2018 Group 1 GPS calibration trip

Summary

The 2018 visit to Group 1 laboratories is the third Group 1 trip and started in March 2018.
The trip is decomposed into several phases, each enclosed with closure at the BIPM. Some phases may be run in parallel.

- Phase 1 (March-September 2018). BIPM-TL-NICT-NIM-BIPM with the traveling receivers BP1C and BP0U;
- Phase 2 (April-October 2018): BIPM-SU-BIPM with the traveling receivers BP1K;
- Phase 3 (November 2018-February 2019): BIPM-PTB-ROA-OP-BIPM with the traveling receivers BP1C and BP1X;
- Phase 4 (March-September 2019): BIPM-USNO-NIST-BIPM with the traveling receivers BP1C and BP25;

Since the 2016 Group 1 trip, results are provided for the GPS codes P1, P2 and C1.
Starting with phase 3 of 1001-2018, results will also be provided for Galileo E1 and E5 codes, as defined in the CGGTTS V2E format (The notation E5 corresponds to E5a).
This report provides intermediate results which are determined with respect to one BIPM receiver.
Final results for all three GPS codes for all Group 1 receivers are determined in a separate document BIPM Technical Memorandum 266.

Trip 1001-2018: Report of phase 4

1. Description of equipment and operations

1.1 Traveling equipment

- Traveling systems:

Two systems are included in the BIPM traveling calibrator: BP1C and BP25, see Table 1 and the report of operations 1001-2018-phase4-cv.pdf .

The long term stability of the BIPM systems is described in the BIPM Technical Memorandum 204.

- Other traveling equipment:

See Annex 1 of the Guidelines.

1.2 Visited equipment

See a summary in Table 1. The detailed information on the set-up and the measurements performed is in the report of operations 1001-2018-phase4-cv.pdf.
The receiver BP1J from the BIPM serves as a reference for the closure, with the receiver BP21 included as a backup system.

Table 1. Summary information on phase 4 of the calibration trip 1001-2018

Institute	Status of equipment	Dates of measurement	BIPM code	RINEX name	Receiver type
BIPM	Traveling		BP1C	BP1C	Septentrio PolaRx3eTR
BIPM	Traveling		BP25	BP25	Mesit GTR55
BIPM	BIPM reference	58547-58552	BP1J	BP1J	Septentrio PolaRx4
BIPM	BIPM backup	58547-58552	BP21	BP21	Septentrio PolaRx5TR
USNO	G1 reference	58584-58595	USN6	USN6	NovAtel ProPak-V3
USNO	G1 backup	58584-58595	USN7	USN7	Septentrio PolaRx5TR
USNO	G1 backup	58584-58595	USN8	USN8	Septentrio PolaRx5TR
NIST	G1 reference	58699-58705	NIST	NIST	Novatel
NIST	G1 backup	58699-58705	NISG	NISG	Septentrio PolaRx5TR
NIST	G1 backup	58699-58705	NIS4	NIS4	Novatel
NIST	G1 backup	58699-58705	NISS	NISS	Septentrio PolaRx3TR
BIPM	BIPM reference	58742-58744	BP1J	BP1J	Septentrio PolaRx4
BIPM	BIPM backup	58742-58744	BP21	BP21	Septentrio PolaRx5TR

2. Data used

Rinex files have been obtained from all receivers participating to this trip.

3. Results of raw data processing

- The raw code differences have been generated by the DCLRINEX procedure (see Guidelines Annex 3). Each run for a pair of stations generates 3 files (summary .sum, data .dif, plot .pdf). Summary files and plots are available in 1001-2018-phase4-cv.pdf. All P1/P2 measurements are indicated with 2 digits numeric precision in order to minimize rounding errors in computing P3 values.

- For each pair (traveling – visited) or (traveling – reference):
  - Plots of the data differences and of the statistical analysis (Tdev) are in the report of operations 1001-2018-phase4-cv.pdf;
  - The inferred RAWDIF(P1), RAWDIF(P2) and RAWDIF(C1) are taken as the median of the raw differences. The associated uncertainties are taken as the floor of the Tdev values, with a minimum of 0.1 ns.

