems (all values in ns).

Pair	MJD of Measurement	INTDLY P1	INTDLY P2	P1 – P2
OP72 – OP73	60052-60060	224.485	222.574	1.911
OP74 – OP73	60052-60060	225.122	223.269	1.853
OP72 – OP73	60126-60130	224.239	222.432	1.807
OP74 – OP73	60126-60130	224.892	223.138	1.754
BRUX– OP72	60070-60078	27.896	23.882	4.014
BRUX– OP74	60070-60078	27.903	23.871	4.032
GRCB – OP72	60070-60078	32.734	28.268	4.466
GRCB – OP74	60070-60078	32.740	28.257	4.483
ORBA – OP72	60070-60078	54.621	55.470	-0.849
ORBA – OP74	60070-60078	54.628	55.459	- 0.831
ZTB5 – OP72	60070-60078	170.316	168.373	1.943
ZTB5 – OP74	60070-60078	170.322	168.361	1.961

6.2. Galileo delays calibration.

The plots of the Galileo codes raw data processing and related TDEV can be found in Annex B. Table 8 to 10 provide a summary of all the delays involved in the Galileo code calibrations for all stations. First, the calibration of the traveling stations OP72 and OP74 against the reference station OP73, leading to the OP72 and OP74 delay mean values between the start and the end of the campaign. Second, the calibration of the visited stations against these mean values. As typically expected, the noise estimates from the TDEVs are well below100 ps, and are hence remaining low enough in the uncertainty budgets (see Section 7).

*Table 8. Summary of **Galileo** delays for traveling stations **OP72 and OP74** (all values in ns).*

Receiver	Reference	MJD of Measurement	REFDLY	CABDLY	E1 DLY	TDEV	E5a DLY	TDEV
OP73	***1001-2020***	***60052-60060***	***85.2***	***129.6***	***31.700***	***NC***	***31.300***	***NC***
OP72	OP73	60052-60060	93.4	0.0	226.766	0.027	225.986	0.038
OP74	OP73	60052-60060	111.4	0.0	227.547	0.029	226.678	0.039
OP73	***1001-2020***	***60126-60130***	***85.2***	***129.6***	***31.700***	***NC***	***31.300***	***NC***
OP72	OP73	60126-60130	93.4	0.0	226.577	0.032	225.799	0.040
OP74	OP73	60126-60130	111.4	0.0	227.376	0.033	226.530	0.040

Table 9. Summary of ***Galileo*** *delays for all visited stations against* ***OP72 mean delays*** *(all values in ns).*

Receiver	Reference	MJD of Measurement	REFDLY	CABDLY	E1 DLY	TDEV	E5a DLY	TDEV
OP72	***OP73***	***60070-60078***	***53.6***	***0.0***	***226.671***	***NC***	***225.893***	***NC***
BRUX	OP72	60070-60078	68.7	237.5	30.139	0.023	30.117	0.045
GRCB	OP72	60070-60078	70.6	96.3	35.405	0.021	33.813	0.019
ORBA	OP72	60070-60078	158.7	149.2	55.669	0.027	65.559	0.031
ZTB5	OP72	60070-60078	79.4	0.0	173.049	0.042	171.593	0.031

Table 10. Summary of ***Galileo*** *delays for all visited stations against* ***OP74 mean delays*** *(all values in ns).*

Receiver	Reference	MJD of Measurement	REFDLY	CABDLY	E1 DLY	TDEV	E5a DLY	TDEV
OP74	***OP73***	***60070-60078***	***71.6***	***0.0***	***227.461***	***NC***	***226.604***	***NC***
BRUX	OP74	60070-60078	68.7	237.5	30.149	0.023	30.119	0.044
GRCB	OP74	60070-60078	70.6	96.3	35.415	0.021	33.816	0.020
ORBA	OP74	60070-60078	158.7	149.2	55.679	0.027	65.562	0.031
ZTB5	OP74	60070-60078	79.4	0.0	173.058	0.041	171.595	0.031

Table 11 provides the differential Galileo delays of the visited systems with respect to the traveling system, according to BIPM Guidelines [2]. We note here that the offsets of the differences between either OP72 or OP74 and OP73 at the start and at the end of the campaign are about 0.189 ns (E1) and 0.187 ns (E5a) for OP72 or 0.171 ns (E1) and 0.148 ns (E5a) for OP74, which is small enough to provide excellent resulting uncertainty budgets (see Section 7). In addition, there is also an excellent consistency of the remote station delays obtained either from OP72 or from OP74 in each visited location, the maximum offset between both staying equal or below 10 ps.

Table 11. Visited systems with respect to reference system via traveling system (all values in ns).

Pair	MJD of Measurement	INTDLY E1	INTDLY E5a	E1 – E5a
OP72 – OP73	60052-60060	226.766	225.986	0.780
OP74 – OP73	60052-60060	227.547	226.678	0.869
OP72 – OP73	60126-60130	226.577	225.799	0.778
OP74 – OP73	60126-60130	227.376	226.530	0.846
BRUX – OP72	60070-60078	30.139	30.117	0.022
BRUX – OP74	60070-60078	30.149	30.119	0.030
GRCB – OP72	60070-60078	35.405	33.813	1.592
GRCB – OP74	60070-60078	35.415	33.816	1.599
ORBA – OP72	60070-60078	55.669	65.559	- 9.890
ORBA – OP74	60070-60078	55.679	65.562	- 9.883
ZTB5 – OP72	60070-60078	173.049	171.593	1.456
ZTB5 – OP74	60070-60078	173.058	171.595	1.463

7. Uncertainty budgets.

We provide in this section an estimation of the combined uncertainty of the differential calibration for the receivers located in the visited laboratory. All the uncertainty budgets have been built according to the reference [2] in order to provide the required u_{CAL0} values. More details on the uncertainty estimations are provided in Annex C.

The Type A uncertainty on measured codes is estimated from the high value of the 1 sigma statistical uncertainty of the TDEV(1 d). The Type A uncertainty of the difference between codes is the quadratic sum between both estimations. But the P3 and E3 Type A uncertainties are estimated from the high value of the 1 sigma statistical uncertainty of the related TDEV(1 d). All TDEV plots are in Annex B. Table 12 shows the P3 and E3 TDEV(1 d) computed values for all receiver pairs during the campaign. The conservative values eventually chosen for the uncertainty budget computation are highlighted in **bold**. Note that all values in Table 12 are within 110 ps, which is an excellent result at one day.

Table 12. One sigma statistical uncertainty computed values of TDEV(1 d) for P3 and E3 for all station pairs (all values in ns).

Linear combination	**P3**	**E3**
OP72 – OP73 Start	0.096	**0.073**
OP72 – OP73 End	0.071	0.050
OP74 – OP73 Start	**0.100**	0.073
OP74 – OP73 End	0.075	0.050
BRUX – OP72	**0.040**	**0.064**
BRUX – OP74	0.038	0.063
GRCB – OP72	**0.047**	0.048
GRCB – OP74	0.040	**0.049**
ORBA – OP72	**0.080**	**0.070**
ORBA – OP74	0.079	0.066
ZTB5 – OP72	0.087	**0.110**
ZTB5 – OP74	**0.094**	0.109

In the calibration process only P1 and P2 delays for GPS and E1 and E5a delays for Galileo are estimated, therefore the misclosure for P3 delay (GPS) or E3 delay (Galileo) is not directly available from the calibration computation. The GPS P3 misclosure is estimated by applying to the misclosure values computed for P1- and P2-code the ionosphere-free linear combination formula:

$$P3 = P1 + 1.546 \times (P1 - P2)$$

The Galileo E3 misclosure is estimated by applying to the misclosure values computed for E1- and E5a-code the ionosphere-free linear combination formula:

$$E3 = E1 + 1.261 \times (E1 - E5a)$$

Table 13 shows the values of the considered misclosures. All these results are within 400 ps, which is excellent and even close to the state of the art, leading to uncertainty budgets which will be in the lowest part for such computation.

Table 13. Mean values of deviation from closure between traveling stations and reference station OP73 (all values in ns).

Misclosure	***ΔP1***	***ΔP2***	***Δ(P1 - P2)***	***ΔP3***	***ΔE1***	***ΔE5a***	***Δ(E1 - E5a)***	***ΔE3***
OP72	0.246	0.142	0.104	**0.407**	0.189	0.187	0.002	**0.192**
OP74	0.230	0.131	0.099	**0.383**	0.171	0.148	0.023	**0.200**
Mean value	**0.238**	**0.137**	**0.102**	**0.395**	**0.180**	**0.168**	**0.013**	**0.196**

Table 14 to 17 are providing the uncertainty budgets for GPS delays of all visited stations. Table 18 to 21 are providing similar uncertainty budgets for Galileo delays of all visited stations tracking Galileo signal. We have not computed any uncertainty budget for RTBS.

*Table 14. **BRUX** uncertainty budget for **GPS** calibrated delays (all values in ns).*

Uncertainty type	P1	P2	P1 – P2	P3	Description
u_a(reference)	0.030	0.043	0.052	0.100	Largest TDEV(1 d) sigma between the start and the end of OP72 or OP74 against OP73
u_a(**BRUX**)	0.015	0.017	0.023	0.040	Largest TDEV(1 d) sigma of offset between visited station and OP72 or OP74
Type A uncertainties					
u_a	0.034	0.046	0.057	0.108	Visited against reference
Misclosure					
$u_{b,1}$	0.238	0.137	0.102	0.395	Actual misclosure offset
Systematic components related to RAWDIF					
$u_{b,11}$	0.200	0.200	0.200	0.200	Position error at OP
$u_{b,12}$	0.200	0.200	0.200	0.200	Position error at visited site
$u_{b,13}$	0.200	0.200	0.200	0.200	Multipaths at OP
$u_{b,14}$	0.200	0.200	0.200	0.200	Multipaths at visited site
Link of the traveling system to local time scales					
$u_{b,21}$	0.220	0.220		0.220	REFDLY at OP
$u_{b,22}$	0.220	0.220		0.220	REFDLY at visited site
$u_{b,TOT}$	0.560	0.525		0.643	
Link of the reference system to UTC(OP)					
$u_{b,31}$	0.220	0.220		0.220	REFDLY at OP
Link of the visited system to its local time scale					
$u_{b,32}$	0.220	0.220		0.220	REFDLY at visited site
Antenna cable delays					
$u_{b,41}$	0.0	0.0		0.0	CABDLY at OP
$u_{b,42}$	0.0	0.0		0.0	CABDLY at visited site
Type B uncertainties					
$u_{b,SYS}$	0.641	0.610		0.714	Quadratic sum of u_b
Combined uncertainties					
u_{CAL0}	0.641	0.612		**0.722**	Composed of u_a and $u_{b,SYS}$

*Table 15. **GRCB** uncertainty budget for **GPS** calibrated delays (all values in ns).*

Uncertainty type	P1	P2	P1 – P2	P3	Description
u_a(reference)	0.030	0.043	0.052	0.100	Largest TDEV(1 d) sigma between the start and the end of OP72 or OP74 against OP73
u_a(**GRCB**)	0.016	0.023	0.028	0.047	Largest TDEV(1 d) sigma of offset between visited station and OP72 or OP74
Type A uncertainties					
u_a	0.034	0.049	0.059	0.110	Visited against reference
Misclosure					
$u_{b,1}$	0.238	0.137	0.102	0.395	Actual misclosure offset
Systematic components related to RAWDIF					
$u_{b,11}$	0.200	0.200	0.200	0.200	Position error at OP
$u_{b,12}$	0.200	0.200	0.200	0.200	Position error at visited site
$u_{b,13}$	0.200	0.200	0.200	0.200	Multipaths at OP
$u_{b,14}$	0.200	0.200	0.200	0.200	Multipaths at visited site
Link of the traveling system to local time scales					
$u_{b,21}$	0.220	0.220		0.220	REFDLY at OP
$u_{b,22}$	0.220	0.220		0.220	REFDLY at visited site
$u_{b,TOT}$	0.560	0.525		0.643	
Link of the reference system to UTC(OP)					
$u_{b,31}$	0.220	0.220		0.220	REFDLY at OP
Link of the visited system to its local time scale					
$u_{b,32}$	0.220	0.220		0.220	REFDLY at visited site
Antenna cable delays					
$u_{b,41}$	0.0	0.0		0.0	CABDLY at OP
$u_{b,42}$	0.0	0.0		0.0	CABDLY at visited site
Type B uncertainties					
$u_{b,SYS}$	0.641	0.610		0.714	Quadratic sum of u_b
Combined uncertainties					
u_{CAL0}	0.642	0.612		**0.722**	Composed of u_a and $u_{b,SYS}$

*Table 16. **ORBA** uncertainty budget for **GPS** calibrated delays (all values in ns).*

Uncertainty type	P1	P2	P1 – P2	P3	Description
u_a(reference)	0.030	0.043	0.052	0.100	Largest TDEV(1 d) sigma between the start and the end of OP72 or OP74 against OP73
u_a(**ORBA**)	0.020	0.023	0.030	0.080	Largest TDEV(1 d) sigma of offset between visited station and OP72 or OP74
Type A uncertainties					
u_a	0.036	0.049	0.060	0.128	Visited against reference
Misclosure					
$u_{b,1}$	0.238	0.137	0.102	0.395	Actual misclosure offset
Systematic components related to RAWDIF					
$u_{b,11}$	0.200	0.200	0.200	0.200	Position error at OP
$u_{b,12}$	0.200	0.200	0.200	0.200	Position error at visited site
$u_{b,13}$	0.200	0.200	0.200	0.200	Multipaths at OP
$u_{b,14}$	0.200	0.200	0.200	0.200	Multipaths at visited site
Link of the traveling system to local time scales					
$u_{b,21}$	0.220	0.220		0.220	REFDLY at OP
$u_{b,22}$	0.220	0.220		0.220	REFDLY at visited site
$u_{b,TOT}$	0.560	0.525		0.643	
Link of the reference system to UTC(OP)					
$u_{b,31}$	0.220	0.220		0.220	REFDLY at OP
Link of the visited system to its local time scale					
$u_{b,32}$	0.220	0.220		0.220	REFDLY at visited site
Antenna cable delays					
$u_{b,41}$	0.0	0.0		0.0	CABDLY at OP
$u_{b,42}$	0.0	0.0		0.0	CABDLY at visited site
Type B uncertainties					
$u_{b,SYS}$	0.641	0.610		0.714	Quadratic sum of u_b
Combined uncertainties					
u_{CAL0}	0.642	0.612		**0.725**	Composed of u_a and $u_{b,SYS}$

*Table 17. **ZTB5** uncertainty budget for **GPS** calibrated delays (all values in ns).*

