

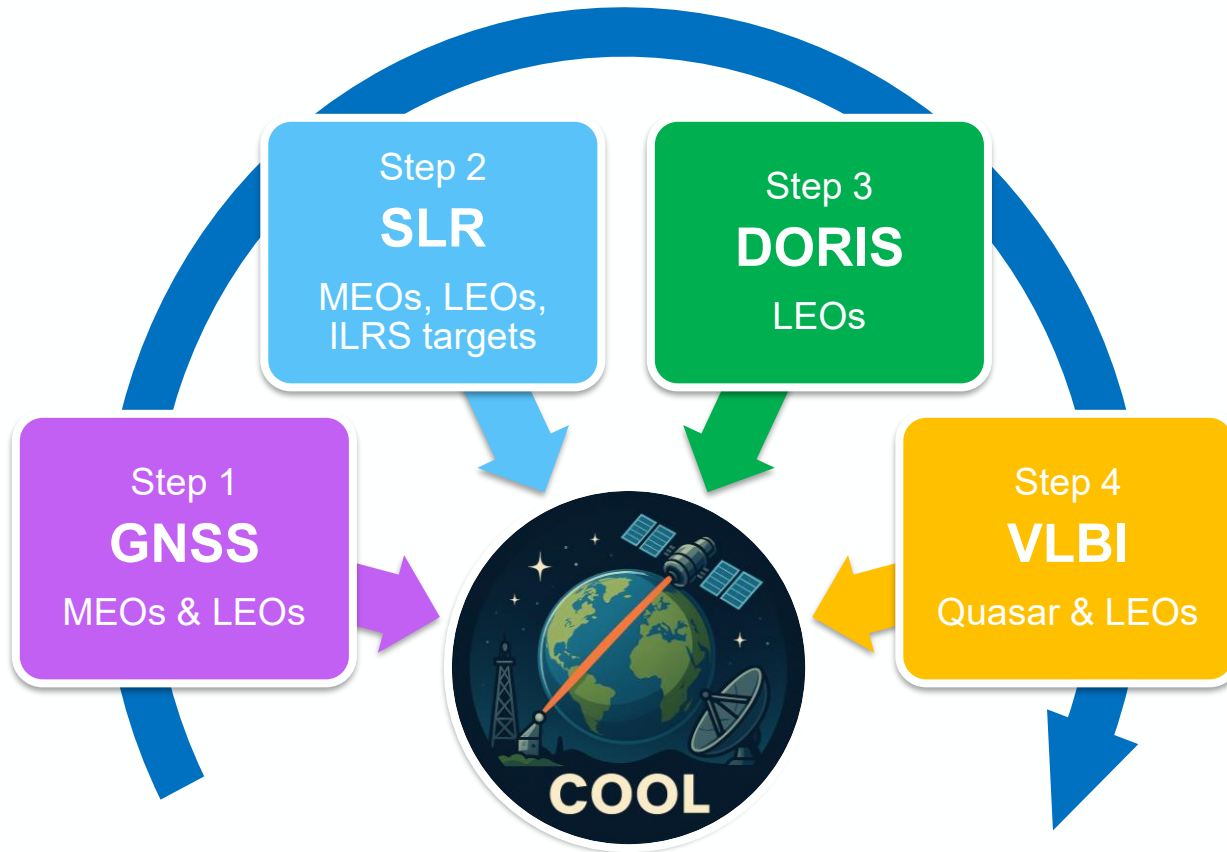
ESA's efforts towards a Combination On the Observation Level (COOL)