- Summary tables.

For this report, the BIPM system BP1J is considered to be the reference. However another system (BP21) is used as a backup and is listed in Table 2.1.

Table 2.1 Raw differential results for all pairs (Traveling – Reference) (ns) for three reference receivers at the BIPM. Measurements for the local backup BP0R are also included.

Labo	Date	Pair	RDIF(P1)	Unc	RDIF(P2)	Unc	RDIF(C1)	Unc	RDIF(E1)	Unc	RDIF(E5)	Unc
BIPM	58547-58552	BP1C-BP1J	45.37	0.1	51.31	0.1	45.91	0.1				
BIPM	58742-58748	BP1C-BP1J	32.09	0.1	38.05	0.1	32.63	0.1				
BIPM	58547-58552	BP25-BP1J	138.23	0.1	142.74	0.1	137.68	0.1	137.92	0.1	134.36	0.1
BIPM												
BIPM	58554-58566	BP21-BP1J	68.11	0.1	67.55	0.1	68.99	0.1	69.64	0.1	60.03	0.1
BIPM	58742-58744	BP21-BP1J	88.17	0.1	87.40	0.1	88.98	0.1	89.62	0.1	79.85	0.1

Table 2.2 Raw differential results for all pairs (Traveling – Visited) (ns)

Labo	Date	Pair	RDIF(P1)	Unc	RDIF(P2)	Unc	RDIF(C1)	Unc	RDIF(E1)	Unc	RDIF(E5)	Unc
USNO	58584-58595	BP1C-USN6	-1.17	0.1	6.94	0.1	0.27	0.1				
USNO	58584-58595	BP25-USN6	112.17	0.1	119.31	0.2	112.77	0.1				
USNO	58584-58595	BP1C-USN7	-213.45	0.1	-203.97	0.1	-213.82	0.1				
USNO	58584-58595	BP25-USN7	-99.85	0.1	-91.59	0.2	-101.31	0.1	-101.67	0.1	-97.12	0.1
USNO	58584-58595	BP1C-USN8	-208.12	0.1	-199.60	0.1	-208.52	0.1				
USNO	58584-58595	BP25-USN8	-94.51	0.1	-87.22	0.2	-96.01	0.1	-96.39	0.1	-91.98	0.1
NIST	58699-58705	BP1C-NIST	-434.74	0.1	-430.29	0.1	-433.40	0.1				
NIST	58699-58705	BP25-NIST	-325.88	0.1	-322.61	0.1	-325.42	0.1				
NIST	58699-58705	BP1C-NISG	-60.60	0.1	-53.42	0.1	-61.25	0.1				
NIST	58699-58705	BP25-NISG	48.22	0.1	54.23	0.1	46.62	0.1	46.30	0.1	52.06	0.1
NIST	58699-58705	BP1C-NIS4	-457.09	0.1	-440.02	0.1	-455.60	0.1				
NIST	58699-58705	BP25-NIS4	-348.37	0.1	-332.34	0.2	-347.71	0.1				
NIST	58699-58705	BP1C-NISS	-342.22	0.1	-337.16	0.1	-342.20	0.1				
NIST	58699-58705	BP25-NISS	-233.42	0.1	-229.49	0.1	-234.32	0.1				

4. Calibration results

In the first step, one computes **ΔSYSDLY,** the differences of SYSDLY for all pairs (Traveling-Reference) and (Traveling-Visited), from

$$\Delta SYSDLY_{A\text{-}B}(Code) = RAWDIF_{A\text{-}B}(Code) + REFDLY_A - REFDLY_B \quad (1)$$

where RAWDIF(Code) is read in Table 2 and where the values REFDLY are in the report of operations 1001-2018-phase4-cv.pdf.

The **ΔSYSDLY** values are reported in Table 3 for the pairs Traveling-Reference (section 4.1) and in Table 4 for the pairs Traveling-Visited (section 4.2).

