Evolution of Precise Navigation Products at ESA

Frank Zimmermann[1], Iván Sermanoukian[2], Francesco Gini[1], Erik Schönemann[1], Tim Springer[3], Michiel Otten[3], Florian Dilssner[3], Volker Mayer[4], Birgit Traiser[4]

[1] ESA/ESOC, Darmstadt, Germany
[2] VisionSpace Technologies GmbH, Darmstadt, Germany
[3] PosiTim UG, Darmstadt, Germany
[4] LSE Space GmbH, Darmstadt, Germany

European Navigation Conference (ENC) 2025, Wrocław, Poland
Session on Precise Navigation Products and Galileo HAS – 21/05/2025

ESA UNCLASSIFIED – Releasable to the Public

The Navigation Support Office at ESOC

Precise Orbit and Clock Determination (POD)

for all GNSS with focus on Galileo/EGNOS and for LEO Satellites

Generating reference products + geodetic reference

Operations of a Global GNSS Sensor Station Network

Precise Navigation

Independent Reference for Europe

We support/enable Navigation!

3rd Party Customers Contracts

Supporting / enabling European Industry

International Activities

International GNSS Service (IGS)
International Committee on GNSS (ICG)
Interagency Operations Advisory Group (IOAG)

Promoting ESA's and European Industry's interests

Products & Services

Precise Navigation Products

- High-accuracy GNSS orbits and clocks (batch processing and real-time)
- Precise Orbit Determination of satellites ranging from Low Earth Orbit (LEO) via High Eccentric Orbit (HEO) to Lunar Orbit

Galileo Terrestrial Reference Frame (GTRF)

- Dedicated reference frame, computed based on Galileo infrastructure
- Requirement that GTRF remains aligned with ITRF within 3 cm (95.4%)

Earth Orientation Parameters (EOP)

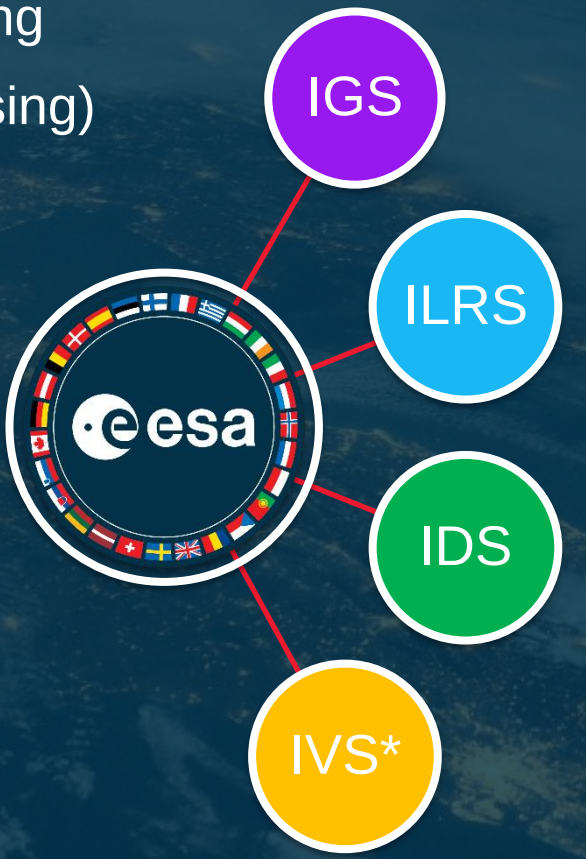
- EOP data provides the link between the coordinate systems on Earth and in space.
- Represent a critical input for Precise Orbit Determination

Coordinated Universal Time (UTC)

- We operate the Timing Facility at ESOC, where local timescale generation is based on two active hydrogen masers operated in a thermally stable environment.

Contribution to International Geodetic Services

- **GNSS** products, contributing to **IGS**
  - Constellation-wise processing with Normal Equation stacking
  - CHAMP (Consolidated High Accuracy Multi-GNSS Processing)
- **SLR** products:
  - SLR targets: contributing to **ILRS**
  - SLR to MEOs & LEOs for validation purposes
- **DORIS** products
  - DORIS-equipped LEOs: contributing to **IDS**
- **VLBI** products:
  - VLBI to Quasars and *soon* to contribute to **IVS**



Genesis – At the Foundation of Navigation

Contribute to improve ITRF accuracy and stability:

- Parameter **accuracy of 1 mm**
- Parameter **stability of 0.1 mm/year**

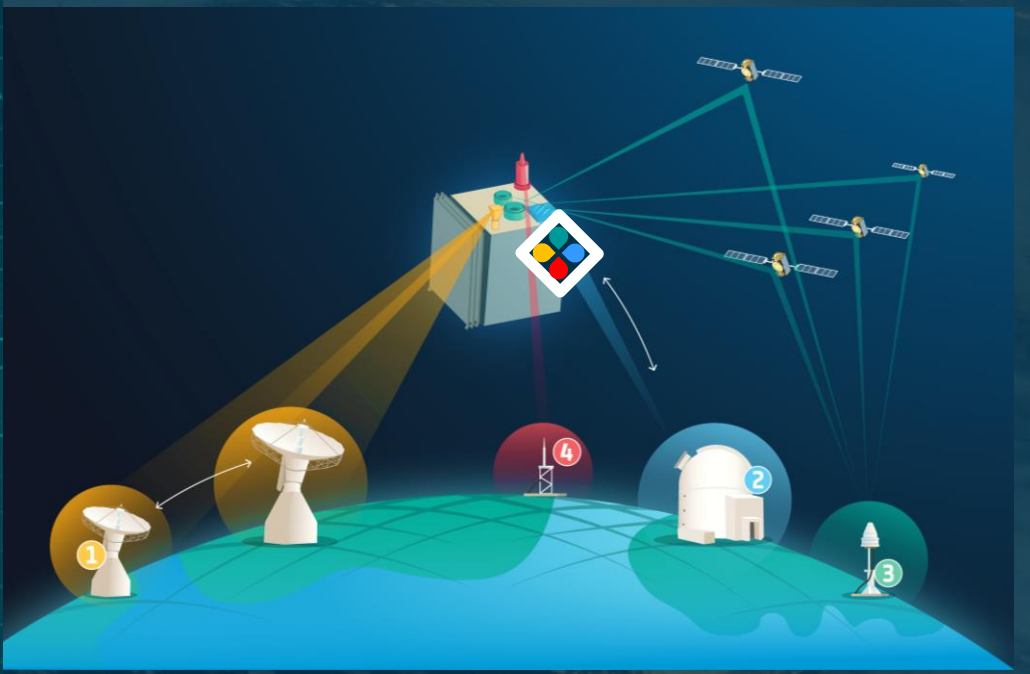
Contribute to improve the link between the ITRF and the ICRF

