

Advancements in Operational GNSS Processing: A Comprehensive Analysis of ESA's New Methodology

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Navigation Support Office @ ESA / ESOC

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- Introduction: motivation behind the new system
- Main aspects of the system
- System performance and data analysis
- Conclusions and evolutions

In 2023-2024 ESA/ESOC's Navigation Support Office underwent a revision of the GNSS processing system.

The Objectives

- Redesign with these objectives in mind:
 - **Optimize the processes** and eliminate the duplications
 - Make **efficient use of resources** (RAM and CPU)
 - Improve **reliability, maintainability** and **timeliness**
 - Have a **modular system** to streamline reconfiguration

The Outcome

- **CHAMP - Consolidated High Accuracy Multi-GNSS Processing***
The new system to generate ESA's precise GNSS-based products
- It relies on a **constellation-wise** processing approach and takes advantage of the **Normal Equation stacking**



*Consolidated High Accuracy
Multi-GNSS Processing*

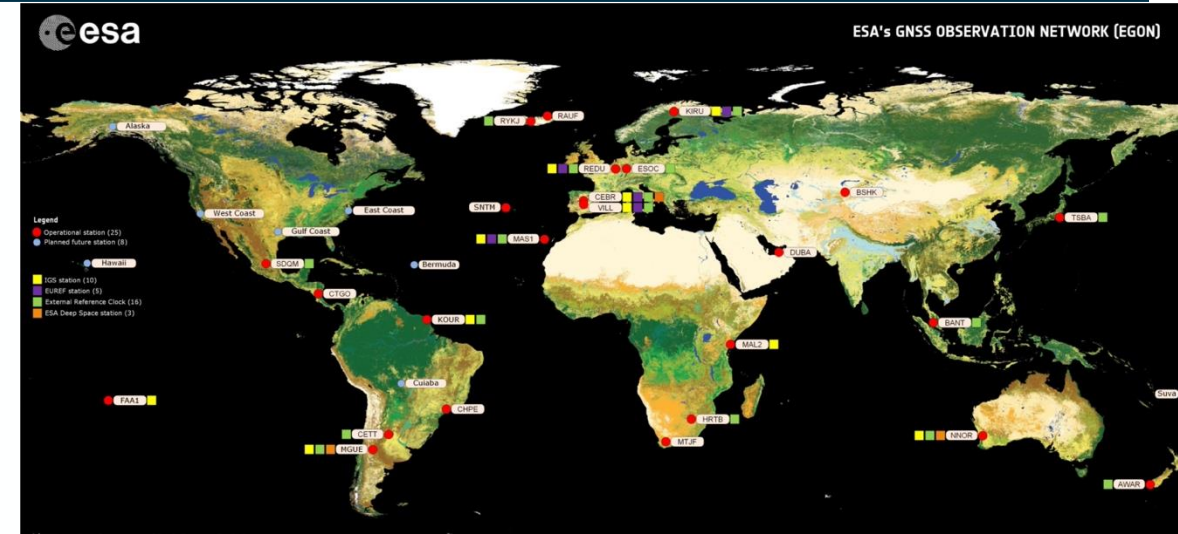
**not to be confused with the CHAMP satellite* ₃

CHAMP customers pool

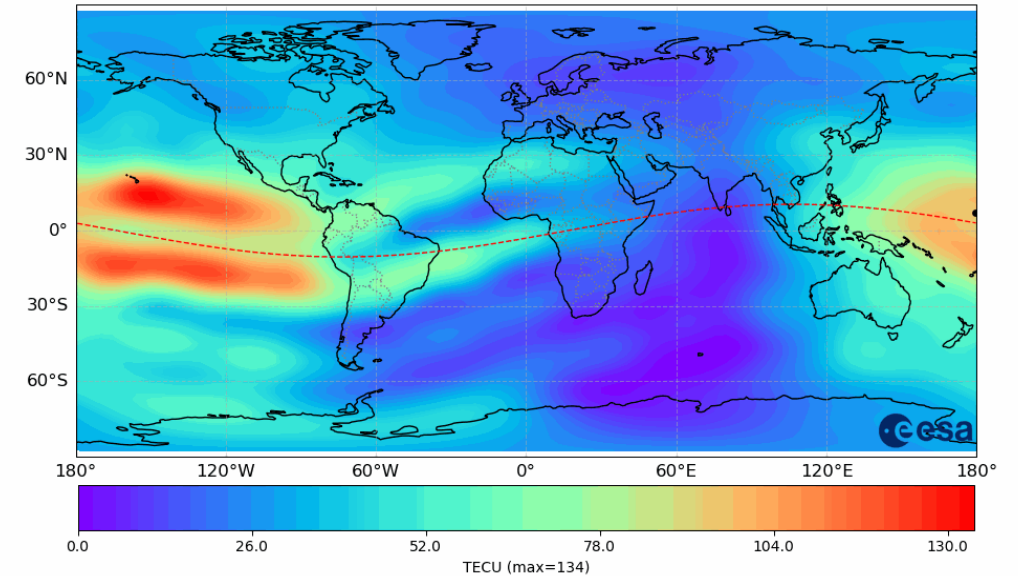
Our CHAMP's products are used for most of our projects:

- ESA Space Weather programme
- ESA Ground Observation Network (EGON)
- ESA Tracking Site Monitoring
- ESA UTC realization
- ESA's Earth Orientation and Reference Service
- Galileo Space Segment
- LEO POD processing (EC Copernicus and ESA missions)
- IGS Analysis Center ESA (~Oct. 2024)
- IGS Ionosphere Analysis Center ESA

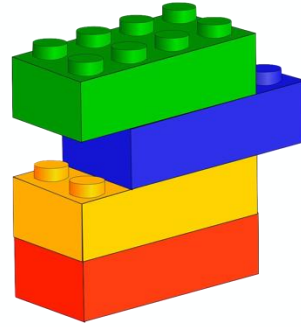
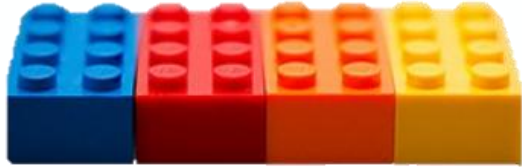
CHAMP-based products will soon be made available on the Navigation Office webpage (~Oct. 2024)



ESOC'S GLOBAL IONOSPHERE MAPS FOR DAY 248, 2024, 00:00:00
SH: SPHERICAL HARMONIC MODEL FROM 240 STATS; N = 15, M = 15



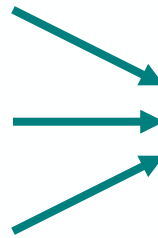
The Modular Design: (re)configurable blocks



Constellation-wise POD

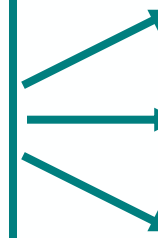
1. Fit of Broadcast ephemeris
2. POD solution with float ambig.
3. Ambiguity Fixing
4. POD solution with fixed ambig.
5. Alignment to ITRF

Parallelized processes



Normal Equations stacking

1. Solve Stacked NEQ
2. 30s Clock solution
3. Clocks alignment to UTC



Secondary processes

1. Ionosphere
2. Biases
3. Others...

Parallelized processes

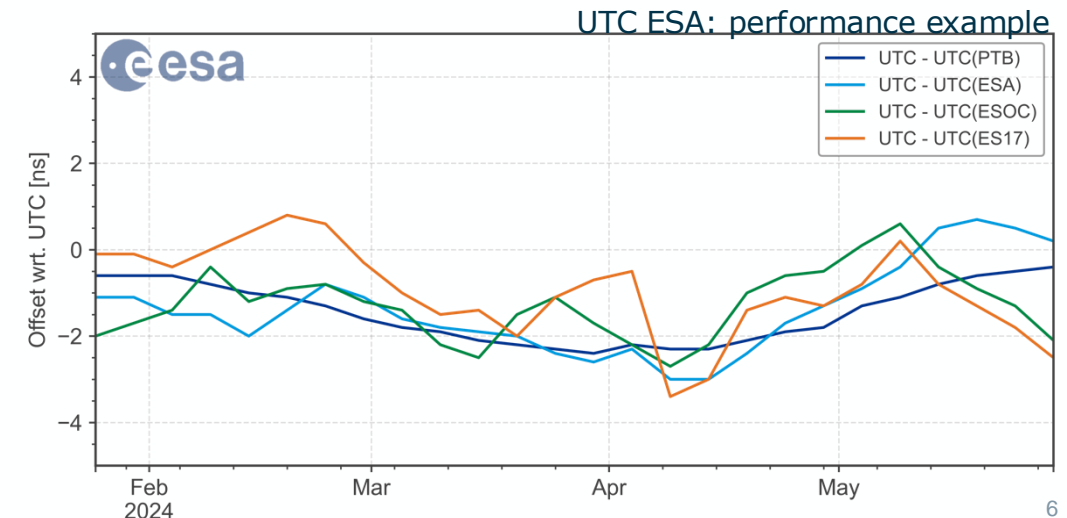
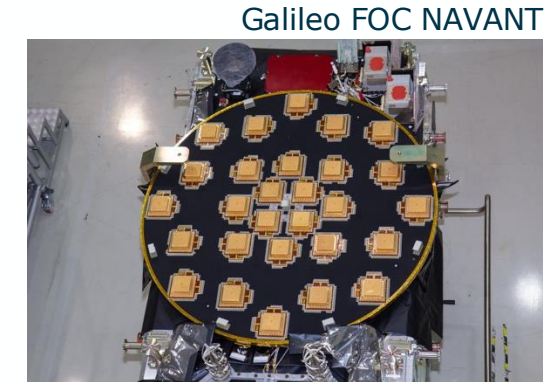
Main advantages

- Each constellation-wise process and each secondary process can run in parallel
- Stacking allows flexibility for various combinations
- Quality checks and validation is performed cross-constellation and against the stacked solution(s)