In the second step one computes **ΔSYSDLY** (Visited-Reference) for all visited systems.

$$\Delta SYSDLY_{V\text{-}R} = \Delta SYSDLY_{T\text{-}R} - \Delta SYSDLY_{T\text{-}V.} \quad (2)$$

One can then compute **ΔINTDLY** (Visited-Reference) for all visited systems.

$$\Delta INTDLY_{V\text{-}R} = \Delta SYSDLY_{V\text{-}R} - CABDLY_V + CABDLY_R \quad (3)$$

where the values CABDLY are taken from the report of operations 1001-2018-phase4-cv.pdf;
Tables 5 reports the $\mathbf{\Delta INTDLY_{V\text{-}R}}$ results for the pairs Visited-Reference (section 4.3).
Using assumed $\mathbf{INTDLY_R}$ values for the Reference system, Table 6 then reports $\mathbf{INTDLY_V}$ for all visited systems (section 4.4).

4.1 Traveling system with respect to the reference system

Table 3.1. Computed **ΔSYSDLY** values for the traveling systems with respect to BP1J used as a reference. The misclosures are also indicated. (all values in ns)

Pair	Date	$REFDLY_T$	$REFDLY_R$	Note	P1 (ns)		P2 (ns)		C1 (ns)		E1 (ns)		E5 (ns)	
					RAWDIF	**ΔSYSDLY**	RAWDIF	**ΔSYSDLY**	RAWDIF	**ΔSYSDLY**	RAWDIF	**ΔSYSDLY**	RAWDIF	**ΔSYSDLY**
BP1C-BP1J	58547-58552	237.9	181.7		45.37	101.57	51.31	107.51	45.91	102.11				
BP1C-BP1J	58742-58748	261.3	191.6		32.09	101.81	38.05	107.77	32.63	102.35				
		Misclos.				0.24		0.26		0.24				
BP1C-BP1J		Mean				101.69		107.64		102.23				
BP25-BP1J	58547-58552	52.6	181.7		138.23	9.12	142.74	13.63	137.68	8.57	137.92	8.81	134.36	5.25
		Misclos.												
BP25-BP1J		Mean												

Results for the traveling systems are reported in Table 3.1. Note that the traveling receiver BP25 was not functioning when returning to the BIPM so that no closure could be computed. See section 4.4 for the consequence on the calibration results.

Results for the local backup BP21 vs. BP1J are shown in Table 3.2. The misclosure for this pair is an indicator of the relative instabilities of the two stationary receivers.

Table 3.2. Computed **ΔSYSDLY** values for the local backup BP21 with respect to BP1J used as a reference. All values in ns

Pair	Date	$REFDLY_T$	$REFDLY_R$	Note	P1 (ns)		P2 (ns)		C1 (ns)		E1 (ns)		E5 (ns)	
					RAWDIF	**ΔSYSDLY**	RAWDIF	**ΔSYSDLY**	RAWDIF	**ΔSYSDLY**	RAWDIF	**ΔSYSDLY**	RAWDIF	**ΔSYSDLY**
BP21-BP1J	58554-58566	100.9	181.6		68.11	-12.58	67.55	-13.14	68.99	-11.70	69.64	-11.05	60.03	-20.66
BP21-BP1J	58742-58744	91.0	191.6		88.17	-12.40	87.40	-13.17	88.98	-11.59	89.62	-10.95	79.85	-20.72
		Misclos.				0.18		0.03		0.11		0.10		0.06
BP0R-BP1J		Mean				-12.49		-13.16		-11.65		-11.00		-20.69

4.2 Traveling system with respect to the visited systems

Table 4. Traveling vs. Visited systems (all values in ns)

