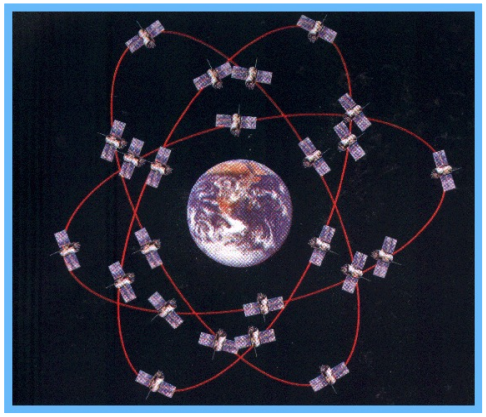

Monitoring Galileo (GNSS) – Key Performance Indicators

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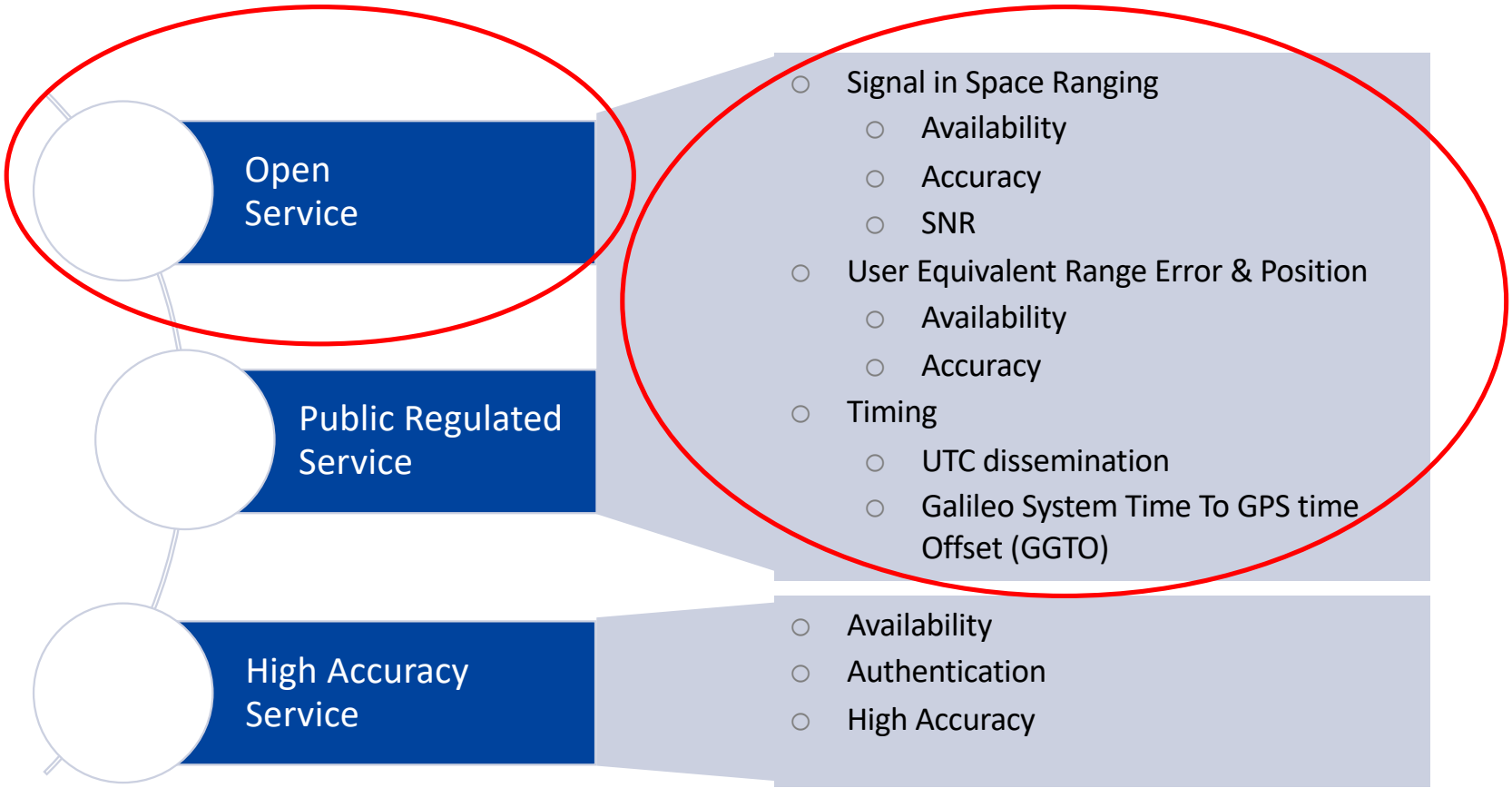
Chalmers University of Technology, 2021

Onsala Space Observatory

=> Co-location sites allow to integrate different geodetic techniques

SERVICE SPECIFIC KPI



Example of projects monitoring Galileo KPIs

The **Signal In Space Error (*SISE*)** is the satellite-to-user **range error due to satellite signal generation and navigation message** clock and ephemeris error, which is a function of time and user location within the satellite coverage area.

The **User Equipment Error (*UEE*)** is the satellite-to-user **range error due to all residual error contribution** in the range domain that are **not under the direct control of the GNSS system.**

The **User Equivalent Range Error (*UERE*)** is the total satellite-to user range error, **the combination of SISE and UEE.**