CHAMP setup details - highlights

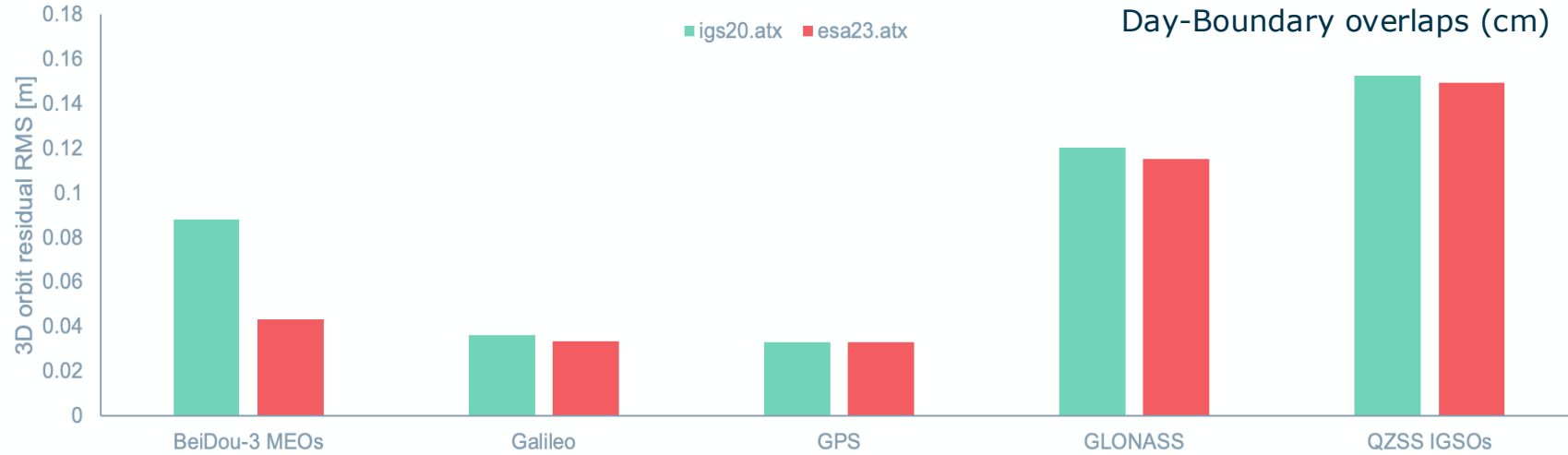
- All **5 constellations**
 - QZSS and GPS in combined processing
- Network of **200 well-calibrated stations**
- Runs with **3 latencies**:
 - Ultra-rapid (6h+ predictions)
 - Rapid (1 day)
 - Final (4 days)
- Based on **ESA ANTEX***, based on ground calibration values for:
 - Galileo
 - GPS Block-III
 - QZSS
- **Clocks alignment to UTC ESA:**
 - ESOC+ESTEC contribute to UTC as BIPM laboratory
 - CHAMP-based clocks are kept aligned to UTC (<5ns)

Constellation	GPS	GLO	GAL	BEI	QZS
Signal selection	L1W L2W	L1P L2P	E1C E5Q	L1P L5P	L1C L2L

