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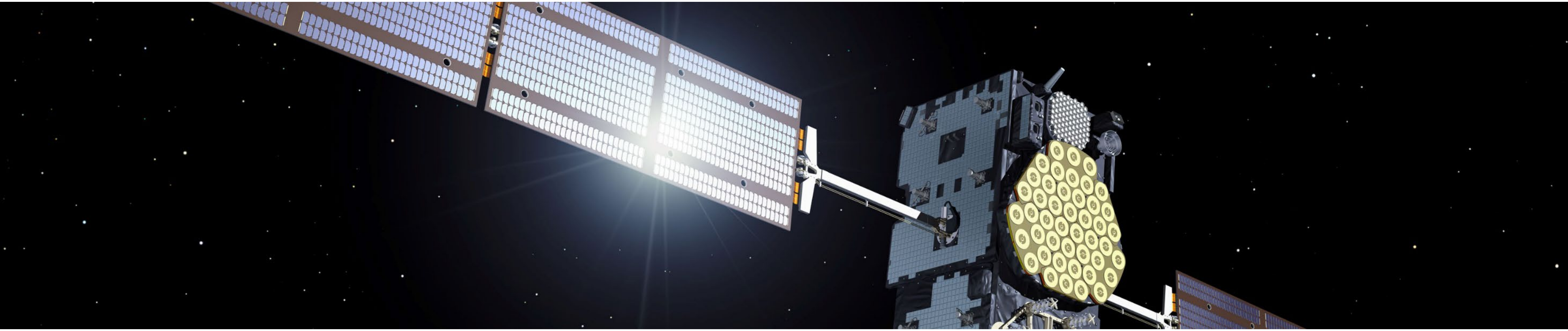

# Applicability of the Galileo system in the estimation of geocenter coordinates and Earth rotation parameters

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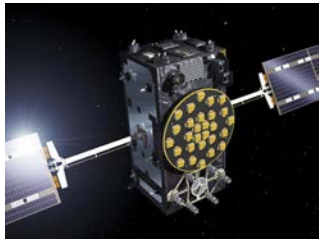
# Introduction

One of the **major task of the satellite geodesy** is determination of the **global geodetic parameters**, which help us to describe the planet Earth



