GNSS Timing monitoring with calibrated receivers at ESA

ESA ESTEC

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Background and Objectives

(multi-)GNSS calibration in 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

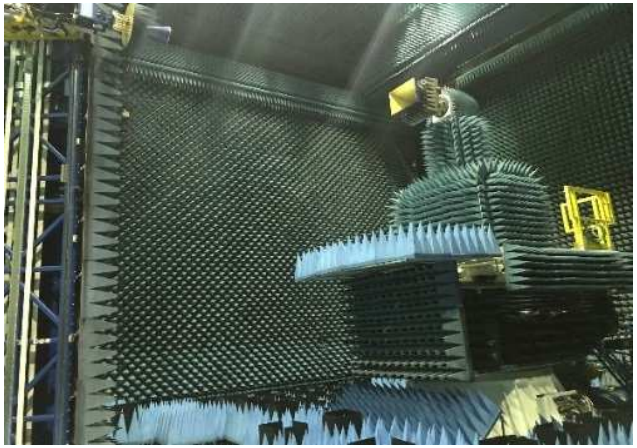
Objectives:

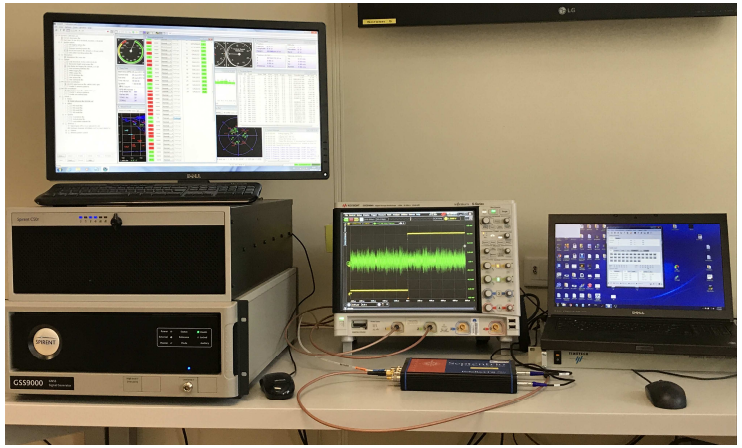
To have independent capabilities (equipment, tools, processes, know-how…) for the continuous monitoring of multi-GNSS timing performance at the ~ns level

Multi-GNSS Calibration

Based on consistent measurement/processing of absolute delay measurement:

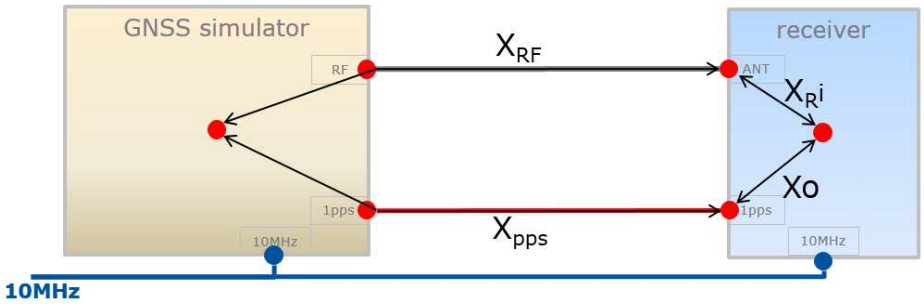
- Antenna: Group-Delay measurement in anechoic chamber
- Antenna Cable: Vector Network Analyser
- Receiver: GNSS Simulator

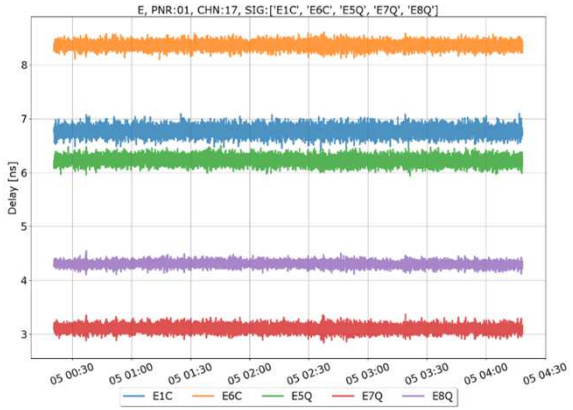




Multi-GNSS Calibration

Receiver absolute Calibration:





Receiver Delay for signal component i:

$$X_{Ri} = (PR_i - D_{sim})/c - (X_{RF} - X_{pps})_i + Xo$$

PRi: measured pseudorange

Dsim: Simulated pseudorange

XRF, Xpps: cable delays

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 → New

Multi-GNSS Calibration

Uncertainty Budget, Test and Validation:

