GNSS Timing monitoring with calibrated receivers at ESA: an update

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Intro

Facilities, tools and capabilities available at ESA/ESTEC for

- Multi-GNSS (absolute) calibration
- Multi-GNSS timing monitoring

where presented in WG-D Meeting at last ICG (ICG-16, Oct 2022)

This presentation provides an update of these capabilities, associated results and recommendations.

Recap: why is it required and useful?

(multi-)GNSS calibration is required for

- System level: Generation of System Time Offsets (GGTOs), UTC-GNSST parameters …etc…
- User level: GNSS-Time transfer and dissemination at the few ns level, traceability…

Multi-GNSS Timing Monitoring is required for

- Consistency check/assessment of system timing performance (GGTO, UTC, DCB…)
- Estimation of inter-system biases for e.g. interoperability

multi-GNSS calibration: what is the status today?

Time metrology community (BIPM/CCTF) has established*:

- GPS P1/P2 (2000) and GAL E1/E5a (2020) initial references, based on absolute calibration approach
- Procedure for the transfer of references based on relative calibration approach
- Calibration values and associated uncertainties are published on the BIPM server
- Other GNSS references (e.g. GAL E5b and E6, GLO, BDS,...) not officially available

GNSS Operators:

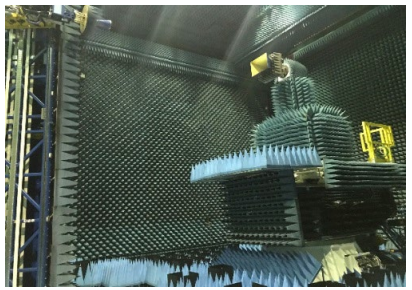
- Need to guarantee correctness and consistency of timing delays in their infrastructure
- Usually publish minimum system-level performance, but not how internal delays are estimated
- Need calibration values beyond the limited set established by the Time metrology community

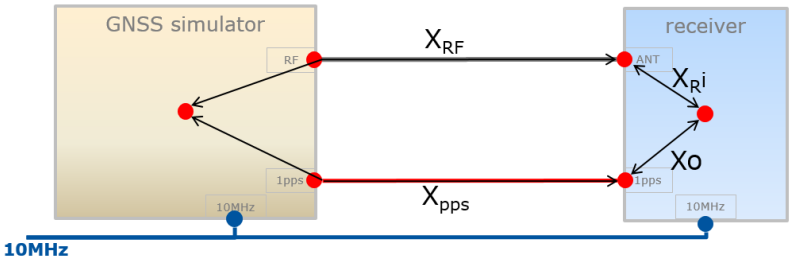
* G.Petit, P.Defraigne, “Calibration of GNSS station for UTC”, Metrologia 60 (2023)

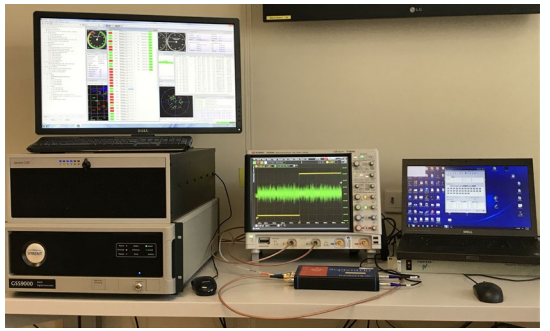
Absolute GNSS calibration at ESA/ESTEC

Based on consistent measurement/processing of absolute delay measurement:

- Antenna: Group-Delay measurement in anechoic chamber
- Antenna Cable: Vector Network Analyser
- Receiver: GNSS Simulator