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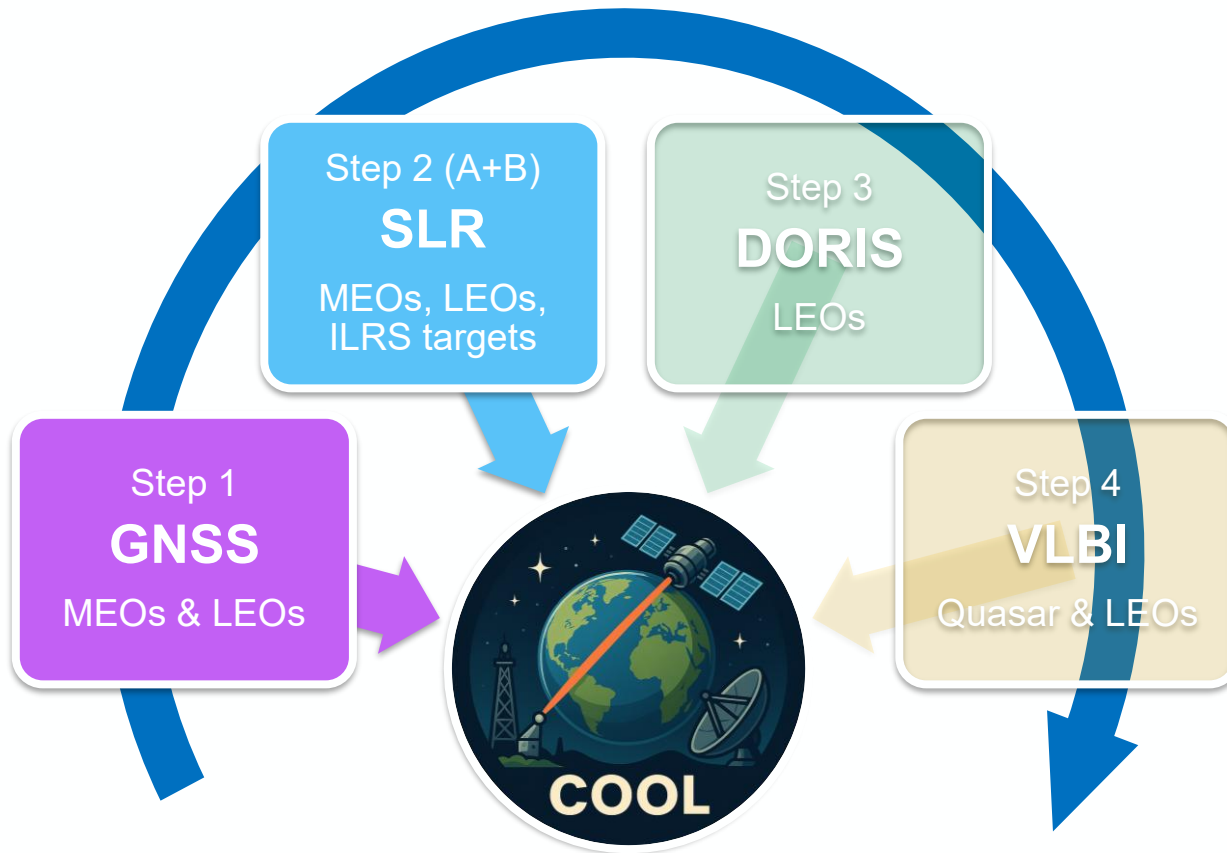
²Genesis Project @ ESA / ESTEC

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Main objectives:

- Combine **all 4 geodetic techniques** together in one single processing run
- Highlight the **strengths of each technique**
- Detect and **reduce technique-specific systematics**
- Exploit **Normal Equation Stacking** developed for Consolidated High-Accuracy Multi-GNSS Processing (CHAMP - 2024)
- Prepare the path, software and knowledge to achieve the **Genesis** mission goals



Where we are now:

Step 1

GNSS + LEOs*

- LEOs added to **Galileo** processing
- LEOs added to the **Multi-GNSS** processing

Step 2A

SLR to Galileo and LEOs

- **SLR observations to Galileo and LEOs** added to the GNSS processing (previous step)