$$UERE = \sqrt{SISE^2 + UEE^2}$$

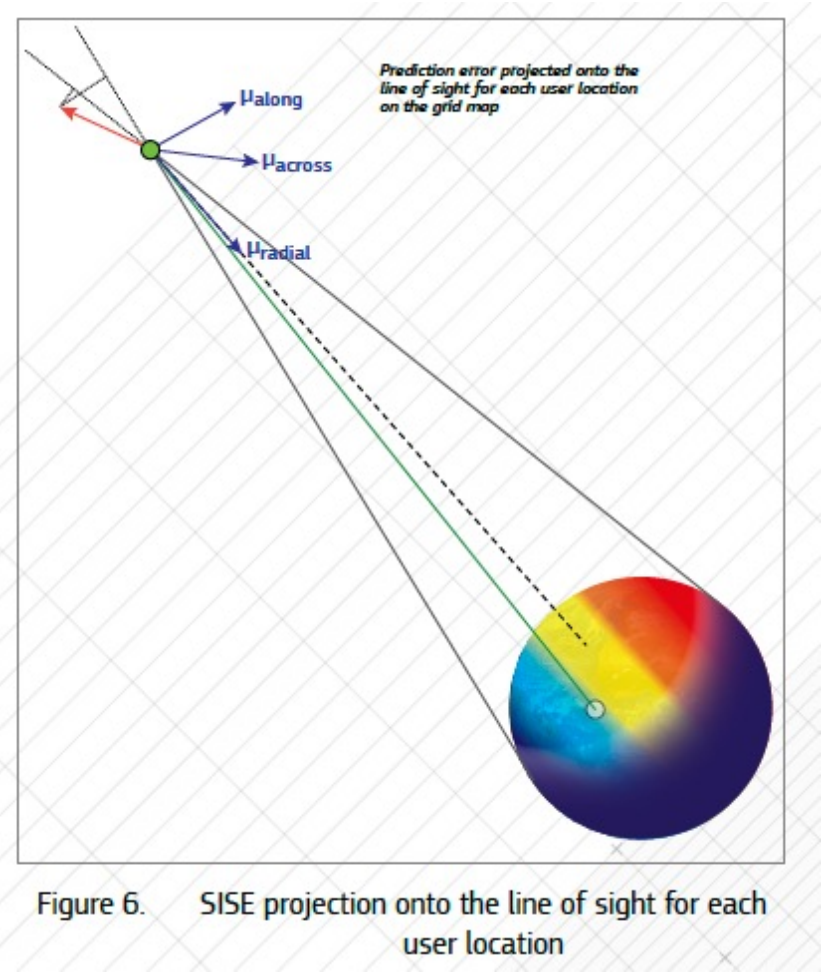
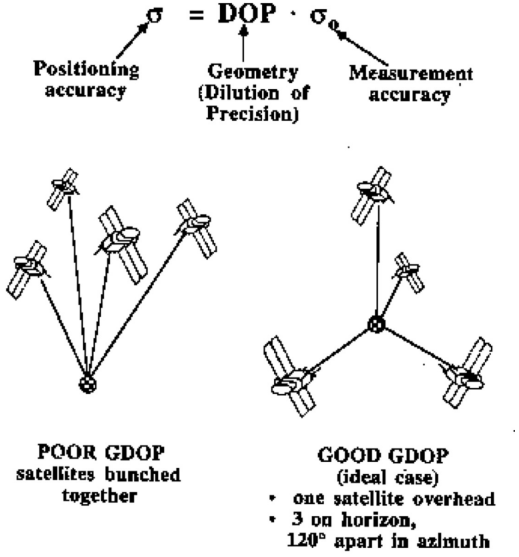


Figure 6. SISE projection onto the line of sight for each user location

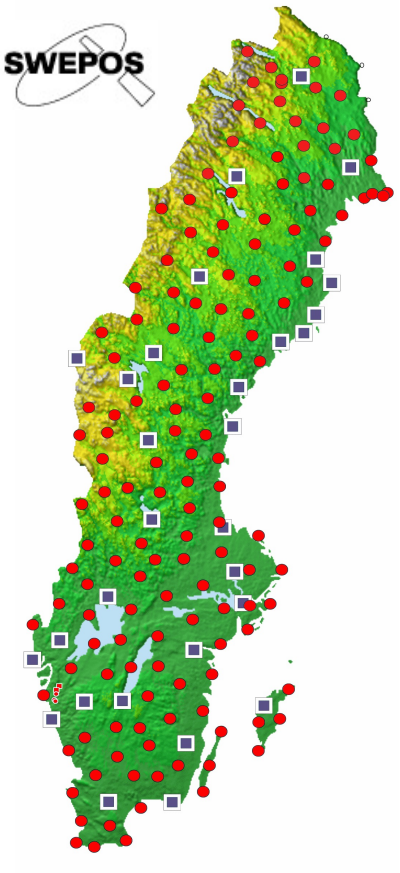
(from Open Service Service Definition Document)

GPS ERROR BUDGET AND DILUTION OF PRECISION (DOP)

Segment Source	Error Source	GPS 1σ Error (m)	
Space	Satellite clock stability	3.0	
	Satellite perturbations	1.0	
	Selective availability	~~32.3~~	0.0
	Other (solar radiation pressure)	0.5	
Control	Ephemeris prediction error	4.2	
	Other	0.9	
User	Ionosphere delay	5.0	
	Troposphere delay	1.5	
	Receiver noise and resolution	1.5	
	Multipath	2.5	
	Other (internal biases etc)	0.5	
System User Equivalent. Range Error	Total root sum square	~~33.3~~	8.0

