# ESA combined processing for Genesis

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# Genesis Primary Objectives

**Contribute to improve ITRF accuracy and stability** by providing in-orbit colocation and necessary combined processing for the four space-based geodetic techniques that contribute to its realization. The goal is to contribute to the achievement of the Geodetic Global Observing System (GGOS) objectives for the ITRF realisation, aiming for a parameter **accuracy of 1 mm and a stability of 0.1 mm/year**, in order to provide significant scientific benefits in Earth modelling, and to support a wide range of societal applications (as endorsed by the United Nation resolution A/RES/69/266).

**Contribute to improve the link between the ITRF and the ICRF**, thanks to the increased consistency of the Earth Orientation Parameters (EOP). In particular, this mission shall allow for the first time a link between the orbit reference frame, ITRF and ICRF.

United Nations A/RES/69/266

General Assembly

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Agenda item 9

**Resolution adopted by the General Assembly on 26 February 2015**

*[without reference to a Main Committee (A/69/L.53 and Add.1)]*

**69/266. A global geodetic reference frame for sustainable development**

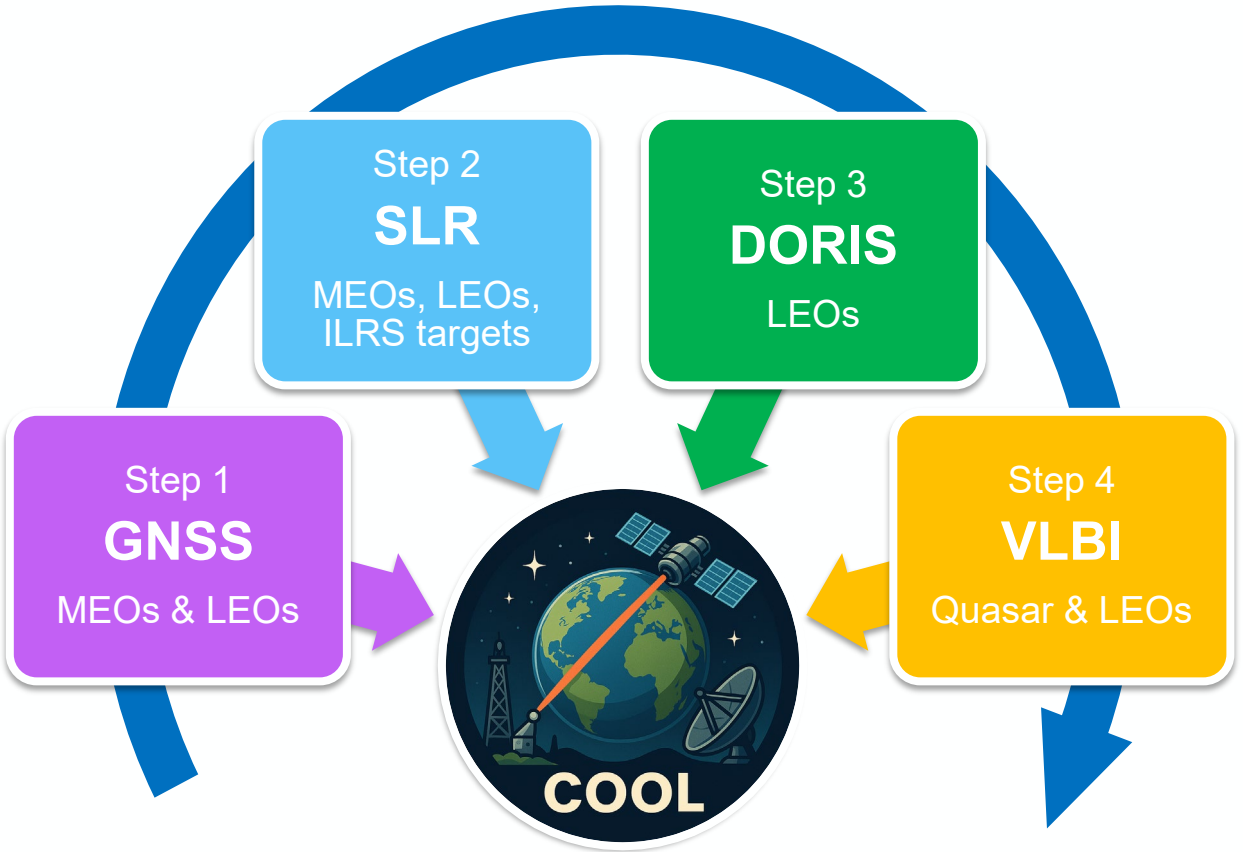