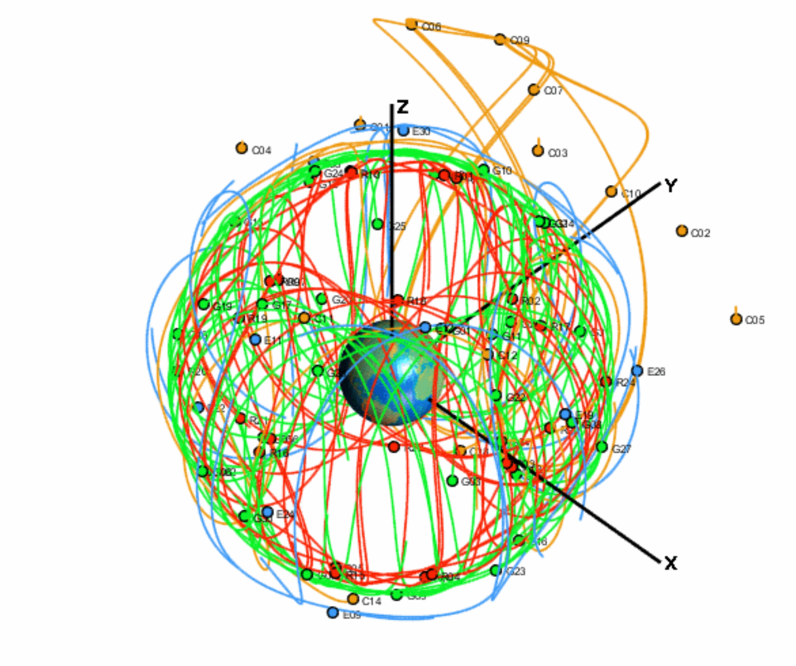


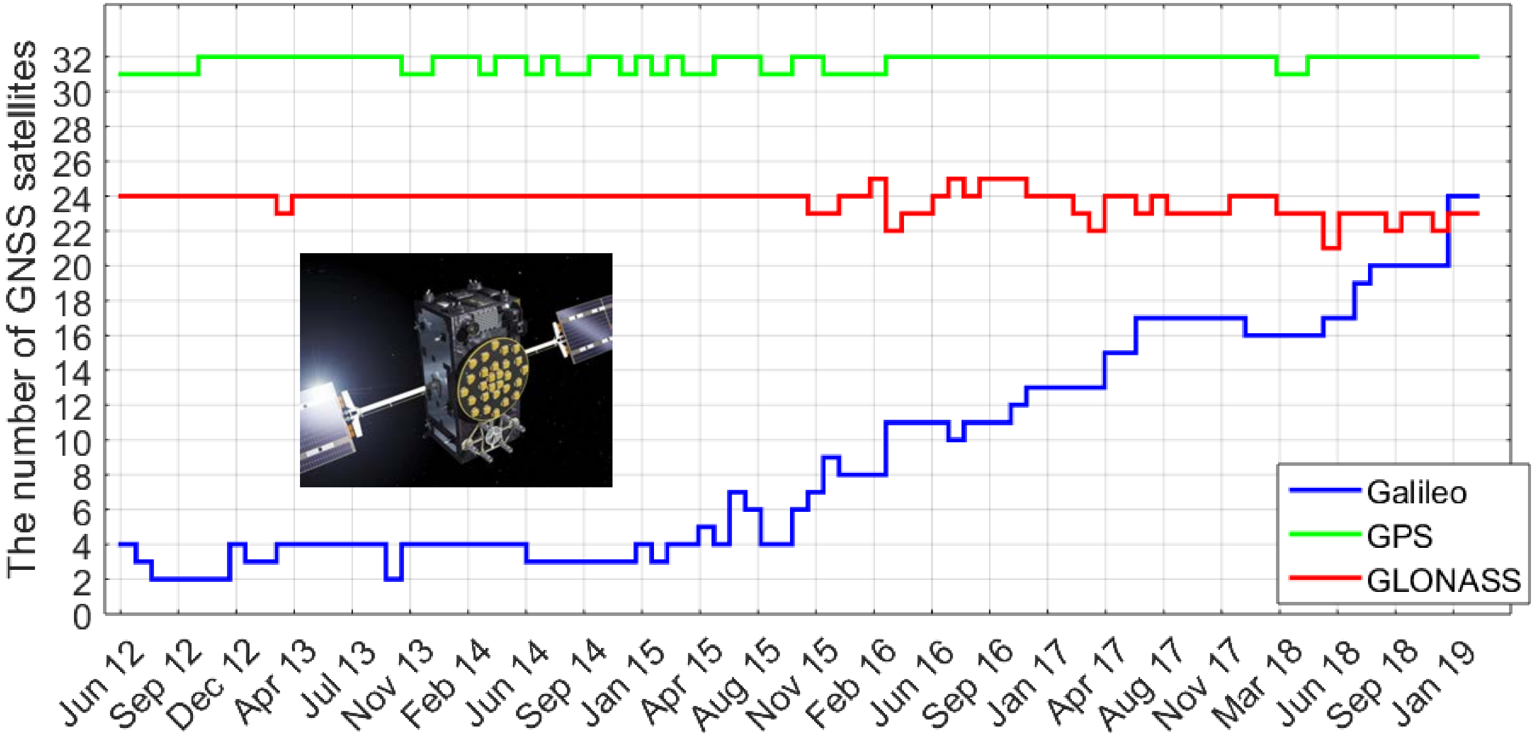
| Parametr | SLR | LLR | VLBI | GPS GLONASS | DORIS | Altimetry, InSAR | Gravity missions | Galileo |
|---|---|---|---|---|---|---|---|---|
| Quasars | | | XXX | | | | | |
| Nutation | X | XX | XXX | X | | | | |
| Pole coordinates | XX | X | XX | XXX | X | | | ? |
| UT1-UTC | | XX | XXX | | | | | ? |
| Length of Day | XXX | XX | XX | XXX | X | | | ? |
| Sub-daily ERP | XX | X | XX | XXX | X | X | | ? |
| Sea level | | | | XX | | XXX | XX | |
| CRD and VEL | XXX | X | XXX | XXX | XXX | X | | |
| Deformations | XX | X | XX | XXX | XX | XXX | XX | |
| Scale | XXX | XX | XXX | XX | XX | X | | |
| GM | XXX | XXX | | X | X | | | |
| Geocenter motion | XXX | XX | | X | XX | X | XX | ? |
| Gravity field | XXX | X | | X | XX | XX | XXX | |
| Orbits | XXX | XX | | XXX | XXX | X | XX | |
| Ionosphere | | | XX | XXX | XX | XX | X | |
| Troposphere | X | X | XX | XXX | XX | XX | X | |
| Clocks | XXX | | XX | XXX | X | X | | |
| Relativistic effects | XXX | XXX | XXX | XXX | X | X | XX | |


The main goal of this study is to investigate the applicability of Galileo (particular GNSS systems) in the estimation of geocenter coordinates and Earth rotation parameters

# multi-GNSS

In space there are almost **100 GNSS** satellites: 32 GPS, 24(+2) GLONASS, 24+2 Galileo




The multi-GNSS solutions are a challenge for IGS due to the **increasing number of satellites**, **new signals observations types**, and **orbit modeling difficulties caused by different attitude steering modes as well as different satellites' sensitivities to perturbing forces.**

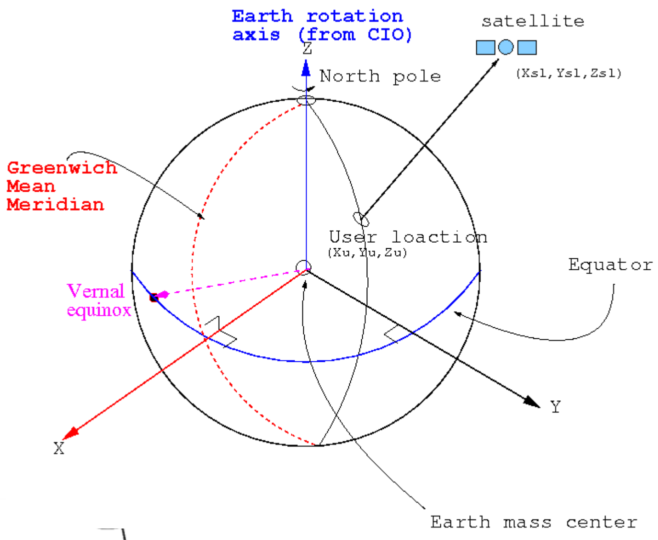
MGEX

IGS INTERNATIONAL GNSS SERVICE

# ERP – Earth Rotation Parameters

Parameters:

- UT1-UTC [s]
  *Real Rotation – 24h. The excess revolution time is called length of day (LOD).*
- Coordinates of the pole [as]
- Celestial pole offset (nutation and precession) – *conventional models* [as]