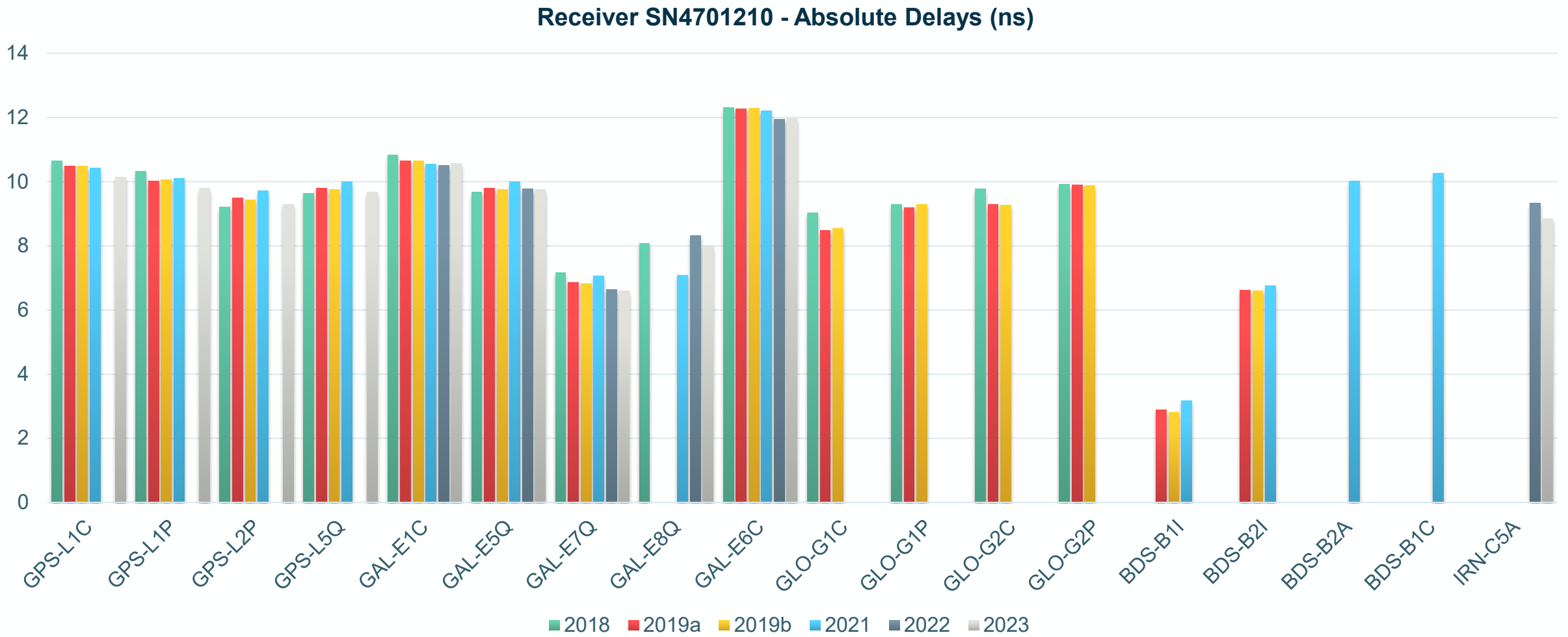


Constellation/Signals covered:
GPS: L1C/A, L1P, L2P, L5
GAL: E1, E6, E5a, E5b, E5
GLO: L1C, L2C, L1P, L2P
BDS2: B2i, B3I, B1i
BDS3: B2a, B2b, B3I, B1C
NavIC: L5

Uncertainty	Type	Description	Value (ps)
Sim_noise	A	Measurement Noise (std over 16 runs/PRNs)	50 to 350
Sim_resol	B	Oscilloscope Resolution (10GSps)	100
Sim_trigger	B	Oscilloscope Trigger error (specs)	15
Sim_config	B	Simulator output power effects (tests)	100
Sim_filter	B	Correlator low-pass filter effects (test)	100
PR_noise	A	Pseudorange Noise (std of the PR differences)	10 to 155
PR_icb	B	Receiver inter-channel biases (test)	10
PR_agc	B	Receiver AGC-dependant biases (test)	100
PR_temp*	B	Thermal effects on receiver (test)	200
LD	A	LD measurement noise (conservative assumption)	40
LD	B	Receiver autocalibration (test)	300
		TOTAL:	418 to 564