*The General Assembly,*

**Targets:**

**Accuracy:** 1 mm

**Stability:** 0.1 mm per year

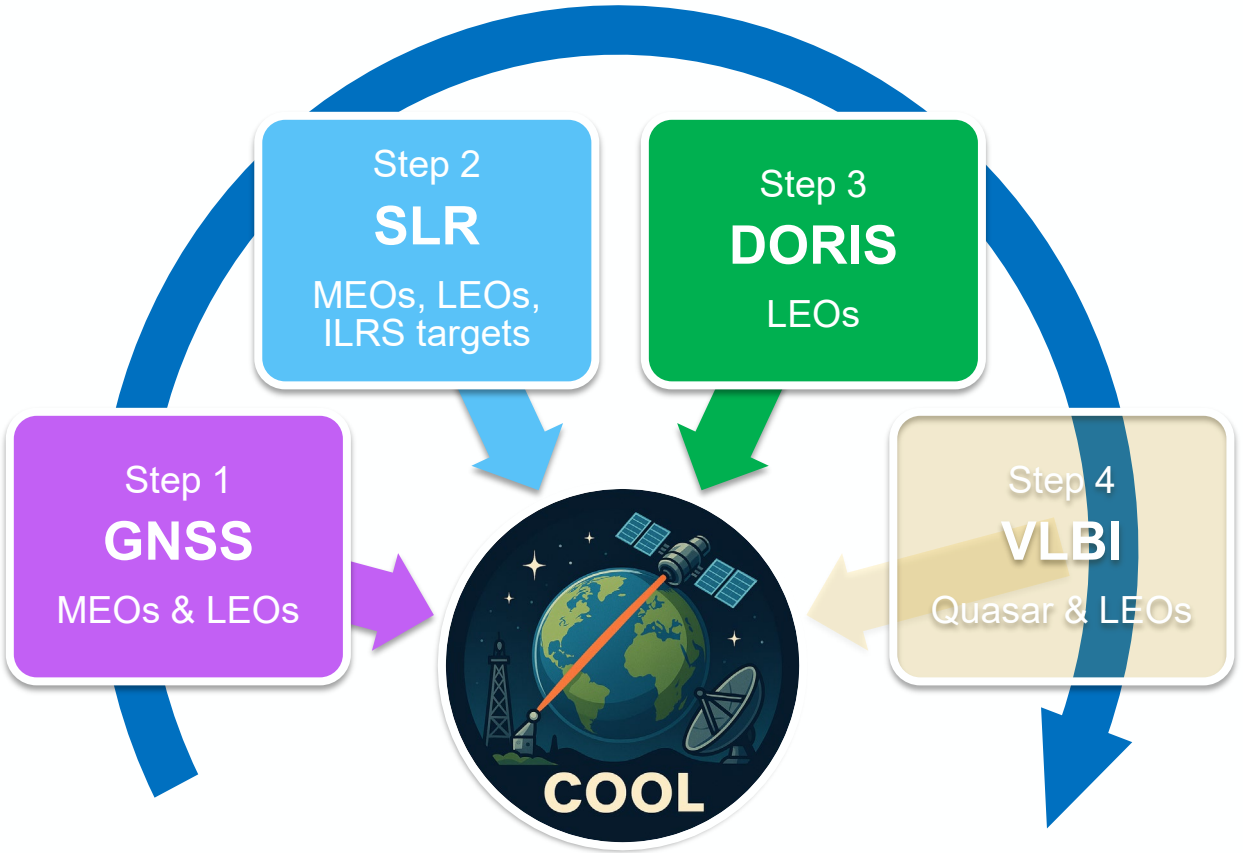
# COmbination at the Observation Level - COOL




**Main objectives:**

- Combine **all 4 geodetic techniques** together in one single processing run
- Benefit from the **strengths of each technique**
- Detect and **reduce technique-specific systematics**
- Exploit additional **Normal Equation Stacking**
- Pave the path, software and knowledge to contribute to the **Genesis** mission objectives achievement

# COOL – Current Status




Step 1

## GNSS + Sentinel satellites

- **Sentinel satellites** added to **Galileo** and **GPS** processing
- **Sentinel satellites** added to the **Multi-GNSS** processing

Step 2

## SLR to Galileo, Sentinel and ILRS targets

- **SLR observations to Galileo and Sentinel** added to the GNSS processing at the observation level
- **SLR observations to ILRS** targets (ETALON, LARES & LAGEOS) added to the GNSS processing at the normal equation level

Step 3

## DORIS (Work in Progress)

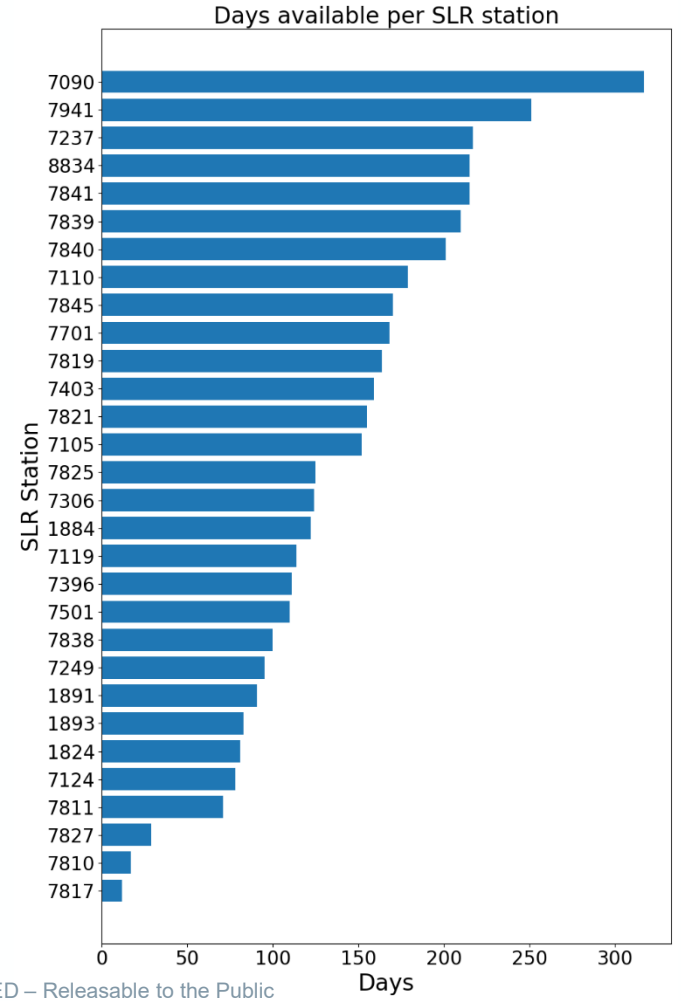
- **DORIS observation to Sentinel** added to the GNSS+SLR processing at the observation level
- **DORIS observations to IDS targets** added to the GNSS+SLR processing at the normal equation level