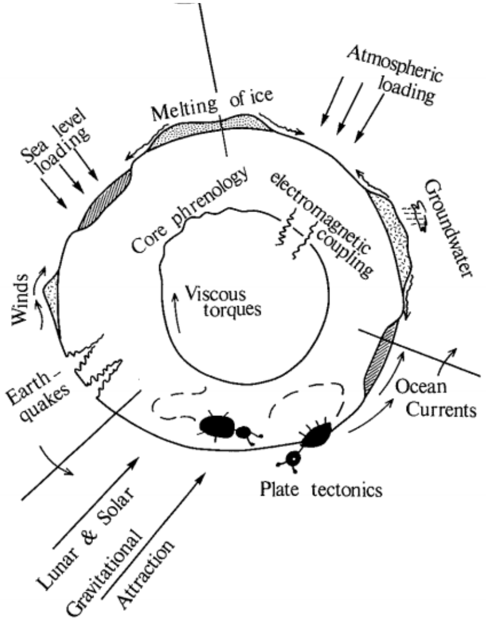


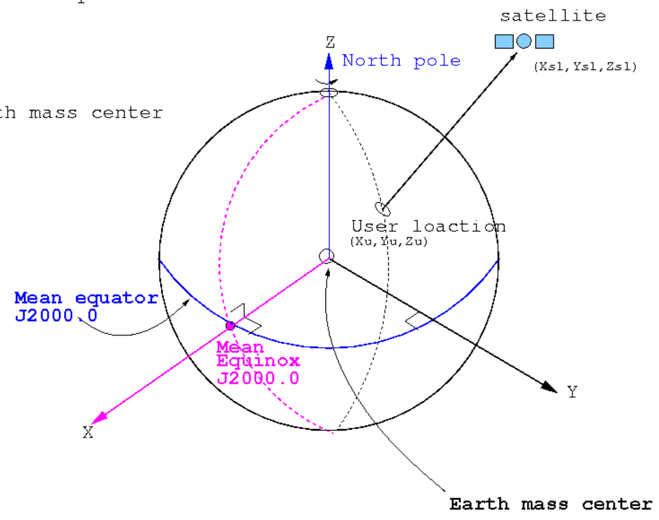

ITRS
*co-rotating with the earth in its diurnal rotation*

ICRS
quasi-inertial, axis refered to the mean equinox and plane of mean equator at J2000.0 epoch

Application:

(1) Geophysical: The parameters **describe irregularities** of the Earth's rotation caused by deformation of the solid Earth, of fluid motions in the core and the magnetic field, of the mass redistributions and motions within the oceans and atmosphere, and of the interactions between the solid and fluid regions.
(2) Geodetic: Technically, they provide the parameters of rotation from the *ITRS to the **ICRS as a function of time.




Official solution of ERP is C04 distributed by IERS – combined solution of GNSS, VLBI, SLR and DORIS (sorted by influence).
Resolution: 24 h

*International **Terrestrial** Reference System ~ **Stations**
** International **Celestial** Reference System ~ **Satellites**

Seidelmann, P.K. 1982: Celest. Mech., 27, 79.
https://www.iers.org/IERS/EN/Science/EarthRotation/EOP.html

# GCC – Geocenter Coordinates | Geocenter Motion

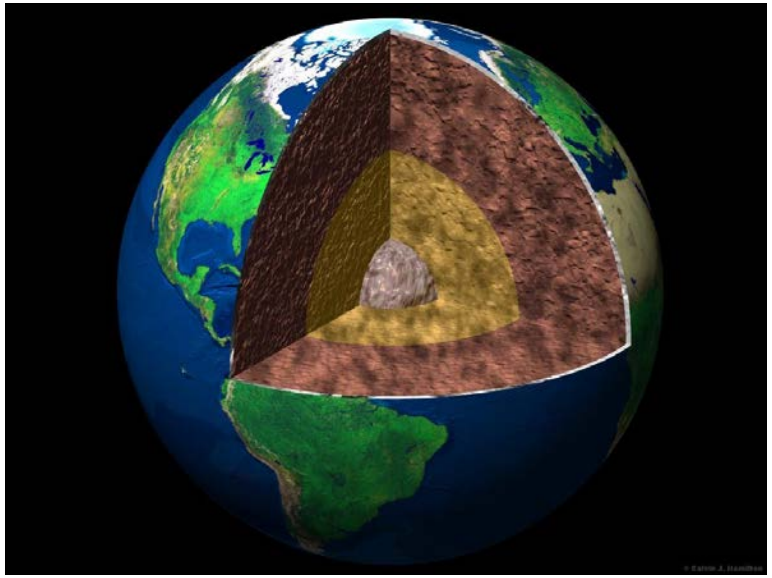
Satellites move on an orbit about the Earth's **center of mass** (variable)
Coordinates of the network of GNSS stations are referenced to the origin in the center of network, which should represent the **center of figure – origin of the reference frame** (quasi-stable)