Uncertainty type	P1	P2	P1 – P2	P3	Description
u_a(reference)	0.030	0.043	0.052	0.100	Largest TDEV(1 d) sigma between the start and the end of OP72 or OP74 against OP73
u_a(**ZTB5**)	0.039	0.023	0.045	0.094	Largest TDEV(1 d) sigma of offset between visited station and OP72 or OP74
Type A uncertainties					
u_a	0.049	0.049	0.069	0.137	Visited against reference
Misclosure					
$u_{b,1}$	0.238	0.137	0.102	0.395	Actual misclosure offset
Systematic components related to RAWDIF					
$u_{b,11}$	0.200	0.200	0.200	0.200	Position error at OP
$u_{b,12}$	0.200	0.200	0.200	0.200	Position error at visited site
$u_{b,13}$	0.200	0.200	0.200	0.200	Multipaths at OP
$u_{b,14}$	0.200	0.200	0.200	0.200	Multipaths at visited site
Link of the traveling system to local time scales					
$u_{b,21}$	0.220	0.220		0.220	REFDLY at OP
$u_{b,22}$	0.220	0.220		0.220	REFDLY at visited site
$u_{b,TOT}$	0.560	0.525		0.643	
Link of the reference system to UTC(OP)					
$u_{b,31}$	0.220	0.220		0.220	REFDLY at OP
Link of the visited system to its local time scale					
$u_{b,32}$	0.220	0.220		0.220	REFDLY at visited site
Antenna cable delays					
$u_{b,41}$	0.0	0.0		0.0	CABDLY at OP
$u_{b,42}$	0.0	0.0		0.0	CABDLY at visited site
Type B uncertainties					
$u_{b,SYS}$	0.641	0.610		0.714	Quadratic sum of u_b
Combined uncertainties					
u_{CAL0}	0.643	0.612		**0.727**	Composed of u_a and $u_{b,SYS}$

*Table 18. **BRUX** uncertainty budget for **Galileo** calibrated delays (all values in ns).*

Uncertainty type	E1	E5a	E1 – E5a	E3	Description
u_a(Reference)	0.033	0.040	0.052	0.073	Largest TDEV(1 d) sigma between the start and the end of OP72 or OP74 against OP73
u_a(**BRUX**)	0.023	0.045	0.051	0.064	Largest TDEV(1 d) sigma of offset between visited station and OP72 or OP74
Type A uncertainties					
u_a	0.040	0.060	0.051	0.097	Visited against reference
Misclosure					
$u_{b,1}$	0.180	0.168	0.013	0.196	Actual misclosure offset
Systematic components related to RAWDIF					
$u_{b,11}$	0.200	0.200	0.200	0.200	Position error at OP
$u_{b,12}$	0.200	0.200	0.200	0.200	Position error at visited site
$u_{b,13}$	0.200	0.200	0.200	0.200	Multipaths at OP
$u_{b,14}$	0.200	0.200	0.200	0.200	Multipaths at visited site
Link of the traveling system to local time scales					
$u_{b,21}$	0.220	0.220		0.220	REFDLY at OP
$u_{b,22}$	0.220	0.220		0.220	REFDLY at visited site
$u_{b,TOT}$	0.538	0.534		0.543	
Link of the reference system to UTC(OP)					
$u_{b,31}$	0.220	0.220		0.220	REFDLY at OP
Link of the visited system to its local time scale					
$u_{b,32}$	0.220	0.220		0.220	REFDLY at visited site
Antenna cable delays					
$u_{b,41}$	0.0	0.0		0.0	CABDLY at OP
$u_{b,42}$	0.0	0.0		0.0	CABDLY at visited site
Type B uncertainties					
$u_{b,SYS}$	0.621	0.618		0.626	Quadratic sum of u_b
Combined uncertainties					
u_{CAL0}	0.622	0.621		**0.633**	Composed of u_a and $u_{b,SYS}$

*Table 19. **GRCB** uncertainty budget for **Galileo** calibrated delays (all values in ns).*

Uncertainty type	E1	E5a	E1 – E5a	E3	Description
u_a(Reference)	0.033	0.040	0.052	0.073	Largest TDEV(1 d) sigma between the start and the end of OP72 or OP74 against OP73
u_a(**GRCB**)	0.021	0.020	0.029	0.049	Largest TDEV(1 d) sigma of offset between visited station and OP72 or OP74
Type A uncertainties					
u_a	0.039	0.045	0.060	0.088	Visited against reference
Misclosure					
$u_{b,1}$	0.180	0.168	0.013	0.196	Actual misclosure offset
Systematic components related to RAWDIF					
$u_{b,11}$	0.200	0.200	0.200	0.200	Position error at OP
$u_{b,12}$	0.200	0.200	0.200	0.200	Position error at visited site
$u_{b,13}$	0.200	0.200	0.200	0.200	Multipaths at OP
$u_{b,14}$	0.200	0.200	0.200	0.200	Multipaths at visited site
Link of the traveling system to local time scales					
$u_{b,21}$	0.220	0.220		0.220	REFDLY at OP
$u_{b,22}$	0.220	0.220		0.220	REFDLY at visited site
$u_{b,TOT}$	0.538	0.534		0.543	
Link of the reference system to UTC(OP)					
$u_{b,31}$	0.220	0.220		0.220	REFDLY at OP
Link of the visited system to its local time scale					
$u_{b,32}$	0.220	0.220		0.220	REFDLY at visited site
Antenna cable delays					
$u_{b,41}$	0.0	0.0		0.0	CABDLY at OP
$u_{b,42}$	0.0	0.0		0.0	CABDLY at visited site
Type B uncertainties					
$u_{b,SYS}$	0.621	0.618		0.626	Quadratic sum of u_b
Combined uncertainties					
u_{CAL0}	0.622	0.620		**0.632**	Composed of u_a and $u_{b,SYS}$

*Table 20. **ORBA** uncertainty budget for **Galileo** calibrated delays (all values in ns).*

Uncertainty type	E1	E5a	E1 – E5a	E3	Description
u_a(Reference)	0.033	0.040	0.052	0.073	Largest TDEV(1 d) sigma between the start and the end of OP72 or OP74 against OP73
u_a(**ORBA**)	0.027	0.031	0.041	0.070	Largest TDEV(1 d) sigma of offset between visited station and OP72 or OP74
Type A uncertainties					
u_a	0.043	0.051	0.066	0.101	Visited against reference
Misclosure					
$u_{b,1}$	0.180	0.168	0.013	0.196	Actual misclosure offset
Systematic components related to RAWDIF					
$u_{b,11}$	0.200	0.200	0.200	0.200	Position error at OP
$u_{b,12}$	0.200	0.200	0.200	0.200	Position error at visited site
$u_{b,13}$	0.200	0.200	0.200	0.200	Multipaths at OP
$u_{b,14}$	0.200	0.200	0.200	0.200	Multipaths at visited site
Link of the traveling system to local time scales					
$u_{b,21}$	0.220	0.220		0.220	REFDLY at OP
$u_{b,22}$	0.220	0.220		0.220	REFDLY at visited site
$u_{b,TOT}$	0.538	0.534		0.543	
Link of the reference system to UTC(OP)					
$u_{b,31}$	0.220	0.220		0.220	REFDLY at OP
Link of the visited system to its local time scale					
$u_{b,32}$	0.220	0.220		0.220	REFDLY at visited site
Antenna cable delays					
$u_{b,41}$	0.0	0.0		0.0	CABDLY at OP
$u_{b,42}$	0.0	0.0		0.0	CABDLY at visited site
Type B uncertainties					
$u_{b,SYS}$	0.621	0.618		0.626	Quadratic sum of u_b
Combined uncertainties					
u_{CAL0}	0.622	0.620		**0.634**	Composed of u_a and $u_{b,SYS}$

*Table 21. **ZTB5** uncertainty budget for **Galileo** calibrated delays (all values in ns).*

Uncertainty type	E1	E5a	E1 – E5a	E3	Description
u_a(Reference)	0.033	0.040	0.052	0.073	Largest TDEV(1 d) sigma between the start and the end of OP72 or OP74 against OP73
u_a(**ZTB5**)	0.042	0.031	0.052	0.110	Largest TDEV(1 d) sigma of offset between visited station and OP72 or OP74
Type A uncertainties					
u_a	0.053	0.051	0.074	0.132	Visited against reference
Misclosure					
$u_{b,1}$	0.180	0.168	0.013	0.196	Actual misclosure offset
Systematic components related to RAWDIF					
$u_{b,11}$	0.200	0.200	0.200	0.200	Position error at OP
$u_{b,12}$	0.200	0.200	0.200	0.200	Position error at visited site
$u_{b,13}$	0.200	0.200	0.200	0.200	Multipaths at OP
$u_{b,14}$	0.200	0.200	0.200	0.200	Multipaths at visited site
Link of the traveling system to local time scales					
$u_{b,21}$	0.220	0.220		0.220	REFDLY at OP
$u_{b,22}$	0.220	0.220		0.220	REFDLY at visited site
$u_{b,TOT}$	0.538	0.534		0.543	
Link of the reference system to UTC(OP)					
$u_{b,31}$	0.220	0.220		0.220	REFDLY at OP
Link of the visited system to its local time scale					
$u_{b,32}$	0.220	0.220		0.220	REFDLY at visited site
Antenna cable delays					
$u_{b,41}$	0.0	0.0		0.0	CABDLY at OP
$u_{b,42}$	0.0	0.0		0.0	CABDLY at visited site
Type B uncertainties					
$u_{b,SYS}$	0.621	0.618		0.626	Quadratic sum of u_b
Combined uncertainties					
u_{CAL0}	0.623	0.620		**0.640**	Composed of u_a and $u_{b,SYS}$

8. Validation of the results.

8.1. Stability of the reference station.

The reference station in OP was based on a Septentrio PolaRx5TR receiver called OP73. Figure 1 is showing a plot which demonstrate the stability of this GNSS station during the calibration campaign. The plot is the daily averaged offset between the Two-Way Satellite Time and Frequency Transfer (TWSTFT) between OP and PTB, based on the Software-Defined Radio (SDR) technique, and the GNSS Common View (CV) time transfer using P3 GPS data between OP and PTB, based on OP73 in OP side and on PTBB in PTB side. In both laboratories, the signal source is a UTC(k) time scale: UTC(PTB) and UTC(OP). In this computation, the time scales being cancelled, what remains is only the offset between the two time transfer techniques.

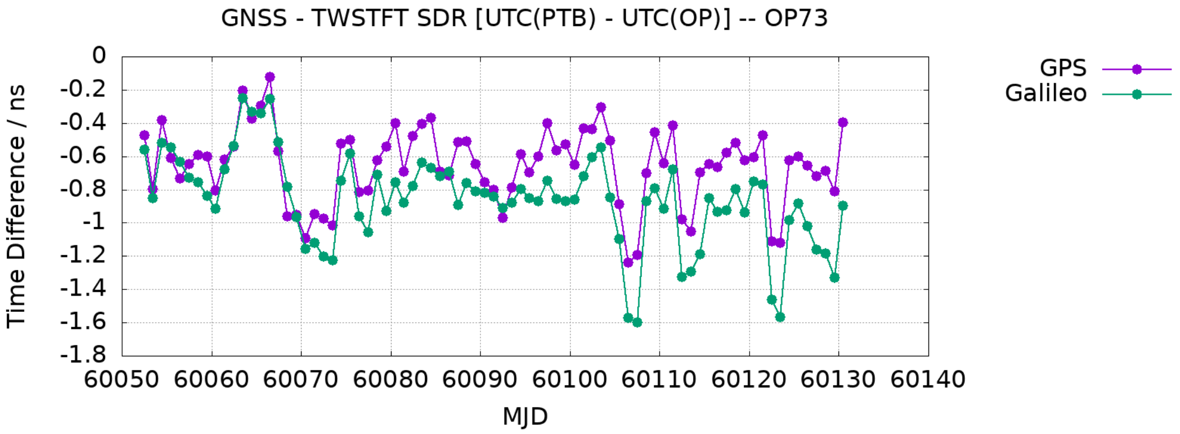


Figure 1. Daily averaged offset between TWSTFT and GPS P3 CV on the link OP-PTB during the calibration campaign.

The mean offsets over that period of time are about – 0.65 ns, when using GPS data, with a standard deviation of about 0.23 ns, and – 0.86 ns, when using Galileo data, with a standard deviation of about 0.27 ns. These mean offsets are mostly coming from the last G1 calibration of GNSS stations achieved by BIPM for OP and PTB stations (#1001-2020) and from the last TWSTFT relative calibration (#0546-2021). We remind here that the conventional combined uncertainty of GNSS stations located in G1 laboratories is 1.5 ns, as decided by the CCTF Working Group (WG) on GNSS time transfer. The offset seen here is in full agreement with the claimed uncertainties. We note a small slope of TWSTFT – Galileo offset when compared to TWSTFT – GPS one. We are having no explanation about it, but the analysis below remains valid.

What can be seen on Figure 1 is the excellent sub-ns stability of this ensemble of four systems, two inside each laboratory, among which OP73 in OP. The standard deviation of the equipment ensemble is staying below 300 ps over the campaign duration. We estimate that any potential effect of OP73 on this calibration campaign can be disregarded with respect to the final uncertainty of the calibration (see Section 9).

8.2. Offset between the two traveling receivers.

Figure 2 is showing the offset between the two traveling receivers during the whole calibration campaign, based on CV between CGGTTS P3 (GPS), and Figure 3 is showing similar offset based on CV between CGGTTS E3 (Galileo) data, by using for OP72 and OP74 the average delays computed against OP73 between the start and the closure of the campaign.

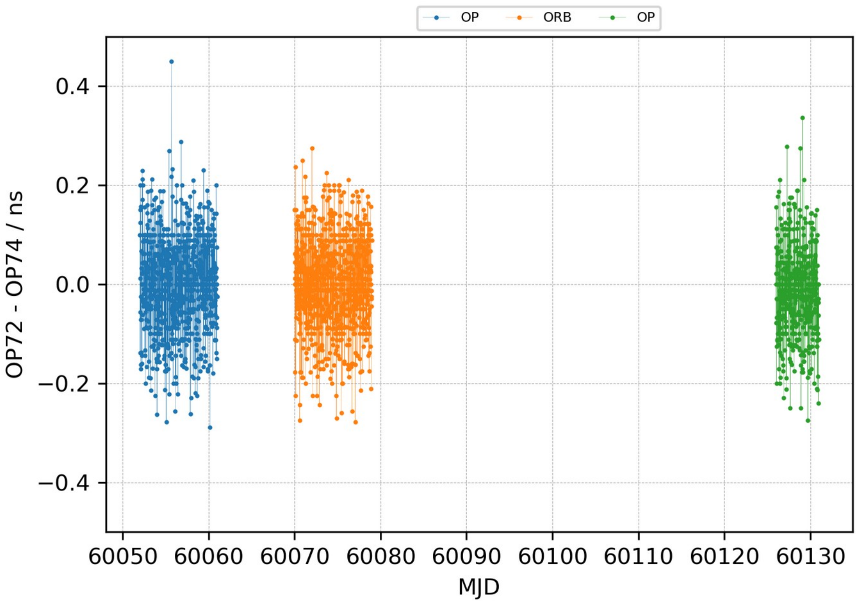


Figure 2. Offset between OP72 and OP74 during the UTC(k) calibration campaign, based on CGGTTS P3 CV data. From left to right, the sequence of data sets is: start at OP, ORB and closure at OP.