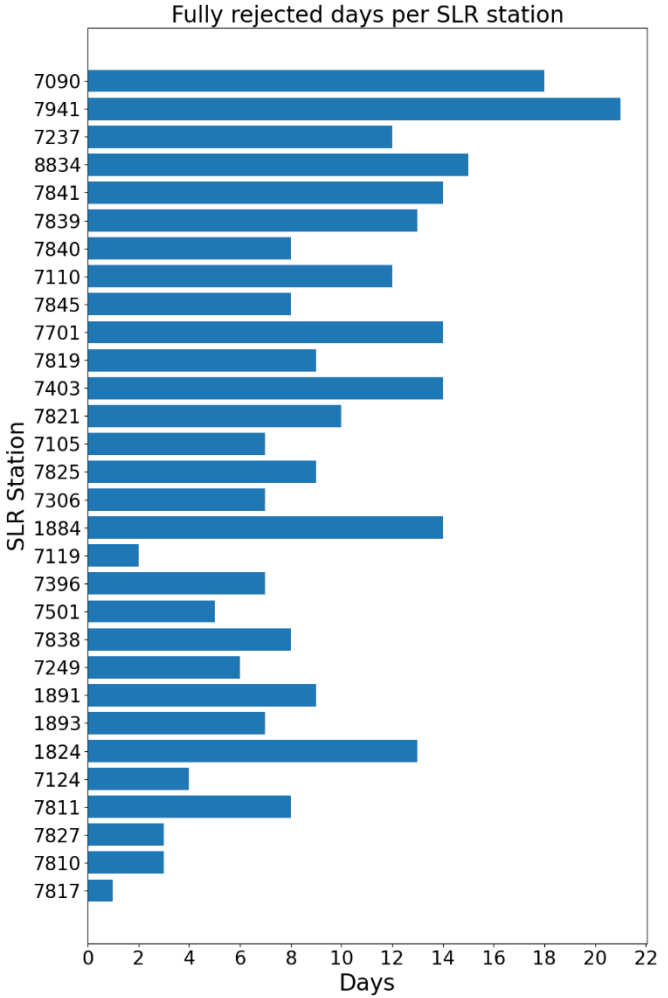
# COmbination at the Observation Level - COOL

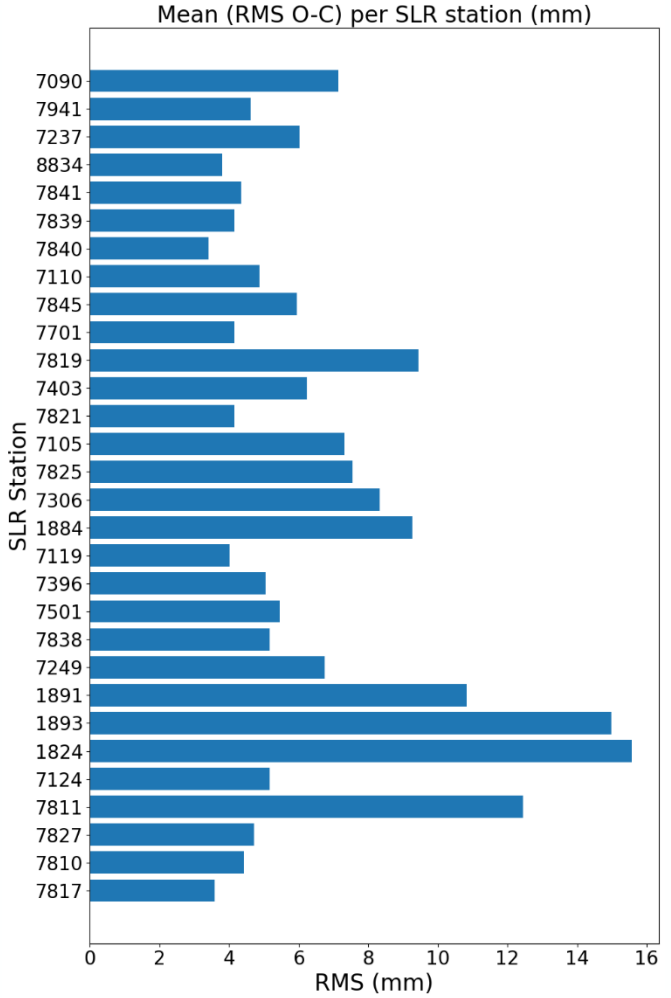
| Solution Label | Description |
|---|---|
| **GAL** | Galileo (GNSS) |
| **GAL+S6A** | Galileo (GNSS) + S6A (GNSS) |
| **GAL+SLR** | Galileo (GNSS, SLR) |
| **GAL+S6A+SLR** | Galileo (GNSS, SLR) + S6A (GNSS, SLR) |
| | |
| **MGNSS** | Galileo + GPS + GLONASS + BeiDou + QZSS (All GNSS) |
| **MGNSS+S6A** | MGNSS (GNSS) + S6A (GNSS) |
| **MGNSS+SLR** | Galileo (GNSS, SLR) + GPS + GLONASS + BeiDou + QZSS (GNSS) |
| **MGNSS+S6A+SLR** | Galileo (GNSS, SLR) + GPS + GLONASS + BeiDou + QZSS (GNSS) + S6A (GNSS, SLR) |
| | |
| **+ILRS** | LARES-2, LAGEOS-1 -2, ETALON-1 -2 |
| **+IDS** | SENT-3A, SENT-3B, SENT-6A, SARAL, JASON-3, CRYOSAT 2 |