Absolute GNSS calibration at ESA/ESTEC

Stability/Repeatability of Absolute Calibration results



Other available absolute calibration measurements

		CNES	JPL	VNIIFTRI	ESA
GPS	L1CA	✓	✓	✓	✓
	L1P	✓	✓	✓	✓
	L2P	✓	✓	✓	✓
	L2C	×	✓	×	×
	L5	✓	✓	×	✓
GAL	E1	✓	✓	×	✓
	E6	×	×	×	✓
	E5a	✓	✓	×	✓
	E5b	×	✓	×	✓
	E5 AltBOC	×	✓	×	✓
GLO	L1C	×	×	✓	✓
	L2C	×	×	✓	✓
	L1P	×	×	✓	✓
	L2P	×	×	✓	✓
BDS	B1I	✓	✓	×	✓
	B2I	✓	✓	×	✓
	B1C	×	×	×	✓
	B2A	×	×	×	✓
IRNSS	L5	×	×	×	✓

source: https://webtai.bipm.org/ftp/pub/tai/publication/gnss-calibration/absolute/

Available Cross-Validation of Absolute Measurements

2019 Joint IFCS-EFTF: ESA-CNES cross-validation

TABLE II. ANTENNA CALIBRATION

	CNES – ESA (ns)	
	delay difference	combined uncertainty
L1C	0.28	0.66
L1P	0.24	0.68
L2P	0.32	0.54
L5Q	-0.51	0.54
E1C	0.23	0.58
E5Q	-0.56	0.55
E7Q	0.19	0.54

TABLE V. RECEIVER ABSOLUTE CALIBRATION

	CNES PolaRx4TR		ESA PolaRx5TR	
	CNES-ESA (ns)	combined uncertainty (ns)	CNES-ESA (ns)	combined uncertainty (ns)
L1C	-0.70	0.37	-0.71	0.70
L1P	-0.87	0.38	-0.52	0.70
L2P	-2.67	0.36	-1.01	0.35
L5Q	-	-	-1.09	0.42
E1C	-0.59	0.36	-0.38	0.51
E5Q	-1.71	0.35	-1.1	0.29