1 - VERY-LONG-BASELINE INTERFEROMETRY (VLBI) Transmitter

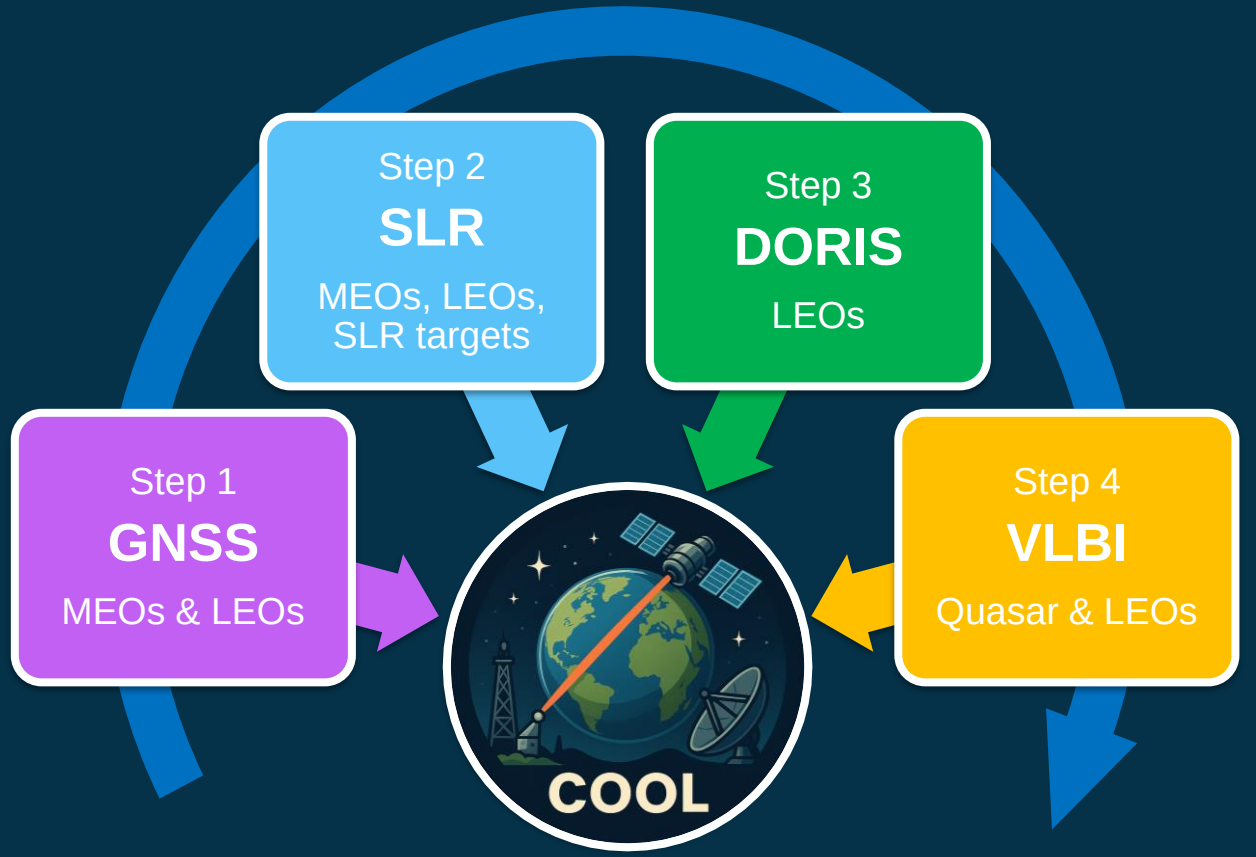
2 - SATELLITE LASER RANGING (SLR) Retroreflector

3 - GLOBAL SATELLITE NAVIGATION SYSTEMS (GNSS) Receiver (Nadir and Zenith antennas)

4 - DORIS Receiver

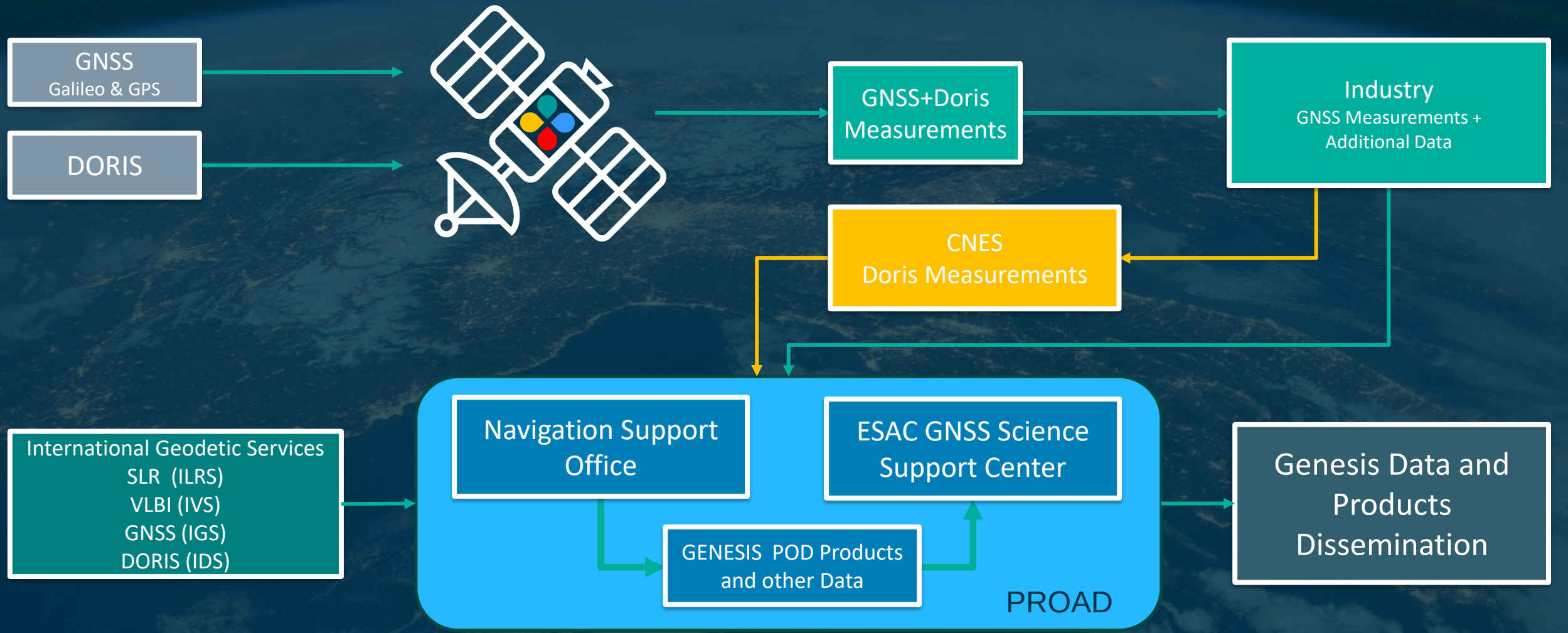


Combination On Observation Level (COOL)