- Detailed uncertainty budget
- Several test campaign conducted
- Several Receiver types/brands tested
- Validation campaign with CNES absolute calibration*
- Validation campaign against relative calibration
- Overall agreement/consistency at the 1~2ns level

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

* IEEE IFCS-EFTF 2019, “Cross-calibrations of multi-GNSS Receiver Chains”, ESA, CNES

Multi-GNSS Calibration

Results (example: BP27, calibrated for the BIPM):

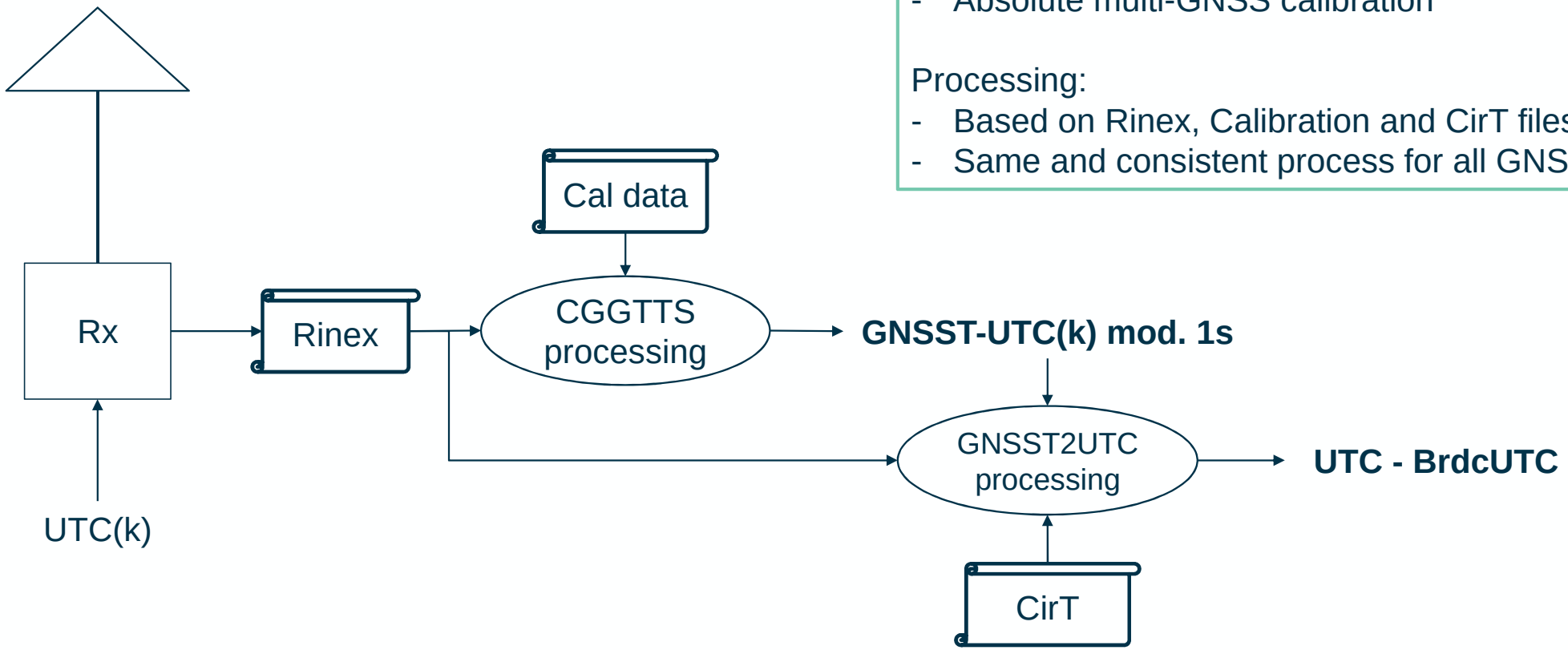
			BP27			
			FW 3.2.0		FW 5.4.0	
	Signal		value	uncert.	value	uncert.
GPS	L1C	C1C	11.16	0.48	11.45	0.48
	L1P	C1W	10.83	0.45	11.11	0.45
	L2P	C2W	10.19	0.47	10.49	0.47
	L5Q	C5Q	10.90	0.42	11.19	0.42
GAL	E1C	C1C	11.26	0.42	11.56	0.42
	E5Q	C5Q	10.89	0.44	11.20	0.44
	E7Q	C7Q	7.11	0.43	7.40	0.43
	E8Q	C8Q	8.88	0.45	9.18	0.45
	E6C	C6C	6.82	0.47	7.13	0.47
BDS-2	B1I	C2I	4.22	0.54	4.51	0.54
	B2I	C7I	6.79	0.53	7.09	0.53
BDS-3	B1C	C1P			11.29	0.44
	B2A	C5P			11.29	0.52