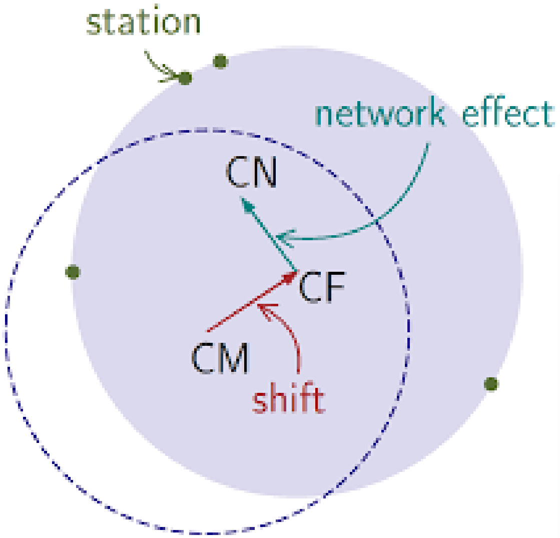
GCC = CoM – CoF

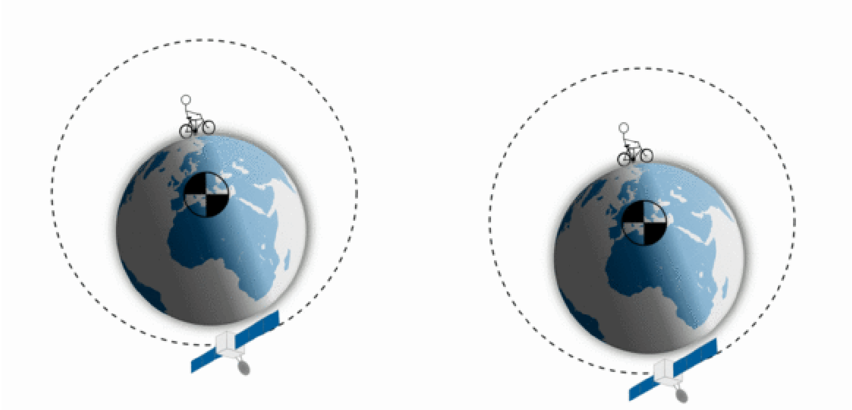
Three components: X, Y, Z [m]

There is no official/operational product of geocenter.

There are some geophysical models which describe the motion of geocenter.

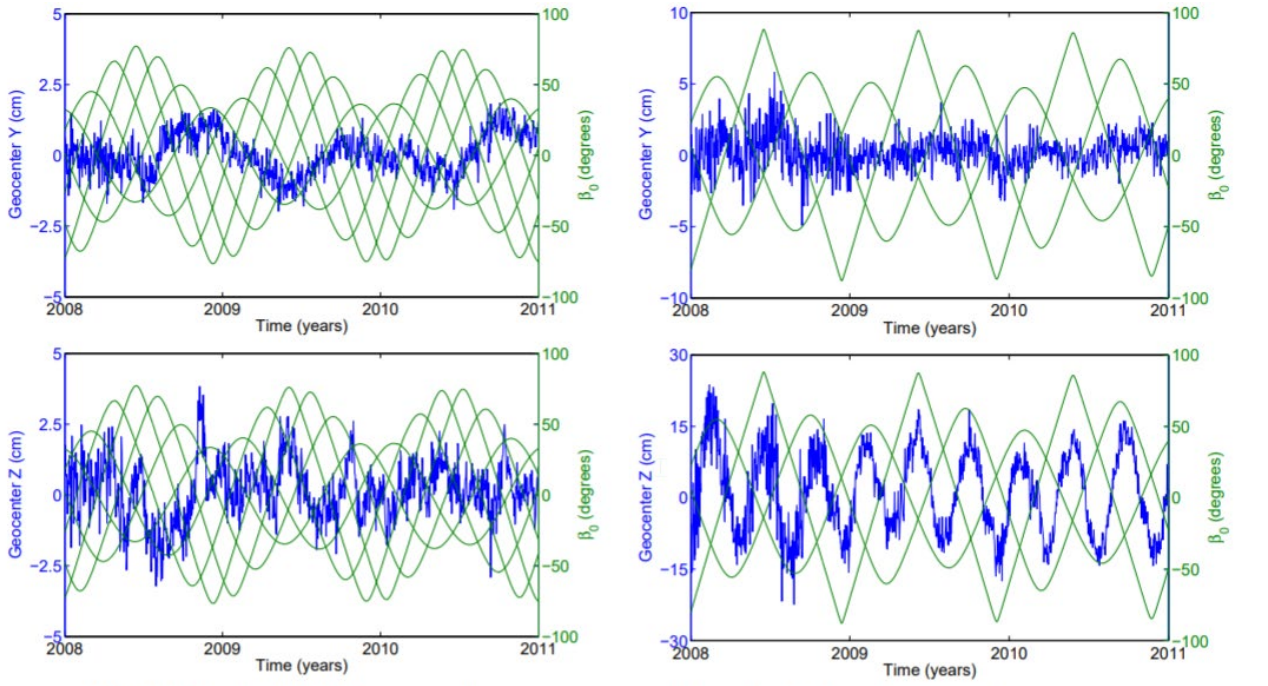


# Literature – System specific parameters

- **Meindl [2011] - Combined Analysis of Observations from Different Global Navigation Satellite Systems**
- **Meind [2013] - Geocenter coordinates estimated from GNSS data as viewed by perturbation theory**
- Scaramuzza [2018] - Dependency of geodynamic parameters on the GNSS constellation

  - The GCC time series derived from GLONASS solutions **show a different behavior than GPS, especially for the Z component**
  - Relation between GCC and t**he elevation of the Sun above the orbital planes implies a correlation with the orbital parameters**
  - The **spurious signal can be significantly reduced by changing the setup of the orbital parameters**
  - Galileo: The authors predict that the GCC estimated with **Galileo will have a signature like GLONASS** (3 orbital planes), **but with substantially reduced amplitudes** (because the orbit is more like GPS)




(a) GPS-derived GCC parameters.

(b) GLONASS-derived GCC parameters.

**Figure 7.6:** Geocenter coordinates derived from GPS and GLONASS observations and elevation $\beta_0$ of the Sun above the orbital planes (session length DAY).