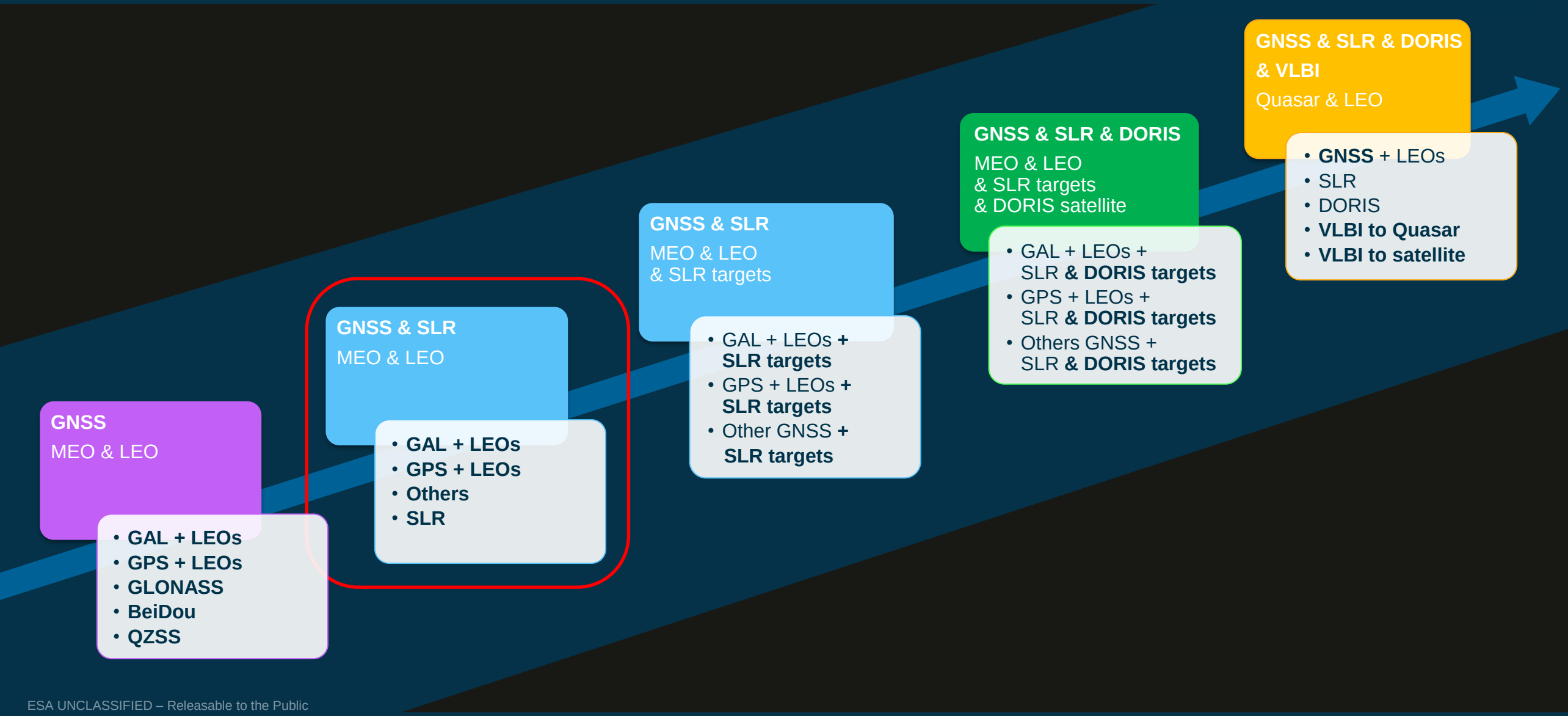


- Combine satellite-geodetic techniques on observation level
- Process techniques together in one run
- Apply Normal Equation Stacking approach developed for CHAMP
- Make use of different strengths and weaknesses of techniques
- Detect and reduce technique-specific systematic behaviour
- Implemented in one software package (EPNS)

Genesis Data PROcessing, Archiving and Distribution



Roadmap to Combination On the Observation Level



ESA UNCLASSIFIED – Releasable to the Public

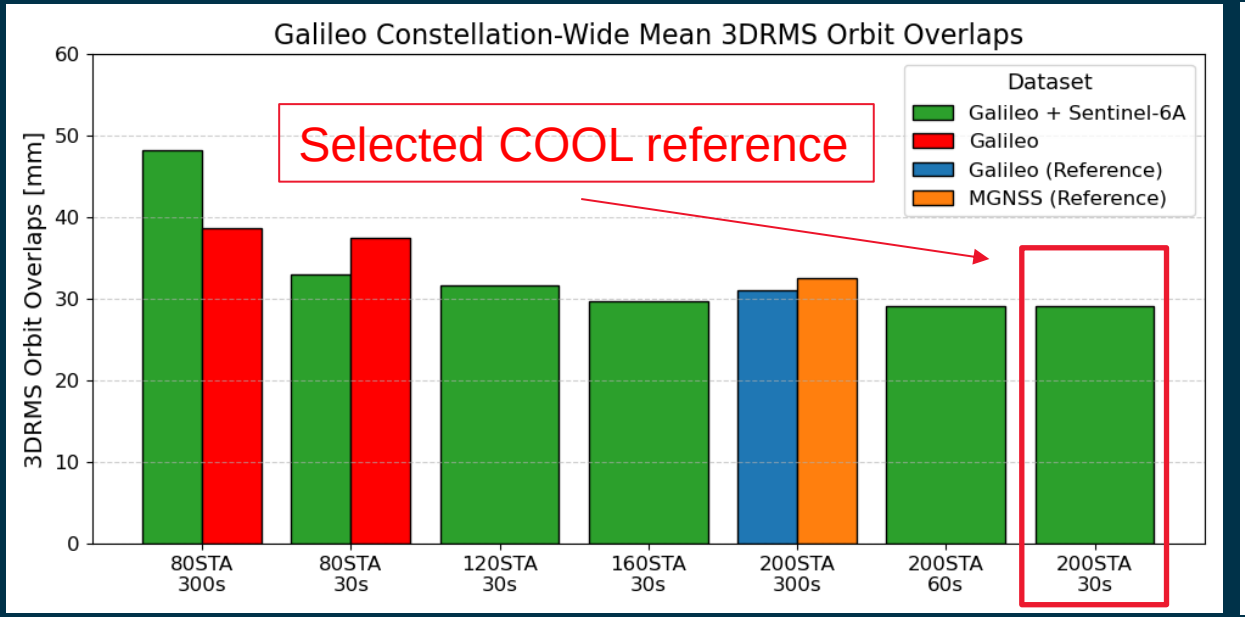
Results for Combined MEO & LEO POD Processing