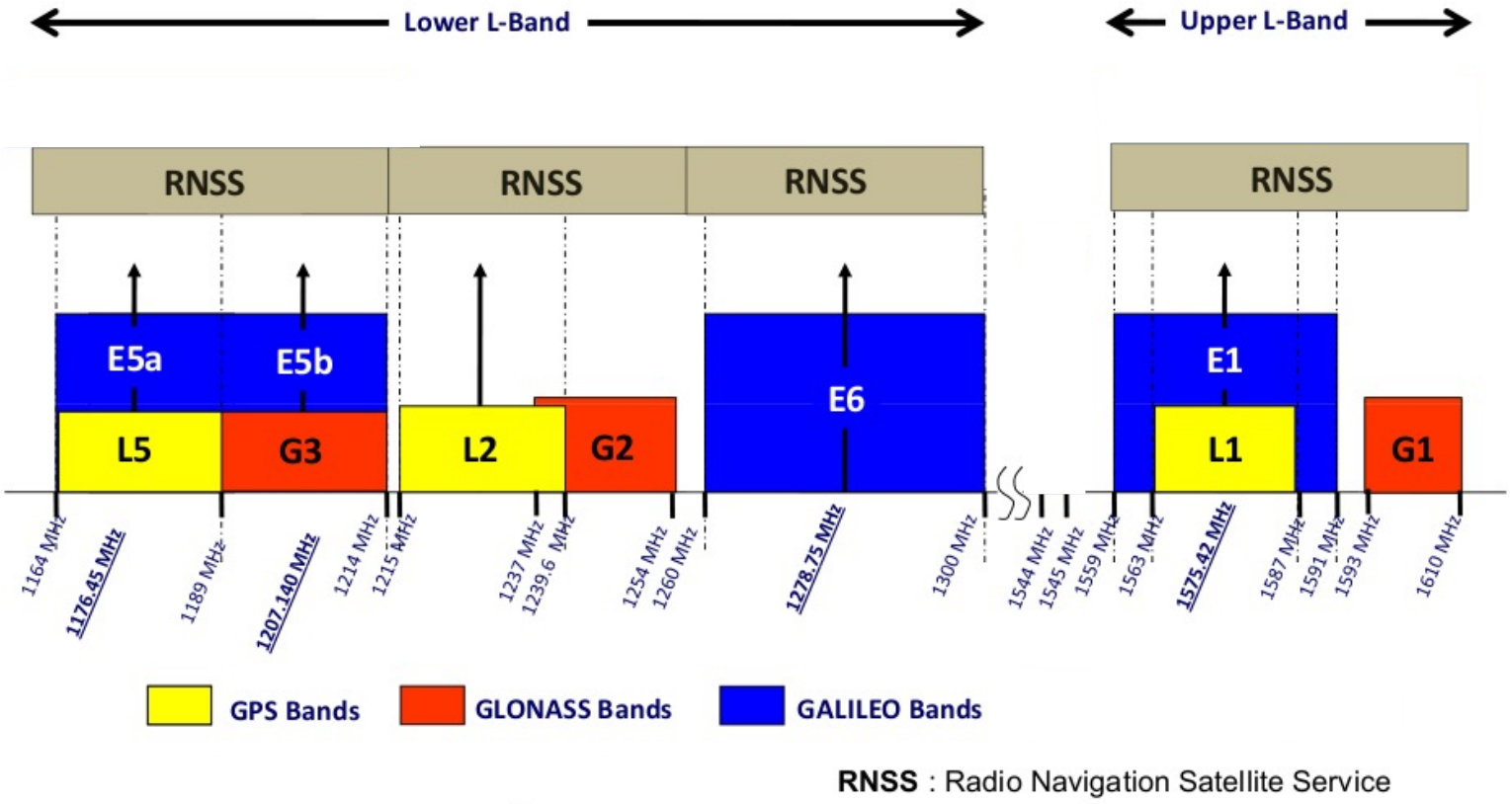


SWEPOS stations used for KPI calculation



#	Station ID	Station name	lat	lon	since	until
1	ARJ6	Arjeplog	66.3180	18.1250	1/7/2018	present
2	HAS6	Hassleholm	56.0921	13.7180	1/7/2018	present
3	JON6	Jonkoping	57.7454	14.0597	1/7/2018	present
4	KAD6	Karlstad	59.4440	13.5056	1/7/2018	present
5	KIR8	Kiruna	67.8775	21.0602	1/7/2018	present
6	LEK6	Leksand	60.7221	14.8771	1/7/2018	present
7	LOV6	Lovo	59.3378	17.8289	1/7/2018	present
8	MAR7	Gavle	60.5950	17.2584	1/7/2018	present
9	NOR7	Norrkoping	58.5901	16.2464	1/7/2018	present
10	ONS1	Onsala	57.3953	11.9245	1/7/2018	present
11	OSK6	Oskarshamn	57.0656	15.9969	1/7/2018	present
12	OST6	Ostersund	63.4427	14.8580	1/7/2018	present
13	OVE6	Overkalix	66.3178	22.7734	1/7/2018	present
14	SKE8	Skellefteaa	64.8792	21.0481	1/7/2018	present
15	SUN6	Sundsvall	62.2324	17.6598	1/7/2018	present
16	SVE6	Sveg	62.0173	14.7001	1/7/2018	present
17	UME6	Umea	63.5781	19.5095	1/7/2018	present
18	VAE6	Vanersborg	58.6931	12.0351	1/7/2018	present
19	VIL6	Vilhelmina	64.6978	16.5599	1/7/2018	present
20	VIS6	Visby	57.6539	18.3673	1/7/2018	present