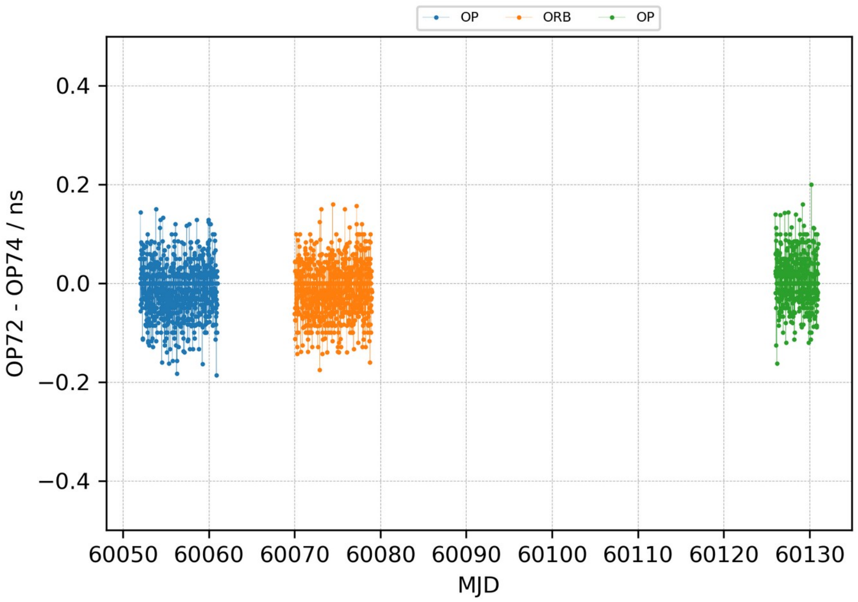


Figure 3. Offset between OP72 and OP74 during the UTC(k) calibration campaign, based on CGGTTS E3 CV data. From left to right, the sequence of data sets is: start at OP, ORB and closure at OP.

Table 22 provides the mean values and standard deviations for all periods and data related to the plots above. What can be seen here is a clear consistency largely below 100 ps between both traveling receivers all over the campaign, which was expected as both units are connected to one single antenna and one single antenna cable. We also see here that, even if the mean offsets are staying very close, all the GPS CV are appearing significantly more noisy than the related Galileo CV by a well known factor of about 1.8. In other words, the traveling equipment remained very stable during the calibration campaign. We can consider that the effect of these offsets on the calibration results is insignificant.

Table 22. Offsets between OP72 and OP74 during the ORB calibration campaign (all values in ns).

OP72 – OP74	GPS CV mean value	Standard deviation	Galileo CV mean value	Standard deviation
OP (start)	0.001	0.097	- 0.013	0.053
ORB	0.002	0.093	- 0.013	0.053
OP (closure)	- 0.013	0.094	0.009	0.053

9. Final results for the systems to calibrate.

In this Section, we provide the final results of the calibration campaign, based on the uncertainty budgets of Section 7, and according to the BIPM guidelines [2]. In addition, we also provide a conservative k = 2 computation of the uncertainties (95 % confidence interval), according to the EURAMET recommendations. All visited stations are calibrated for P3 (GPS) time transfer and for E3 (Galileo) time transfer within the given combined uncertainties.

9.1. GPS delays.

Table 23 provides the final results of the calibration campaign for GPS delays for all involved stations. Table 24 provides the conservative k = 2 expanded uncertainties for all GPS codes in line with EURAMET requirements.

Table 23. Summary of GPS calibrations on the calibration trip (all values in ns).

BIPM code	RINEX name	Cal Id	Date	u_{CAL}(P3)	INTDLY P1	INTDLY P2
Reference system						
OP73	OP7300FRA	1001-2020	2021	1.5 [*]	29.5	26.3
Visited systems						
OR5Z	BRUX00BEL	1017-2023	2023	0.8	27.9	23.9
OR20	GRCB00BEL	1017-2023	2023	0.8	32.7	28.3
OR4Z	ORBA00BEL	1017-2023	2023	0.8	54.6	55.5
ZTB5	ZTB500BEL	1017-2023	2023	0.8	170.3	168.4

[*] Conventional combined uncertainty value for G1/G1 laboratories in the frame of the TAI network.

Table 24. Conservative k = 2 expanded GPS code uncertainties following EURAMET standard (all values in ns).

BIPM code	RINEX name	u(P1)	u(P2)	u(P3)
OR5Z	BRUX00BEL	1.3	1.3	1.5
OR20	GRCB00BEL	1.3	1.3	1.5
OR4Z	ORBA00BEL	1.3	1.3	1.5
ZTB5	ZTB500BEL	1.3	1.3	1.5

9.2. Galileo delays.

Table 25 provides the final results of the calibration campaign for Galileo delays for all involved stations. Table 26 provides the conservative k = 2 expanded uncertainties for all Galileo codes in line with EURAMET requirements.

Table 25. Summary Galileo calibrations on the calibration trip (all values in ns).

BIPM code	RINEX name	Cal Id	Date	u_{CAL}(E3)	INTDLY E1	INTDLY E5a
Reference system						
OP73	OP7300FRA	1001-2020	2021	1.5 [*]	31.7	31.3
Visited systems						
OR5Z	BRUX00BEL	1017-2023	2023	0.7	30.1	30.1
OR20	GRCB00BEL	1017-2023	2023	0.7	35.4	33.8
OR4Z	ORBA00BEL	1017-2023	2023	0.7	55.7	65.5
ZTB5	ZTB500BEL	1017-2023	2023	0.7	173.1	171.6

[*] Conventional combined uncertainty value for G1/G1 laboratories in the frame of the TAI network.

Table 26. Conservative k = 2 expanded Galileo code uncertainties following EURAMET standard (all values in ns).

BIPM code	RINEX name	u(E1)	u(E5a)	u(E3)
OR5Z	BRUX00BEL	1.3	1.3	1.3
OR20	GRCB00BEL	1.3	1.3	1.3
OR4Z	ORBA00BEL	1.3	1.3	1.3
ZTB5	ZTB500BEL	1.3	1.3	1.3

9.3. Comparison with former calibrated delays.

Table 27 is showing the direct comparison with former known delays which had been calibrated in 2021. We note that all these offsets are included between – 0.5 ns and 0.5 ns, which is an excellent result, showing a very good stability of the visited stations over time.

Table 27. Comparison of calibrated delays between 2023 and 2021 (all values in ns).

Station	Code	2021	2023	2023 - 2021
BRUX	**P1**	28.0	27.9	**- 0.1**
	P2	23.8	23.9	**0.1**
	E1	30.4	30.1	**- 0.3**
	E5a	29.6	30.1	**0.5**
GRCB	**P1**	33.0	32.7	**- 0.3**
	P2	27.8	28.3	**0.5**
	E1	35.8	35.4	**- 0.3**
	E5a	33.7	33.8	**0.1**
ORBA	**P1**	55.1	54.6	**- 0.5**
	P2	55.2	55.5	**0.3**
	E1	56.2	55.7	**- 0.5**
	E5a	65.6	65.5	**- 0.1**

10. Appendix.

ANNEX A

Implementation of OP traveling stations in visited sites.

A1. Implementation in OP.

Figure A1 is showing the implementation of OP traveling equipment, namely OP72 and OP74 connected to the same antenna cable and antenna, alongside OP73 reference station in LNE-SYRTE in OP at the start and at the end of the campaign.

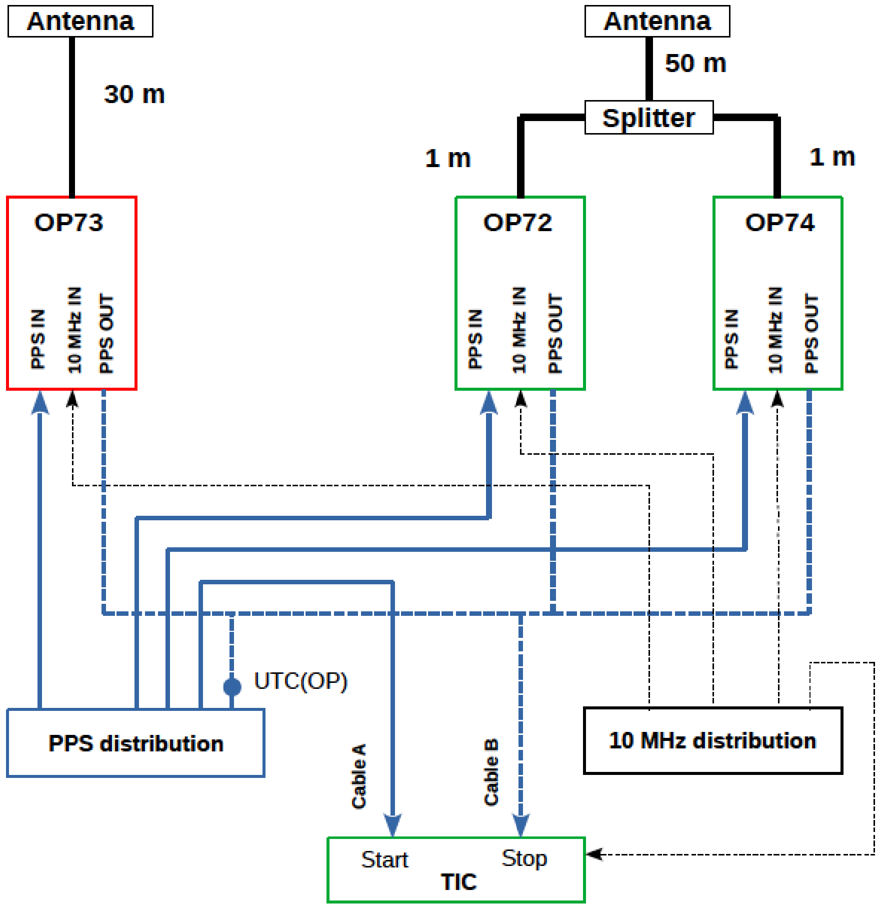


Figure A1. Implementation of OP traveling equipment in OP.

The next pages are providing the BIPM information sheets for OP72 and OP74.

Cal Id: 1014-2023 | Version / Date: 19/04/2023

BIPM Information sheet

Laboratory	OP (Open)		
Date and hour beginning of measurements	11 02 2023 00:00		
Date and hour end measurements	16 02 2023 00:00		
Information on the system			
	Local	**Traveling**	
4-Character BIPM code	OP73	OP72	OP74
Receiver maker and type	Septentrio PolaRx5TR	Septentrio PolaRx5TR	Septentrio PolaRx5TR
Receiver serial number	4701467	4701463	4701497
1 PPS triger level / V	1 V	1 V	1 V
Antenna cable marker and type		HY 400 UF	HY 400 UF
Phase stabilized cable (Y/N)			
Cable length outside building / m	20 m	20 m	20 m
Antenna maker and type	SEPCHOCKE_B2E6	TWIVP6000	TWIVP6000
Antenna serial number	5759	33-685000-01-01	33-685000-01-01
Temperature if stabilized / °C			
Mesured delays / ns			
	Local	**Traveling**	
Delay from local UTC(k) to receiver 1 PPS_IN			
Delay from 1 PPS_IN to internal reference (see Annex 1)			
Antenna cable delay			
Splitter delay			
Additional cable delay			
Data used for the generation of CGGTTS files			
	Local	**Traveling**	
INT DLY (GPS) / ns	P1: 29.5 P2: 26.3	P1: 0 P2: 0	P1: 0 P2: 0
INT DLY (Galileo) / ns	E1: 31.7 E5a: 31.3	E1: 0 E5a: 0	E1: 0 E5a: 0
CAB DLY / ns	129.6		
REF DLY / ns	85.2	93.408	111.400
Coordinate reference frame	ITRF	ITRF	ITRF
Latitude or X / m	4202777.071	4202781.470	4202781.470
Longitude or Y / m	171367.028	171369.360	171369.360
Height or Z / m	4778661.392	4778659.104	4778659.104
General Information			
Rise time of local UTC pulse	< 1 ns		
Air conditioning (Y/N)	Y		
Set temperature value and uncertainty	22¡C +/- 1¡C		
Set humidity value and uncertainty	22¡C +/- 1¡C		

Cal Id: 1014-2023

Version / Date: 19/04/2023

BIPM Information sheet

Laboratory	OP (Close)		
Date and hour beginning of measurements	22 03 2023 00:00		
Date and hour end measurements	27 03 2023 00:00		
Information on the system			
	Local	**Traveling**	
4-Character BIPM code	OP73	OP72	OP74
Receiver maker and type	Septentrio PolaRx5TR	Septentrio PolaRx5TR	Septentrio PolaRx5TR
Receiver serial number	4701467	4701463	4701497
1 PPS triger level / V	1 V	1 V	1 V
Antenna cable marker and type		HY 400 UF	HY 400 UF
Phase stabilized cable (Y/N)			
Cable length outside building / m	20 m	20 m	20 m
Antenna maker and type	SEPCHOCKE_B2E6	TWIVP6000	TWIVP6000
Antenna serial number	5759	33-685000-01-01	33-685000-01-01
Temperature if stabilized / °C			
Mesured delays / ns			
	Local	**Traveling**	
Delay from local UTC(k) to receiver 1 PPS_IN			
Delay from 1 PPS_IN to internal reference (see Annex 1)			
Antenna cable delay			
Splitter delay			
Additional cable delay			
Data used for the generation of CGGTTS files			
	Local	**Traveling**	
INT DLY (GPS) / ns	P1: 29.5 P2: 28.3	P1: 0 P2: 0	P1: 0 P2: 0
INT DLY (Galileo) / ns	E1: 31.7 E5a: 31.3	E1: 0 E5a: 0	E1: 0 E5a: 0
CAB DLY / ns	129.6		
REF DLY / ns	85.2	93.350	111.372
Coordinate reference frame	ITRF	ITRF	ITRF
Latitude or X / m	4202777.071	4202781.456	4202781.456
Longitude or Y / m	171367.028	171369.346	171369.346
Height or Z / m	4778661.392	4778659.090	4778659.090
General Information			
Rise time of local UTC pulse	< 1 ns		
Air conditioning (Y/N)	Y		
Set temperature value and uncertainty	22¡C +/- 1¡C		
Set humidity value and uncertainty	22¡C +/- 1¡C		

A2. Implementation in ORB.

The next pages are providing the BIPM information sheets for each ORB station.