# SLR Reference Station Selection

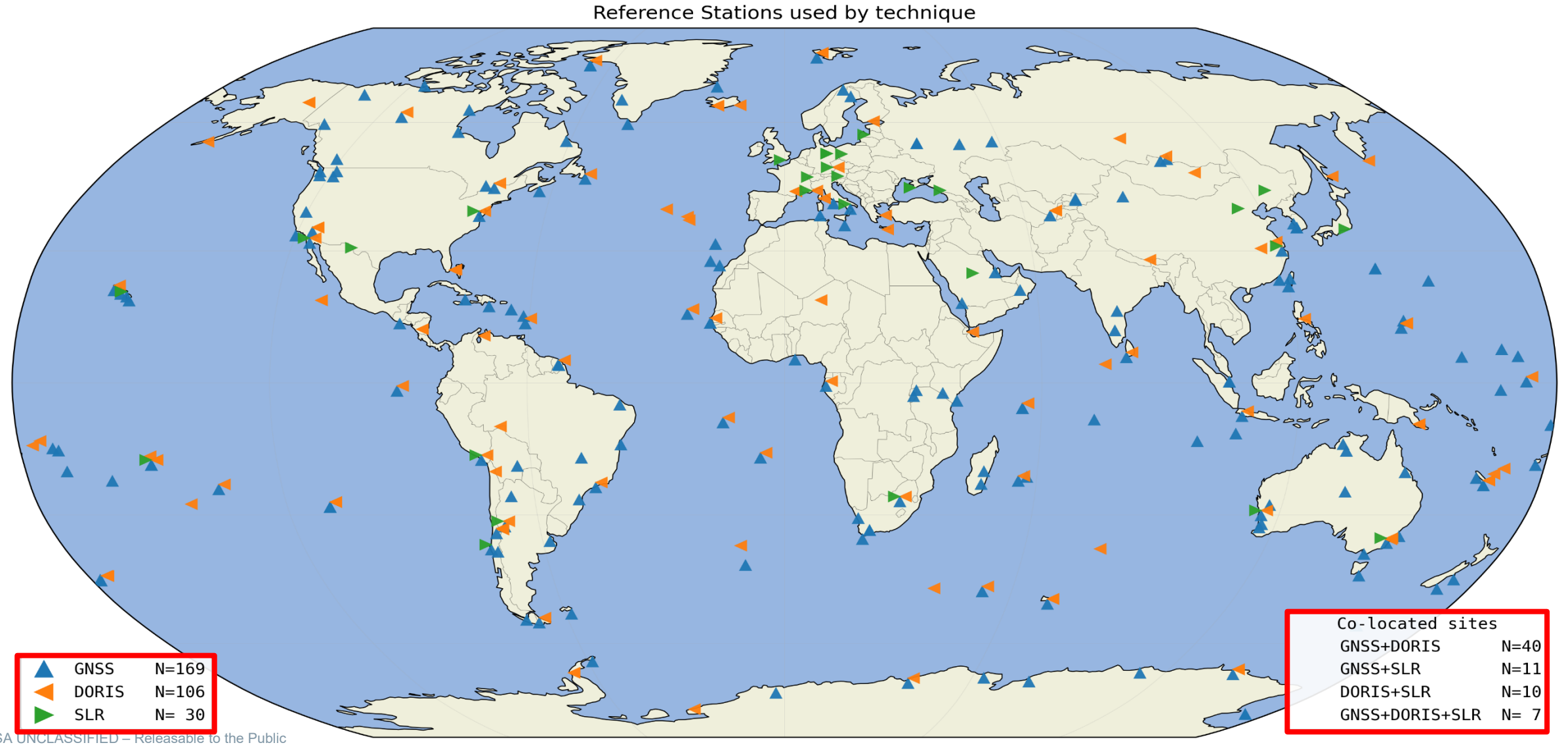
In addition to the IGS20 core stations for GNSS, the ILRS core sites list is extended for the current processing based on the general statistics throughout 2024. For the GAL+S6A+SLR case:



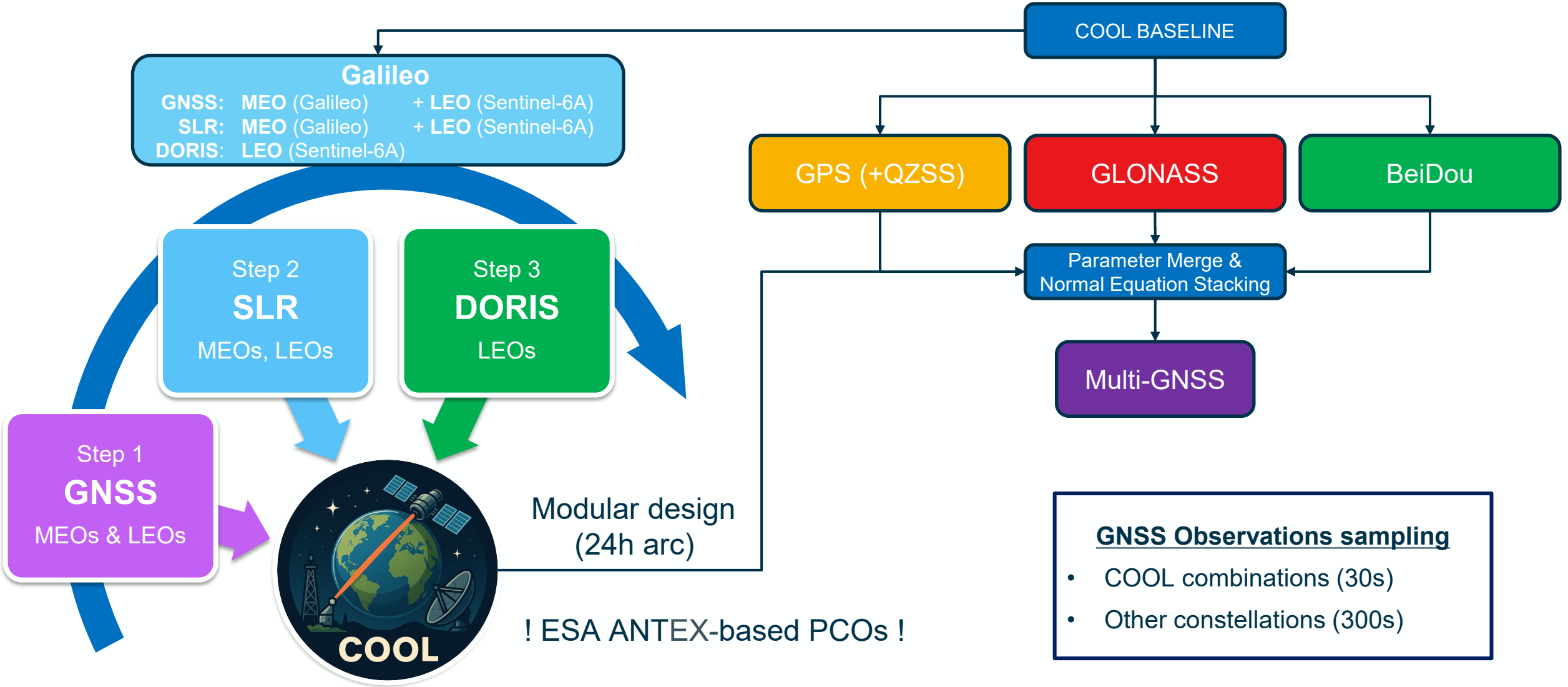



# Map of GNSS, DORIS and SLR reference stations



# COOL processing with Multi-GNSS NEQ stacking



# Scale Analysis between COOL and ITRF Coordinates

Comparison of the **nominal COOL solution** vs. a COOL solution incl. station coordinates constrained to ITRF *a priori* values. Results based on equal weighting of all (GNSS and SLR, as applicable) stations with removal of outliers

| Case | Scale [ppb] | | |
|---|---|---|---|
| | Mean | Sigma | RMS |
| GAL | -0.92 | 0.18 | 0.94 |
| GPS | -0.76 | 0.19 | 0.78 |
| BEI | -0.68 | 0.18 | 0.71 |
| GAL + S6A | -0.92 | 0.18 | 0.93 |
| GAL + S6A + SLR | -0.85 | 0.33 | 0.91 |
| GAL + SLR | -0.99 | 0.37 | 1.05 |

Processing Year 2024

| Helmert Transformation conditions |
|---|
| No-Net-Translation Condition (NNT) |
| No-Net-Rotation Condition (NNR) |
| Free scaling |

⇒ GAL scale offset is consistent with the use of esa23.atx and the different Galileo z-PCOs

⇒ As expected, Sentinel-6A alone does not contribute further independent scale information

⇒ The effect of SLR seems small

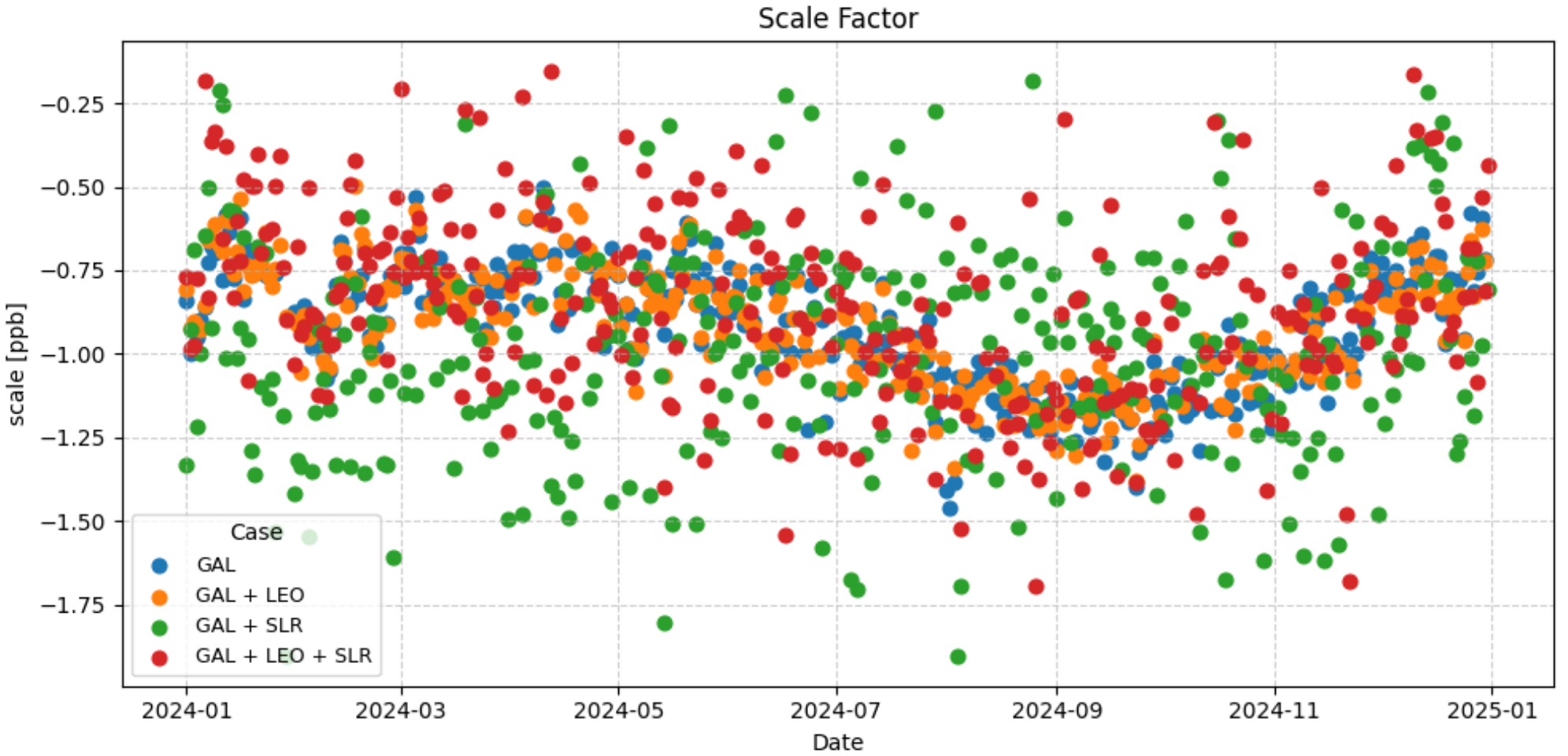
⇒ Most of the SLR observations refer to Sentinel-6A rather than Galileo itself