Multi-GNSS Timing Monitoring

Principle:

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

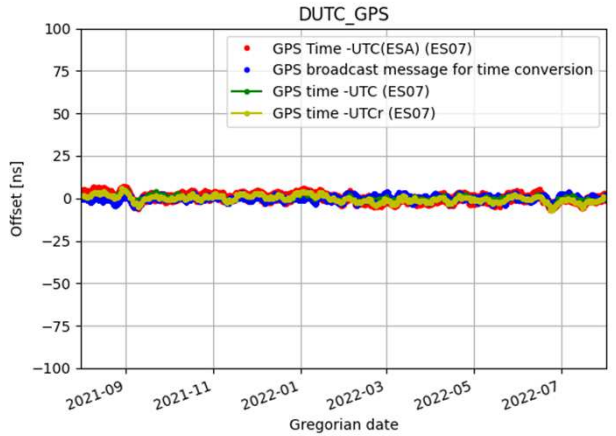
Processing:
- Based on Rinex, Calibration and CirT files
- Same and consistent process for all GNSS



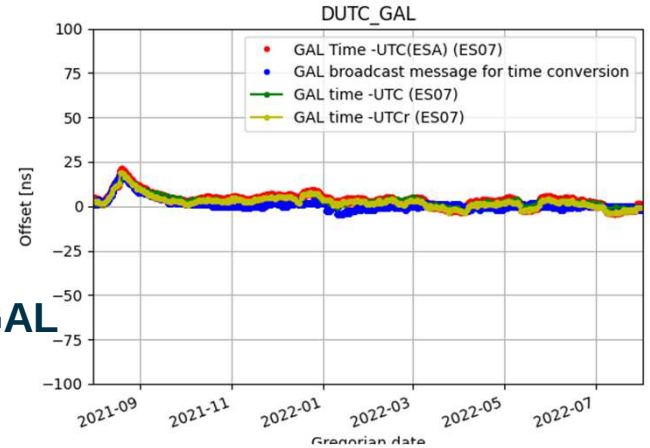
Multi-GNSS Timing Monitoring

GNSSTime – UTC (modulo 1sec), Aug-2021 to Aug-2022

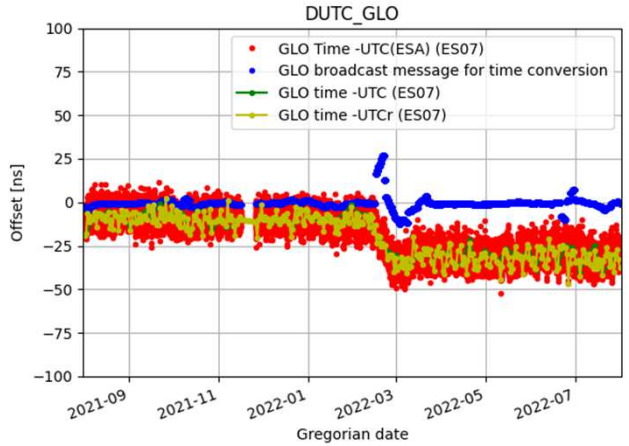
GPS



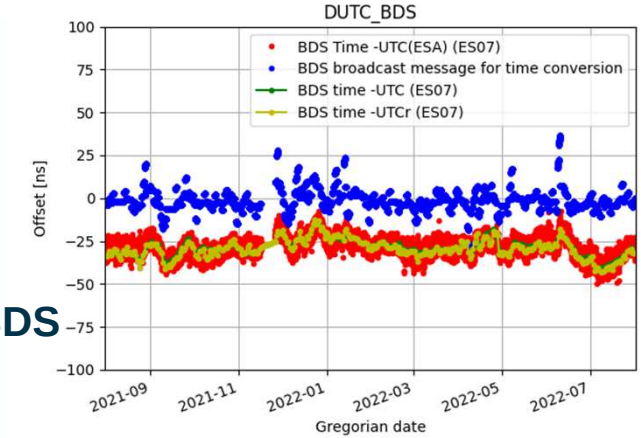
GAL



GLO

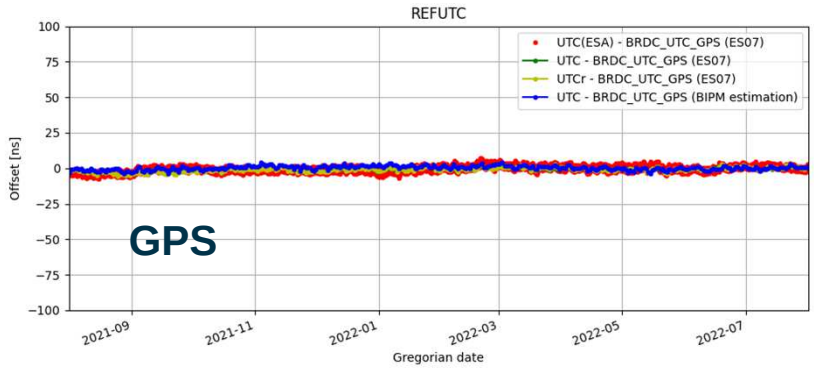


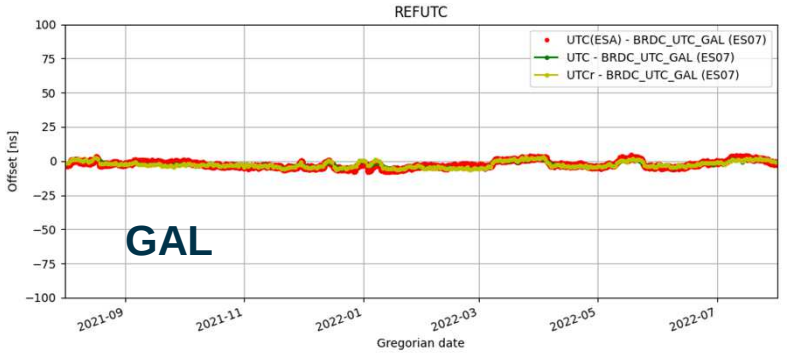
BDS

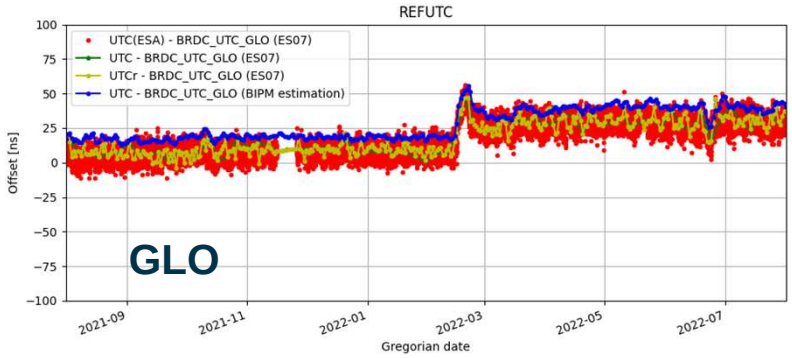


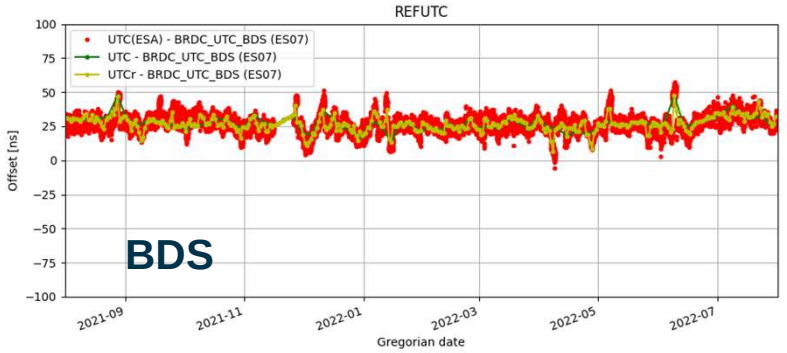
Multi-GNSS Timing Monitoring

UTC – BrdcUTC, Aug-2021 to Aug-2022









Conclusions, Outlook

Multi GNSS calibration

- Equipment, tools and processes available for multi-GNSS receiver chain calibration
- Covers all operational GNSSes
- Validation campaign demonstrated agreement/consistency at the 1~2ns level

Multi-GNSS Timing Monitoring

- Consistent tools and processes available for multi-GNSS timing monitoring
- Covers all operational GNSSes (NAViC to come soon)
- Observed GLO and BDS inconsistencies need further investigations

Outlook

- Implement NAViC in routine processes
- Investigate observed inconsistencies
- Further validate tools and processes, in particular with non-EU entities