Cal Id: 1017-2023 Version / Date: 16/05/2023

BIPM Infortion sheet

Laboratory	Royal Observatory of Belgium		
Date and hour beginning of measurements	05-05-2023 10:06		
Date and hour end measurements	15-05-2023 12:04		
Information on the system			
	Local	**Traveling**	
4-Character BIPM code	OR5Z	OP72	OP74
Receiver maker and type	SEPTPolaRx5TR 5.5.0	SEPTPolaRx5TR	SEPTPolaRx5TR
Receiver serial number	3057609	4701463	4701497
1 PPS triger level / V	1 V	1 V	1 V
Antenna cable marker and type	armoured cab.,N-conn.	HY 400 UF (50 m)	HY 400 UF (50 m)
Phase stabilized cable (Y/N)	N	N	N
Cable length outside building / m	ca 15 m	ca 20 m	ca 20 m
Antenna maker and type	JAVRINGANT_DM	TWI VeraPhase 6000	TWI VeraPhase 6000
Antenna serial number	00464	33-685000-01-01	33-685000-01-01
Temperature if stabilized / °C	0.1°C	0.1°C	0.1°C
Mesured delays / ns			
	Local	**Traveling**	
Delay from local UTC(k) to receiver 1 PPS_IN	68.658	53.589	71.619
Delay from 1 PPS_IN to internal reference (see Annex 1)	auto-compens. OFF	auto-compens. OFF	auto-compens. OFF
Antenna cable delay	237.5	N/A	N/A
Splitter delay	N/A		
Additional cable delay	N/A		
Data used for the generation of CGGTTS files			
	Local	**Traveling**	
INT DLY (GPS) / ns	P1: 28.0 P2: 23.8	P1: 224.424 P2: 222.600	P1: 225.125 P2: 223.377
INT DLY (Galileo) / ns	E1: 30.4 E5a: 29.6	E1: 226.719 E5a: 226.020	E1: 227.563 E5a: 226.781
CAB DLY / ns	237.5	0.0	0.0
REF DLY / ns	68.5	53.6	71.6
Coordinate reference frame	ITRF	ITRF	ITRF
Latitude or X / m	4027881.63	4027863.6560	4027863.6567
Longitude or Y / m	306998.83	307007.6329	307007.6332
Height or Z / m	4919499.42	4919506.2194	4919506.2206
General Information			
Rise time of local UTC pulse	3.2 ns		
Air conditioning (Y/N)	Y		
Set temperature value and uncertainty			
Set humidity value and uncertainty			

Cal Id: 1017-2023   Version / Date: 16/05/2023

BIPM Infortion sheet

Laboratory	Royal Observatory of Belgium		
Date and hour beginning of measurements	05-05-2023 10:06		
Date and hour end measurements	15-05-2023 12:04		
Information on the system			
	Local	**Traveling**	
4-Character BIPM code	OR20	OP72	OP74
Receiver maker and type	SEPTPolaRx5TR(5.2.0	SEPTPolaRx5TR	SEPTPolaRx5TR
Receiver serial number	4701221	4701463	4701497
1 PPS triger level / V	1 V	1 V	1 V
Antenna cable marker and type	armoured cab., N-conn	HY 400 UF (50 m)	HY 400 UF (50 m)
Phase stabilized cable (Y/N)	N	N	N
Cable length outside building / m	ca 15 m	ca 20 m	ca 20 m
Antenna maker and type	LEIAR 20 LEIM	TWI VeraPhase 6000	TWI VeraPhase 6000
Antenna serial number	20220022	33-685000-01-01	33-685000-01-01
Temperature if stabilized / °C	0.1°C	0.1°C	0.1°C
Mesured delays / ns			
	Local	**Traveling**	
Delay from local UTC(k) to receiver 1 PPS_IN	70.581	53.589	71.619
Delay from 1 PPS_IN to internal reference (see Annex 1)	auto-compens. OFF	auto-compens. OFF	auto-compens. OFF
Antenna cable delay	96.31	N/A	N/A
Splitter delay	N/A		
Additional cable delay	N/A		
Data used for the generation of CGGTTS files			
	Local	**Traveling**	
INT DLY (GPS) / ns	P1: 33.0 P2: 27.8	P1: 224.424 P2: 222.600	P1: 225.125 P2: 223.377
INT DLY (Galileo) / ns	E1: 35.8 E5a: 33.7	E1: 226.719 E5a: 226.020	E1: 227.563 E5a: 226.781
CAB DLY / ns	96.3	0.0	0.0
REF DLY / ns	70.5	53.6	71.6
Coordinate reference frame	ITRF	ITRF	ITRF
Latitude or X / m	4027861.60	4027863.6560	4027863.6567
Longitude or Y / m	307007.48	307007.6329	307007.6332
Height or Z / m	4919507.64	4919506.2194	4919506.2206
General Information			
Rise time of local UTC pulse	3.2 ns		
Air conditioning (Y/N)	Y		
Set temperature value and uncertainty			
Set humidity value and uncertainty			

Cal Id: 1017-2023 Version / Date: 16/05/2023

BIPM Infortion sheet

Laboratory	Royal Observatory of Belgium		
Date and hour beginning of measurements	05-05-2023 10:06		
Date and hour end measurements	15-05-2023 12:04		
Information on the system			
	Local	**Traveling**	
4-Character BIPM code	OR4Z	OP72	OP74
Receiver maker and type	SEPTPolaRx4TR(2.9.6	SEPTPolaRx5TR	SEPTPolaRx5TR
Receiver serial number	3007657	4701463	4701497
1 PPS triger level / V	1 V	1 V	1 V
Antenna cable marker and type	armoured cab.,N-conn.	HY 400 UF (50 m)	HY 400 UF (50 m)
Phase stabilized cable (Y/N)	N	N	N
Cable length outside building / m	ca 15 m	ca 20 m	ca 20 m
Antenna maker and type	SEPCHOKE_MC	TWI VeraPhase 6000	TWI VeraPhase 6000
Antenna serial number	5467	33-685000-01-01	33-685000-01-01
Temperature if stabilized / °C	0.1 °C	0.1 °C	0.1 °C
Mesured delays / ns			
	Local	**Traveling**	
Delay from local UTC(k) to receiver 1 PPS_IN	158.733	53.589	71.619
Delay from 1 PPS_IN to internal reference (see Annex 1)	auto-compens. OFF	auto-compens. OFF	auto-compens. OFF
Antenna cable delay	149.2	N/A	N/A
Splitter delay	N/A		
Additional cable delay	N/A		
Data used for the generation of CGGTTS files			
	Local	**Traveling**	
INT DLY (GPS) / ns	P1: 55.1 P2: 55.2	P1: 224.424 P2: 222.600	P1: 225.125 P2: 223.377
INT DLY (Galileo) / ns	E1: 56.2 E5a: 65.6	E1: 226.719 E5a: 226.020	E1: 227.563 E5a: 226.781
CAB DLY / ns	149.2	0.0	0.0
REF DLY / ns	158.4	53.6	71.6
Coordinate reference frame	ITRF	ITRF	ITRF
Latitude or X / m	4027865.46	4027863.6560	4027863.6567
Longitude or Y / m	307007.76	307007.6329	307007.6332
Height or Z / m	4919504.40	4919506.2194	4919506.2206
General Information			
Rise time of local UTC pulse	32. ns		
Air conditioning (Y/N)	Y		
Set temperature value and uncertainty			
Set humidity value and uncertainty			

Cal Id: 1017-2023

Version / Date: 16/05/2023

BIPM Infortion sheet

Laboratory	Royal Observatory of Belgium		
Date and hour beginning of measurements	05-05-2023 10:06		
Date and hour end measurements	15-05-2023 12:04		
Information on the system			
	Local	**Traveling**	
4-Character BIPM code	ZTB5	OP72	OP74
Receiver maker and type	PolaRx5TR	PolaRx5TR	PolaRx5TR
Receiver serial number	3089860	4701463	4701497
1 PPS triger level / V	1 V	1 V	1 V
Antenna cable marker and type	armoured cab,N-conn.	HY 400 UF (50 m)	HY 400 UF (50 m)
Phase stabilized cable (Y/N)	N	N	N
Cable length outside building / m	ca 15 m	ca 20 m	ca 20 m
Antenna maker and type	TWIVC6150 SCIS	TWI VeraPhase 6000	TWI VeraPhase 6000
Antenna serial number	710152	33-685000-01-01	33-685000-01-01
Temperature if stabilized / °C	0.1 °C	0.1 °C	0.1 °C
Mesured delays / ns			
	Local	**Traveling**	
Delay from local UTC(k) to receiver 1 PPS_IN	79.4	53.589	71.619
Delay from 1 PPS_IN to internal reference (see Annex 1)	auto-compens. OFF	auto-compens. OFF	auto-compens. OFF
Antenna cable delay		N/A	N/A
Splitter delay			
Additional cable delay			
Data used for the generation of CGGTTS files			
	Local	**Traveling**	
INT DLY (GPS) / ns	P1: P2:	P1: 224.424 P2: 222.600	P1: 225.125 P2: 223.377
INT DLY (Galileo) / ns	E1: E5a:	E1: 226.719 E5a: 226.020	E1: 227.563 E5a: 226.781
CAB DLY / ns		0.0	0.0
REF DLY / ns		53.6	71.6
Coordinate reference frame	ITRF	ITRF	ITRF
Latitude or X / m	4027865.21	4027863.6560	4027863.6567
Longitude or Y / m	307011.85	307007.6329	307007.6332
Height or Z / m	4919504.32	4919506.2194	4919506.2206
General Information			
Rise time of local UTC pulse	3.2 ns		
Air conditioning (Y/N)	Y		
Set temperature value and uncertainty			
Set humidity value and uncertainty			

ANNEX B

Raw data and TDEV.

1. Reminder of equipment and planning.

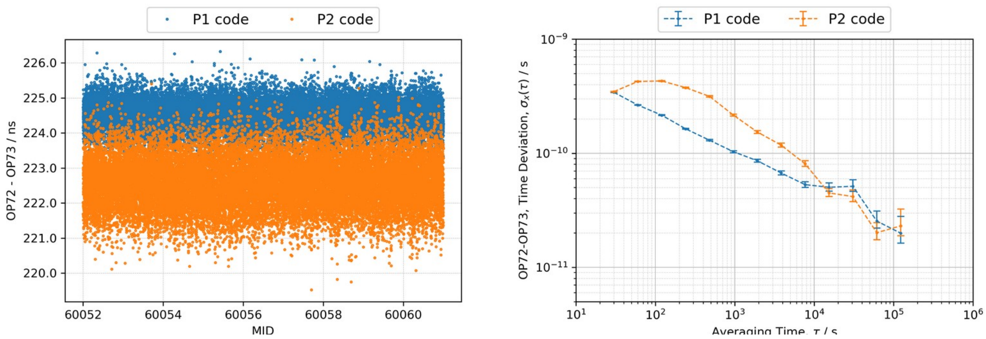
Institute	Equipment status	MJD of measurement	Receiver type	BIPM code	RINEX name
OP	Traveling		Septentrio PolaRx5TR	OP72	OP72
OP	Traveling		Septentrio PolaRx5TR	OP74	OP74
OP	G1 reference		Septentrio PolaRx5TR	OP73	OP7300FRA
ORB	G2	60070-60078	Septentrio PolaRx5TR	OR5Z	BRUX00BEL
ORB	G2	60070-60078	Septentrio PolaRx5TR	OR20	GRCB00BEL
ORB	G2	60070-60078	Septentrio PolaRx4TR	OR4Z	ORBA00BEL
ORB	G2	60070-60078	Septentrio PolaRx5TR	ZTB5	ZTB500BEL

2. GPS calibration of OP72 and OP74 against OP73.

2.1.Results of raw data processing.

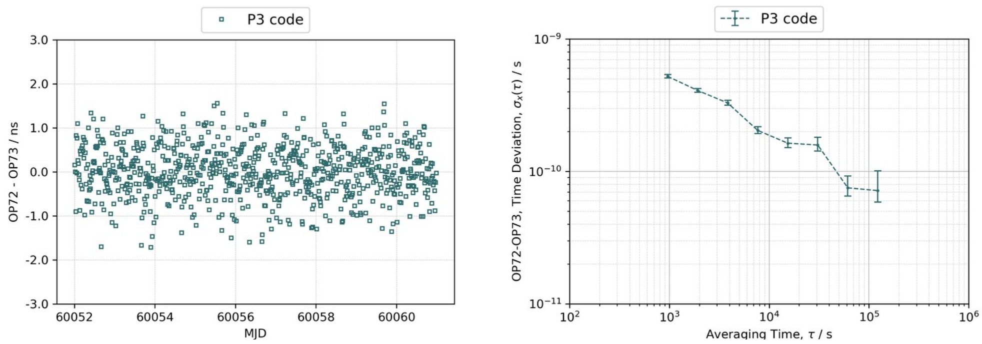
Pair	MJD of measurement	RawDiff P1	TDEV	RawDiff P2	TDEV
OP72 – OP73	60052-60060	- 57.204	0.030	- 58.493	0;028
OP74 – OP73	60052-60060	- 39.832	0.030	- 41.179	0.027
OP72 – OP73	60126-60130	- 56.893	0.013	- 58.286	0.043
OP74 – OP73	60126-60130	- 39.548	0.015	- 40.994	0.042

2.2. Plots of raw data and TDEV.



(a) P-code phase differences (b) TDEV of P-code delays

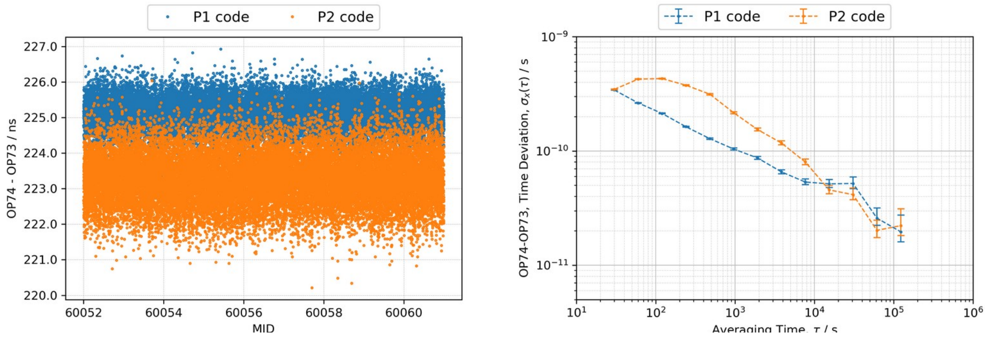
Figure B1: GPS relative calibration of OP72 with respect to OP73 (start).



(a) P3 CV after calibration (b) TDEV of P3 CV

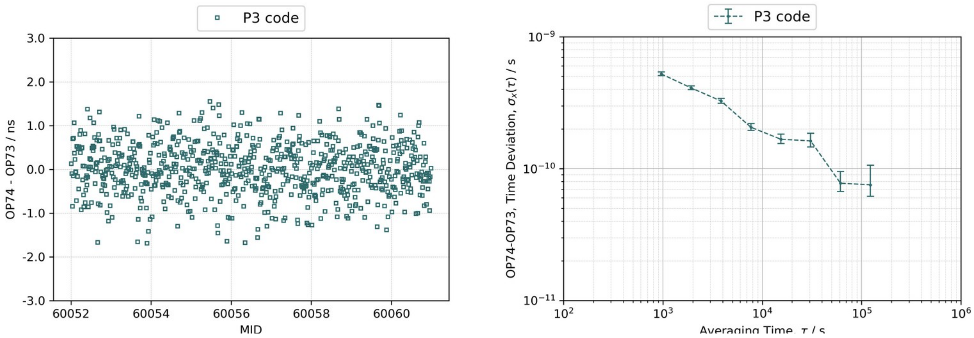
Figure B2: P3 CV time difference of OP72 with respect to OP73 (start).

B2



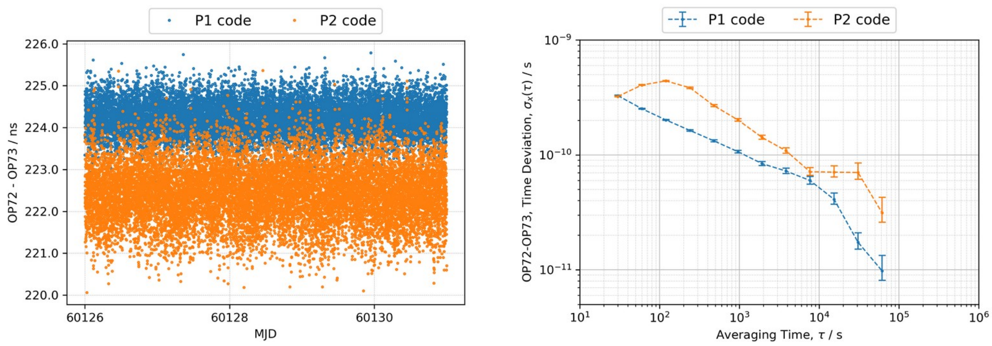
(a) P-code phase differences (b) TDEV of P-code delays

Figure B3: GPS relative calibration of OP74 with respect to OP73 (start).