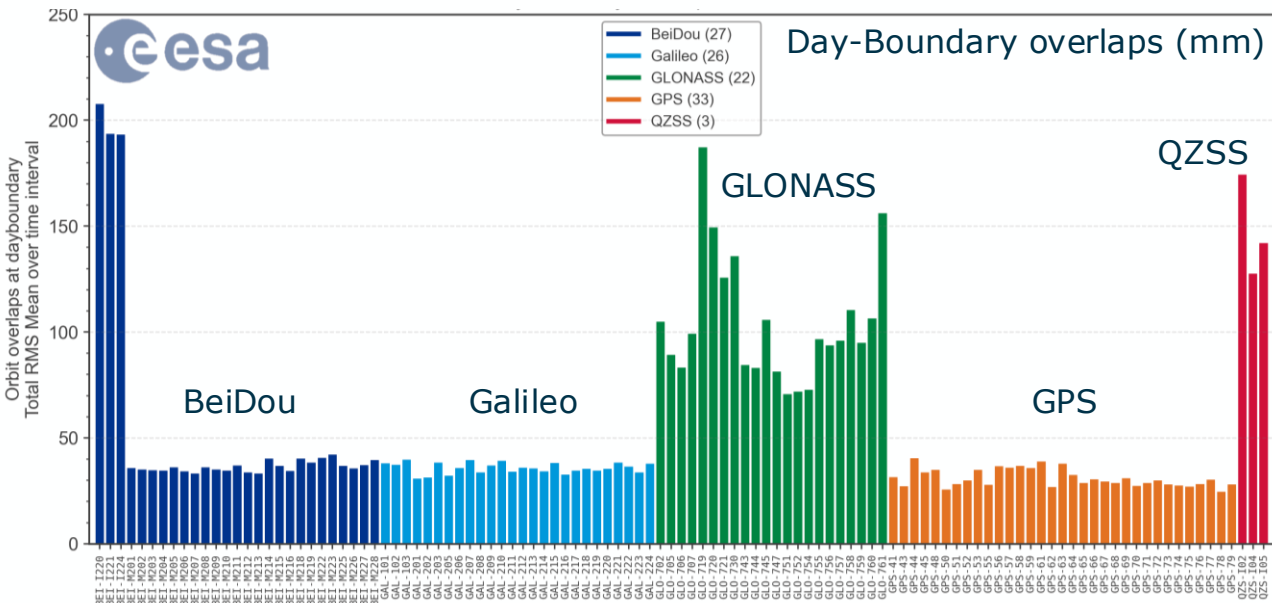


*ANTEX public in our webpage, under the metadata section

CHAMP's products quality – orbital overlaps



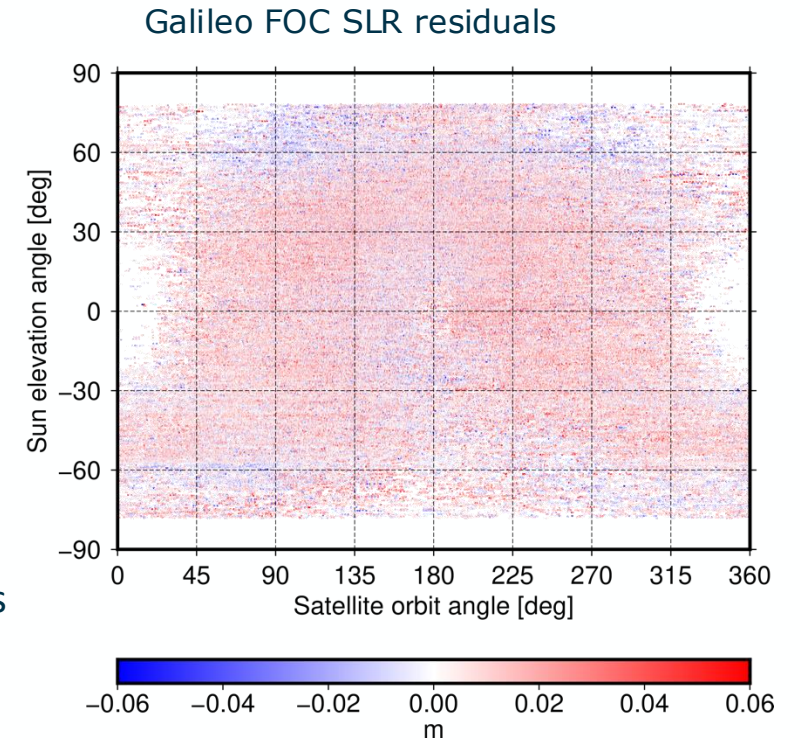
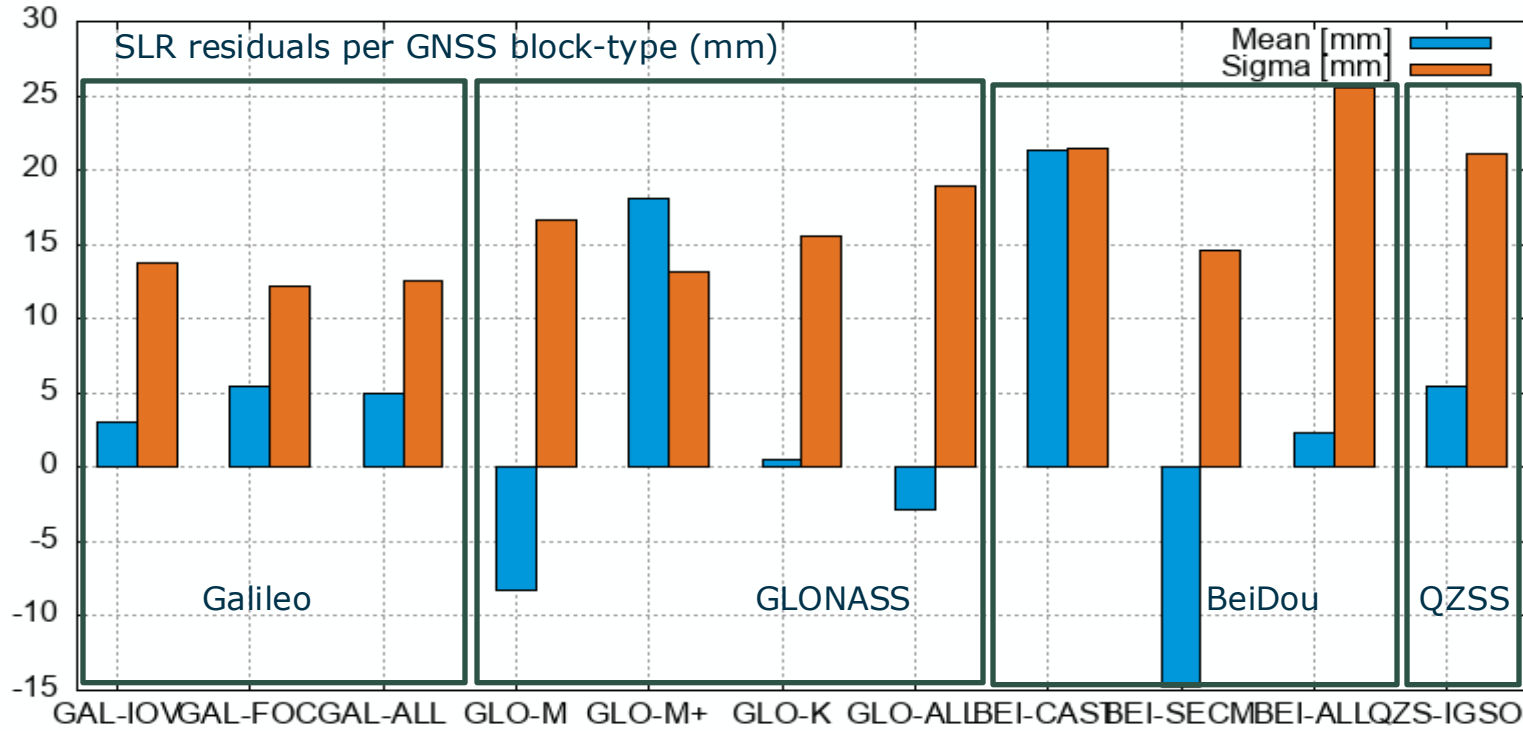
Impact of ESA ANTEX on Orbit Overlaps (IGS20 vs ESA23)