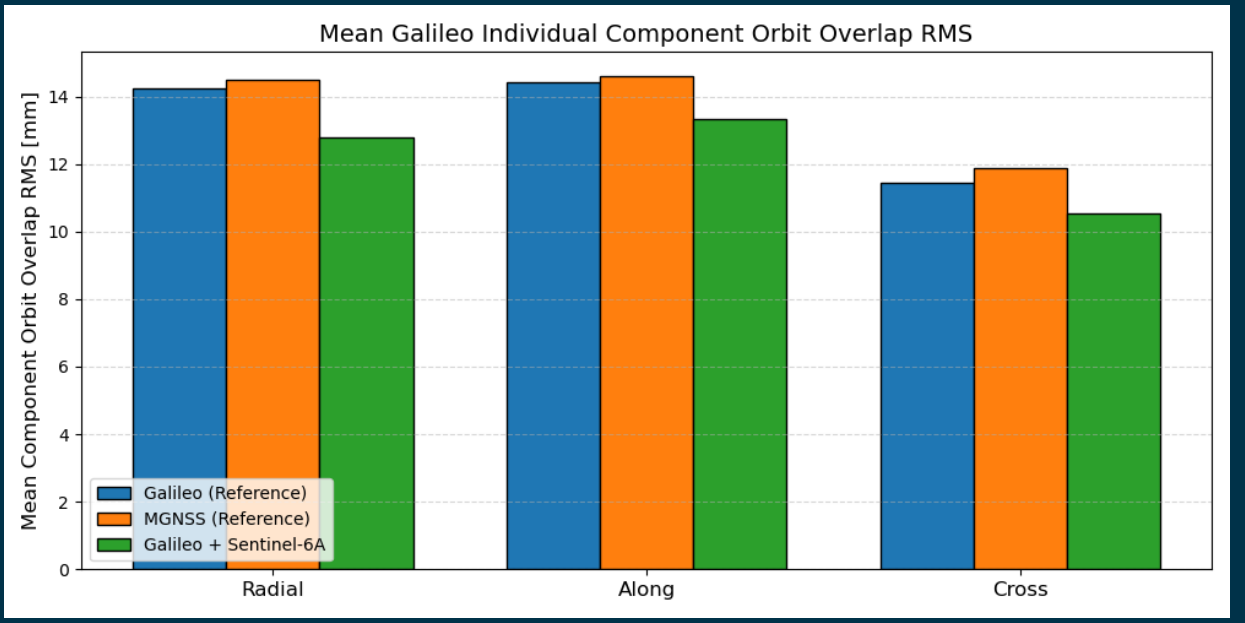
Temporal stability across 24h arcs: **Satellite Orbit Overlaps for Galileo**

- Improved orbital consistency wrt. Galileo-only solutions when using more than 120 ground stations along with Sentinel 6A
- Changes in temporal data sampling do not significantly impact the Galileo-only processing, unless the selected time step does not provide enough observations per pass for the LEO satellites.
- Overall reduction in the individual component overlaps, independent from direction (radial, along- and cross-track)

MGNSS = Galileo + GPS/GLONASS/QZSS/BeiDou

Processing settings:
- Duration: Year 2024 (366 days)
- Arc length: 24h
- Reference Frame: ITRF2020 alignment

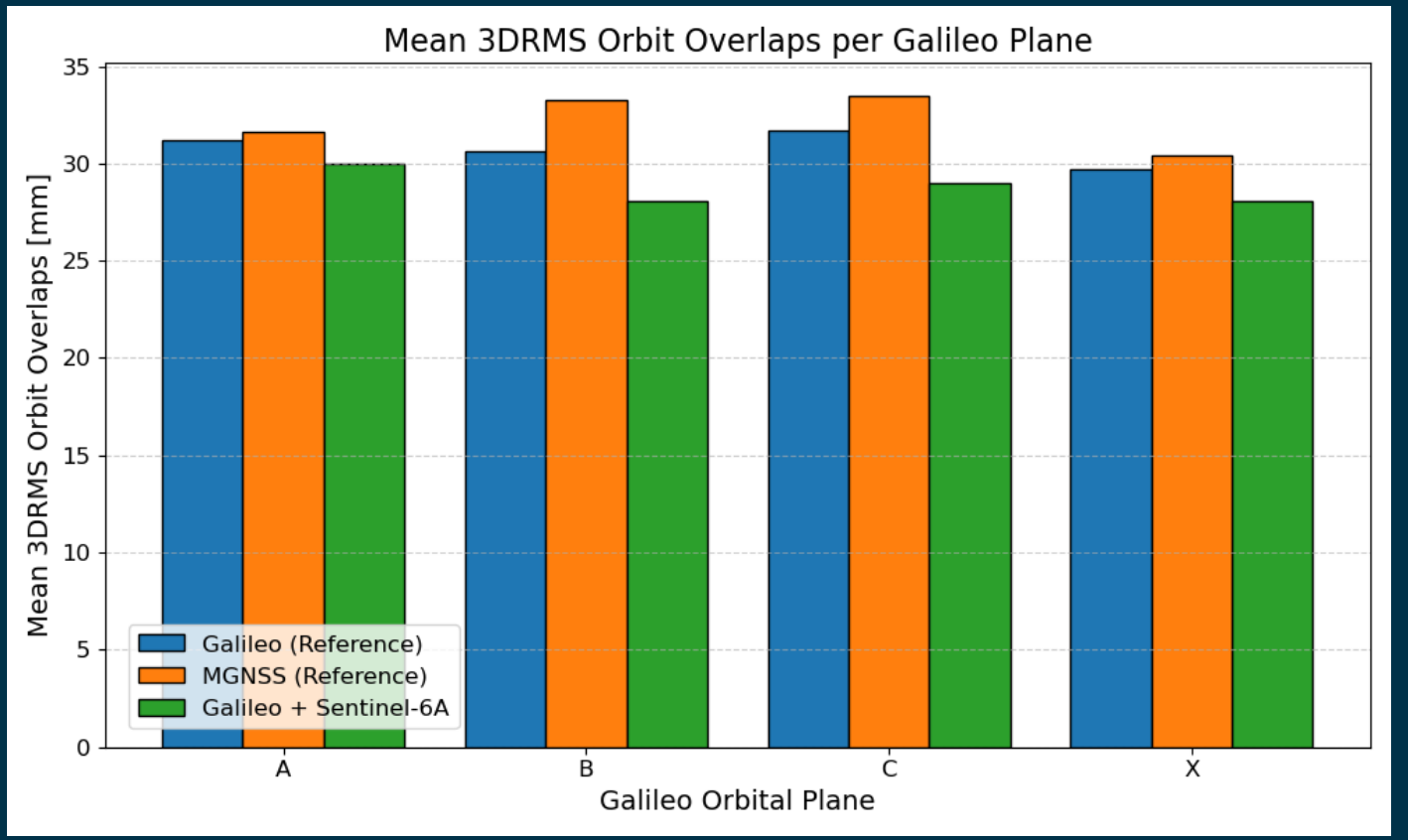




Results for Combined MEO & LEO POD Processing

Temporal stability across 24h arcs: **Satellite Orbit Overlaps for Galileo orbital planes**

- A more detailed analysis of the selected COOL solution along with the CHAMP references shows larger improvements in satellites in either B or C planes, while A and the 2 eccentric satellites (grouped in plane X) do not benefit as much.