Step 2B

SLR to ILRS targets**

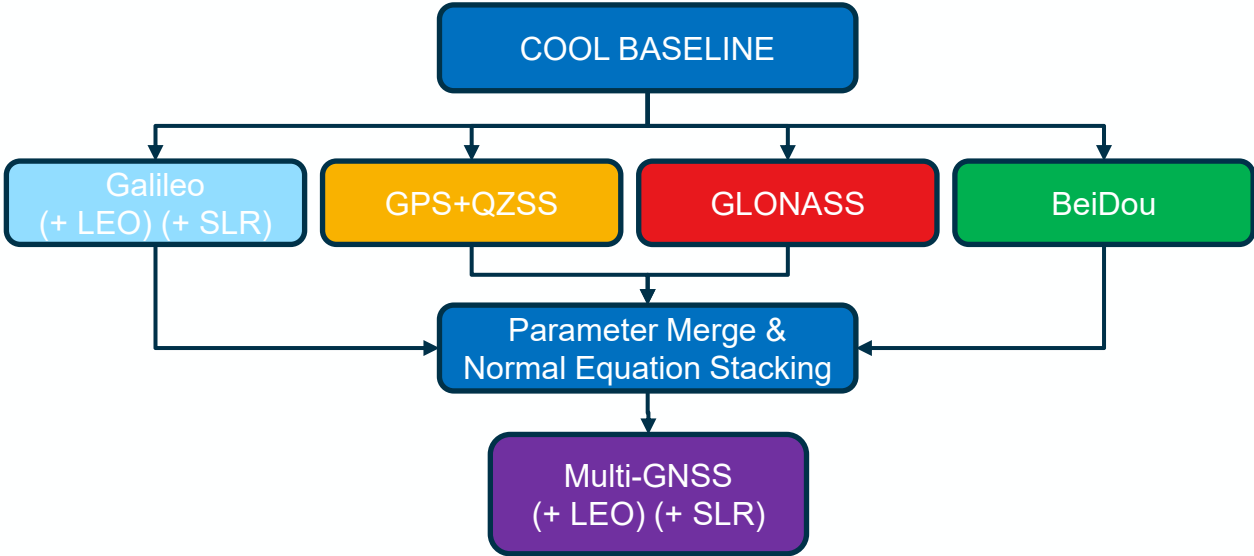
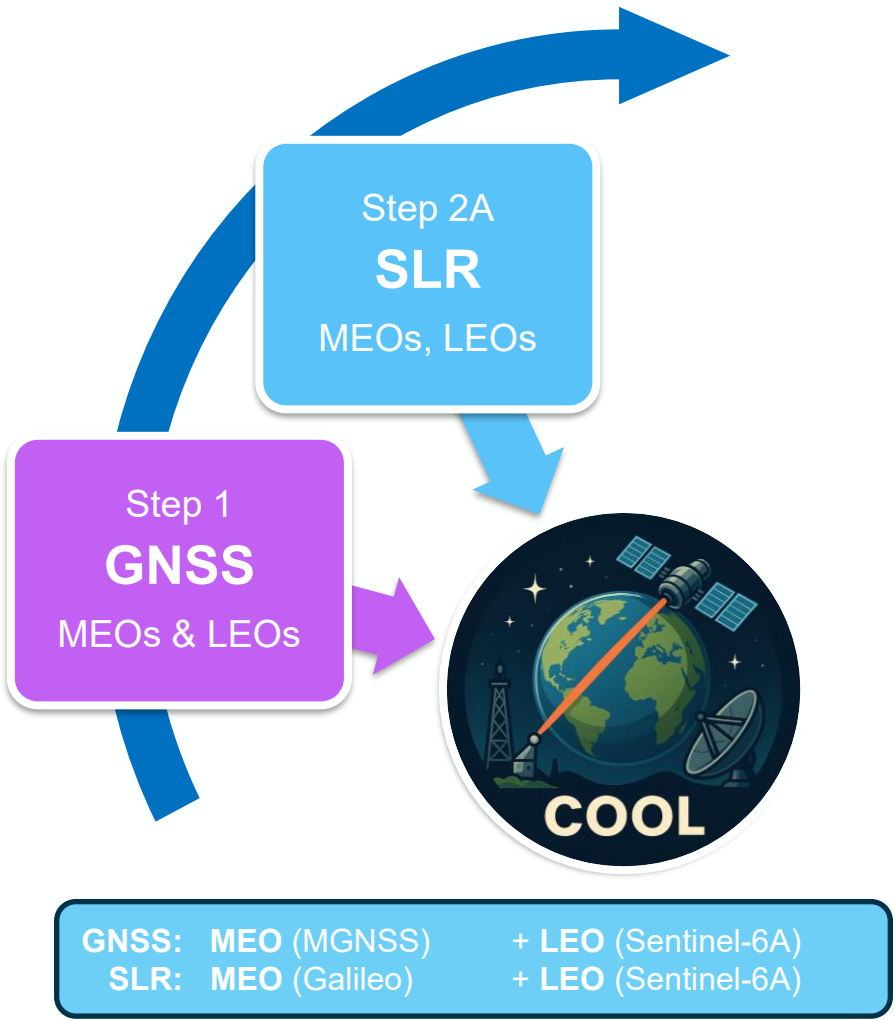
- SLR observations to ILRS targets added to the GNSS+SLR processing (previous step)

* LEO = GNSS from Sentinel-6A (Galileo only obs.)