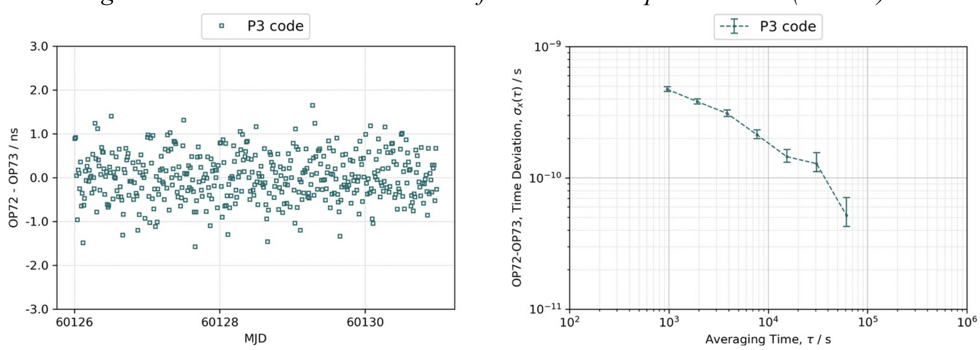
(a) P3 CV after calibration (b) TDEV of P3 CV

Figure B4: P3 CV time difference of OP74 with respect to OP73 (start).



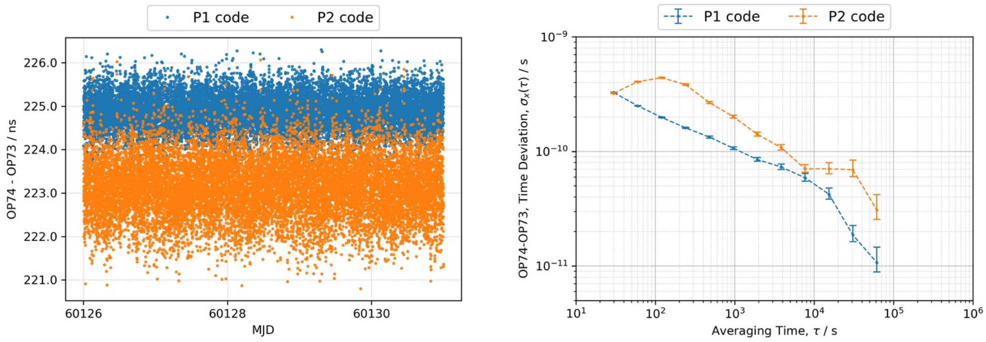
(a) P-code phase differences (b) TDEV of P-code delays

Figure B5: GPS relative calibration of OP72 with respect to OP73 (closure).



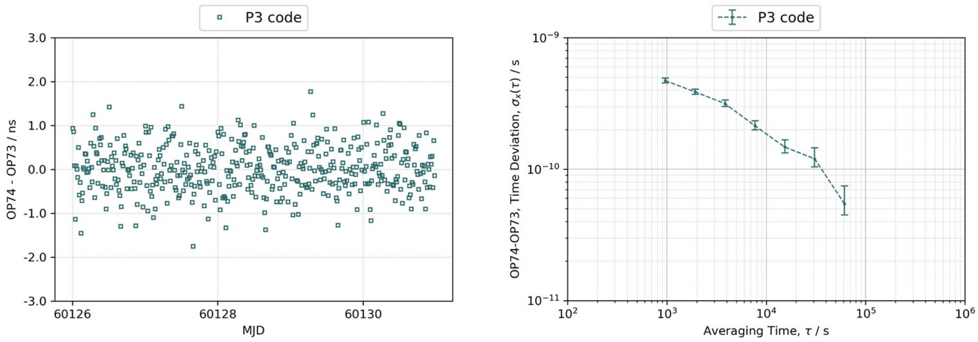
(a) P3 CV after calibration (b) TDEV of P3 CV

Figure B6: P3 CV time difference of OP72 with respect to OP73 (closure).



(a) P-code phase differences (b) TDEV of P-code delays

Figure B7: GPS relative calibration of OP74 with respect to OP73 (closure).



(a) P3 CV after calibration (b) TDEV of P3 CV

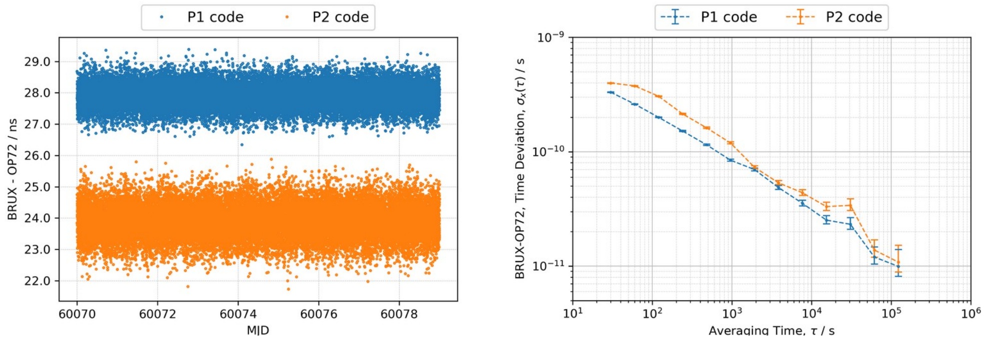
Figure B8: P3 CV time difference of OP74 with respect to OP73 (closure).

3. GPS calibration of visited stations against OP72 and OP74.

3.1.Results of raw data processing.

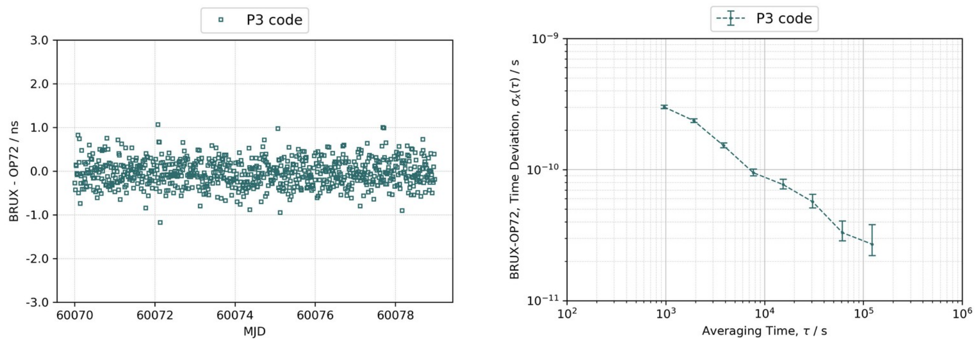
Pair	MJD of measurement	RawDiff P1	TDEV	RawDiff P2	TDEV
OR5Z – OP72	60070-60078	- 25.938	0.014	- 23.783	0.016
OR5Z – OP74	60070-60078	- 43.330	0.015	- 41.101	0.017
OR20 – OP72	60070-60078	112.320	0.015	114.927	0.023
OR20 – OP74	60070-60078	94.929	0.016	97.609	0.023
OR4Z – OP72	60070-60078	125.685	0.020	122.977	0.023
OR4Z – OP74	60070-60078	108.293	0.020	105.659	0.023
ZTB5 – OP72	60070-60078	79.879	0.038	79.963	0.023
ZTB5 – OP74	60070-60078	62.488	0.039	62.646	0.022

3.2. Plots of raw data and TDEV.



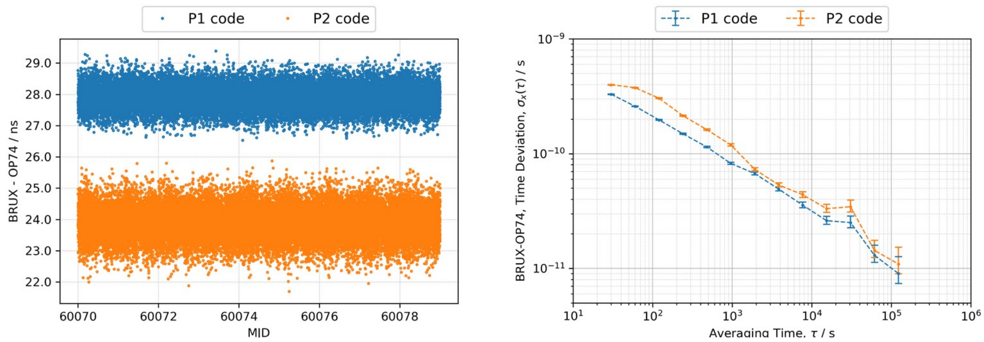
(a) P-code phase differences (b) TDEV of P-code delays

Figure B9: GPS relative calibration of BRUX with respect to OP72.



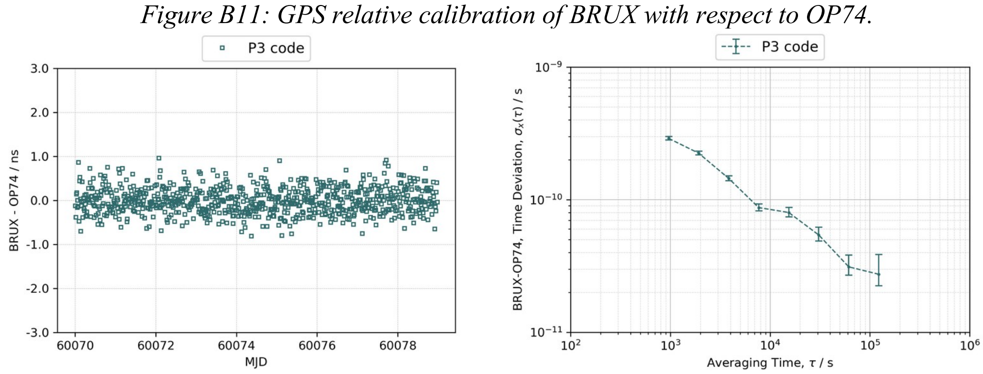
(a) P3 CV after calibration (b) TDEV of P3 CV

Figure B10: P3 CV time difference of BRUX with respect to OP72.



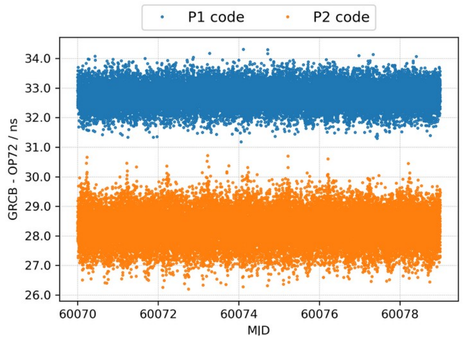
(a) P-code phase differences (b) TDEV of P-code delays

Figure B11: GPS relative calibration of BRUX with respect to OP74.

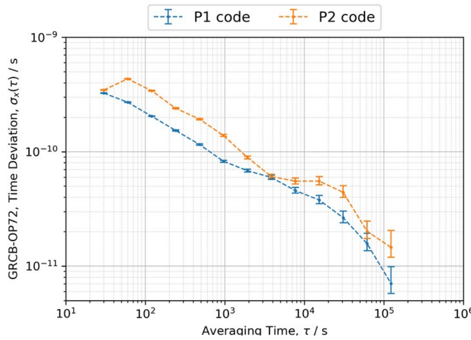


(a) P3 CV after calibration (b) TDEV of P3 CV

Figure B12: P3 CV time difference of BRUX with respect to OP74.

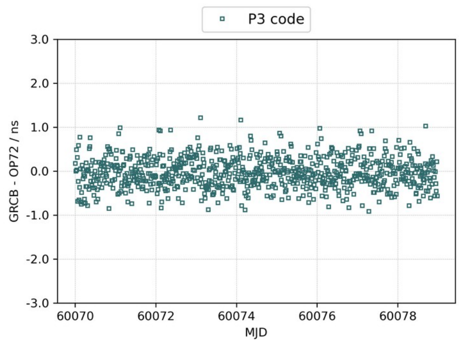


(a) P-code phase differences

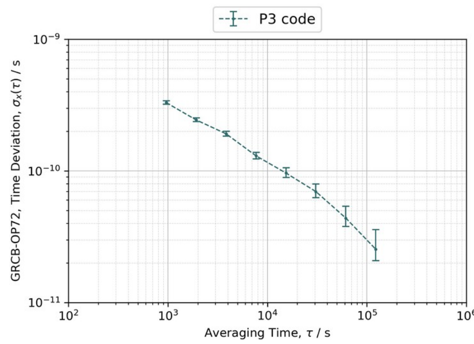


(b) TDEV of P-code delays

Figure B13: GPS relative calibration of GCRB with respect to OP72.

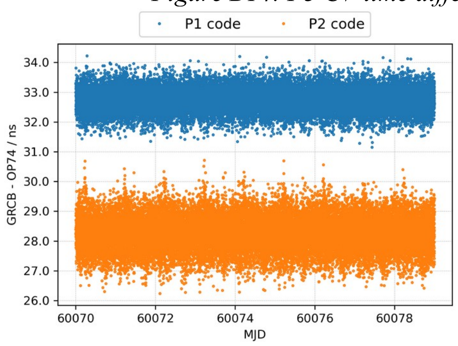


(a) P3 CV after calibration

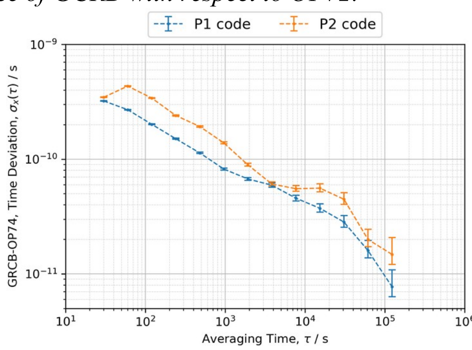


(b) TDEV of P3 CV

Figure B14: P3 CV time difference of GCRB with respect to OP72.

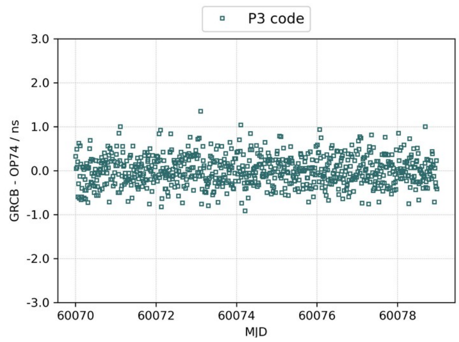


(a) P-code phase differences

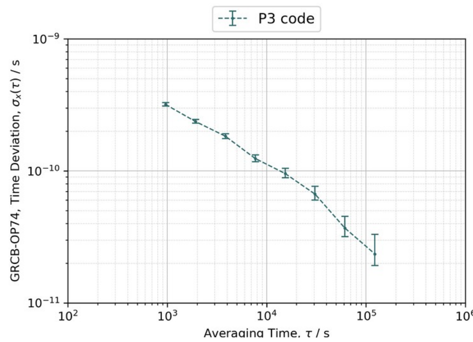


(b) TDEV of P-code delays

Figure B15: GPS relative calibration of GCRB with respect to OP74.