Pair	Date	$REFDLY_T$	$REFDLY_V$	Note	P1 (ns)		P2 (ns)		C1 (ns)		E1 (ns)		E5 (ns)	
					RAWDIF	**ΔSYSDLY**	RAWDIF	**ΔSYSDLY**	RAWDIF	**ΔSYSDLY**	RAWDIF	**ΔSYSDLY**	RAWDIF	**ΔSYSDLY**
BP1C-USN6	58584-58595	292.0	N/A	(1)	-1.17	290.83	6.94	298.94	0.27	292.27				
BP25-USN6	58584-58595	85.9	N/A	(1)	112.17	198.07	119.31	205.21	112.77	198.67				
BP1C-USN7	58584-58595	292.0	N/A	(1)	-213.45	78.55	-203.97	88.03	-213.82	78.18				
BP25-USN7	58584-58595	85.9	N/A	(1)	-99.85	-13.95	-91.59	-5.69	-101.31	-15.41	-101.67	-15.77	-97.12	-11.22
BP1C-USN8	58584-58595	292.0	N/A	(1)	-208.12	83.88	-199.60	92.40	-208.52	83.48				
BP25-USN8	58584-58595	85.9	N/A	(1)	-94.51	-8.61	-87.22	-1.32	-96.01	-10.11	-96.39	-10.49	-91.98	-6.08
BP1C-NIST	58699-58705	581.6	65.9		-434.74	80.96	-430.29	85.41	-433.40	82.30				
BP25-NIST	58699-58705	380.4	65.9		-325.88	-11.38	-322.61	-8.11	-325.42	-10.92				
BP1C-NISG	58699-58705	581.6	452.9		-60.60	68.10	-53.42	75.28	-61.25	67.45				
BP25-NISG	58699-58705	380.4	452.9		48.22	-24.28	54.23	-18.27	46.62	-25.88	46.30	-26.20	52.06	-20.44
BP1C-NIS4	58699-58705	581.6	129.4		-457.09	-4.89	-440.02	12.18	-455.60	-3.40				
BP25-NIS4	58699-58705	380.4	129.4		-348.37	-97.37	-332.34	-81.34	-347.71	-96.71				
BP1C-NISS	58699-58705	581.6	301.0		-342.22	-61.62	-337.16	-56.56	-342.20	-61.60				
BP25-NISS	58699-58705	380.4	301.0		-233.42	-154.02	-229.49	-150.09	-234.32	-154.92				

(1) **$REFDLY_V$** value not available.

4.3 Visited systems with respect to reference system

The Table 5 provides the values obtained by differencing Table 3.1 (BP1J reference) and Table 4. CABDLY values are taken from the report of operations 1001-2018-phase4-cv.pdf and have not been measured during this calibration.

Table 5. Visited vs. BP1J Reference (all values in ns)

Pair	Date	$CABDLY_V$	$CABDLY_R$	Note	P1 (ns)		P2 (ns)		C1 (ns)	
					ΔSYSDLY	ΔINTDLY	ΔSYSDLY	ΔINTDLY	ΔSYSDLY	ΔINTDLY
USN6-BP1J via BP1C	2019.3	N/A	128.7	(1)	-189.15	-60.45	-191.30	-62.60	-190.04	-61.34
USN6-BP1J via BP25	2019.3	N/A	128.7	(1)	-188.95	-60.25	-191.58	-62.88	-190.10	-61.40
USN7-BP1J via BP1C	2019.3	N/A	128.7	(1)	23.14	151.84	19.62	148.32	24.05	152.75
USN7-BP1J via BP25	2019.3	N/A	128.7	(1)	23.07	151.77	19.32	148.02	23.98	152.68
USN8-BP1J via BP1C	2019.3	N/A	128.7	(1)	17.81	146.51	15.25	143.95	18.75	147.45
USN8-BP1J via BP25	2019.3	N/A	128.7	(1)	17.73	146.43	14.95	143.65	18.68	147.38
NIST-BP1J via BP1C	2019.6	275.5	128.7		20.73	-126.08	22.24	-124.57	19.93	-126.87
NIST-BP1J via BP25	2019.6	275.5	128.7		20.50	-126.30	21.74	-125.06	19.49	-127.31
NISG-BP1J via BP1C	2019.6	185.0	128.7		33.59	-22.72	32.36	-23.94	34.78	-21.52
NISG-BP1J via BP25	2019.6	185.0	128.7		33.40	-22.90	31.90	-24.40	34.45	-21.85
NIS4-BP1J via BP1C	2019.6	298.0	128.7		106.58	-62.73	95.47	-73.84	105.63	-63.67
NIS4-BP1J via BP25	2019.6	298.0	128.7		106.49	-62.81	94.97	-74.33	105.28	-64.02
NISS-BP1J via BP1C	2019.6	298.9	128.7		163.31	-6.90	164.21	-5.99	163.83	-6.37
NISS-BP1J via BP25	2019.6	298.9	128.7		163.14	-7.06	163.72	-6.48	163.49	-6.71
BP21-BP1J	2019.2	141.6	128.7		-12.49	-25.39	-13.16	-26.06	-11.65	-24.55

(1) **$CABDLY_V$** value not available.