** SLR = SLR from GNSS and LEO satellites

** ILRS = SLR from ETALON, LARES & LAGEOS

COOL: GNSS & SLR (GNSS and LEO)

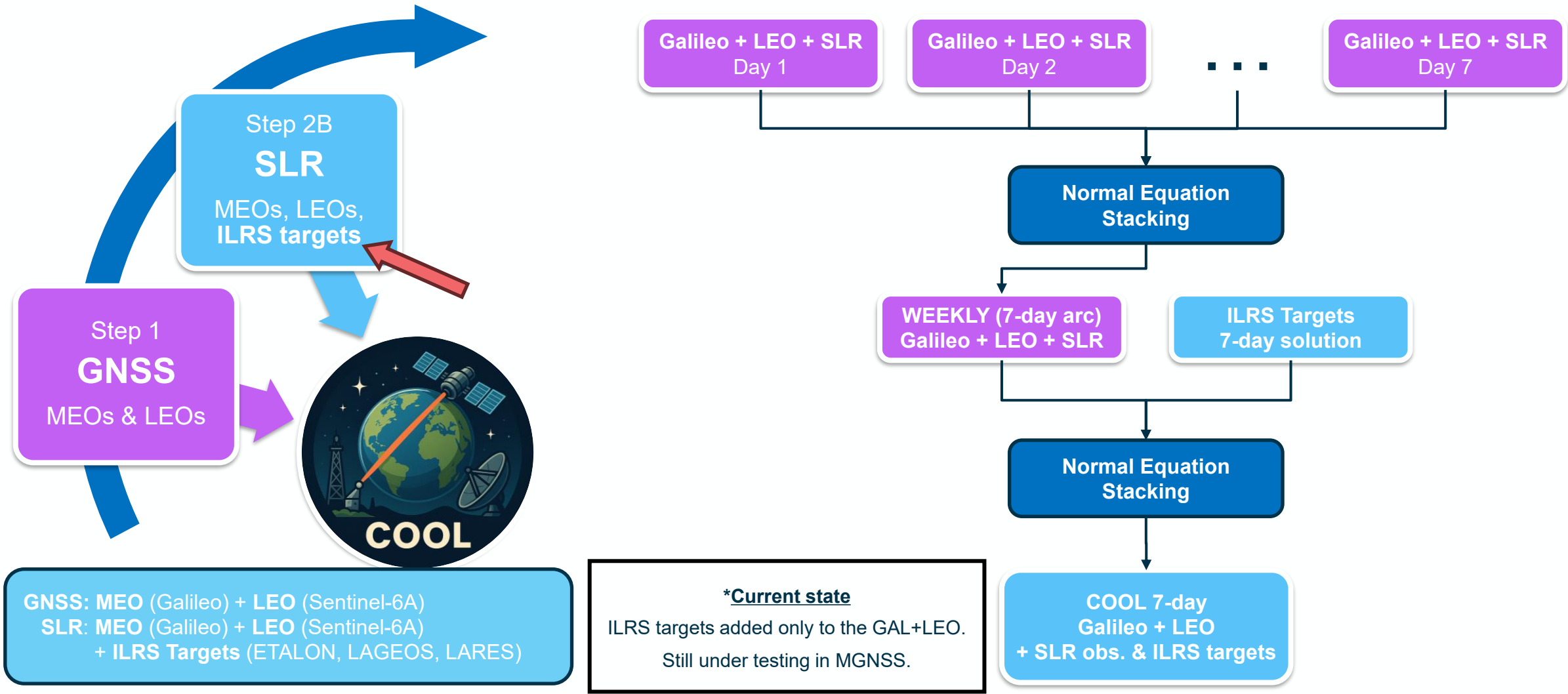


Observations selection
At this step only SLR to GNSS and LEO satellites is included

Observations sampling

- Standalone constellations (300s)
- MEO+LEO combinations (30s)

COOL: Galileo* & SLR (including ILRS targets)