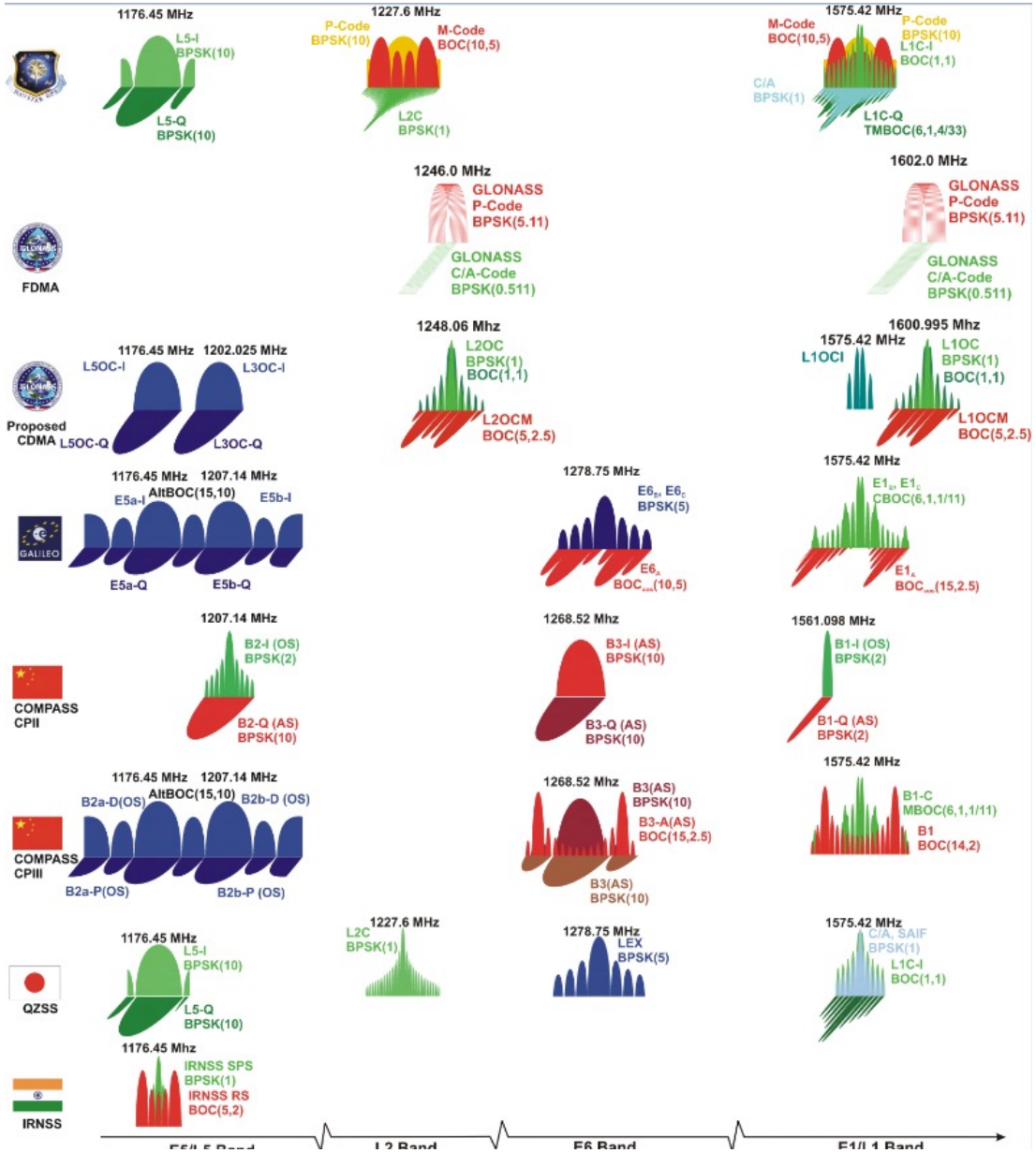
GNSS navigational frequency bands



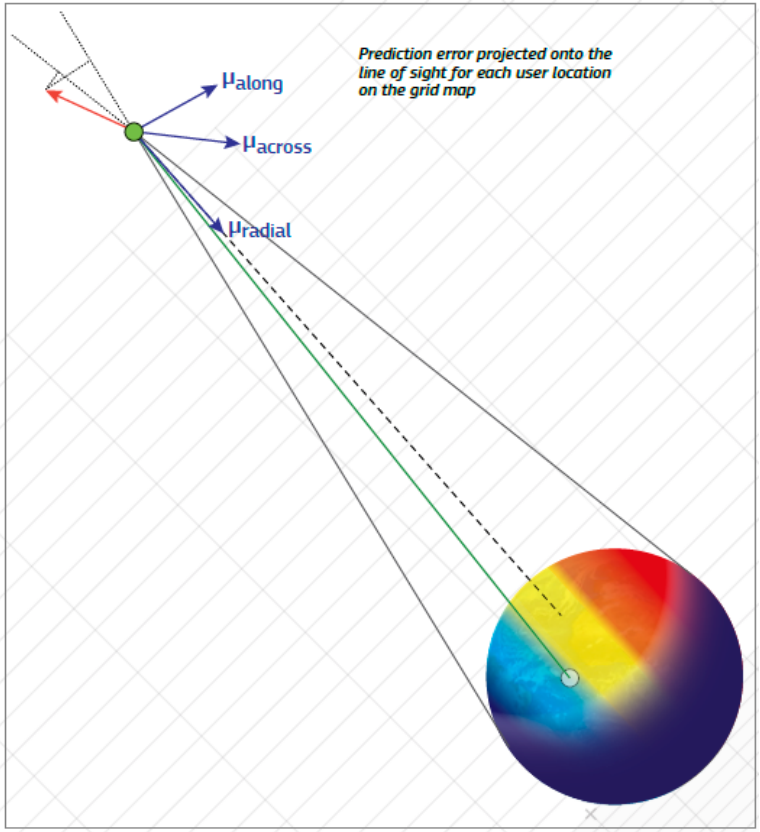
https://gssc.esa.int/navipedia/index.php/GNSS_signal

GNSS - All Signals

https://gssc.esa.int/navipedia/index.php/GNSS_signal



Example of Navigation KPI: Ranging Accuracy



(from Open Service Service Definition Document)

Signal In Space Error (SISE)=

Broadcast Orbit & Clock – Reference Orbit & Clock

Predicted

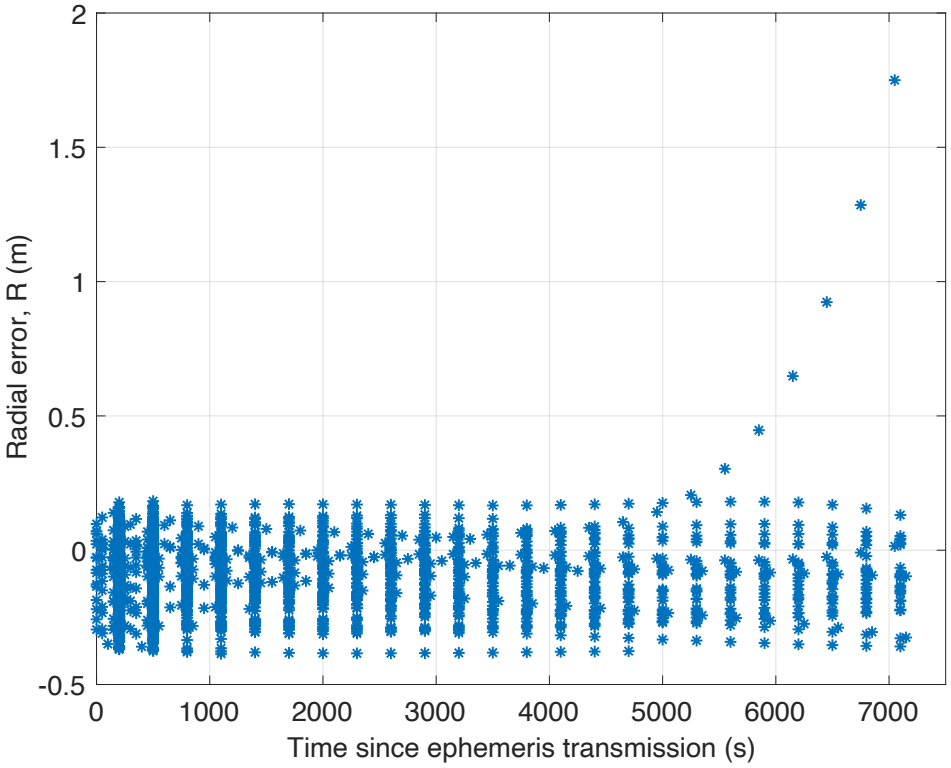
A posteriori

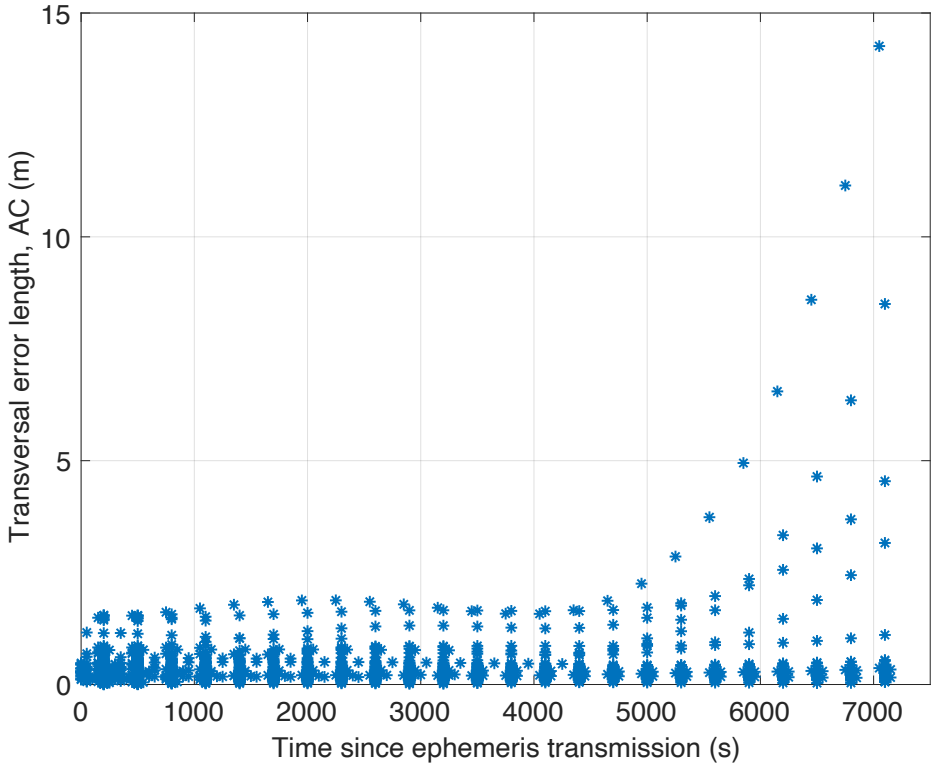
Ranging Error=
Projection of the SISE in the Sat-User direction