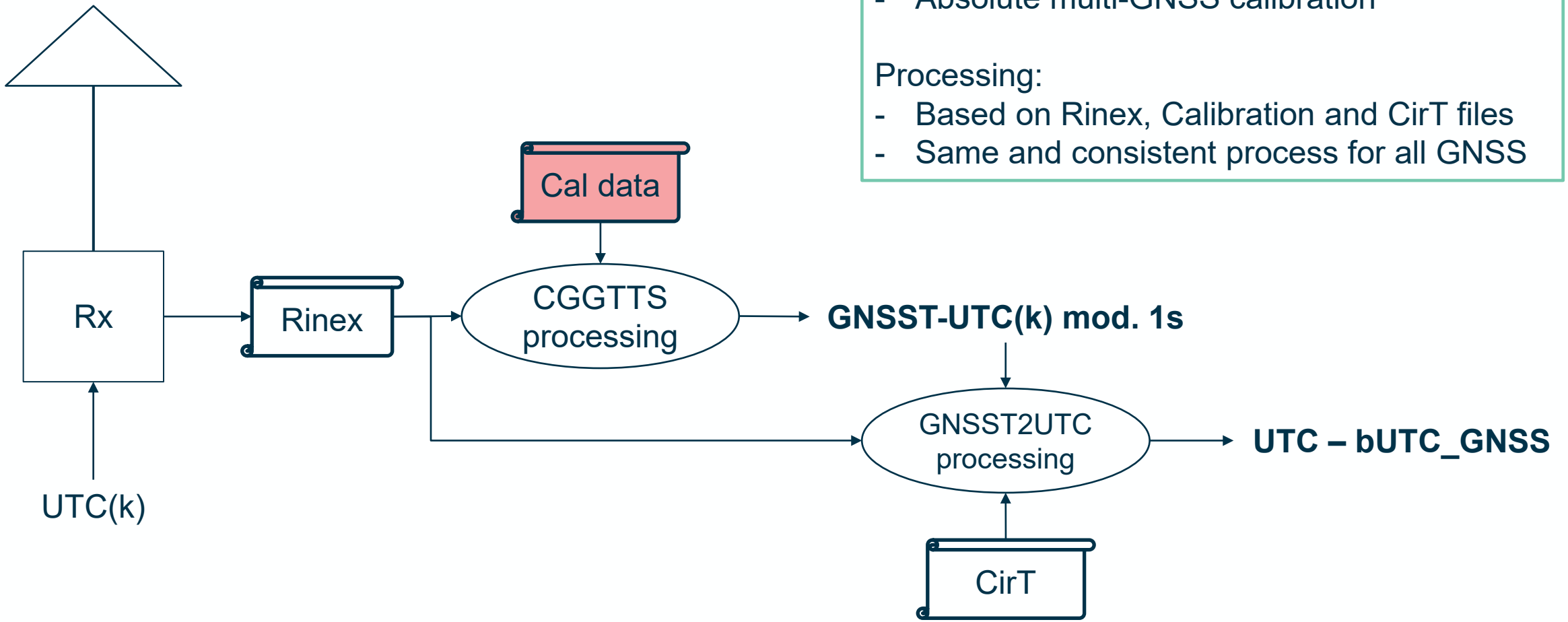
Overall, difference between ESA and CNES absolute calibration are at the level or slightly above the combined uncertainties.

Multi-GNSS Timing Monitoring

Principle:

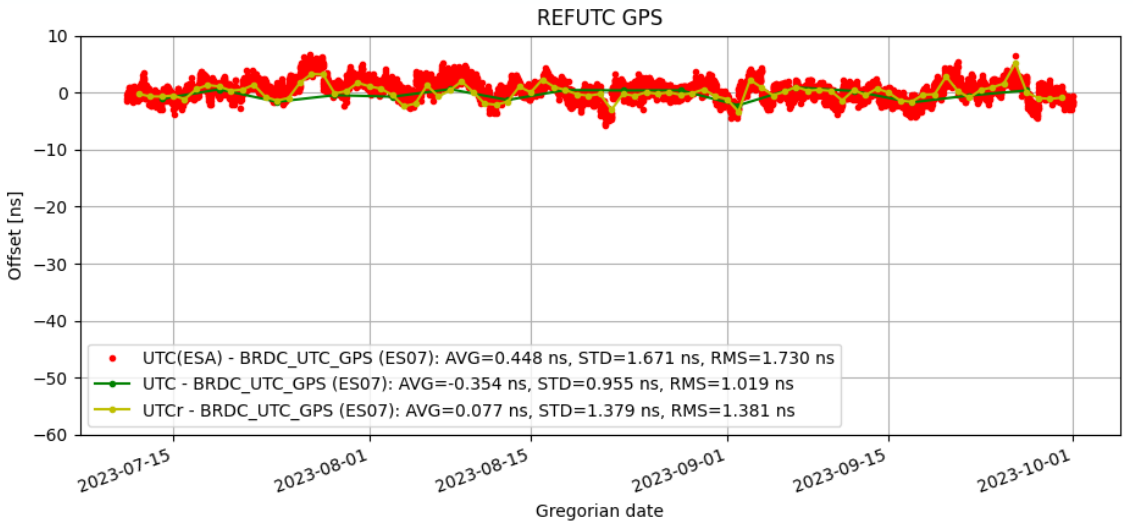
Receiver Chain:
- Fixed multi-GNSS receiver
- Absolute multi-GNSS calibration