⇒ The combination of Sentinel-6A + SLR:

- on top of GAL, provides an external GNSS–SLR consistency check
- has a limited impact on the estimated scale

# Scale Analysis between COOL and ITRF Coordinates

The temporal distribution of the daily scale differences of our COOL solution wrt. ITRF seems to change on the second half of 2024 with a maximum amplitude of 0.5ppb



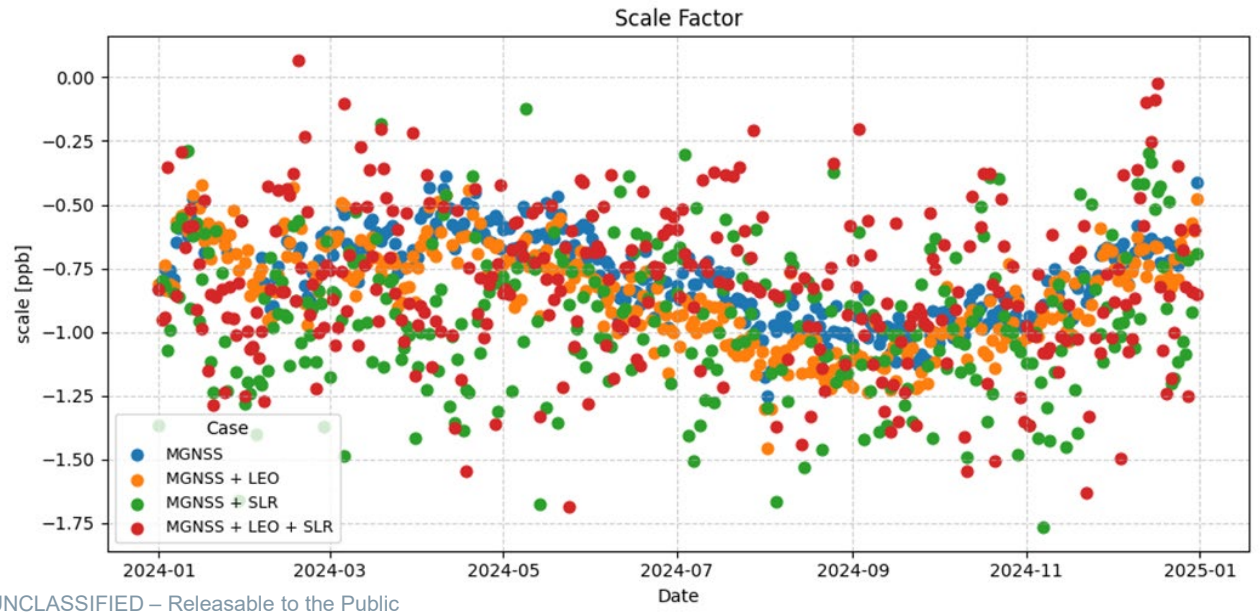
# Scale Analysis between COOL and ITRF Coordinates

Comparison of the **nominal MGNSS COOL solution** vs. a COOL solution incl. station coordinates constrained to ITRF *a priori* values. Results based on equal weighting of all (GNSS and SLR, as applicable) stations with removal of outliers

| Case | Scale [ppb] | | |
|---|---|---|---|
| | Mean | Sigma | RMS |
| GAL (Reference) | -0.92 | 0.18 | 0.94 |
| MGNSS | -0.79 | 0.17 | 0.80 |
| MGNSS + S6A | -0.85 | 0.20 | 0.87 |
| MGNSS + S6A + SLR | -0.82 | 0.30 | 0.87 |
| MGNSS + SLR | -0.94 | 0.28 | 0.98 |

Processing Year 2024

| Helmert Transformation conditions |
|---|
| No-Net-Translation Condition (NNT) |
| No-Net-Rotation Condition (NNR) |
| Free scaling |