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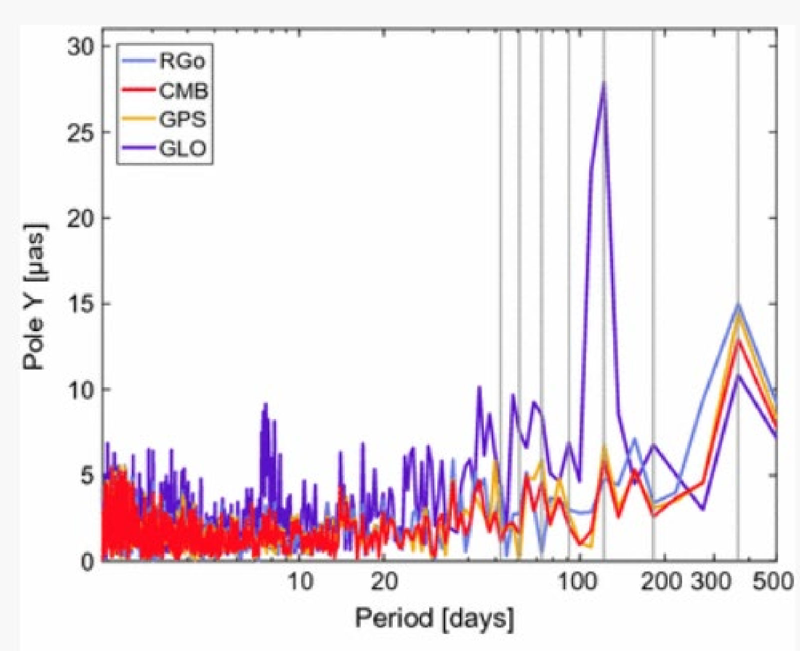
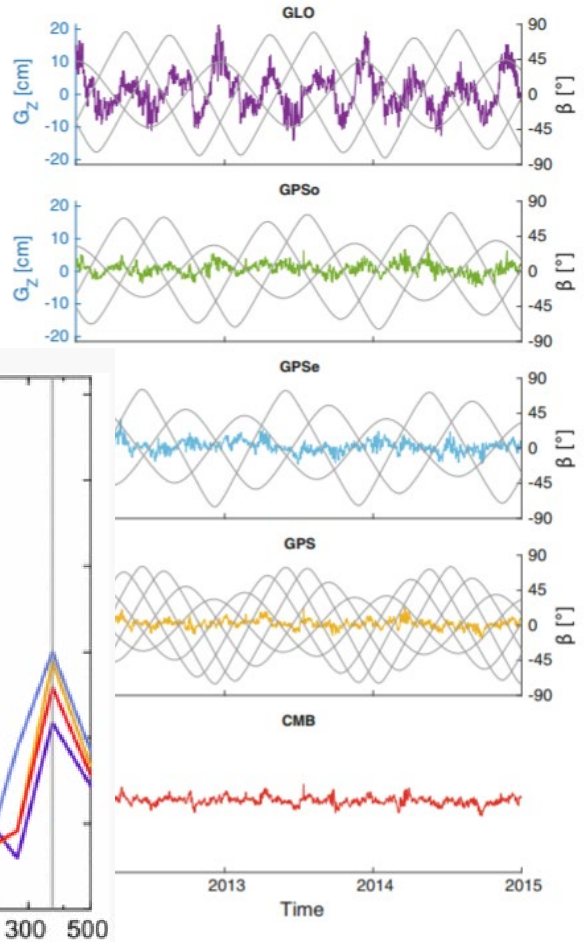
- Meind [2013] - Geocenter coordinates estimated from GNSS data as viewed by perturbation theory
- **Scaramuzza [2018] - Dependency of geodynamic parameters on the GNSS constellation**
  - The authors studied the **impact of the number of orbital planes in a GNSS on the GCC and ERPs** based on GPS, GLONASS, a combined GPS/GLONASS constellation, and two virtual GPS sub-systems (6 planes → 2 constellations of 3 planes)
  - The **number of orbital planes barely influences the geocenter** estimates
  - The generally **larger formal errors of the GLONASS satellite positions** may therefore also contribute to the **bad quality of the GLONASS derived GCCs**
  - A **smaller number of orbital planes** may lead, to **degradations in the estimates of the pole coordinates**. All systems with 3 orbital planes showed a distinct signal at 3 cpy.

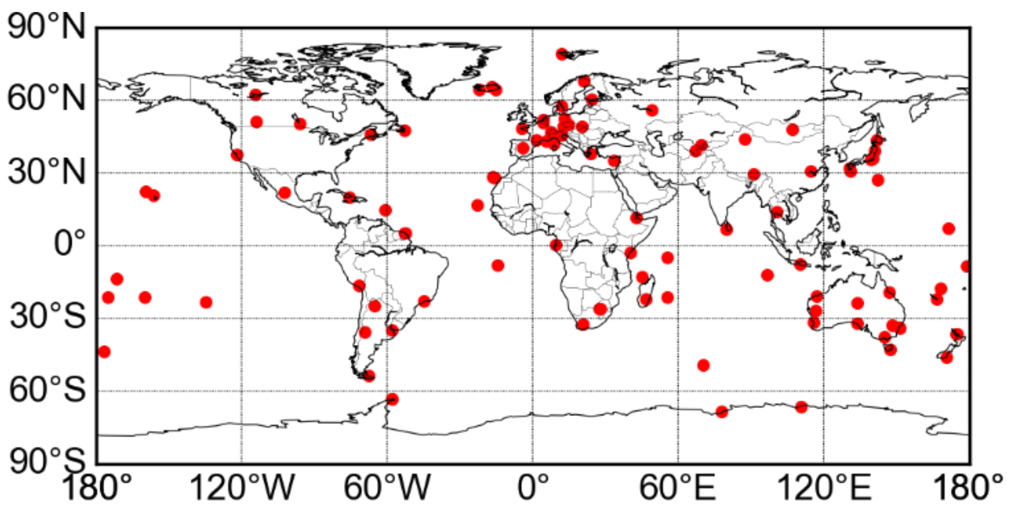



enter z-coordinate and β angles of the corresponding
llation. β is not shown for the combined solution for the
sake of readability