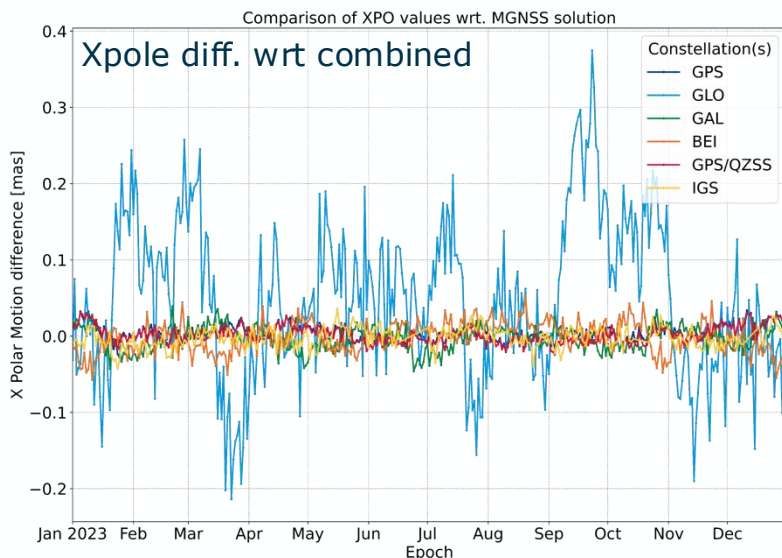
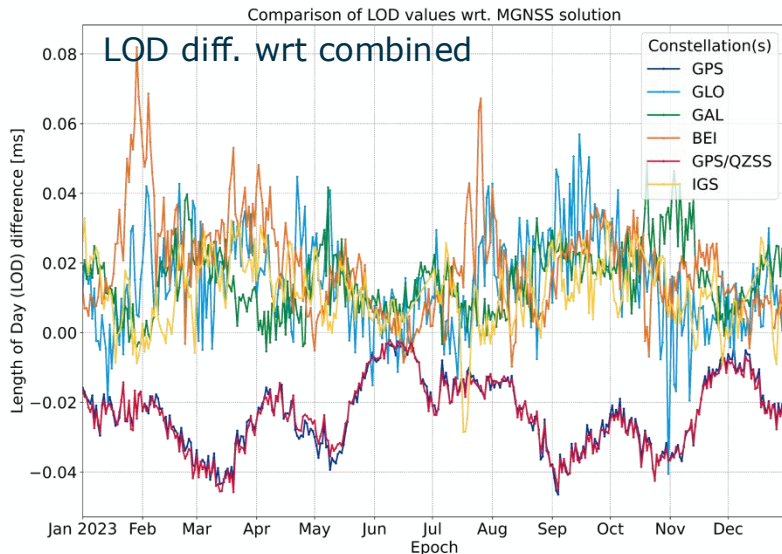
CHAMP Orbit Overlaps

- All constellations' Orbital Overlaps benefit from new ESA23 ANTEX
- Excellent performance of Galileo and GPS constellations
- BeiDou MEO overlaps halved, now in line with GPS/Galileo quality
- IGSOs (BeiDou and QZSS) mostly suffer from poor geometry
- GLONASS solution based on float ambiguities

CHAMP's products quality – SLR residuals analysis



- Available SLR range biases from IIRS Data Handling File (DHF) applied (ETALON bias). Ranges estimated for indicated stations.
- Excellent agreement (15-25mm sigma) of the CHAMP's orbits with SLR
- Galileo performs very well, with SLR residuals below 15mm
- No clear systematic for Galileo, in terms of Sun elevation angle and Satellite Orbit Angle