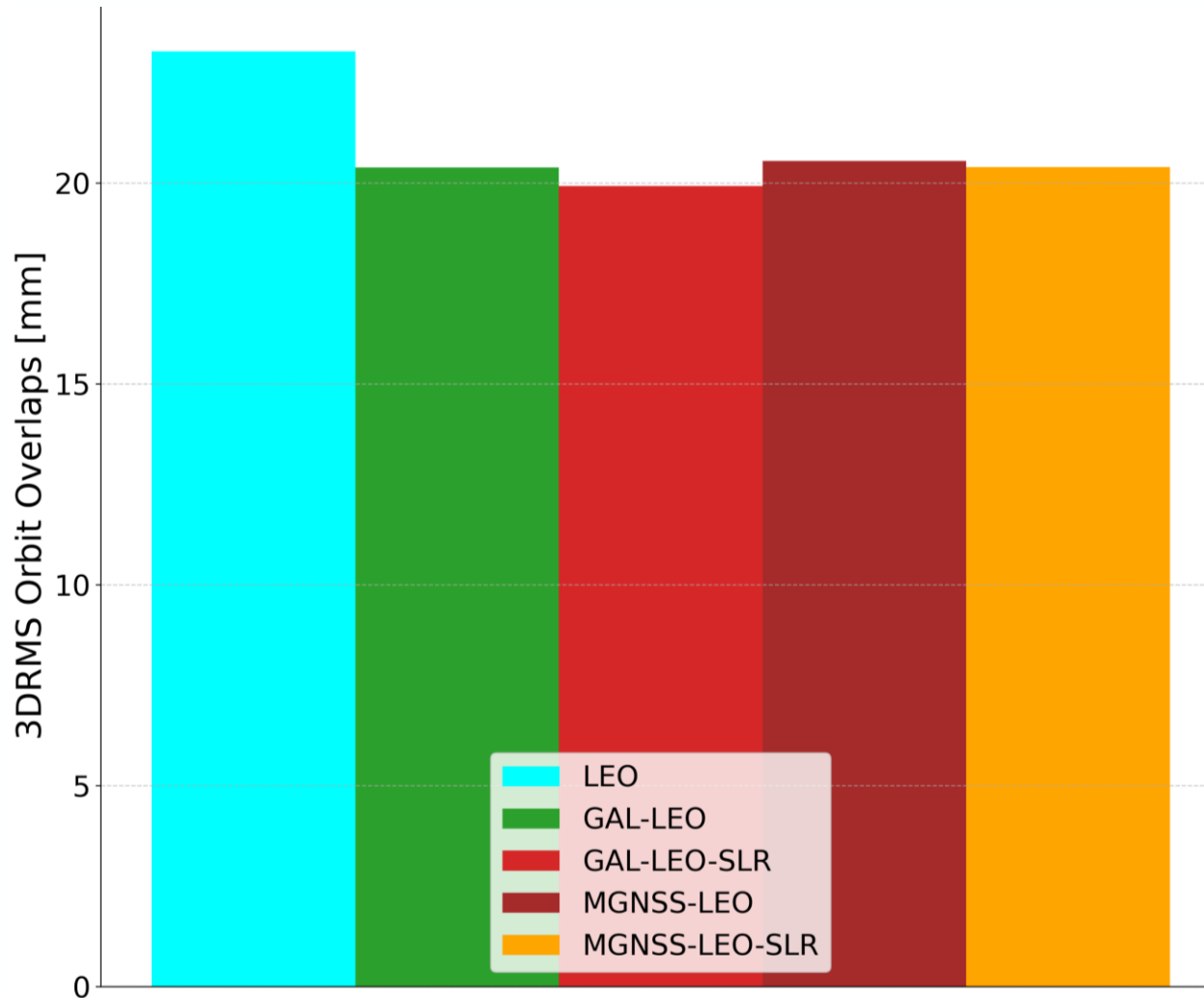
Solution Label	Description
GAL	Galileo only (GNSS only)
GAL-LEO	Galileo + LEO (GNSS only)
GAL-LEO-SLR	Galileo + LEO + SLR - SLR: Galileo and LEO
GAL-LEO-SLR-ILRS	Galileo + LEO + SLR + ILRS - SLR: Galileo and LEO - ILRS: LARES-2, 2xLAGEOS, 2xETALON
MGNSS	All GNSS constellations (GNSS only)
MGNSS-LEO	All GNSS + LEO (GNSS only)
MGNSS-LEO-SLR	All GNSS + LEO +SLR - SLR: Galileo and LEO - ILRS targets not yet included

* First 200 days of 2024 were processed



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Satellite Orbit Overlaps for LEO: Sentinel-6A