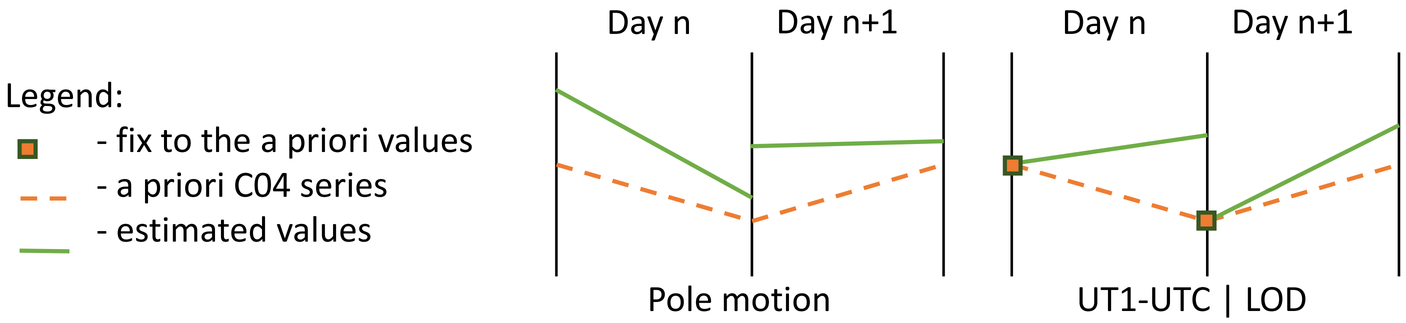
# Methodology

- Processing is based on the standard IGS routine
    - Apriori reference frame IGS14
    - 2017-2018 (2 years)
    - 1-day arc length
    - ~100 stacji
    - GPS, GLONASS i Galileo (ok.70 satelitów)
    - Orbits, Earth Rotation Parameters, Stations coordinates, Troposphere, Geocenter coordinates
    - 5 scenarios
        (a) System-specific parameters
        (b) 2 approches for orbit modeling for Galileo

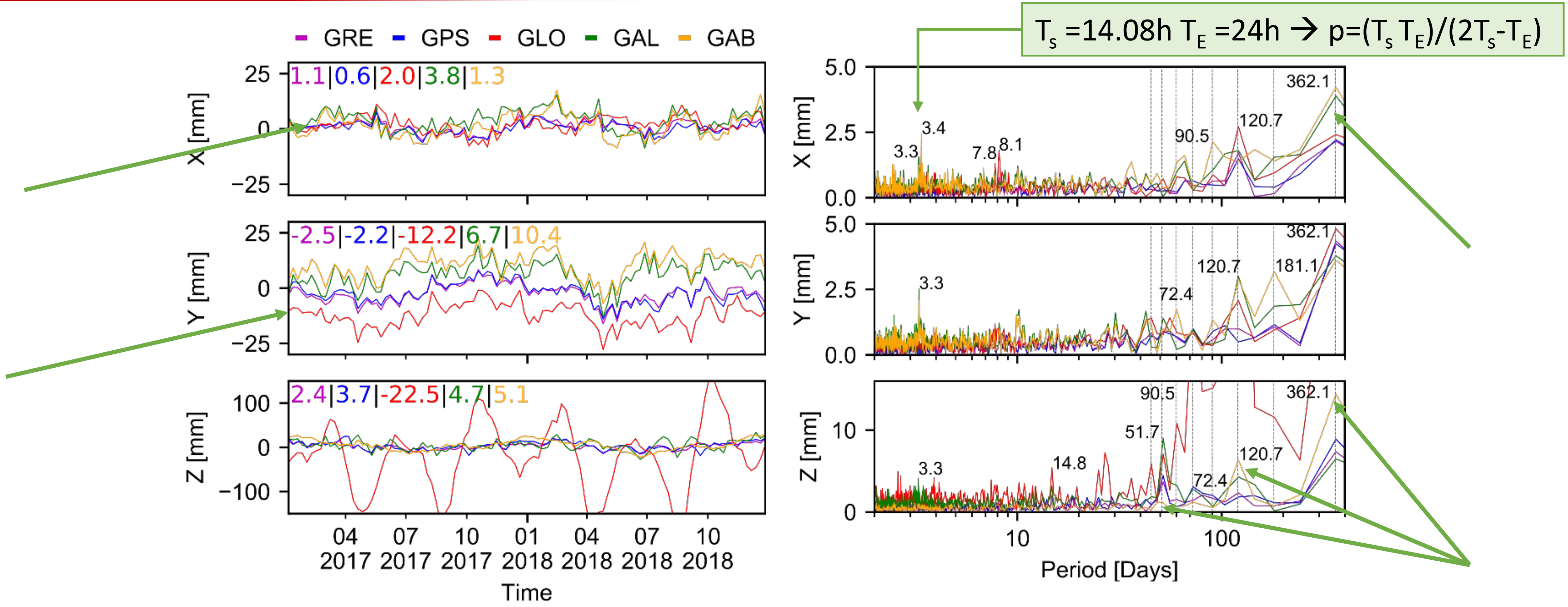



| Symbol | C | Systems | Orbit modelling |
|---|---|---|---|
| GRE | | GPS+Galileo +GLONASS | ECOM2 (7 par) |
| GPS | | GPS | ECOM2 (7 par) |
| GLO | | GLONASS | ECOM2 (7 par) |
| GAL | | Galileo | ECOM2 (7 par) |
| GAB | | Galileo | BOXWING + $D_0$, $Y_0$, $B_0$ |