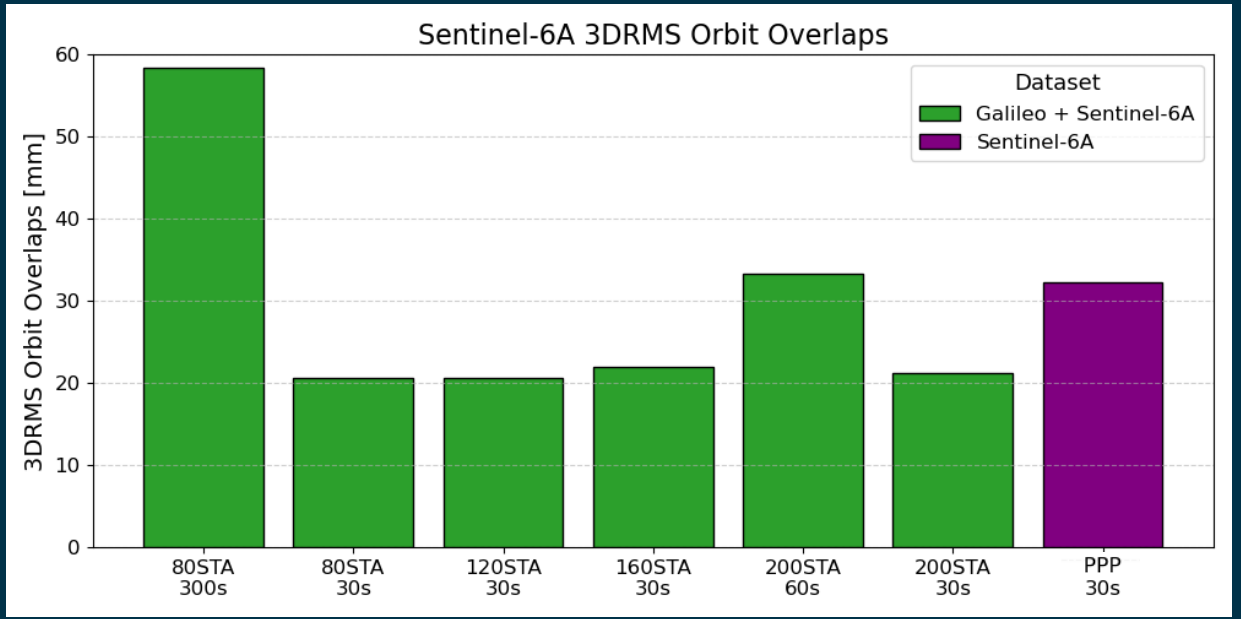


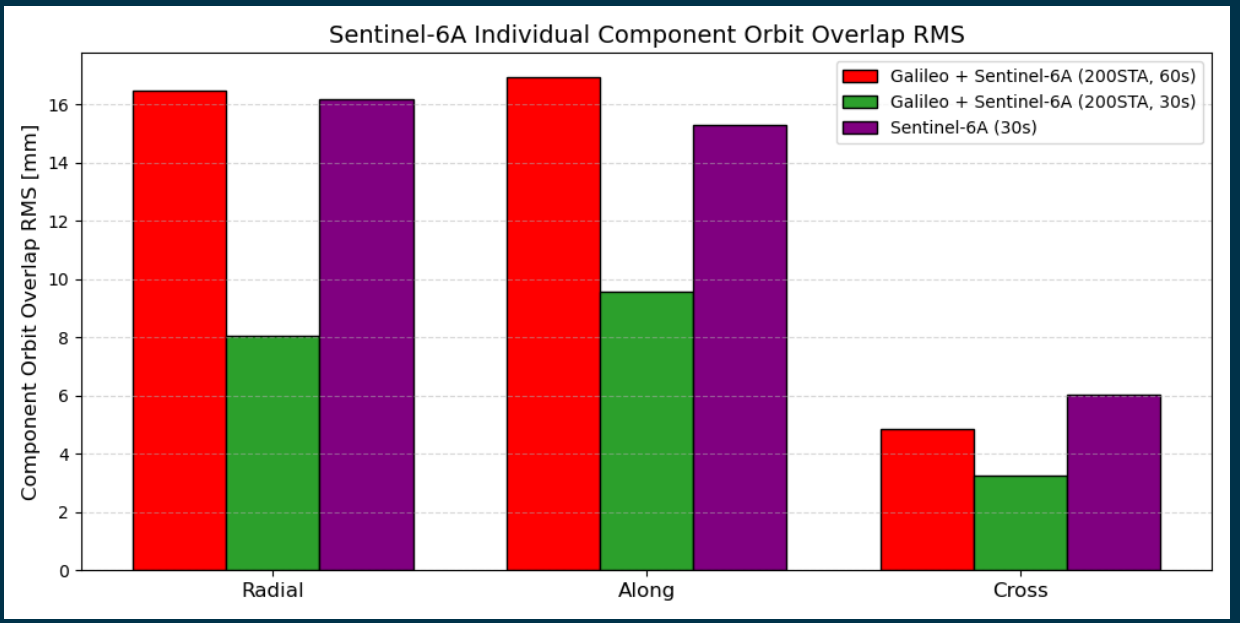
Results for Combined MEO & LEO POD Processing

Temporal stability across 24h arcs: **Satellite Orbit Overlaps for Sentinel-6A**

- Increased relevance of the temporal data sampling for Sentinel-6A within the combined COOL approach, as there is a clear improvement from 60 to 30 second sampling, even better than the regular Galileo-only Sentinel-6A PPP with 24h arcs.
- The largest reductions, up to 50% from the original values, are in the radial and along track axes, with smaller improvement in the cross-track axis.

Processing settings:
- Duration: Year 2024 (366 days)
- Arc length: 24h
- Reference Frame: ITRF2020 alignment