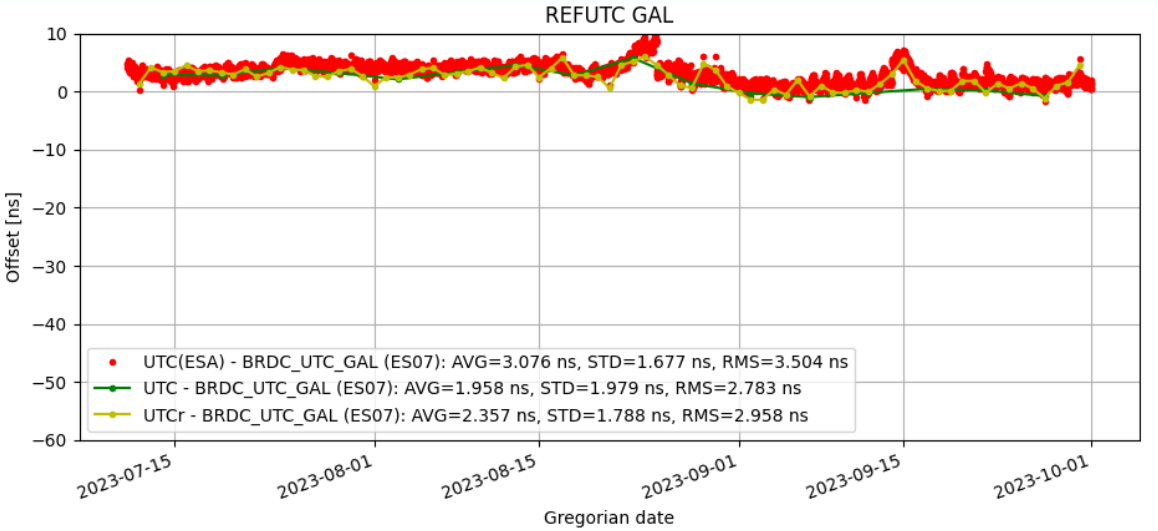
Processing:
- Based on Rinex, Calibration and CirT files
- Same and consistent process for all GNSS