4.4 Provisional INTDLY values of visited systems

Table 6 lists provisional INTDLY values of the visited systems based on INTDLY reference values for BP1J determined from phase 1, which are the same as the final 1001-2016 values (P1=53.0 ns; P2=52.6 ns; C1=54.4 ns), as described in BIPM Technical Memorandum 266. Results for the Galileo codes will be included when a reference value has been determined in the CCTF WG on GNSS.

Final INTDLY values will be based on minimizing changes between 1001-2016 and 1001-2018, as described in BIPM Technical Memorandum 266, and will be reported in the global report of the trip 1001-2018 available here. Since two results can be computed from Table 5, using either BP1C or BP25 as traveling system, the values in Table 6 are based on the two results, and the difference between the two is indicated. However since the closure of BP25 could not be realized, the mean value was computed with a weight of 2/3 for BP1C and 1/3 for BP25.

We note that the difference Δ(BP1C-BP25) is typically of order 0.3 ns. It is taken into account in component $u_{b,1}$ of the uncertainty budget in Table 7.

Table 6. Provisional INTDLY values of Visited systems using 1001-2018 reference values for the reference systems BP1J (all values in ns).

Pair	Date	Note	P1	P2	C1
			$INTDLY_V$	**$INTDLY_V$**	**$INTDLY_V$**
USN6 vs. BP1J	2019.3	(1)	-7.38	-10.09	-6.96
Δ(BP1C-BP25)	2019.3		-0.19	0.29	0.06
USN7 vs. BP1J	2019.3	(1)	204.81	200.82	207.13
Δ(BP1C-BP25)	2019.3		0.06	0.30	0.07
USN8 vs. BP1J	2019.3	(1)	199.48	196.45	201.83
Δ(BP1C-BP25)	2019.3		0.08	0.30	0.07
NIST vs. BP1J	2019.6		-73.15	-72.13	-72.62
Δ(BP1C-BP25)	2019.6		0.22	0.49	0.44
NISG vs. BP1J	2019.6		30.22	28.51	32.77
Δ(BP1C-BP25)	2019.6		0.19	0.46	0.33
NIS4 vs. BP1J	2019.6		-9.75	-21.40	-9.39
Δ(BP1C-BP25)	2019.6		0.08	0.49	0.35
NISS vs. BP1J	2019.6		46.05	46.44	47.92
Δ(BP1C-BP25)	2019.6		0.16	0.48	0.34
BP21 vs. BP1J	2019.5		27.61	26.55	29.86

(1) Results are Total Delay values (TOTDLY)

5 Uncertainty estimation

In this section, we determine the uncertainty of the differential calibration process i.e. we estimate all components that can affect the accuracy. We determine a value U_{CAL0} that is to be used as the accuracy of all P3/PPP links (Visited – Reference) at the epoch of calibration.

$$u_{CAL0} = \sqrt{u_a^2 + u_b^2}$$

with the statistical uncertainty u_a and the systematic uncertainty u_b. (all are 1-sigma).
The statistical uncertainty u_a originates from RAWDIF (see section 3) and is given by the statistical analysis of the raw code differences for (Traveling-Reference) and (Traveling-Visited).

The systematic uncertainty is given by $u_B = \sqrt{\sum_n u_{b,n}^2}$

where all possible terms to be considered in the sum are listed in Table 7 and some detail on their estimation is provided at the end of this section. Values appear separately for each code and for the difference of the two codes (P1, P2 and P1-P2) so as to compute a value u_{CAL} applicable to P3 links. We choose to compute U_{CAL} using for u_b the uncertainty u_{bSYS} of $\Delta SYSDLY_{V-R}$ from equation (2)[1] Table 7 presents all components of the uncertainty budget along with the uncertainty u_{bSYS} of $\Delta SYSDLY_{V-R}$ from equation (2) and the resulting uncertainty value U_{CAL}.