Ranging Accuracy KPI:

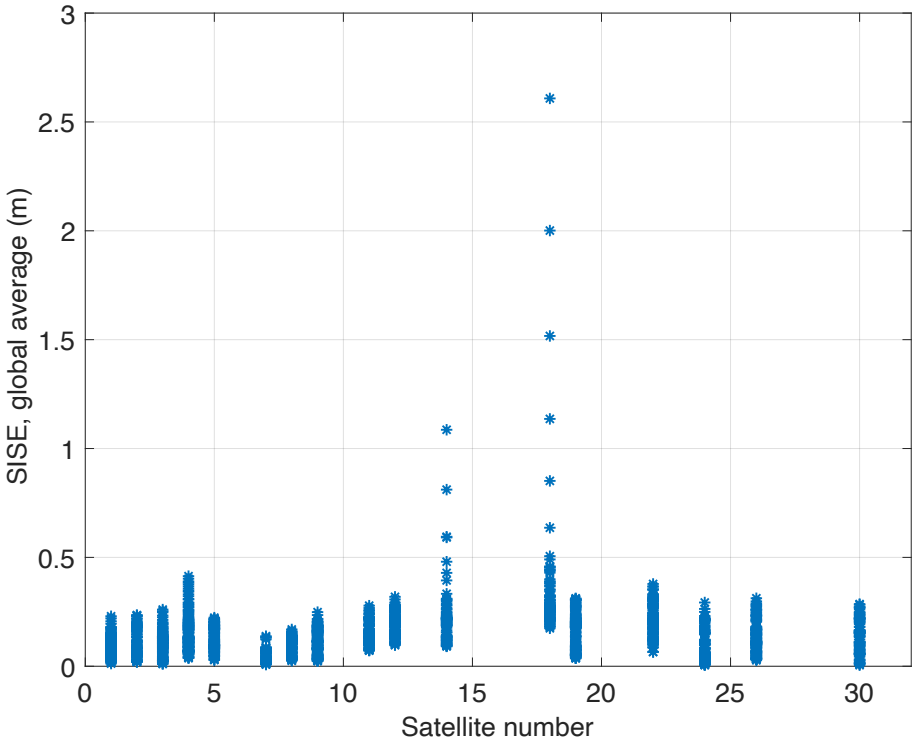
- 95% percentile of the Global Average Ranging Error (above 5 deg Elevation coverage)