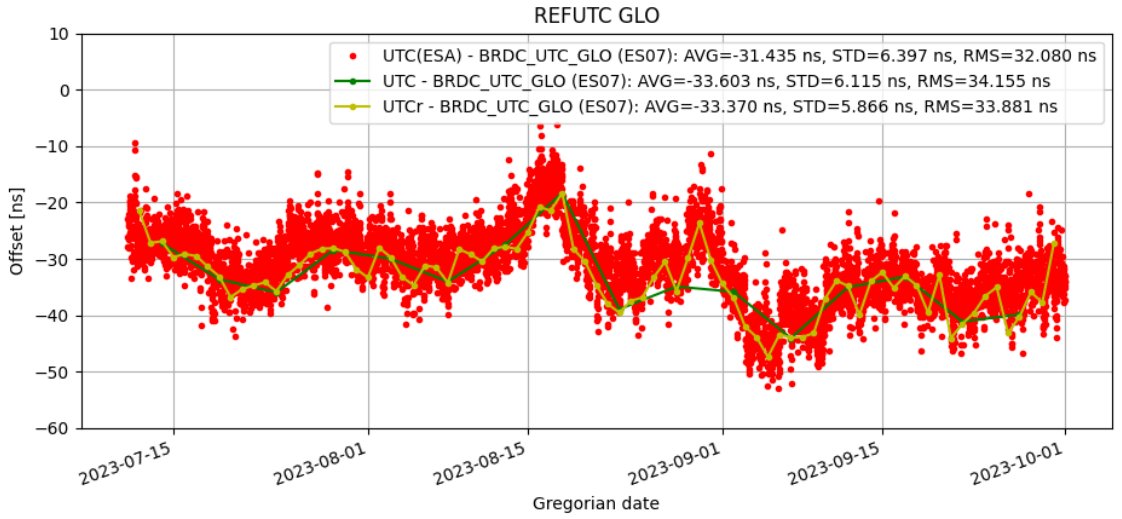


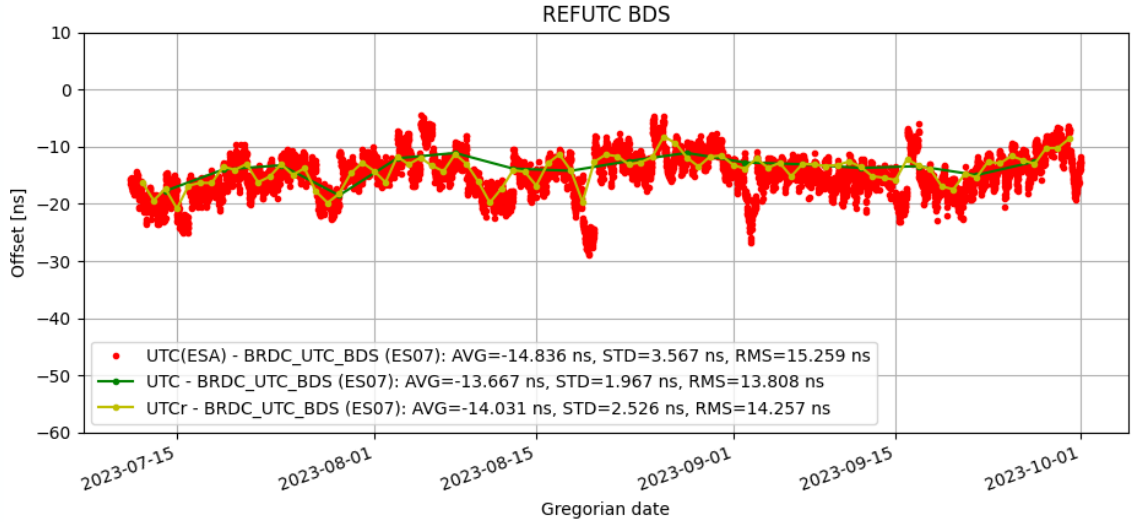
Multi-GNSS Timing Monitoring

UTC – bUTC_GNSS (July-2023 – Sep-2023)









Multi-GNSS Timing Monitoring

UTC – bUTC_GNSS (July-2023 – Sep-2023)

	Avg [ns]	Std [ns]	RMS [ns]
UTC_GPS – UTC(ESA)	0.45	1.67	1.73
UTC_GAL – UTC(ESA)	3.08	1.68	3.50
UTC_GLO – UTC(ESA)	-31.43	6.40	32.08
UTC_BDS – UTC(ESA)	-14.84	3.57	15.26
UTC_GPS – UTCr	0.08	1.38	1.38
UTC_GAL – UTCr	2.36	1.79	2.96
UTC_GLO – UTCr	-33.37	5.87	33.88
UTC_BDS – UTCr	-14.03	2.53	14.26
UTC_GPS – UTC	-0.35	0.95	1.02
UTC_GAL – UTC	1.96	1.98	2.78
UTC_GLO – UTC	-33.60	6.11	34.15
UTC_BDS – UTC	-13.67	1.97	13.81

Conclusions

- Available GNSS Receiver references from Timing community are limited to GPS P1/P2 and GAL E1/E5a
- Accurate GNSS Receiver chain calibration is also required in GNSS operator infrastructures

- Absolute calibration tools are available at ESA/ESTEC and (few) other places: CNES, JPL, VNIIFTRI
- Cross-validation campaigns are limited

- Use of absolutely calibrated multi-GNSS chains show:
  - UTC dissemination with GPS and Galileo at the few ns level
  - UTC dissemination with Glonass and Beidou at the few 10ns level

- We encourage and welcome inputs/feedback/collaboration from/with the Timing Community and the other GNSS Operators on the topic