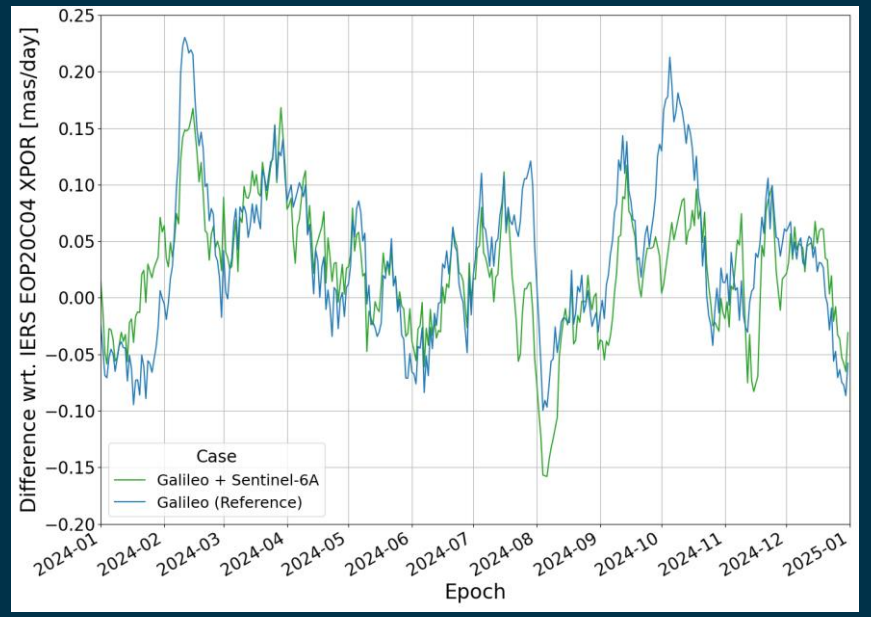


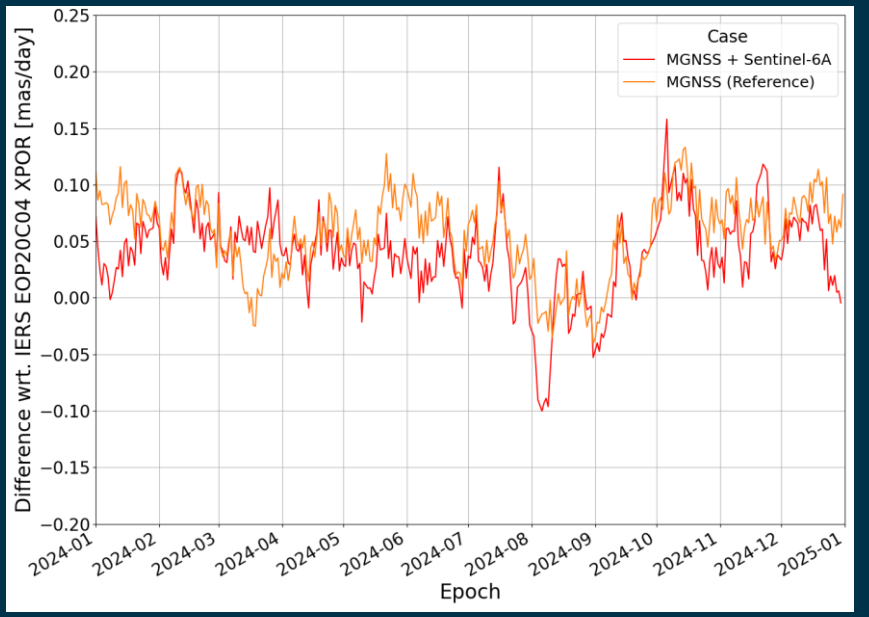


Effects on Earth Orientation Parameters

Impact on the Earth Orientation Parameter (EOP) estimates (e.g. X-Polar Motion Rate)

Satellite constellation	# Stations	Sampling	Information	Mean X-Pole rate bias [ms]	STD X-Pole rate difference [ms]	Drift X-Pole rate difference [ms/year]
Galileo	200	300s	Individual Reference Case	0.0340	0.0761	0.0106
Galileo + Sentinel-6A	200	30s		0.0231	0.0550	-0.0367
MGNSS	200	300s	Current IGS AC output	0.0562	0.0355	0.0008
MGNSS + Sentinel-6A	200	300s/30s		0.0381	0.0362	-0.0094





⇨ The introduction of Sentinel-6A can improve the Polar Motion rate estimates w.r.t. IERS EOP20C04 in terms of mean bias and standard deviation, while increasing the yearly drift for 2024.

Reference Scenario Orbit Overlaps – SLR Addition

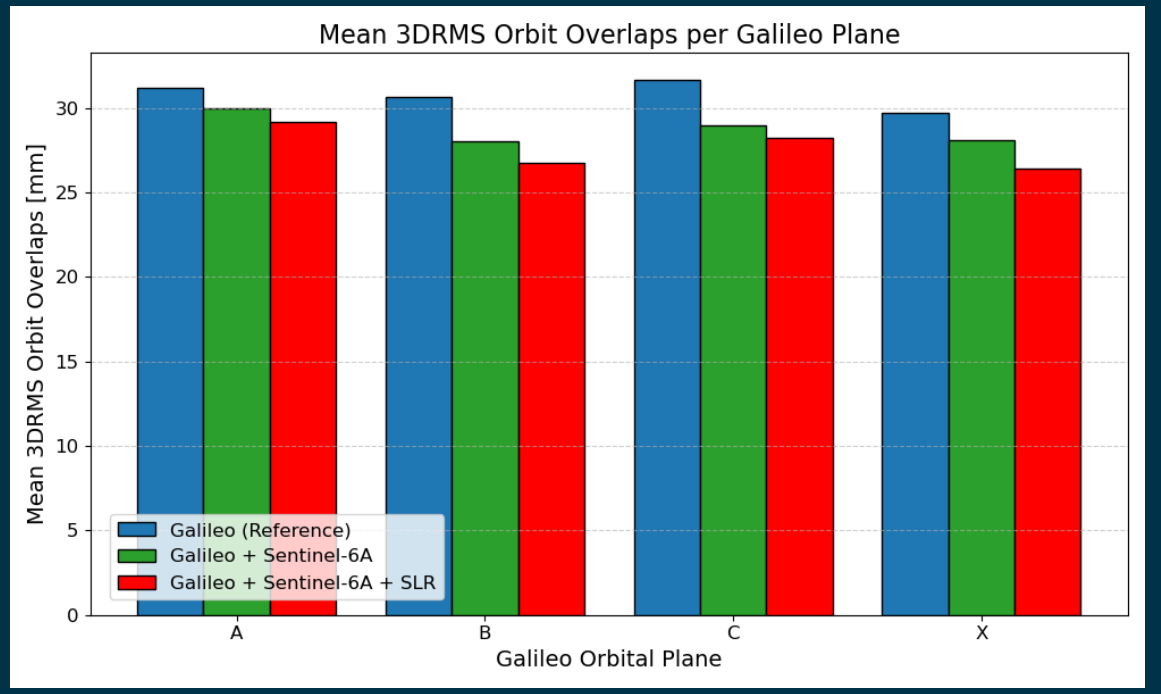
Introduction of SLR observations to the COOL processing, both to Galileo and Sentinel-6A satellites

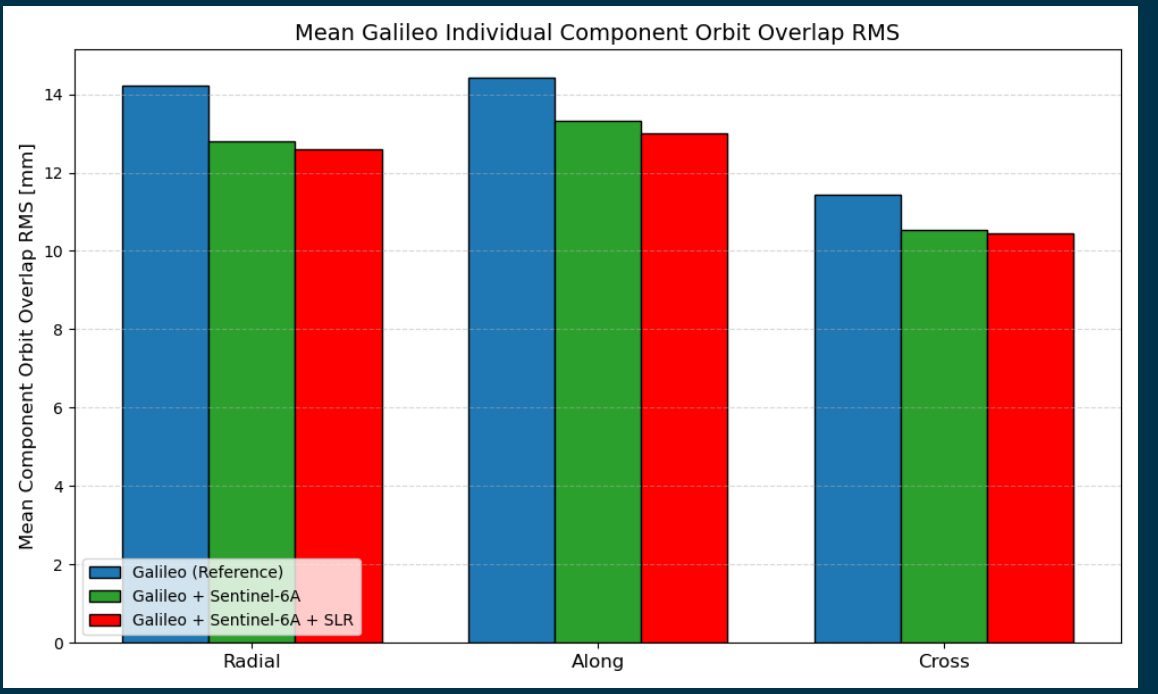
- Maximum number of SLR stations: 17

Result:

- Further improvements compared to adding Sentinel-6A into the Galileo-only solution in terms of temporal stability
- Additional improvement independent from direction

Processing settings:
- Duration: Year 2024 (366 days)
- Arc length: 24h
- Reference Frame: ITRF2020 alignment

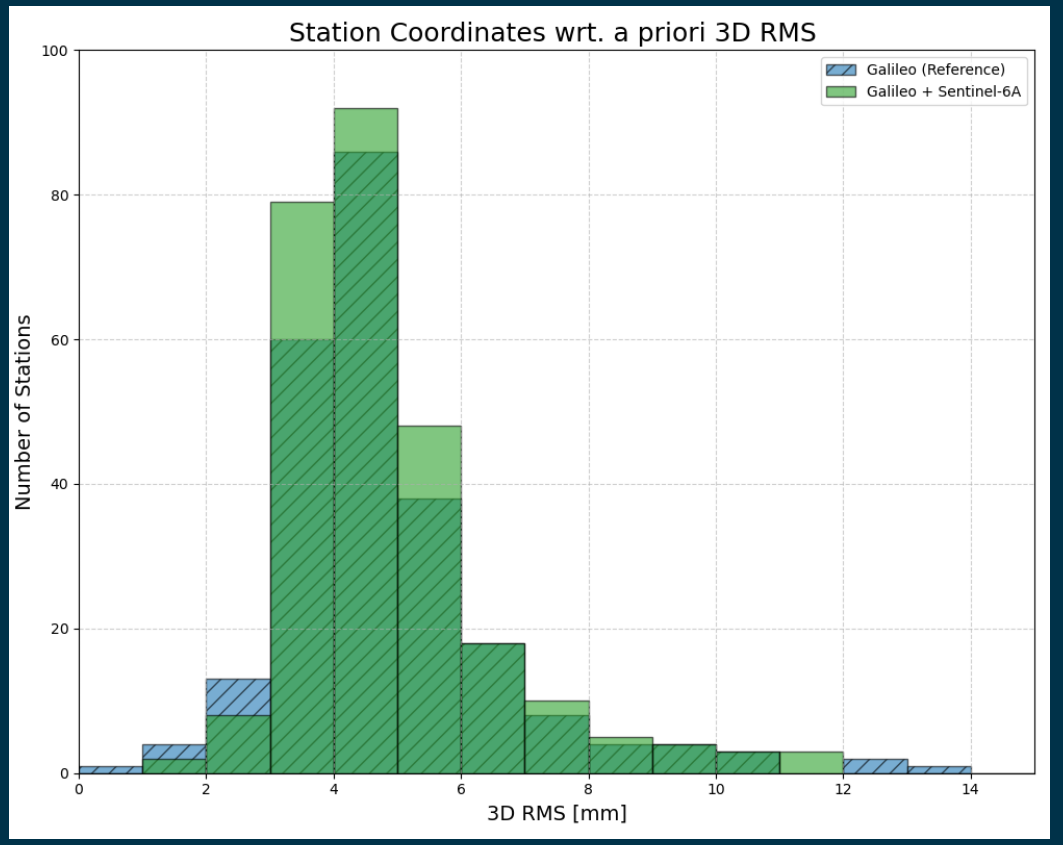


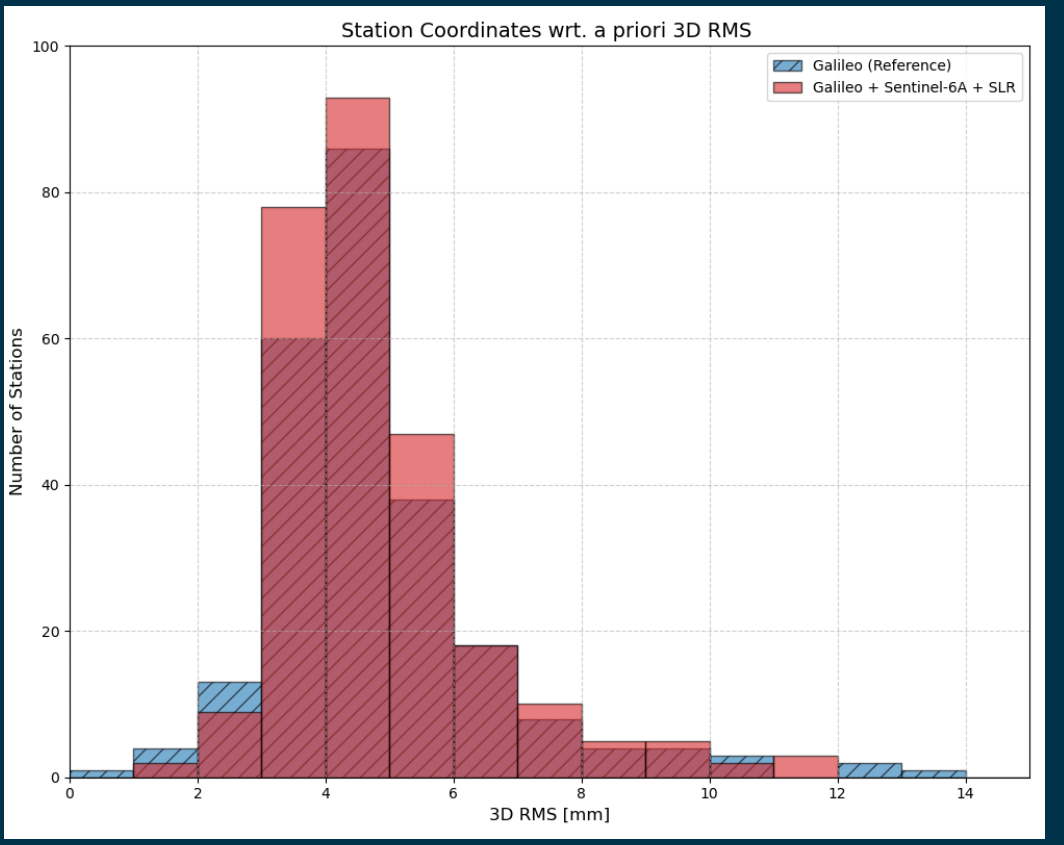


Station Coordinates Analysis

Station coordinate differences are computed with respect to the a priori realisation of the IGS cumulative solution aligned to the ITRF2020. As a result, for both COOL cases with and without SLR contribution:

- Major distribution of differences is located between 3 and 6 mm, as already the case with the Galileo-only reference.
- 97+ % differences below the 1cm-level