CHAMP's individual and combined solutions

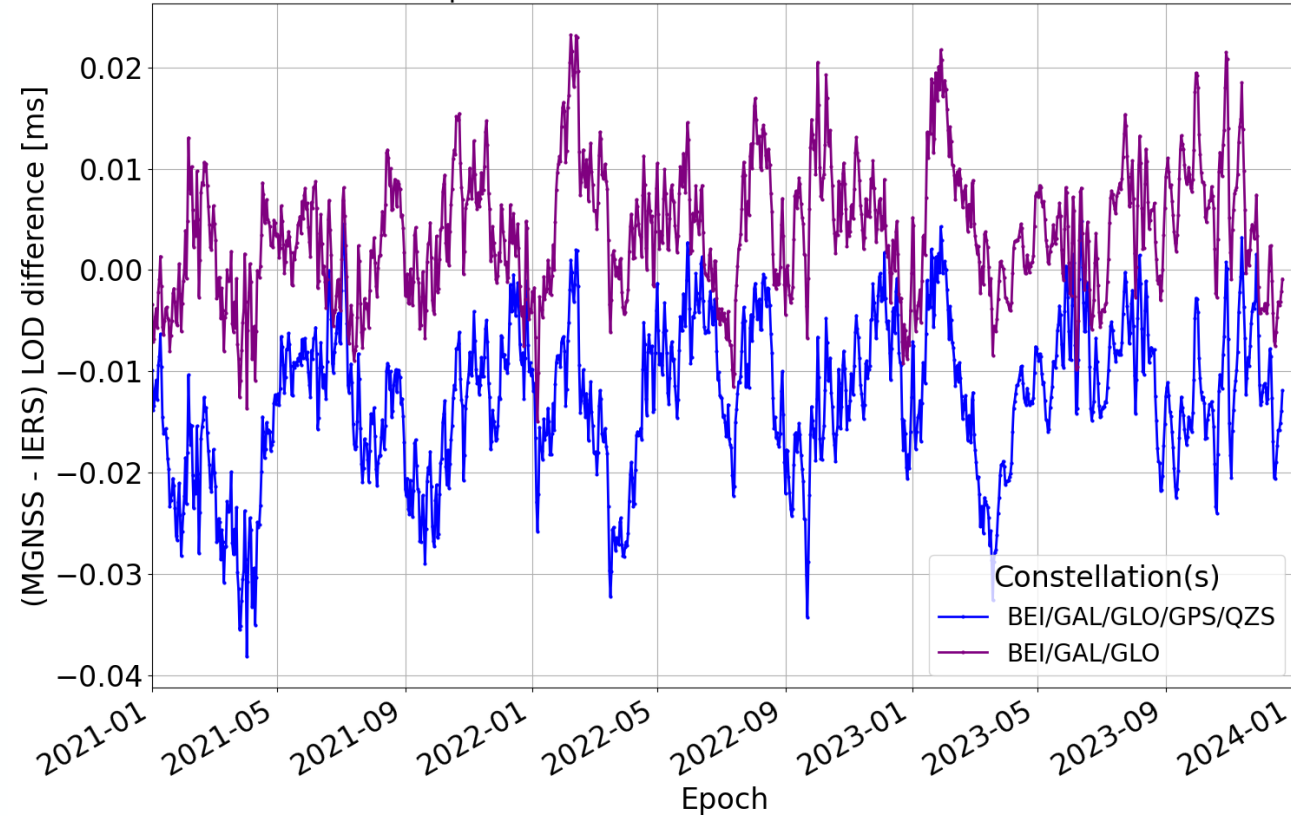
- CHAMP allows for **identifying inconsistencies** between individual constellations and the combined Multi-GNSS solution, facilitating a more thorough analysis of the results and potentially pinpointing the sources of discrepancies.

Major highlights in Earth Orientation Parameters (EOPs)

- Regarding the **Length of Day (LOD)**, the **GPS constellation** (alone or combined with QZSS) shows unique behaviour compared to other constellations and the IGS solution, revealing constellation-specific characteristics.
- In the **Pole values (XPO, YPO)**, and their rates, **GLONASS** exhibits greater fluctuations and lower accuracy compared to other constellations, which generally match well with the combined Multi-GNSS solution and IGS Finals, with only minor inter-constellation differences.

Cross-constellation – Length Of Day parameter

Comparison of LOD values wrt. IERS EOP20C04



LOD estimates VS IERS – impact of GPS

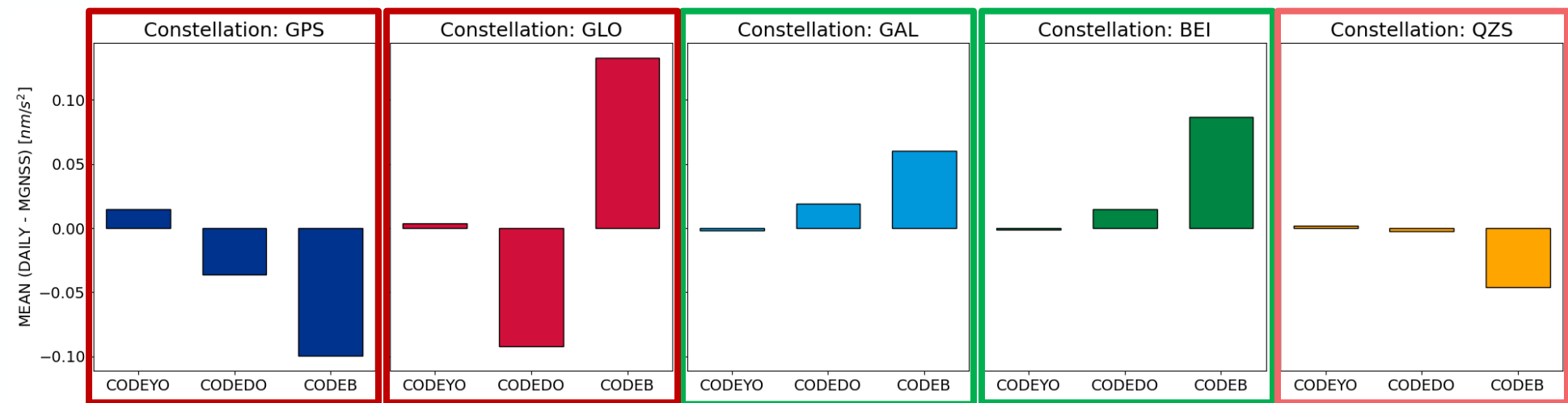
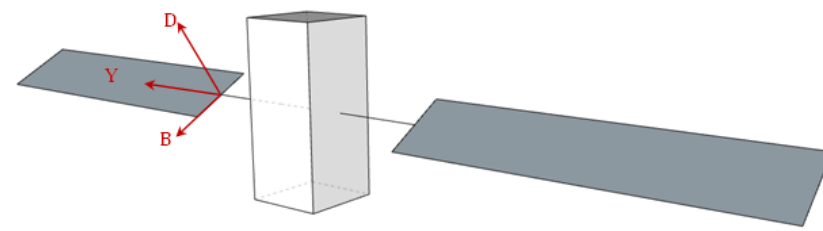
- CHAMP allows for various constellation-wise solutions re-combination
- LOD analysed removing GPS (and QZSS) from the combined solution
- LOD compared to IERS EOPC04 solution
- LOD differences to IERS reduced after removing GPS
- Suggesting a potential systematic bias or constellation-specific issue related to GPS that is affecting the LOD