ERP parameterization – piece-wise-linear

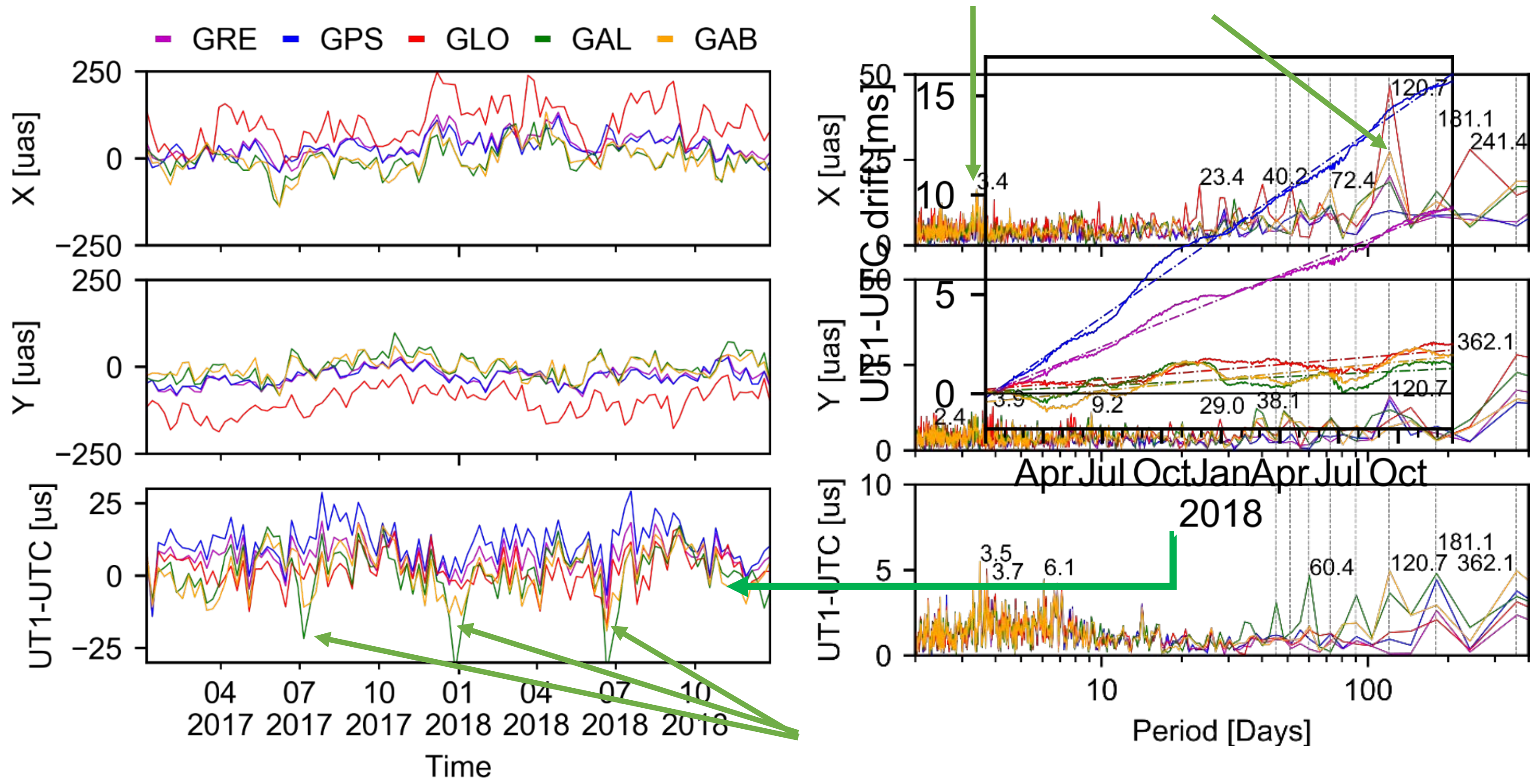


# Geocenter coordinates




- The combined GCC product is **most consistent with GPS-based estimates**
- **Annual signal is 2 times larger for Galileo** when compared to the GPS series for X geocenter coordinate
- The signal with a **period close to 3.4** days and the amplitude of ~2.5 mm for Galileo-based products
- The system-specific Y geocenter coordinate is **systematically shifted** depending on the system
- The 7 cpy signal vanishes when using BOXWING. The annual signal for GAB is 1.7 times larger than for the GPS series

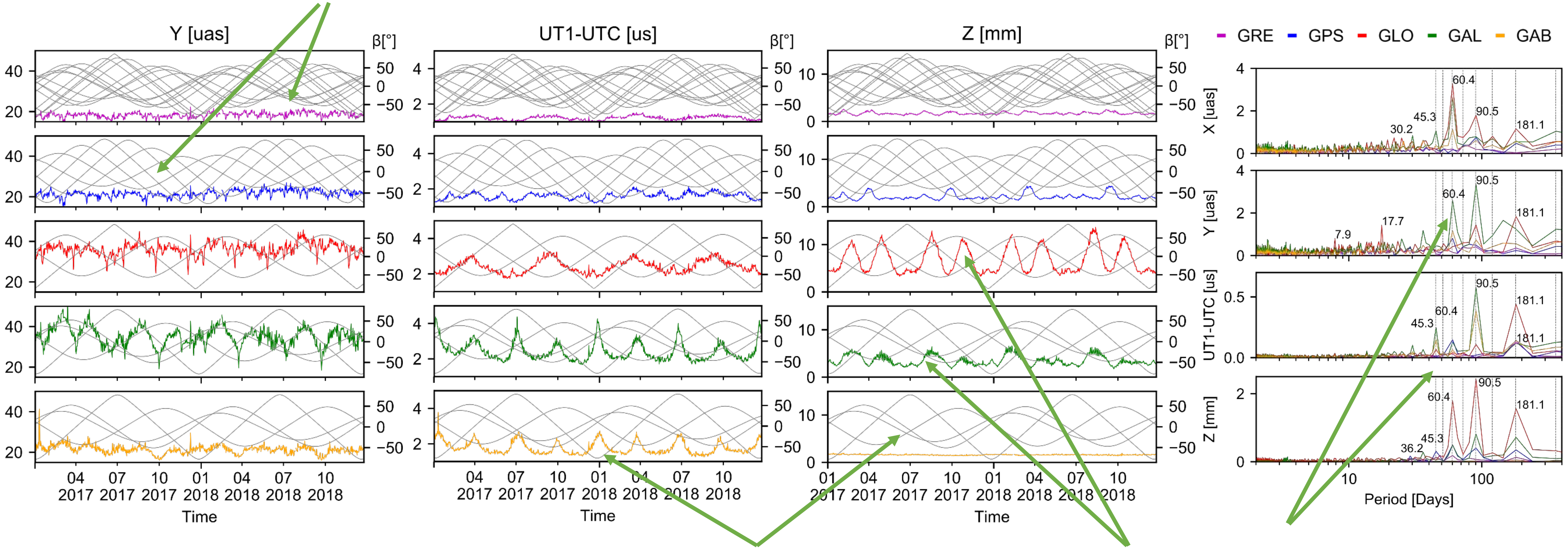
# Earth Rotation Parameters w.r.t. IERS C04 14