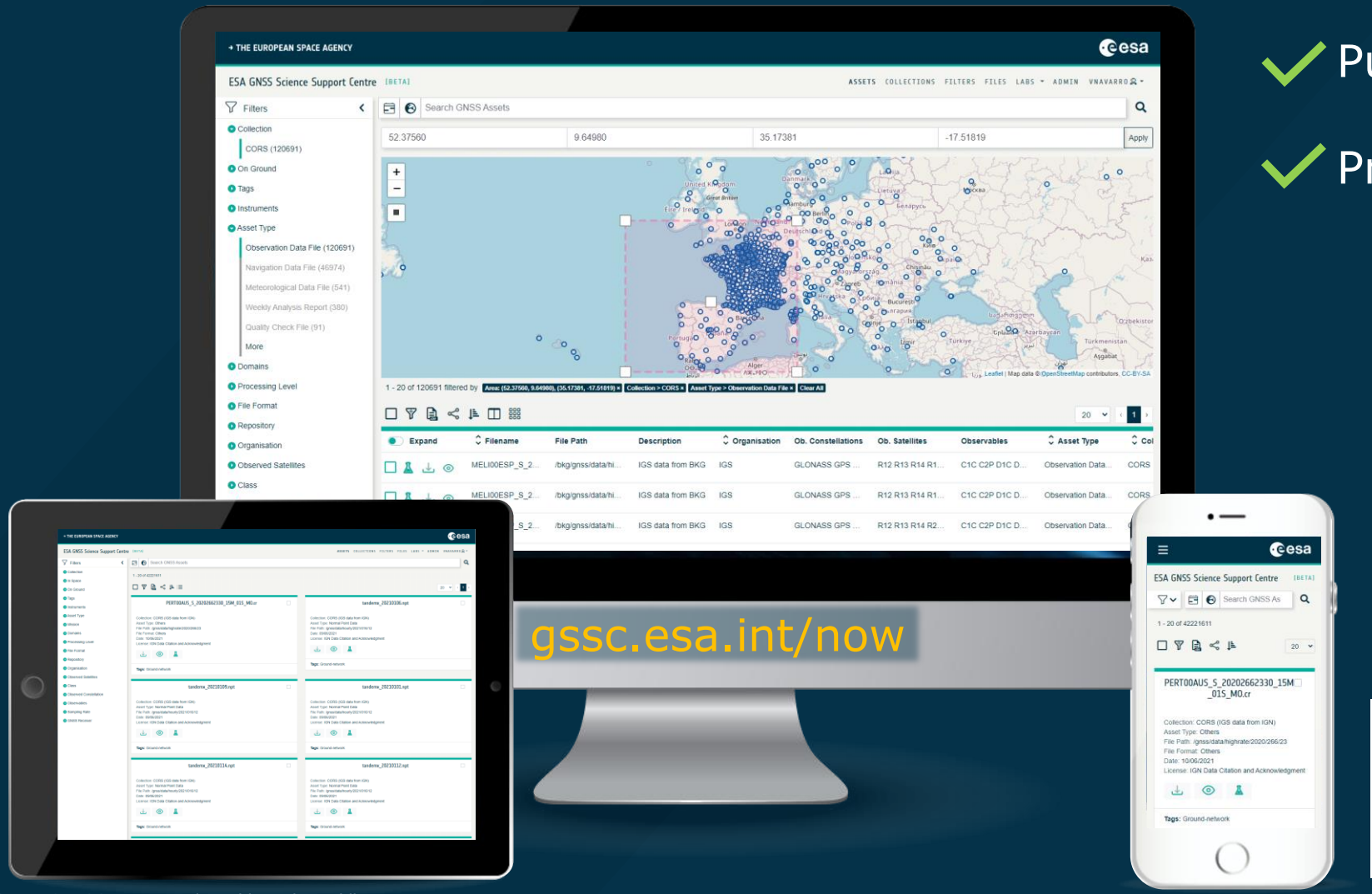
Summary and Way Forward

- The Navigation Support Office contributes to International Geodetic Services (IGS, ILRS, IDS, IVS*).
- We apply constellation-wise processing with Normal Equation stacking implemented in CHAMP (Consolidated High Accuracy Multi-GNSS Processing), which is the official ESA IGS solution since February 2025.
- We have been implementing a methodology for Combination On Observation Level (COOL), dealing with the inconsistencies of the involved geodetic techniques.
- For a combination of GNSS & SLR, both for MEO & LEO satellites, we could already demonstrate a performance improvement in precise orbit determination.
- Solution consistency is demonstrated through smaller deviations at orbit overlaps.
- The Earth Orientation Parameter estimates are improved w.r.t. the Polar Motion Rates (external validation).

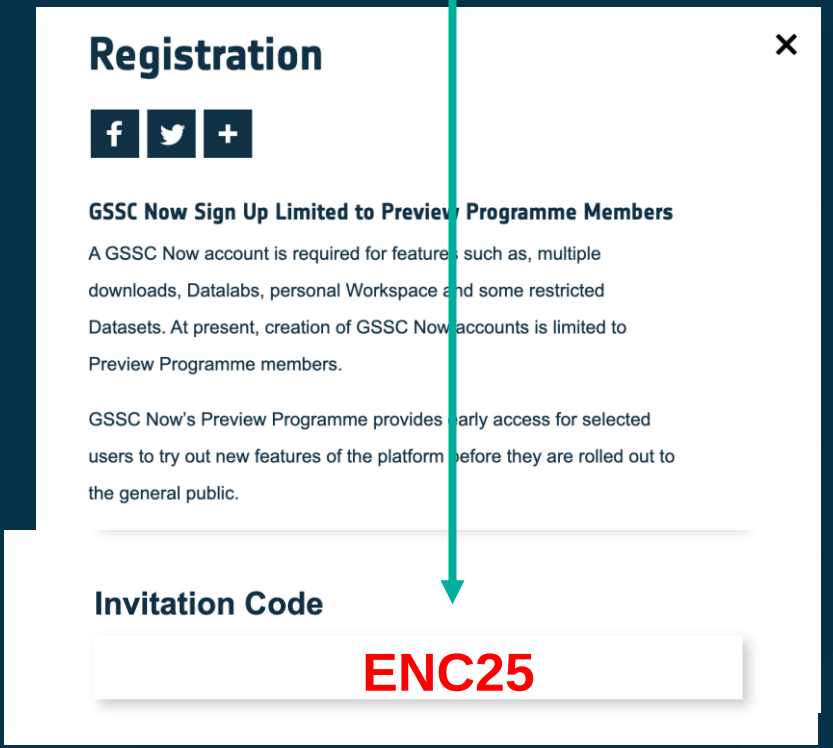
► We plan to support the Genesis mission with our POD processing capabilities.

► As IGS Analysis Centre, we plan to include LEO satellites and Genesis into our current IGS GNSS processing.

GSSC Now – Navigation Science Digital Platform



- ✓ Public Access
- ✓ Preview Access
  → Invitation Code



Thank you!

frank.zimmermann@esa.int
esa.int/Applications/Satellite_navigation/Genesis
gssc.esa.int
navigation-office.esa.int/

navigation-office.esa.int/Products.html