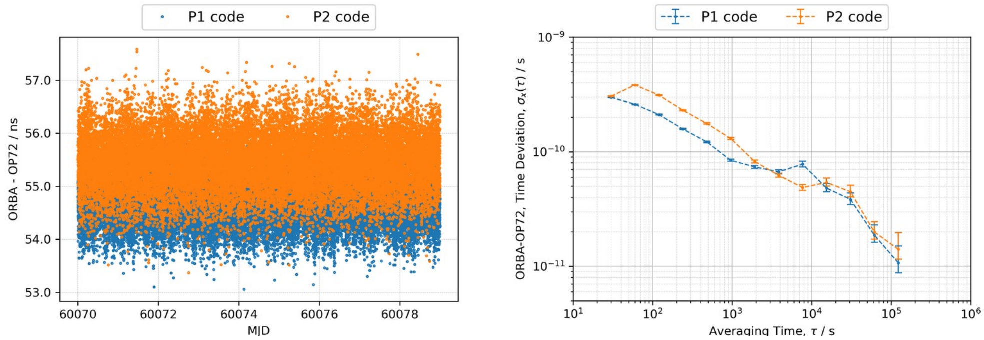


(a) P3 CV after calibration



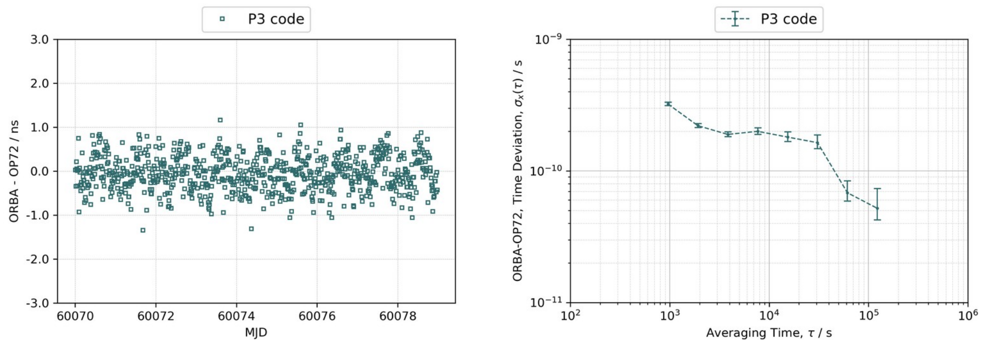
(b) TDEV of P3 CV

Figure B16: P3 CV time difference of GCRB with respect to OP74.



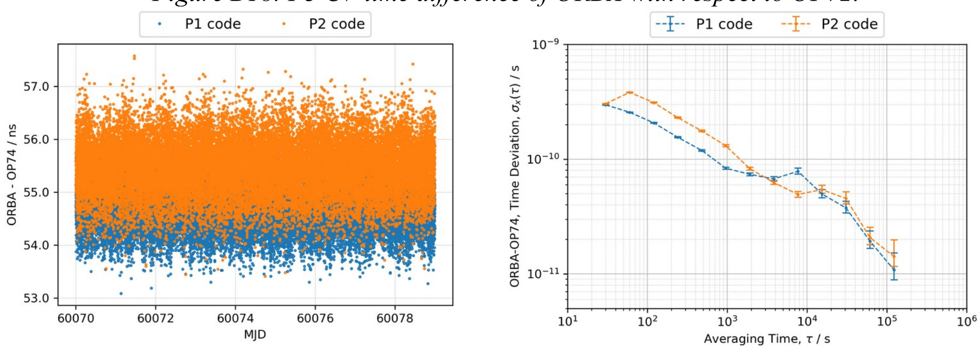
(a) P-code phase differences (b) TDEV of P-code delays

Figure B17: GPS relative calibration of ORBA with respect to OP72.



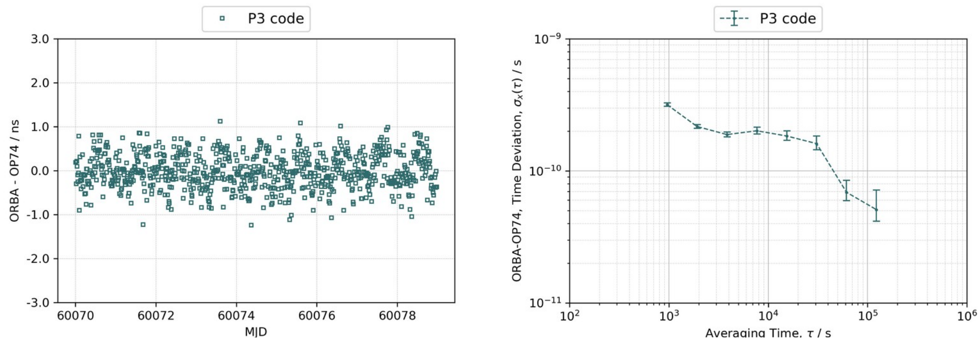
(a) P3 CV after calibration (b) TDEV of P3 CV

Figure B18: P3 CV time difference of ORBA with respect to OP72.



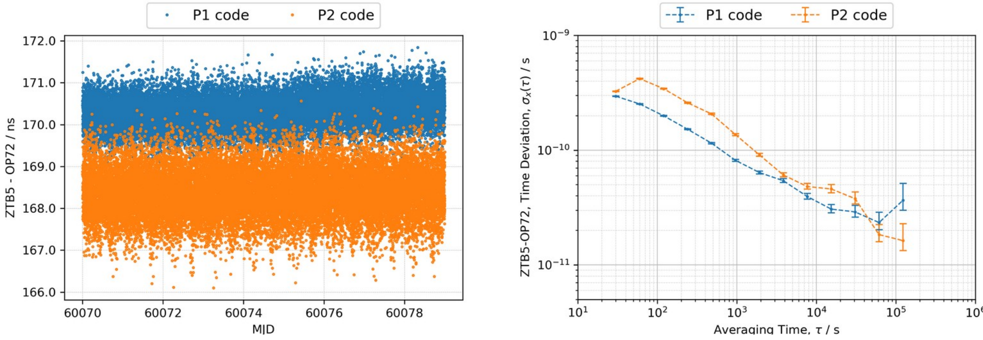
(a) P-code phase differences (b) TDEV of P-code delays

Figure B19: GPS relative calibration of ORBA with respect to OP74.



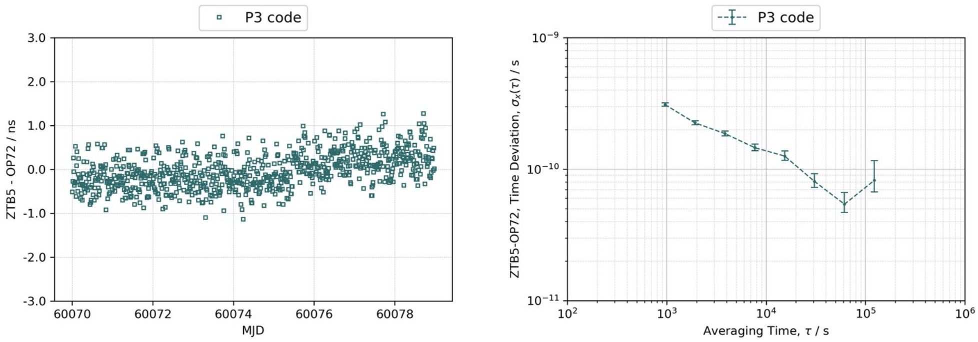
(a) P3 CV after calibration (b) TDEV of P3 CV

Figure B20: P3 CV time difference of ORBA with respect to OP74.



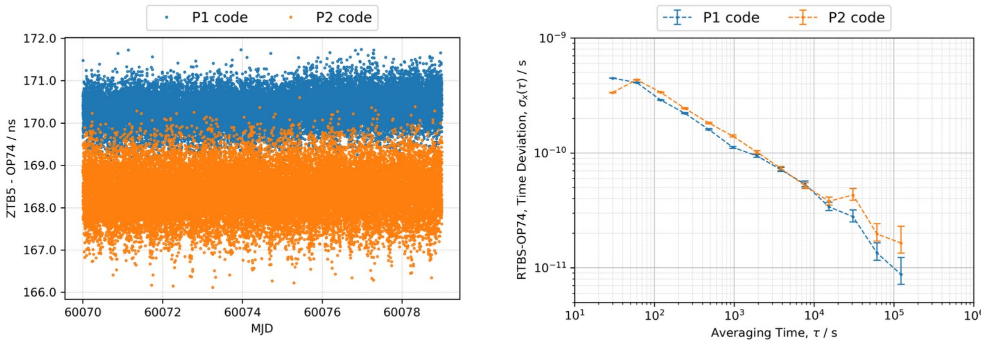
(a) P-code phase differences (b) TDEV of P-code delays

Figure B21: GPS relative calibration of ZTB5 with respect to OP72.



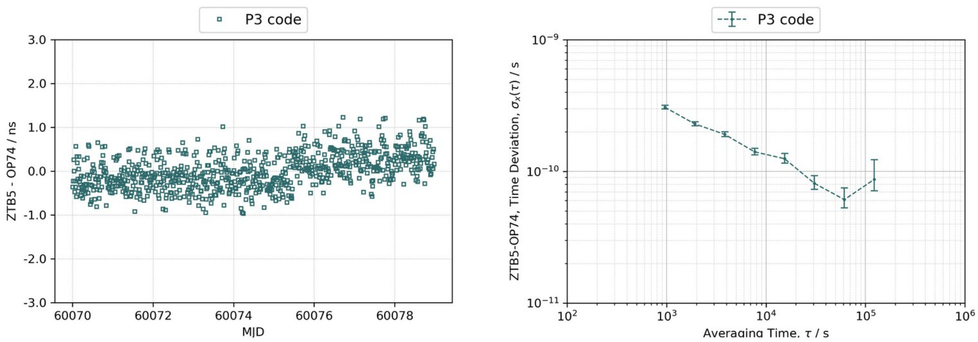
(a) P3 CV after calibration (b) TDEV of P3 CV

Figure B22: P3 CV time difference of ZTB5 with respect to OP72.



(a) P-code phase differences (b) TDEV of P-code delays

Figure B23: GPS relative calibration of ZTB5 with respect to OP74.



(a) P3 CV after calibration (b) TDEV of P3 CV

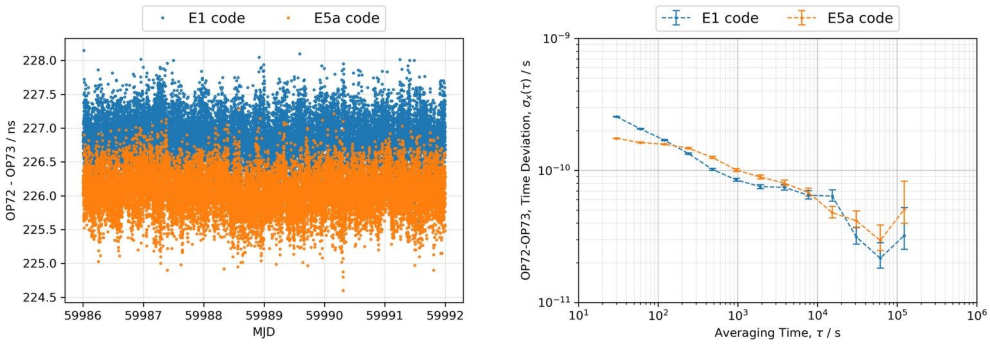
Figure B24: P3 CV time difference of ZTB5 with respect to OP74.

4. Galileo calibration of OP72 and OP74 with respect to OP73.

4.1. Results of raw data processing.

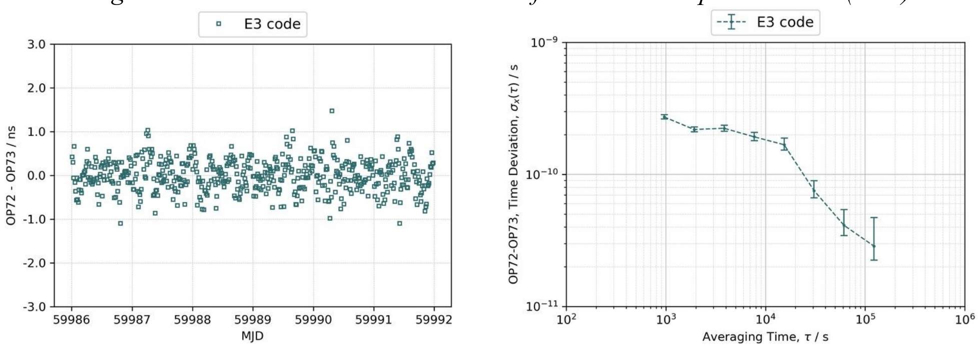
Pair	MJD of measurement	RawDiff E1	TDEV	RawDiff E5a	TDEV
OP72 – OP73	60052-60060	- 57.285	0.027	- 56.905	0.038
OP74 – OP73	60052-60060	- 40.057	0.029	- 39.588	0.039
OP72 – OP73	60126-60130	- 57.031	0.032	- 56.653	0.040
OP74 – OP73	60126-60130	- 39.832	0.033	- 39.386	0.040

4.2 Plots of raw data and TDEV.



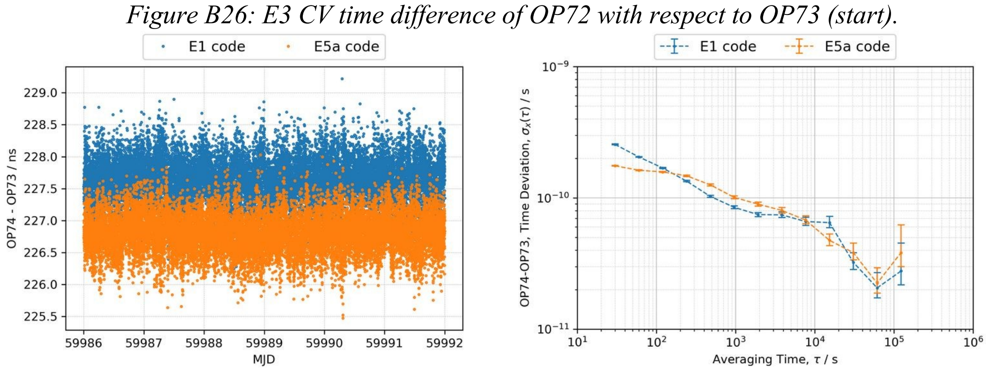
(a) E-code phase differences (b) TDEV of E-code delays

Figure B25: Galileo relative calibration of OP72 with respect to OP73 (start).



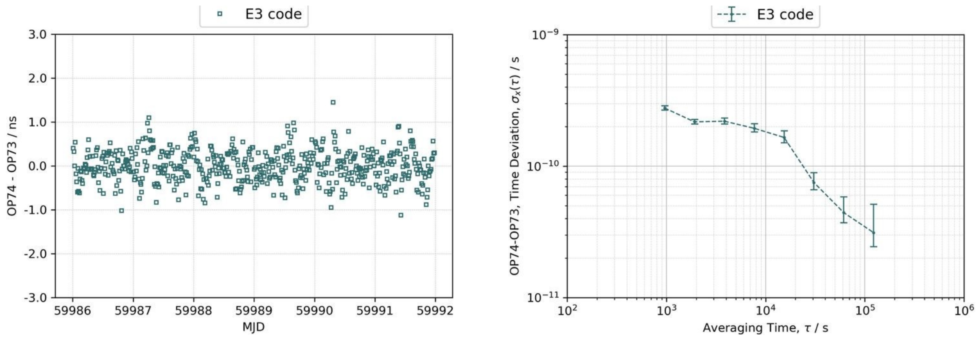
(a) E3 CV after calibration (b) TDEV of E3 CV

Figure B26: E3 CV time difference of OP72 with respect to OP73 (start).