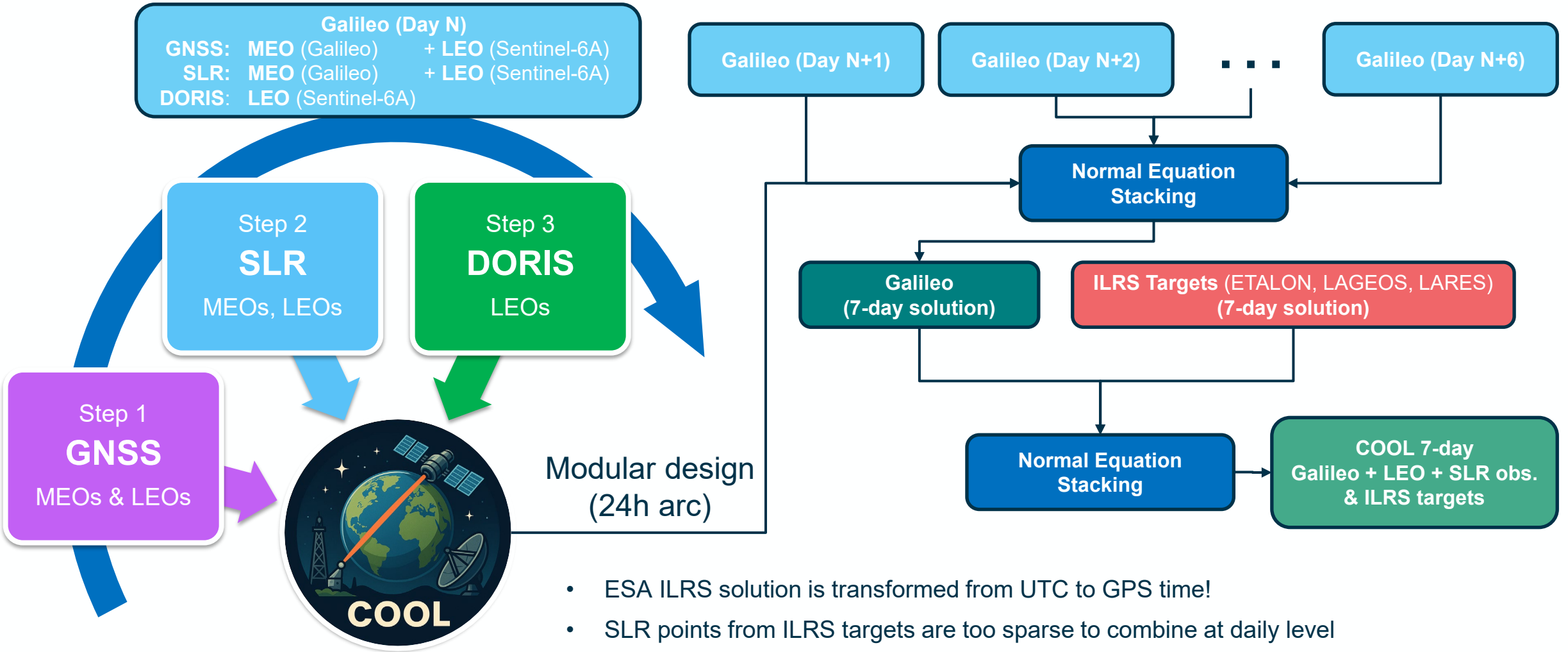



⇒ Overall, the MGNSS combinations do not divergence significantly from the GAL cases

⇒ The effect of Sentinel-6A on the MGNSS combination is larger than in GAL alone

⇒ The addition of SLR shows less but still scattered differences

# COOL processing with ILRS NEQ stacking




- ESA ILRS solution is transformed from UTC to GPS time!
- SLR points from ILRS targets are too sparse to combine at daily level

# Scale Analysis between COOL and ITRF Coordinates

Comparison of the **nominal ILRS COOL solution** vs. a COOL solution incl. station coordinates constrained to ITRF *a priori* values. Results based on equal weighting of all (GNSS and SLR as applicable) stations with removal of outliers

SLR Range Biases are left free to adjust up to a meter of the *a priori* values

| Case | Scale [ppb] | | |
|---|---|---|---|
| | Mean | Sigma | RMS |
| ILRS | -0.64 | 1.34 | 1.47 |
| GAL (Reference) | -0.92 | 0.18 | 0.94 |
| GAL + ILRS | -0.94 | 0.16 | 0.96 |
| GAL + S6A + ILRS | -0.94 | 0.16 | 0.95 |
| GAL + S6A + SLR + ILRS | -0.89 | 0.24 | 0.92 |
| GAL + SLR + ILRS | -1.00 | 0.34 | 1.05 |

Processing Year 2024

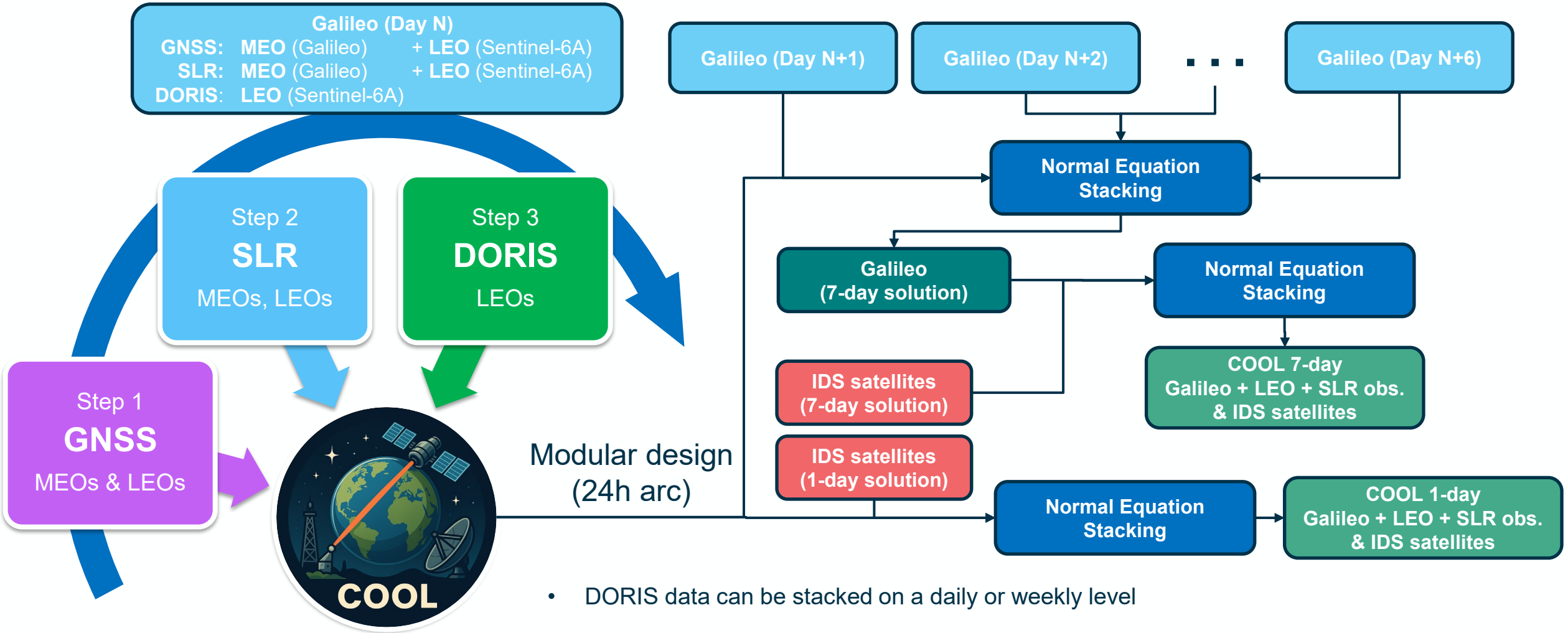
| Helmert Transformation conditions |
|---|
| No-Net-Translation Condition (NNT) |
| No-Net-Rotation Condition (NNR) |
| Free scaling |