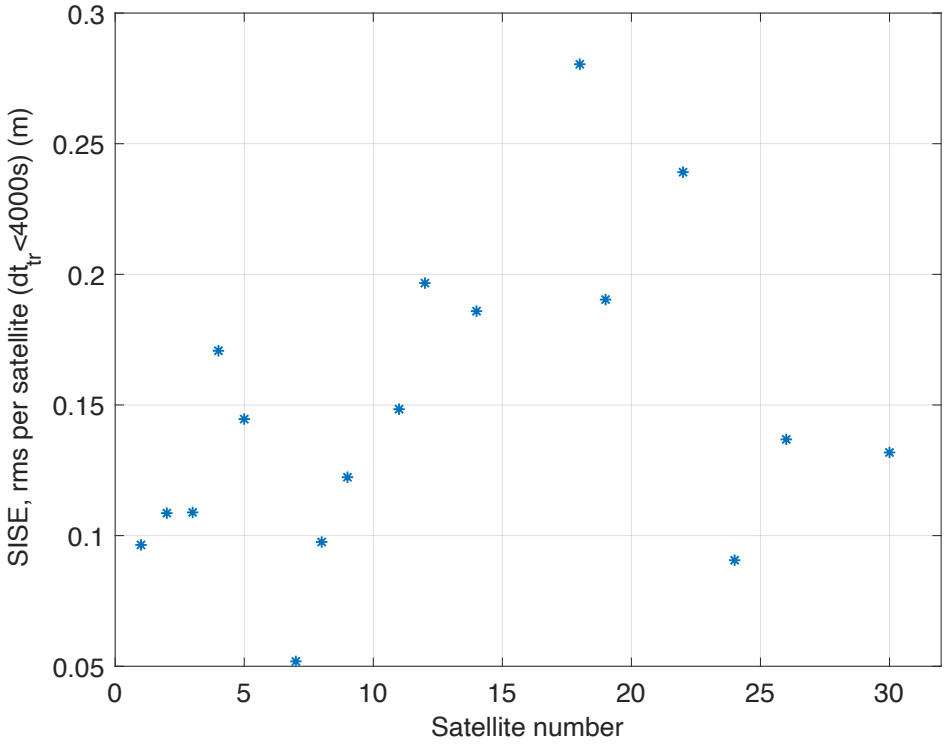
Radial and Transversal Errors



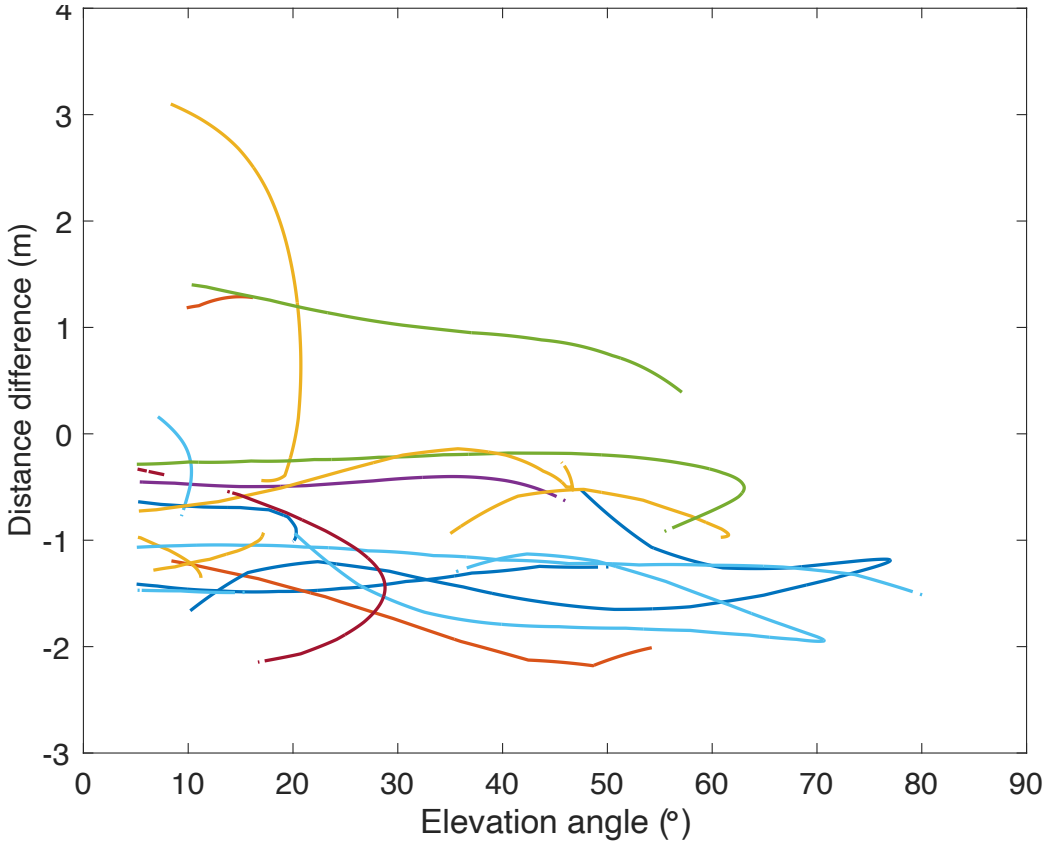


SISE Global Average for each Satellite





GPS – Signal in Space Error



User Equipment Errors - Atmosphere

- Residual Ionosphere error due the imperfection of the ionosphere model as provided in the navigation message, used to correct for the ionospheric delays (only for single-frequency users)
- Residual Troposphere error due to the imperfection of the model used to estimate the tropospheric delays. Models like Saastamoinen combined with the International Telecommunication Union (ITU)-R P.835-3, -4 will easily fulfill the assumptions reflected in the table.

Reference:
Springer Handbook of Global Navigation Satellite Systems
Peter Teunissen, Oliver Montenbruck

Co-located instruments at Onsala

Multi-GNSS station:

ONS1

Microwave radiometer:

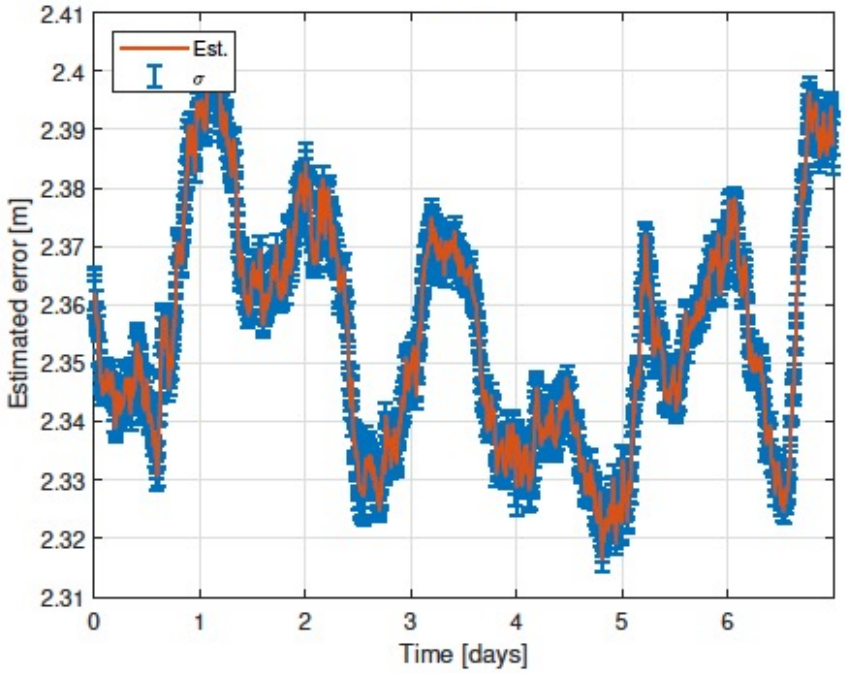
WVR ”Konrad”

Geodetic VLBI:

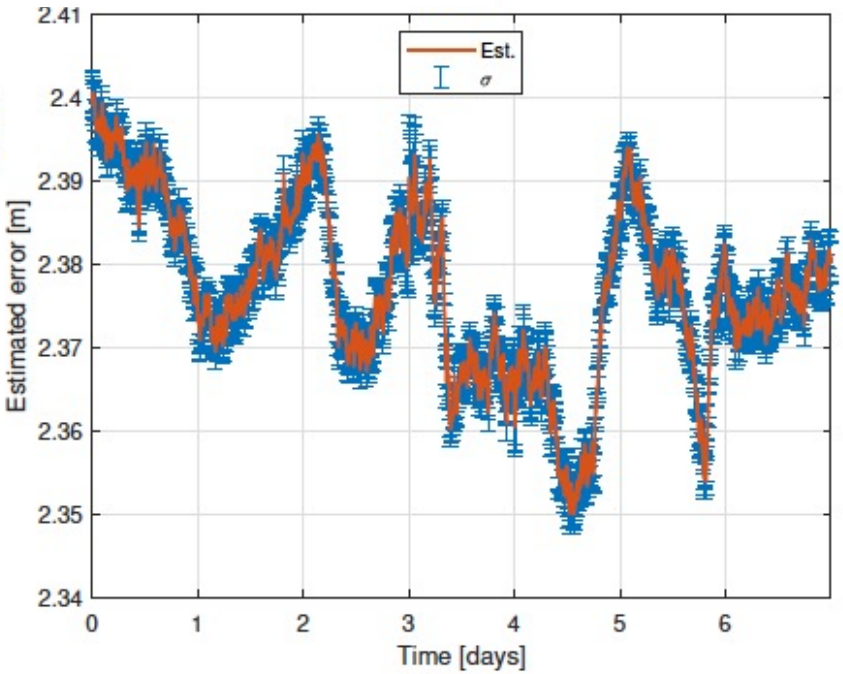
ONSALA60, ONSA13NE, ONSA13SW

Zenith Trop. Delay – Estimated using GipsyX

Onsala



Sundsvall



User Equipment Errors – Receiver & Local Effects

- Errors in the user receiver equipment due to local effects on code error, such as thermal noise, radio frequency interference and multipath
- Multipath Bias Error
- The time variation of the ionosphere introduces a bias in the single frequency smoothed code (Carrier-smoothing), due to the code-carrier divergence (Ref: ESA Navipedia)