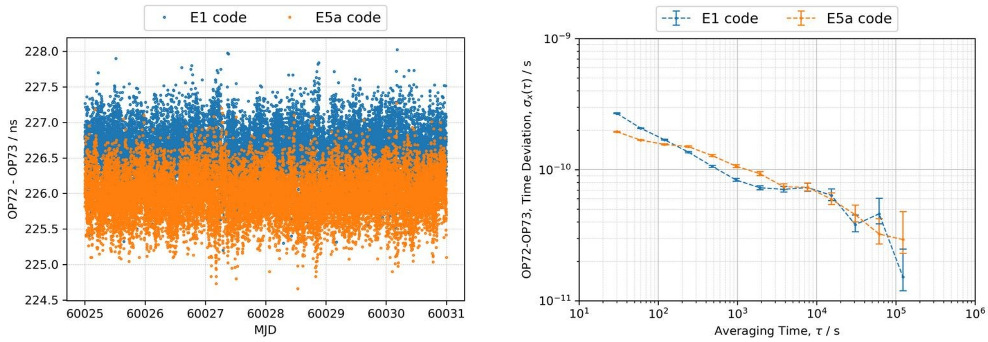
(a) E-code phase differences (b) TDEV of E-code delays

Figure B27: Galileo relative calibration of OP74 with respect to OP73 (start).



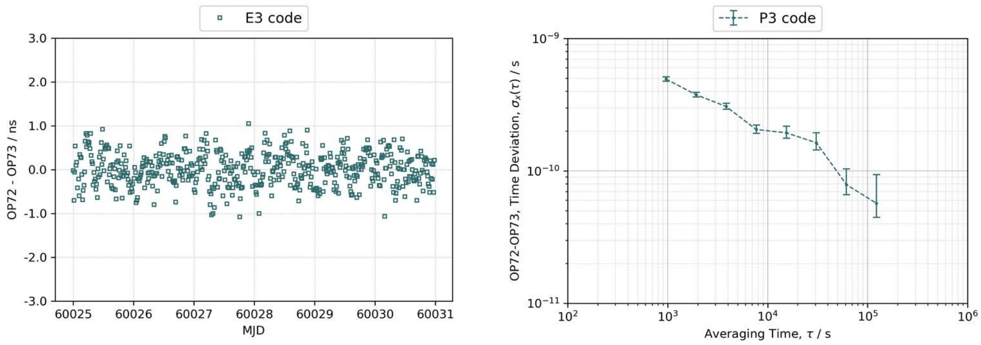
(a) E3 CV after calibration (b) TDEV of E3 CV

Figure B28: E3 CV time difference of OP74 with respect to OP73 (start).



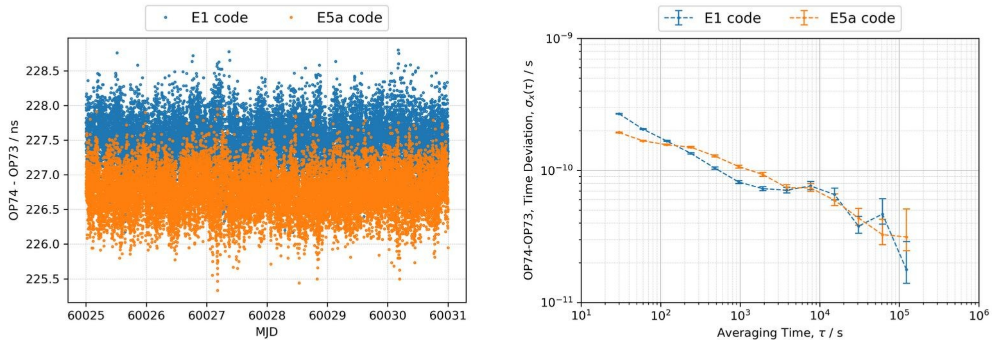
(a) E-code phase differences (b) TDEV of E-code delays

Figure B29: Galileo relative calibration of OP72 with respect to OP73 (closure).



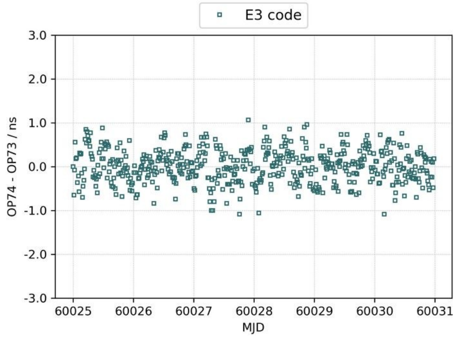
(a) E3 CV after calibration (b) TDEV of E3 CV

Figure B30: E3 CV time difference of OP72 with respect to OP73 (closure).

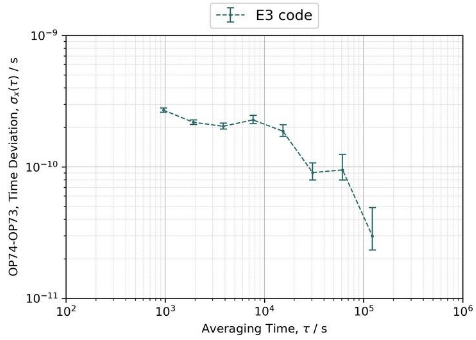


(a) E-code phase differences (b) TDEV of E-code delays

Figure B31: Galileo relative calibration of OP74 with respect to OP73 (closure).



(a) E3 CV after calibration



(b) TDEV of E3 CV

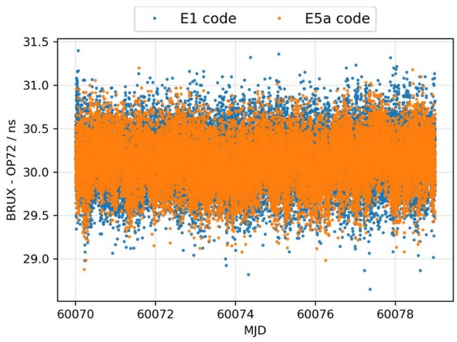
Figure B32: E3 CV time difference of OP74 with respect to OP73 (closure).

5. Galileo calibration of visited stations against OP72 and OP74.

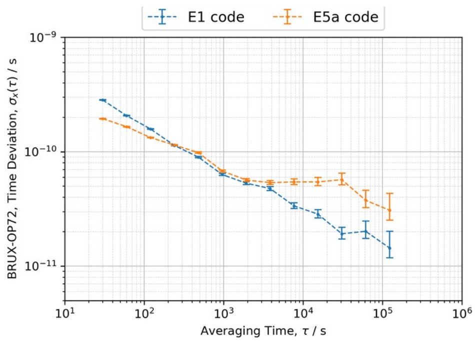
5.1.Results of raw data processing.

Pair	MJD of measurement	RawDiff E1	TDEV	RawDiff E5a	TDEV
OR5Z – OP72	60070-60078	- 25.872	0.023	- 26.628	0.045
OR5Z – OP74	60070-60078	- 43.122	0.023	- 43.949	0.044
OR20 – OP72	60070-60078	111.958	0.021	112.772	0.019
OR20 – OP74	60070-60078	94.708	0.021	95.450	0.020
OR4Z – OP72	60070-60078	126.946	0.027	116.278	0.031
OR4Z – OP74	60070-60078	109.696	0.027	98.956	0.031
ZTB5 – OP72	60070-60078	79.455	0.042	80.133	0.031
ZTB5 – OP74	60070-60078	62.206	0.041	62.812	0.031

5.2. Plots of raw data and TDEV.

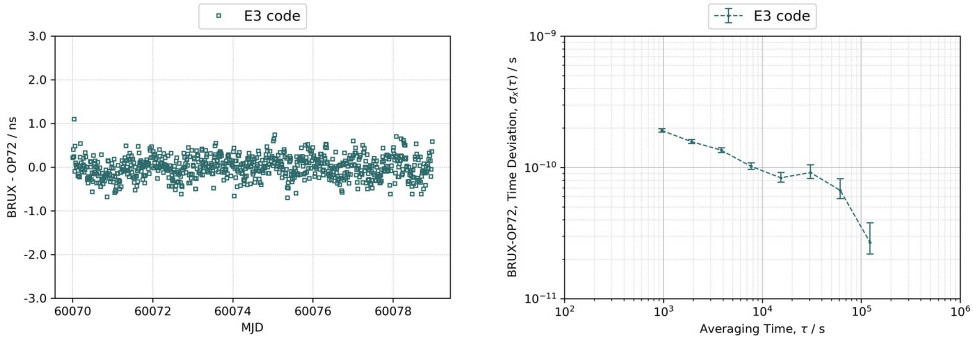


(a) E-code phase differences



(b) TDEV of E-code delays

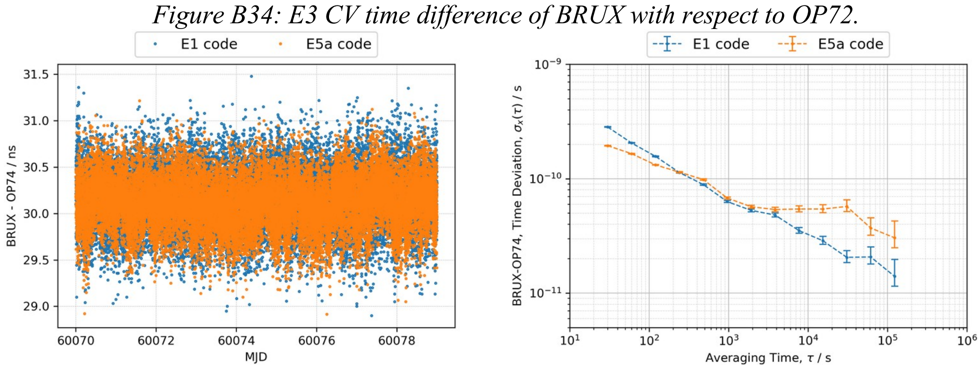
Figure B33: Galileo relative calibration of BRUX with respect to OP72.



(a) E3 CV after calibration

(b) TDEV of E3 CV

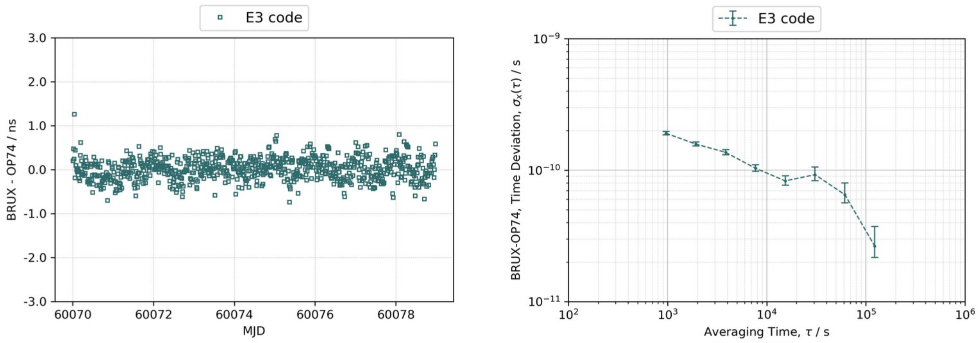
Figure B34: E3 CV time difference of BRUX with respect to OP72.



(a) E-code phase differences

(b) TDEV of E-code delays

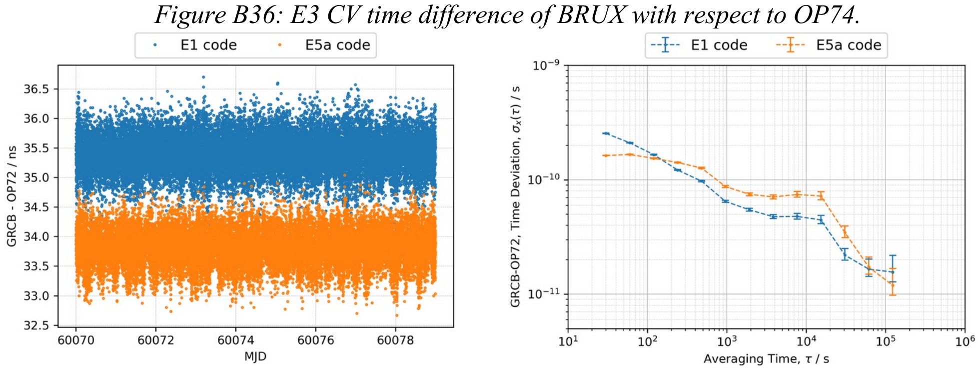
Figure B35: Galileo relative calibration of BRUX with respect to OP74.



(a) E3 CV after calibration

(b) TDEV of E3 CV

Figure B36: E3 CV time difference of BRUX with respect to OP74.

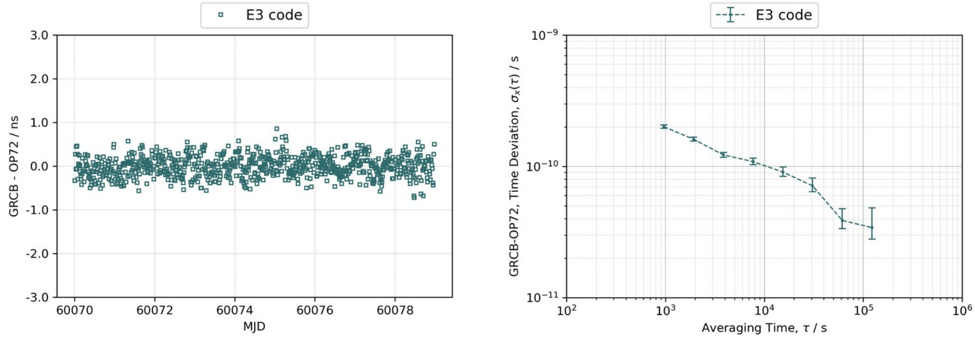


(a) E-code phase differences

(b) TDEV of E-code delays

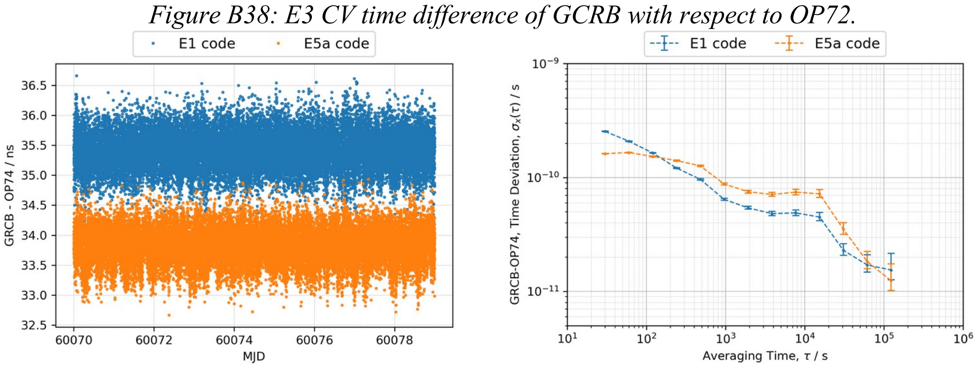
Figure B37: Galileo relative calibration of GCRB with respect to OP72.

B12



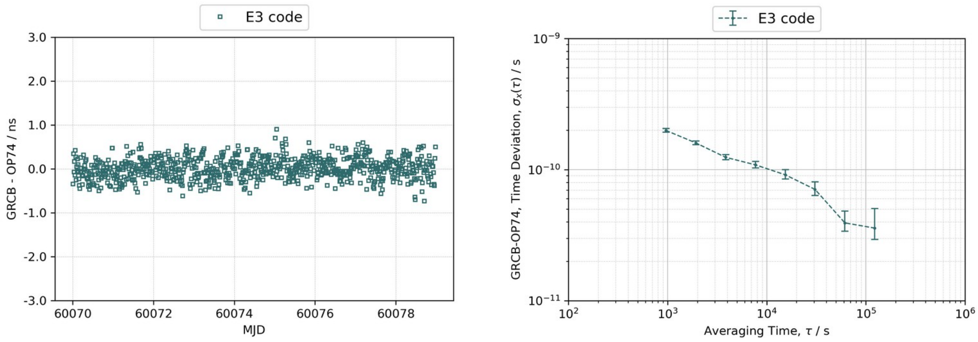
(a) E3 CV after calibration (b) TDEV of E3 CV

Figure B38: E3 CV time difference of GCRB with respect to OP72.