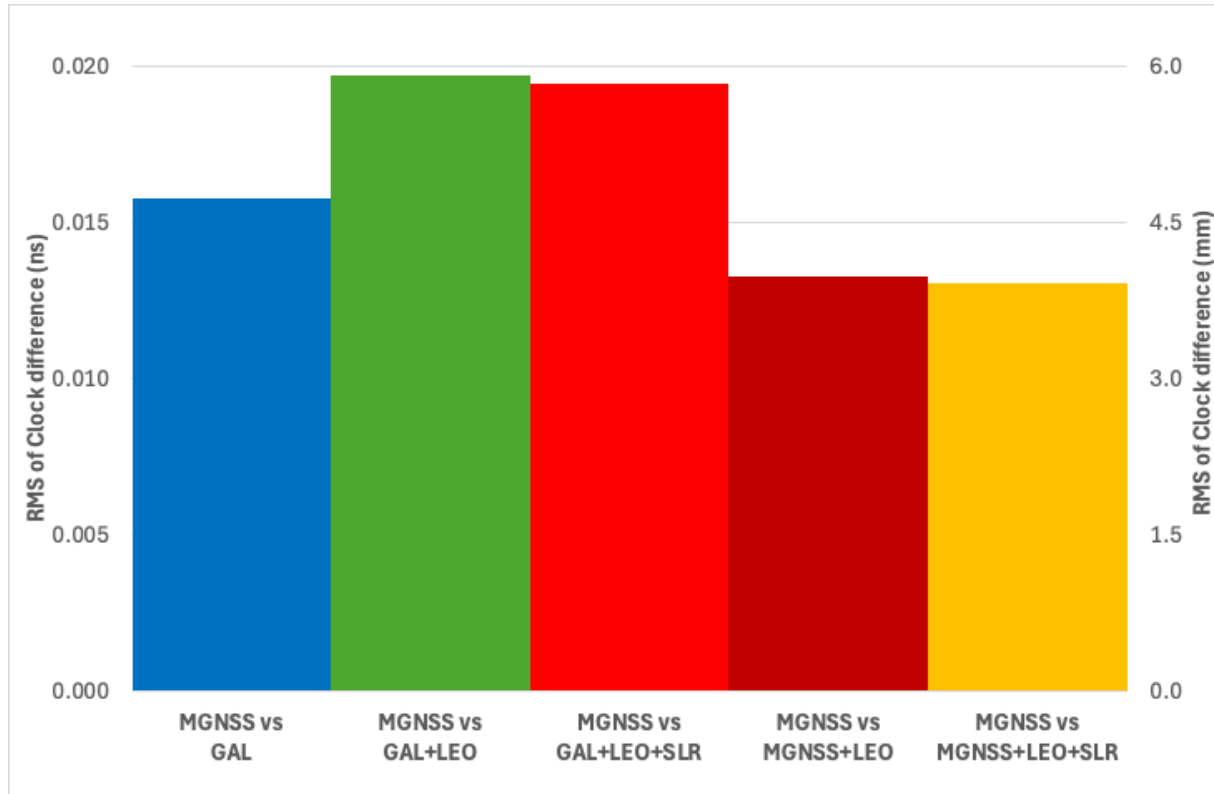


Main findings:

- Combining the LEO with Galileo considerably improves the LEO orbit consistency (20%)
- The addition of the SLR data further improves the LEO orbital consistency
- When combined with other constellations (both in case of GNSS-only and GNSS+SLR) the LEO orbit degrades marginally, but remains at the same level
- Overall, the multi-satellite (GNSS & LEO) and multi-technique (GNSS & SLR) combination is superior in terms of LEO orbit quality

*LEO refers to ESA's Sentinel PPP solution, submitted to the Copernicus Regular Service Review

* See Backup slide for Galileo and LEO satellite specific results 8



Clock differences

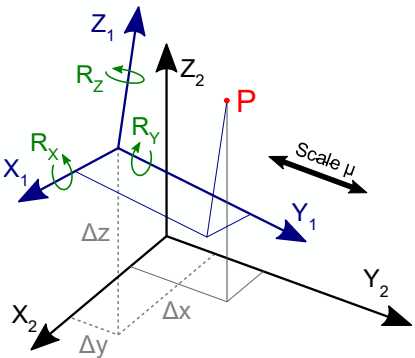
- Adding a single LEO receiver changes the results significantly, at the 35% level, which shows the power of including GNSS LEOs in GNSS solutions.
- SLR impact seems to be limited (after already including the LEO)
- We firmly believe that adding the GNSS LEO and the SLR observations improves the GNSS clocks
 - To be proven!