$$\widehat{R}_1 = r + I_1 + bias_I + \nu_1 \qquad (6)$$

UERE Calculations – E1 and E1/E5a

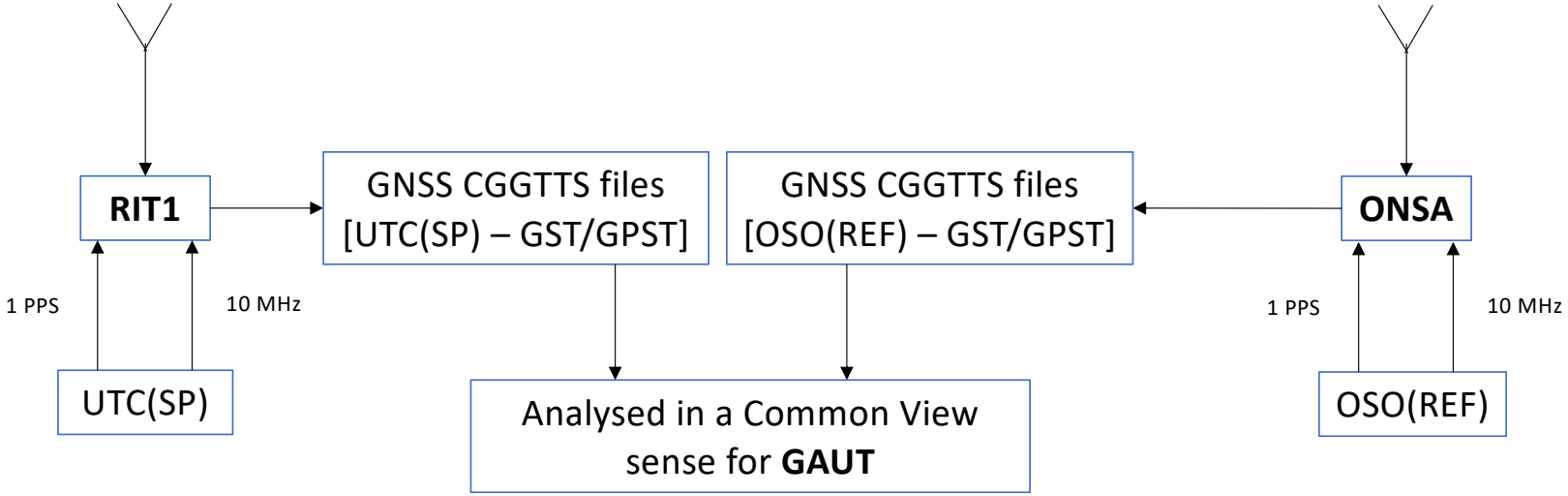
ERROR SOURCE	[METERS]
Signal In Space Ranging Error (SISE)	0.67
Residual Ionosphere error	6 (5°) -3 (90°)
Residual Troposphere error	1.35 (5°) – 0.14 (90°)
Thermal noise, Interfer, Multipath	0.35 (5°) – 0.23 (90°)
Multipath bias error	0.59
Satellite BGD error	0.30
Code-Carrier Ionospheric divergence error	0.30
Total (1-sigma error [cm])	6.26 (5°) – 3.10 (90°)

Table 23. Single Frequency E1 – Rural Pedestrian (RP) User Environment (*)

ERROR SOURCE	[METERS]
Signal In Space Ranging Error (SISE)	0.67
Residual Ionosphere error	0.08 (5°) - 0.03 (90°)
Residual Troposphere error	1.35 (5°) – 0.14 (90°)
Thermal noise, Interfer, Multipath	0.46 (5°) – 0.13 (90°)
Multipath bias error	0.19
Satellite BGD error	0.0
Code-Carrier Ionospheric divergence error	0.0
Total (1-sigma error [cm])	1.59 (5°) – 0.72 (90°)

Table 24. Dual Frequency E1-E5a – Rural Vehicle (RP) User Environment (*)

Calculating ΔGAUT and ΔGGTO



GNSS receivers **RIT1** and **ONSA** are both calibrated for GPS and Galileo

$$\mathbf{GAUT}_{\mathbf{computed}} = [UTC - GST]_{computed} = [UTC\text{-}OSO(REF)] + [OSO(REF)\text{-}GST]$$

OSO(REF) is an hydrogen maser

$$UTC - OSO(REF) = [UTC - UTC(SP)] - [UTC(SP) - OSO(REF)]$$

UTC – UTC(SP), where UTC(SP) is the Swedish national time scale, is extracted monthly from the BIPM Circular T

UTC(SP) – OSO(REF) is data from a GNSS time link with calibrated receivers connected to respective reference

$$\mathbf{dGAUT} = GAUT_{computed} - GAUT_{BRDC}$$

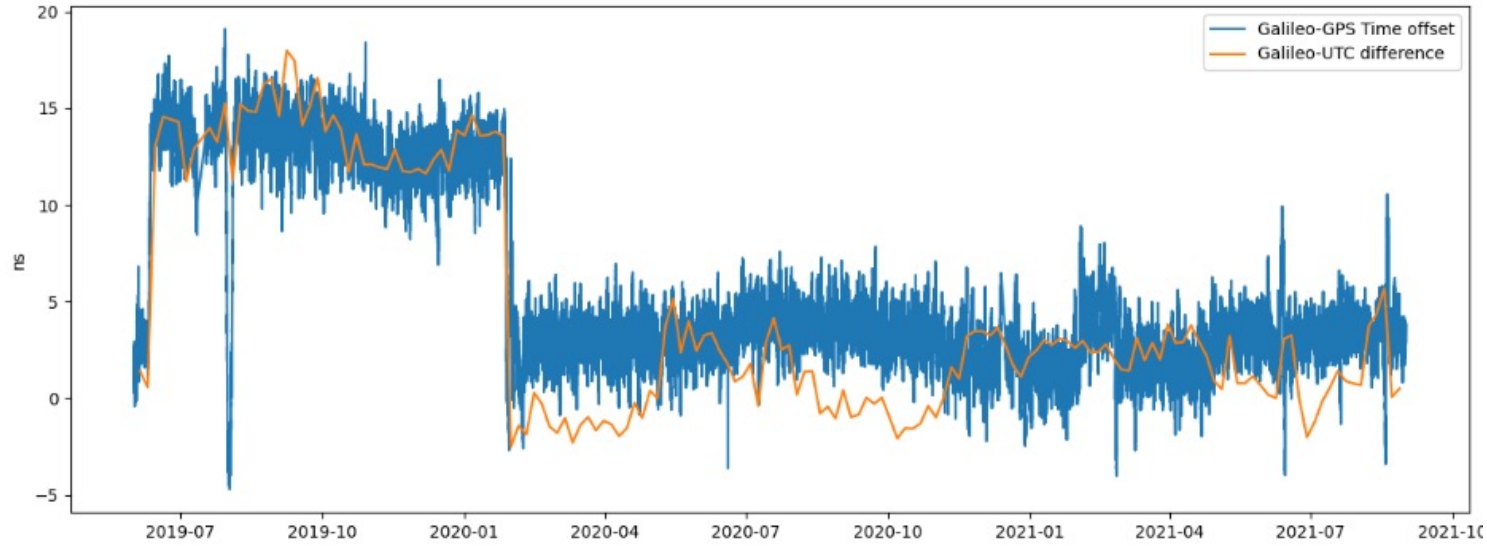
$GAUT_{BRDC}$ is extracted from Galileo NAV files from **ONSA**