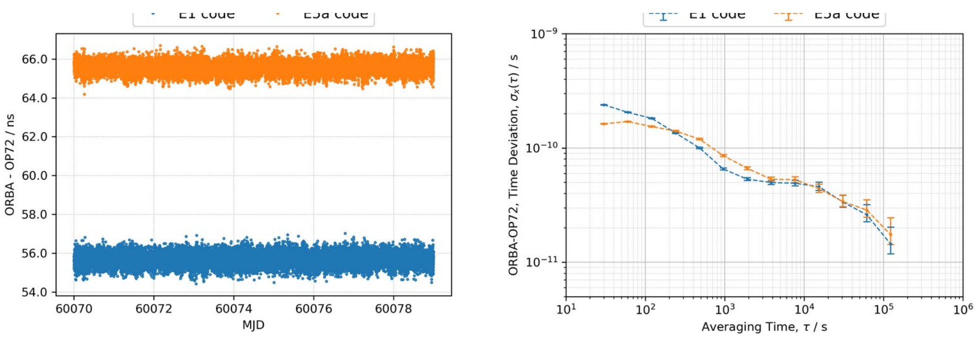
(a) E-code phase differences (b) TDEV of E-code delays

Figure B39: Galileo relative calibration of GCRB with respect to OP74.



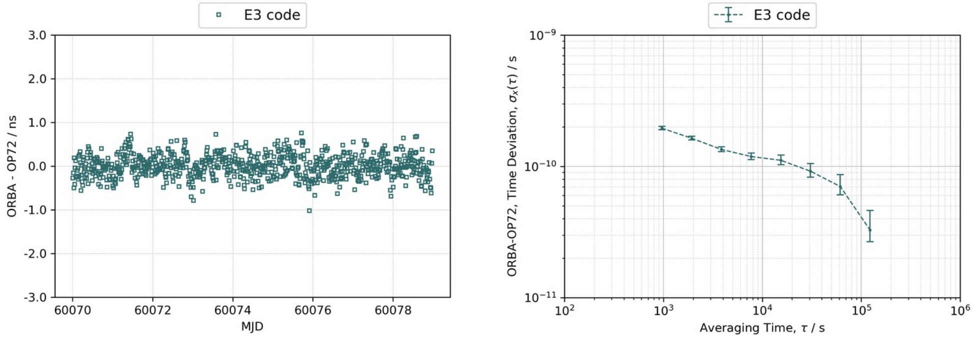
(a) E3 CV after calibration (b) TDEV of E3 CV

Figure B40: E3 CV time difference of GCRB with respect to OP74.



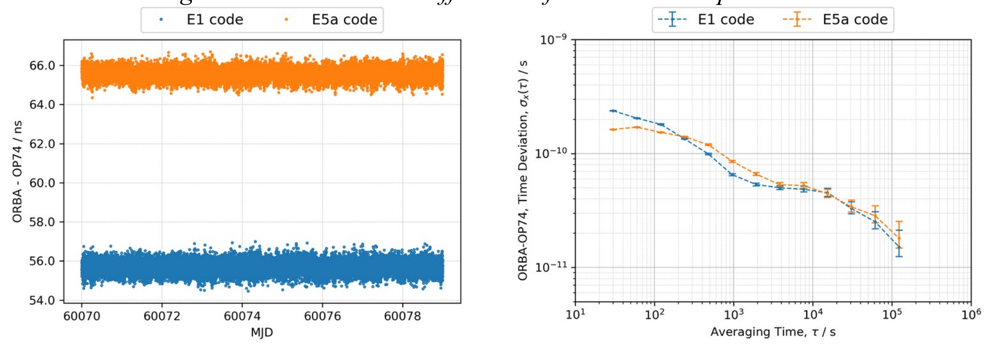
(a) E-code phase differences (b) TDEV of E-code delays

Figure B41: Galileo relative calibration of ORBA with respect to OP72.



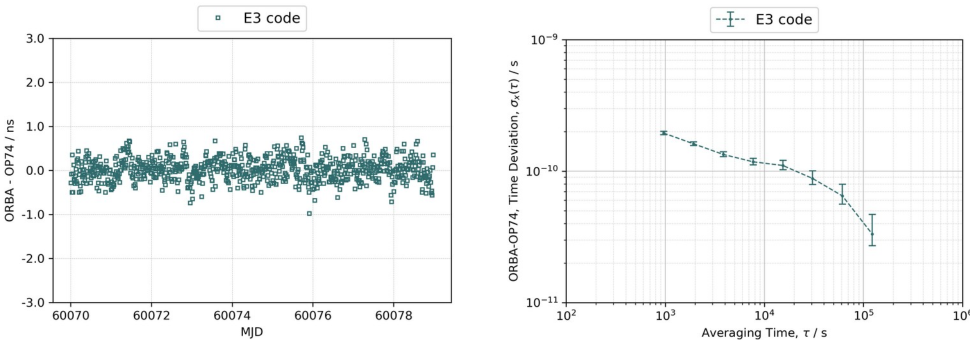
(a) E3 CV after calibration (b) TDEV of E3 CV

Figure B42: E3 CV time difference of ORBA with respect to OP72.



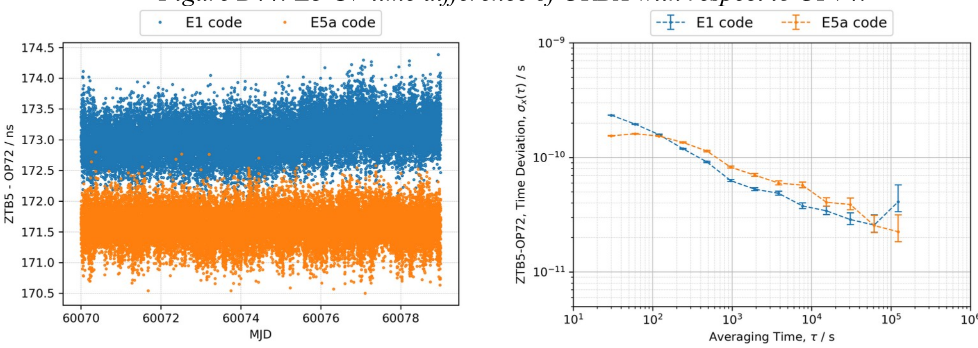
(a) E-code phase differences (b) TDEV of E-code delays

Figure B43: Galileo relative calibration of ORBA with respect to OP74.



(a) E3 CV after calibration (b) TDEV of E3 CV

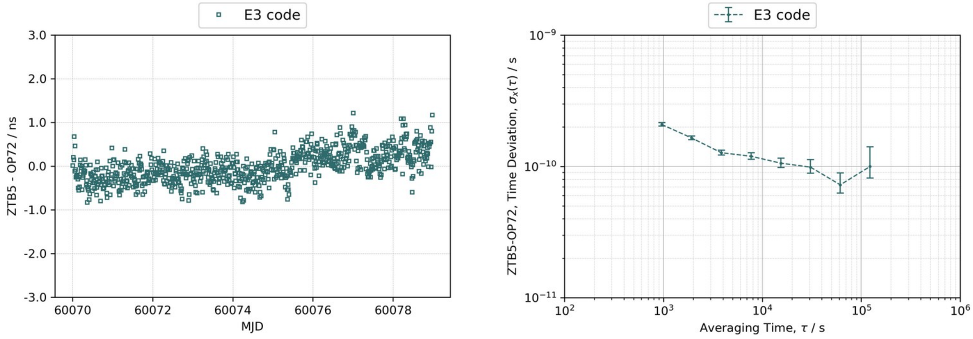
Figure B44: E3 CV time difference of ORBA with respect to OP74.



(a) E-code phase differences (b) TDEV of E-code delays

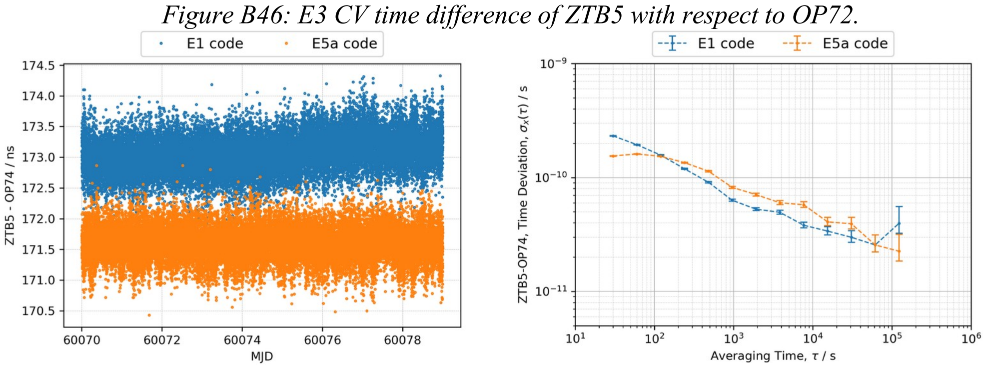
Figure B45: Galileo relative calibration of ZTB5 with respect to OP72.

B14



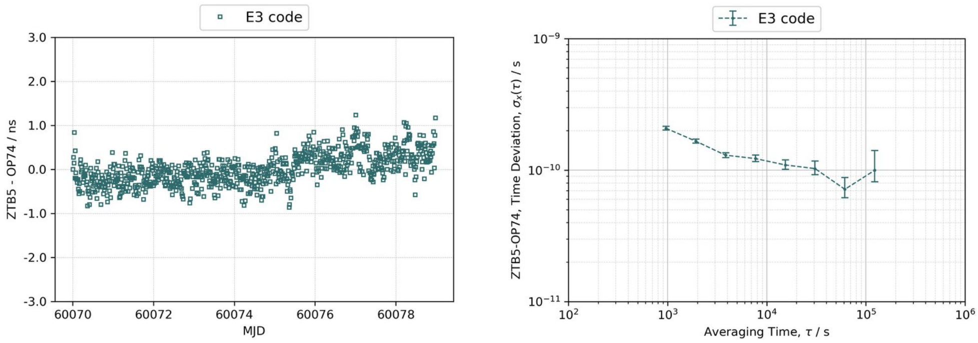
(a) E3 CV after calibration (b) TDEV of E3 CV

Figure B46: E3 CV time difference of ZTB5 with respect to OP72.



(a) E-code phase differences (b) TDEV of E-code delays

Figure B47: Galileo relative calibration of ZTB5 with respect to OP74.



(a) E3 CV after calibration (b) TDEV of E3 CV

Figure B48: E3 CV time difference of ZTB5 with respect to OP74.

ANNEX C

Uncertainty budget terms.

1. Type A uncertainty.

The statistical uncertainty u_a(A-B) for the comparison between two GNSS stations A and B and for each GNSS code is evaluated by computing the upper limit of the error bar of the TDEV at 1 d when possible, or otherwise the upper limit of the last error bar available. The sampling periods of computed calibrated offset usually lead to TDEV data available for 61 440 s and 122 880 s averaging periods. The computed u_a is obtained by a linear interpolation between consecutive TDEV data at an 86 400 s averaging period. When required, a simple quadratic sum leads to the Type A uncertainty required for an uncertainty budget computation.

2. Type B uncertainty.

Here are the u_b uncertainties taken into account in the uncertainty budget computations, together with the way they are estimated when necessary.

- $u_{b,1}$ observed maximum misclosure. This uncertainty component is an estimation of the stability of the traveling equipment during the campaign. The misclosure $u_{b,1}$ we used here is the actual misclosure between the start and the end of the campaign..
- $u_{b,11}$ position error at reference site. The position of the center of phase of traveling antenna is estimated at opening and closure by using the NRCan PPP software, while for the OP reference station antenna the coordinates of the last G1 calibration are used. Note that this computation is achieved by using GPS data only. This might lead to a small bias on the phase center of the antenna for Galileo signals. We safely choose a conventional value of 200 ps (≈ 6 cm) for the position error at the reference site.
- $u_{b,12}$ position error at visited site. At visited sites the position of the center of phase of all antennas is estimated by using the NRCan PPP software. Note that this computation is achieved by using GPS data only. This might lead to a small bias on the phase center of the antenna for Galileo signals. We safely choose a conventional value of 200 ps (≈ 6 cm) for the position error at all visited sites.
- $u_{b,13}$ multipath at reference site. We assume in all cases a conventional value of 200 ps, which is in line with some experiment achieved at OP and ORB, especially when using the calibration software developed at OP, where outliers are properly averaged out. (see: G.D. Rovera, M. Abgrall, P. Uhrich, P. Defraigne and B. Bertrand, "*GNSS antenna multipath effects*", Proc. of the 31st European Frequency and Time Forum (EFTF), Torino, 2018).
- $u_{b,14}$ multipath at visited site. Same as above.
- $u_{b,21}$ REFDLY (traveling receiver at reference lab). Uncertainty of the measure of the time difference between the reference point of the traveling receiver and the local UTC(k). The used value is the quadratic sum of an uncertainty value attributed to the Time Interval Counter (TIC) with the standard deviation of the actual measurement. When the REFDLY is obtained by summing several individual measurement the uncertainty is increased by quadratic sum as required. We use 220 ps as conservative conventional value.
- $u_{b,22}$ REFDLY (traveling receiver at visited lab). Same as above. This is possible because the TIC we are using for all REFDLY measurements is traveling along with the OP GNSS stations.

- $u_{b,TOT}$: Quadratic sum of all previous u_b.
- $u_{b,31}$ REFDLY uncertainty of the GNSS reference station to its local UTC(k). Computed similarly as $u_{b,21}$. This term can be set to 0 when the GNSS reference station has been recently calibrated, the uncertainty of REFDLY being already included in the conventional uncertainty decided by the CCTF WG on GNSS.
- $u_{b,32}$ REFDLY uncertainty (at visited lab) of the link of the visited station to its local UTC(k). Computed similarly as $u_{b,21}$. When this delay is measured and the $u_{b,32}$ is taken into account, the local distribution system can be modified afterwards without loosing the calibration of the local GNSS station, provided the new REFDLY is taken into account afterwards
- $u_{b,41}$ uncertainty of the antenna cable delay at reference station. The chosen value here is based on a comprehensive study which is available in reference [4].
- $u_{b,42}$ uncertainty of antenna cable delay at visited station. Same as just above. When for some reason the antenna cable of the traveling system is changed during the campaign, $u_{b,42}$ is typically obtained from the quadratic sum of the uncertainty of the antenna cable delay actually used at the visited station and the uncertainty of the antenna cable delay of the traveling equipment.
- $u_{b,SYS}$: Quadratic sum of all type B uncertainties above.

3. Combined uncertainty.

- u_{CAL0}: Quadratic sum of u_a and $u_{b,SYS}$. This uncertainty is for the link between the calibrated station and the reference station, without taking into account the uncertainty of this reference station.

Note finally that, in our computation, P3 uncertainty values are not based on a linear combination of P1 and P2 uncertainty values but estimated in a similar way as for P1 and P2. And this is also the case for E3 uncertainty values, which are computed in a similar way as E1 and E5a uncertainty values.

END OF DOCUMENT