The value u_{CAL} =1.5 ns from Table 7 is applicable to P3/PPP links. The value u_{CAL} =1.2 ns is applicable to C1 links. Final values of u_{CAL} are consistent with the conventional value of 1.5 ns for P3/PPP links between G1 laboratories, as used in UTC computation.

Table 7. Uncertainty contributions. For all components of u_b, the P3 values are computed as P1 + 1.545x(P1-P2)

Unc.	Value C1/P1 (ns)	Value P2 (ns)	Value P1-P2 (ns)	Value P3 (ns)	Description
u_a (T-V)	0.1	0.1			RAWDIF (traveling-visited)
u_a (T-R)	0.1	0.1			RAWDIF (traveling-reference)
u_a	0.15	0.15		0.4	See text below
"Misclosure"					
$u_{b,1}$	0.5	0.5	0.5		observed mis-closure
Systematic components related to RAWDIF					
$u_{b,11}$	0.05	0.05	0.05		Position error at reference
$u_{b,12}$	0.05	0.05	0.05		Position error at visited
$u_{b,13}$	0.2	0.2	0.3		Multipaths at reference
$u_{b,14}$	0.2	0.2	0.3		Multipaths at visited
Link of the Traveling system to the local UTC(k)					
$u_{b,21}$	0.5	0.5	0		$REFDLY_T$ (at ref lab)
$u_{b,22}$	0.5	0.5	0		$REFDLY_T$ (at visited lab)
$u_{b,TOT}$	0.9	0.9	0.6	1.3	
Link of the Reference system to its local UTC(k)					
$u_{b,31}$	0.5	0.5	0		$REFDLY_R$ (at ref lab)
Link of the Visited system to its local UTC(k)					
$u_{b,32}$	0.5	0.5	0		$REFDLY_V$ (at visited lab)
$u_{b,SYS}$	1.2	1.2	0.6	1.5	Components of equation (2)
u_{CAL}	1.2			1.5	Composed of u_a and $u_{b,SYS}$

[1] It is somewhat arbitrary to choose SYSDLY to estimate the link accuracy. This reflects the fact that the REFDLY is subject to change e.g. with change of reference clock or distribution and that its uncertainty should better be taken into account.

The components in Table 7 are separated in several categories:

- The u_a value for P3 is conservatively estimated from the linear combination of P1 and P2 values. Lower values would be obtained from a statistical analysis of P3 RAWDIF.
- $u_{b,1}$ accounts for possible variations of the delays of the traveling systems during the trip. This is evaluated on the one hand by the observed misclosure (~ 0.2 ns average for each code, see Table 3.1), on the other hand by the observed discrepancies between the results of the two traveling receivers (up to 0.5 ns for each code, see Table 6). **Because the misclosure could not be computed for BP25, the largest value (0.5 ns) is chosen.**
- $u_{b,11}$ and $u_{b,12}$ account for errors in the differential position (Travel – Local). In general they are estimated to be 1.5 cm (50 ps) because the standard uncertainty of the differential positioning obtained with the data used for calibration is typically at or below this level.
- $u_{b,13}$ and $u_{b,14}$ account for multipaths. This is difficult to estimate and 0.2 ns is conventionally used, following a discussion in the CCTF working group on GNSS in 2017.
- $u_{b,21}$ and $u_{b,22}$ account for the measurement between the reference point of the traveling system and the local UTC(k). They include at least one measurement with a TIC and are taken to be 0.5 ns. Note that lower uncertainties are reported by the participating laboratories: 0.1 ns at USNO, XXXX at NIST.
- $u_{b,31}$ and $u_{b,32}$ account similarly for the measurement between the reference point of the local system and the local UTC(k). They include at least one measurement with a TIC and are taken to be 0.5 ns. Note that lower uncertainties are reported by the participating laboratories: 0.1 ns at USNO, about 0.2 ns at NIST.

Version history
V1.0 2019/10/21: Draft report of phase 4.