Constellation	MEAN [ms]	STD [ms]	Drift [ms/year]
All constellations	-0.0127	0.0197	0.0024
GPS (& QZS) removed	0.0036	0.0194	0.0015

Cross-constellation – ECOM parameters

Impact in the ECOM estimates

- ECOM1-model (D0,Y0,B0,BCos,BSin) estimated for each satellite
- ECOM parameters are compared between the constellation-wise and combined solution
- For **Galileo and BeiDou**, ECOM parameters show **lower values** in the combination
- **GPS ECOM B (+70%)** and **D0 (+40%)** show **higher values** when combined

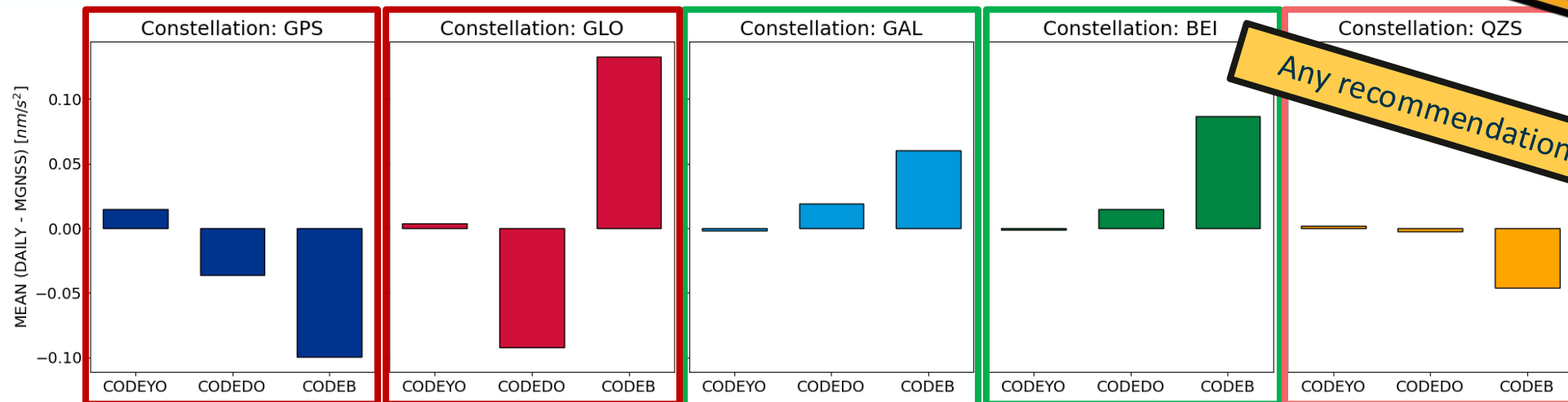
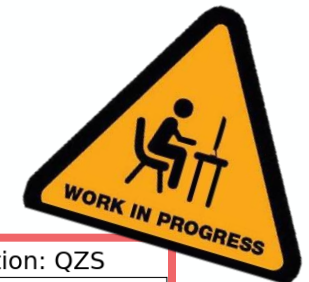
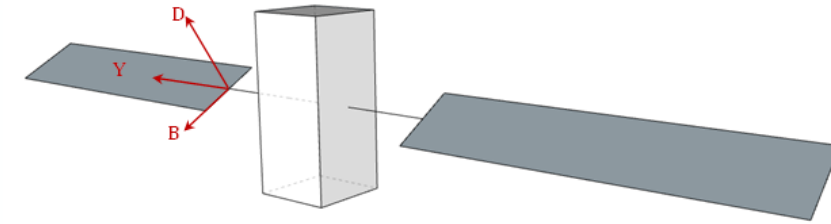


ECOM parameter mean difference (Const.wise – Combined) – *positive values mean a decrement in the combined solution*

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- **GPS ECOM B (+70%) and D0 (+40%)** show **higher values** when combined
- Inconsistency between GPS-based and combined LOD estimates AND increased ECOM values when GPS is combined possibly **pinpoint towards GPS non-gravitational forces mismodelling**.
- Possible similar cause, with impact on Pole offsets and LOD, for GLONASS and QZSS.



Any recommendation is welcome.