- The **Galileo and multi-GNSS solutions provide an almost unbiased** solution for Length Of Day
- Incorporating the **LEO into the solution primarily impacts the Polar estimates**, leading to a substantial decrease in the mean but with a higher standard deviation
- **SLR to Galileo and LEO do not have a significant impact** on ERPs estimates
- The combination with the **ILRS-targets slightly differs from the IERS** solution. Cause still under investigation

Solution	Length of Day [μ s]	X-Pole [mas]	Y-Pole [mas]
Galileo only	-0.02 ± 7.63	7.12 ± 13.96	15.34 ± 8.52
Galileo + LEO	0.92 ± 7.36	-0.11 ± 28.91	8.77 ± 18.24
Galileo + LEO + SLR	0.89 ± 5.73	-0.81 ± 29.29	8.66 ± 18.48
Galileo + LEO + SLR + ILRS	0.65 ± 10.63	4.91 ± 15.11	15.37 ± 8.77
MGNSS	-0.65 ± 5.62	10.39 ± 8.73	12.03 ± 8.75
MGNSS + LEO + SLR	0.66 ± 5.73	6.75 ± 12.65	13.55 ± 6.88

- ITRF alignment based on the common IGS20 and ILRS core stations, considering the origin of the ITRF2020-u2023 as the real Geocentre. Up to 200 GNSS and 14 SLR stations overall

Helmert Transformation conditions	
Reference Case (default)	Free Translation Case
No-Net-Translation Condition	Free Translation
No-Net-Rotation Condition	No-Net-Rotation Condition
Free scaling	Free scaling



- The comparison between these cases shows how stable the origin (Geocentre) of the NNR solutions is
- The addition of LEO (S6A) and, additionally the SLR, brings the solutions closer to the ITRF origin

Cases (units are mm)	Galileo	Galileo + LEO	Galileo + SLR	Galileo + LEO + SLR	Galileo + SLR + ILRS	Galileo + LEO + SLR + ILRS		MGNSS	MGNSS + LEO + SLR
Geocentric offset 3D	13.06 ± 5.73	4.72 ± 1.84	8.63 ± 3.70	4.63 ± 1.83	6.82 ± 3.45	4.07 ± 2.05		6.13 ± 2.53	4.61 ± 2.01
X	0.08 ± 8.41	0.13 ± 2.24	0.01 ± 4.08	0.16 ± 2.22	0.26 ± 3.88	-0.14 ± 1.67		1.07 ± 3.17	0.16 ± 2.25
Y	-1.82 ± 8.87	-2.63 ± 2.00	-1.01 ± 3.63	-2.60 ± 2.06	-0.81 ± 2.99	-1.84 ± 2.94		-0.20 ± 2.66	-2.39 ± 2.05
Z	-2.12 ± 6.87	-0.47 ± 3.08	-5.01 ± 5.70	-0.43 ± 2.95	-4.18 ± 4.14	0.14 ± 2.54		-2.61 ± 4.36	-0.71 ± 3.14

- The addition of one GNSS receiver in LEO into a network of 200 ground-based receivers improves the solution:
 - Orbit overlaps are significantly enhanced, improving consistency and precision
 - Clock estimates show notable changes (likely improvements) pending further validation
 - The Polar Motion estimates within the Earth Rotation Parameters (ERP) show improved accuracy with respect to IERS, while their precision decreases
 - The Geocenter estimates is more consistent with the IERS and exhibit increased stability
- SLR observations to both Galileo and LEO further improve the solution
- The inclusion of ILRS targets is currently under investigation. First results show that the Geocentre estimates improve, whereas the ERPs estimates slightly degrade
- Besides being COOL, this work lays essential ground for the Genesis mission
- Only with hands-on implementation, missing elements can be uncovered

Next steps:

- Galileo Z-offset and ITRF scale validation are underway, incorporating estimated biases from SLR and ILRS
- DORIS and VLBI integration are next, with active development of VLBI-to-satellite functionality in our software



Thank You for your Attention!

Questions and feedback are welcome!

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BACKUP slides