⇒ The results based on ILRS-only targets do not align with the ITRF scale, showing a large spread of the results

⇒ The addition of Sentinel-6A along with ILRS targets remains consistent with the GAL reference

⇒ Overall, the ILRS combinations do not diverge significantly from the GAL case, slightly reducing the data spread

# COOL processing with IDS NEQ stacking




- DORIS data can be stacked on a daily or weekly level

# Scale Analysis between COOL and ITRF Coordinates

Comparison of the **nominal IDS COOL solution** vs. a COOL solution incl. station coordinates constrained to ITRF *a priori* values. Results based on equal weighting of all (GNSS and SLR as applicable) stations with removal of outliers


⇒ IDS solution **is being** transformed from UTC to GPS time in our infrastructure source code!

⇒ DORIS 2024 data reprocessing being completed

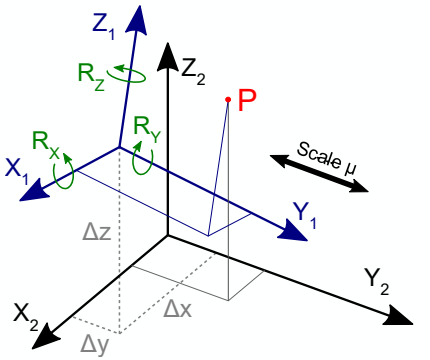
⇒ **Coming soon!**

# COOL Improvement of Geocentre estimates

ITRF alignment based on the IGS20 core stations and the extended ILRS station list

Considering the origin of the ITRF2020-u2023 as reference Geocentre

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




- The comparison shows the stability of the origin (Geocentre) of the NNR solutions
- The addition of LEO and SLR observations brings the solutions closer to the ITRF origin
- The addition of the ILRS targets to LEO and SLR further reduces the geocentric offset in all directions
- SLR Range Biases are left free to adjust up to 1 meter of the *a priori* values

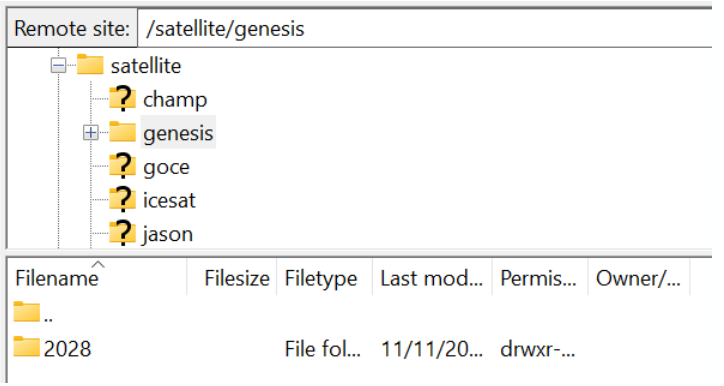
| Cases<br>(Units are mm) | Galileo | Galileo<br>+ LEO | Galileo<br>+ SLR | Galileo<br>+ LEO + SLR | ILRS<br>+ Galileo<br>+ LEO | ILRS<br>+ Galileo<br>+ LEO + SLR | MGNSS | MGNSS<br>+ LEO + SLR |
|---|---|---|---|---|---|---|---|---|
| Geocentric offset 3D | 8.60 ± 3.47 | 5.54 ± 2.02 | 4.31 ± 2.44 | 3.53 ± 1.58 | 4.16 ± 1.76 | 2.70 ± 2.20 | 6.04 ± 2.53 | 3.17 ± 1.42 |
| X<br>Y<br>Z | 1,01 ± 3.88<br>-2.02 ± 3.97<br>-1.64 ± 6.89 | 0.59 ± 2.15<br>-3.42 ± 2.39<br>0.52 ± 3.48 | 0.40 ± 2.28<br>-1.23 ± 2.28<br>-0,87 ± 3.43 | 0.42 ± 1.95<br>-1.81 ± 1.92<br>0.21 ± 2.00 | 0.54 ± 1.41<br>-2.78 ± 1.83<br>0.90 ± 2.54 | 0.30 ± 1.14<br>-1.95 ± 1.94<br>0.49 ± 1.73 | 1.24 ± 2.90<br>-1.02 ± 3.17<br>-1.94 ± 4.27 | 0.46 ± 1.79<br>-1.54 ± 1.70<br>0.11 ± 1.84 |

# Conclusion and Next Steps

- **No clear transfer of scale information from SLR** into the combined solutions in these 2024 scenarios (scale remains largely **GNSS-driven**)
- **Geocentre impact is visible:** adding **LEO (Sentinel-6A)** and **SLR** (to **GNSS**, **Sentinel** and **ILRS targets**) moves the solution closer to the **ITRF origin** and improves stability
- **DORIS results and analysis** of its effect in the combination **upcoming**
- **COOL as Genesis preparation:** modular observation-level combination + Normal Equation Stacking enables controlled sensitivity studies, quantifying what information is (or is not) transferred between techniques
- **Next steps:** refine relative weighting / **SLR range-bias handling**, and extend multi-technique combinations

More to come at **EGU**:
*Keeping It COOL: GNSS–SLR Combination at the Observation Level*

Genesis data available in ftp://gssc.esa.int




Genesis Ref. Orbit File and dynamic model description