ECOM parameter mean difference (Const.wise – Combined) – positive values mean a decrement in the combined solution

Conclusions

- ESA/ESOC's Navigation Support Office has a **new GNSS processing system - CHAMP**
- The new **products will soon be published** on our webpage and submitted to the IGS (including a 7 years repro)
- The **new multi-GNSS products are superior in quality** compared to the previous ones (particularly for BeiDou, see ESA ANTEX presentation)
- Investigation is ongoing and will continue to **identify and solve inconsistencies, improve models and products quality**

Evolution concepts

- **Low Earth Orbit satellites** (e.g., COP, Swarm, GENESIS) will become part of the system, in a joint processing
- Ensure improved **day-boundary products continuity** (e.g., orbits, clocks), valuable for real-time and timing applications
- Definition of a **Code Bias Reference Frame**, by means of satellites' and receivers' calibrations
- Addition of **NavIC constellation** to the current multi-GNSS setup
- **Multi-technique combined processing**: GNSS, SLR, DORIS and VLBI
- Inclusion of **LEO-PNT** signals and processes

Thank you for your attention!

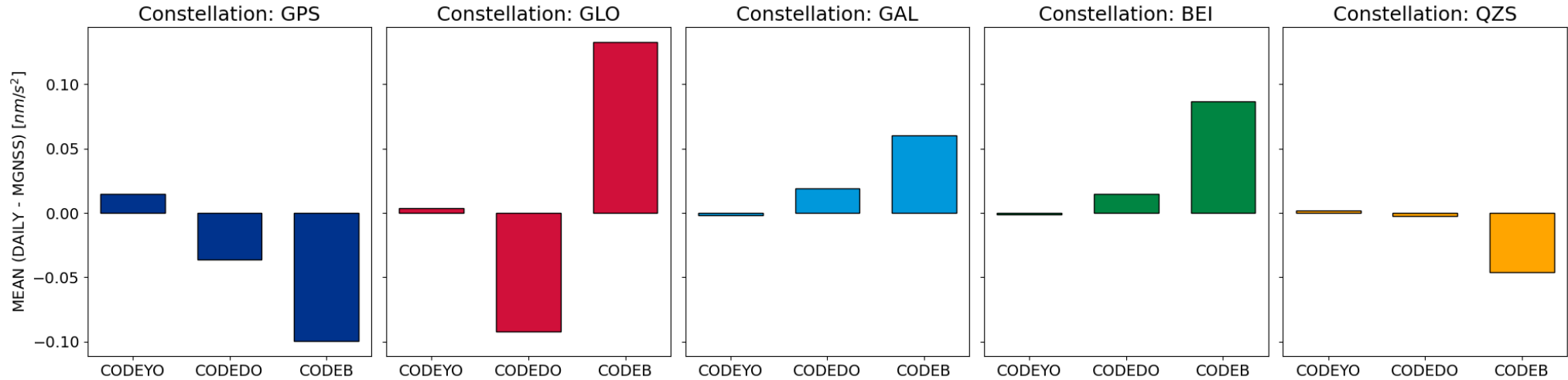
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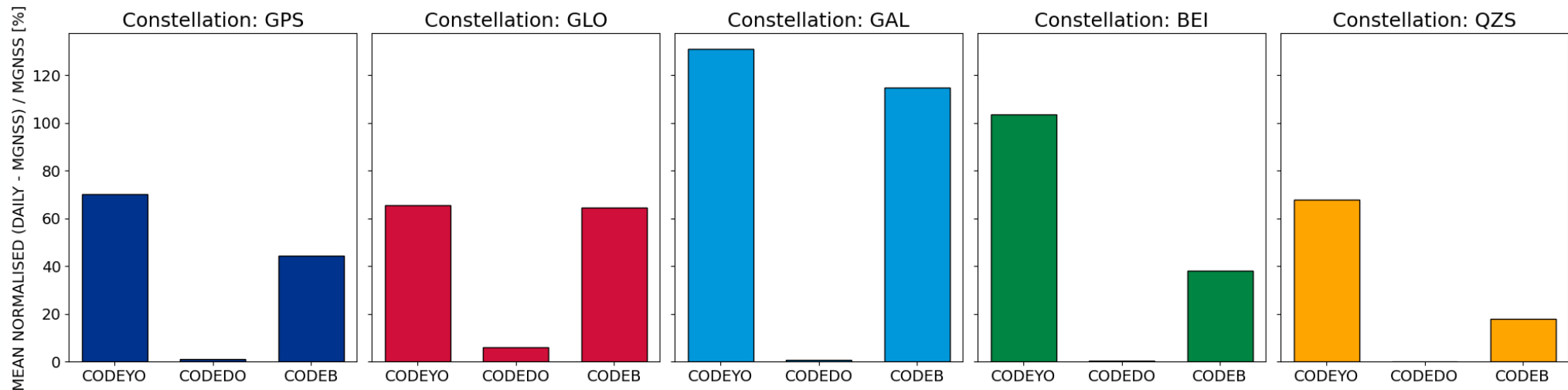


<http://navigation-office.esa.int/Products.html>

Cross-constellation – ECOM parameters



ECOM parameter mean difference (Const.wise – Combined)



ECOM parameter mean difference, in percentage (Const.wise – Combined)

Annex 1 – Number of stations available VS used