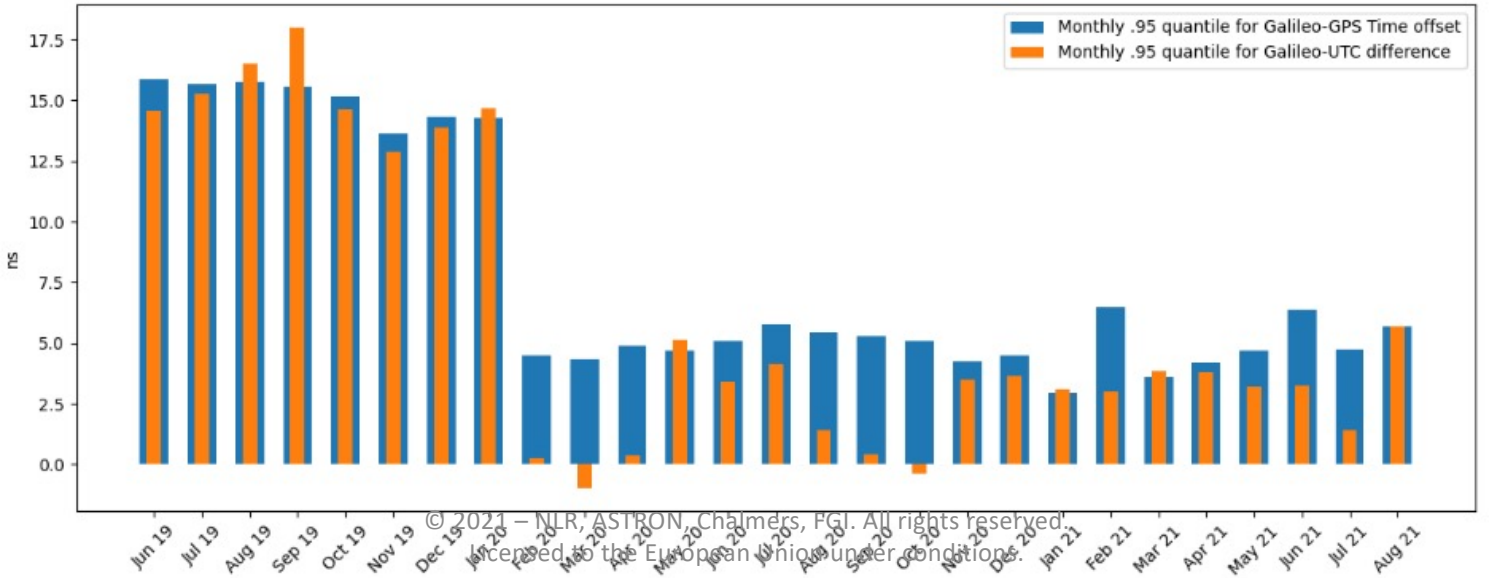
$$\mathbf{GGTO}_{\mathbf{computed}} = [GST - GPST]_{computed} = [OSO(REF) - GPST] - [OSO(REF) - GST]$$

[OSO(REF) – GPST] and [OSO(REF) – GST] is code data from the calibrated GNSS receiver ONSA

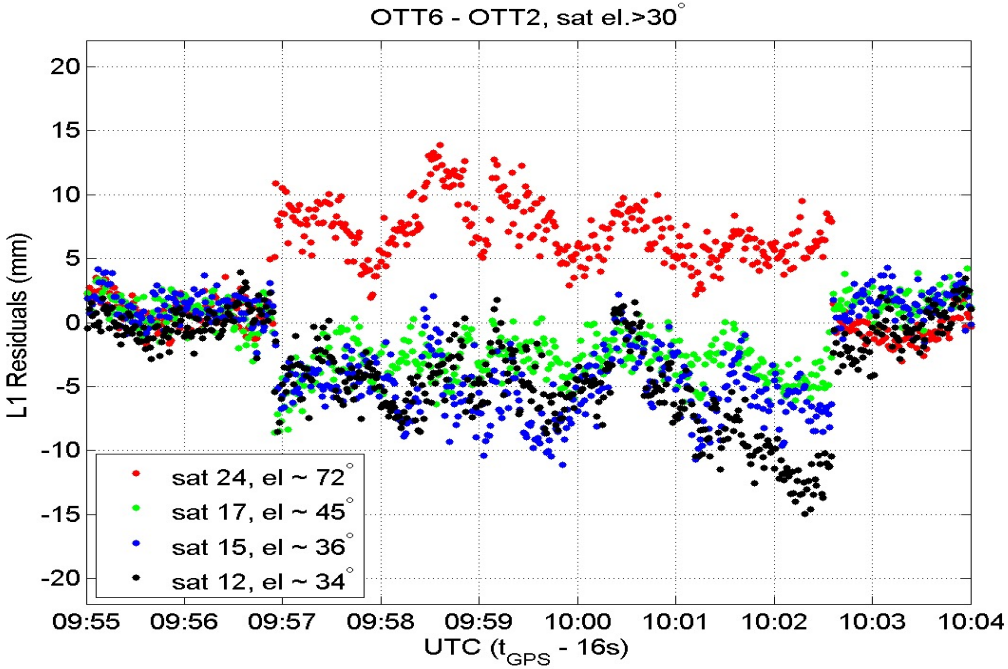
$$\mathbf{dGGTO} = GGTO_{computed} - GGTO_{BRDC}$$

$GGTO_{BRDC}$ is extracted from Galileo NAV files (GPGA) from **ONSA**





User Equipment Errors?



User Equipment Errors – Satellite Delay

- Similar to other GNSSs, the Galileo clock corrections are generated for dual-frequency users, and single-frequency users will need to use the Satellite Broadcast Group Delay BGD(f_1, f_2)
- Satellite Broadcast Group Delay (BGD) error is due to the imperfection of the correction for transmitter delay differences between carriers.
- Only relevant for single-frequency users with correction based on BGD(f_1, f_2) = (TR1-TR2)/(1- $(f_1/f_2)^2$) ≈ 30 cm