| | X [μas] | | Y [μas] | | dUT1 [μs] | |
|---|---|---|---|---|---|---|
| | AVG | RMS | AVG | RMS | AVG | RMS |
| GRE | 36 | 69 | -27 | 57 | 7 | 22 |
| GPS | 31 | 66 | -28 | 57 | 11 | 24 |
| GLO | 100 | 134 | -101 | 123 | 2 | 22 |
| GAL | -2 | 72 | -1 | 66 | 1 | 23 |
| GAB | -3 | 77 | -2 | 61 | 1 | 23 |

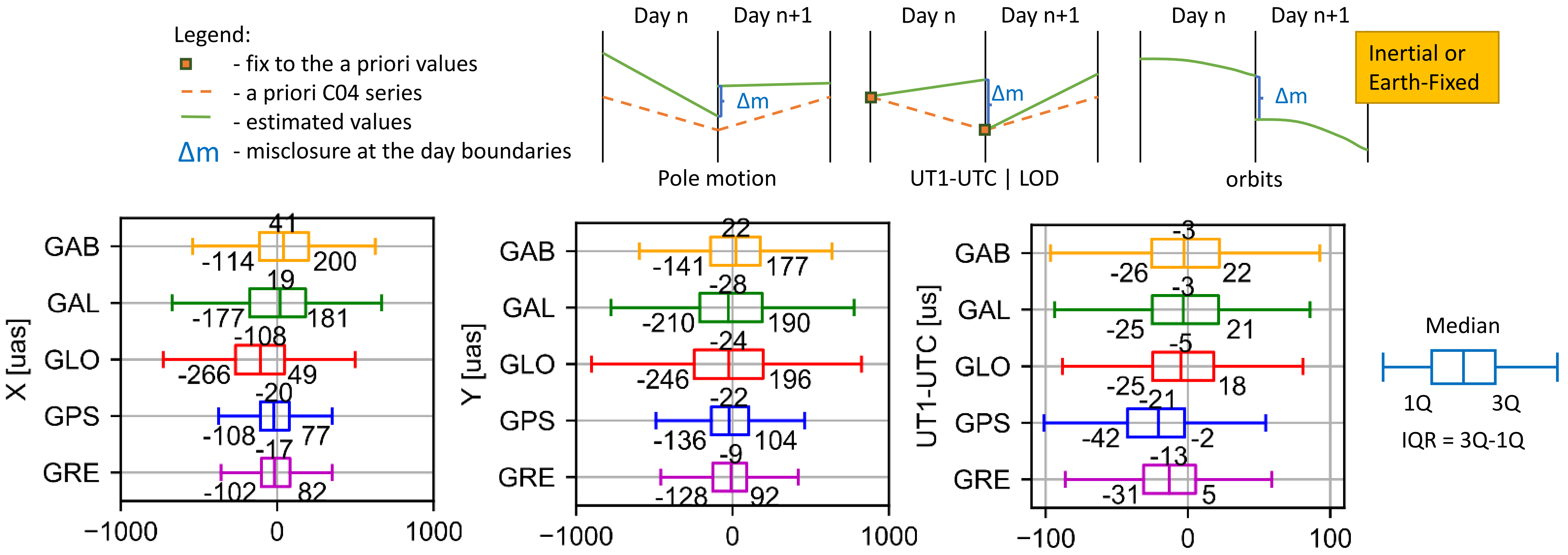
- **Galileo delivers the ERPs of almost the same quality as the GPS does and much better quality than that from GLONASS**
- The spectral analysis of **the X pole coordinate shows the pronounced signal with a 3 cpy for all 3-planes** constellations
- Similarly to the previous analysis, the **spurious signal with a period close to 3.4 days is discernible for the Galileo-based** solutions
- Linear drift of the UT1-UTC in time for GPS is at the level of 8.3 ms/y, so it's even **5 times larger than for GAL**
- Moreover, the outliers are clearly visible in the time series of UT1-UTC for GAL and GAB solutions

# The formal erros of the ERPs and GCC




- The mean error of the parameters is much smaller for the GPS than for the other systems.
- **Dependency between the height of the Sun above the orbital plane (β angle) and the formal errors of the Z GCC**
- When the **hybrid orbit model is applied, the periodic variations of the formal errors are entirely reduced for GCC** but not for ERPs
- Although both, **Galileo and GLONASS, comprise 3 orbital planes**, the periodic variations **of the formal errors have a different pattern.** UT1-UTC → 4 cpy and 2 cpy for Galileo and GLONASS, respectively | Y → 2 cpy for GLONASS; 6 and 4 cpy for Galileo

# ERP misclosures




- In all the cases, GRE solution is most consistent → **many systems improve the consistency**
- **Using hybrid SRP modeling improves the pole misclosures** when compared to the standard ECOM2 solution for Galileo
  The **inter-quartile-range decreases by 12 and 21% for the X and Y** coordinate of the pole, respectively

# Conclusions

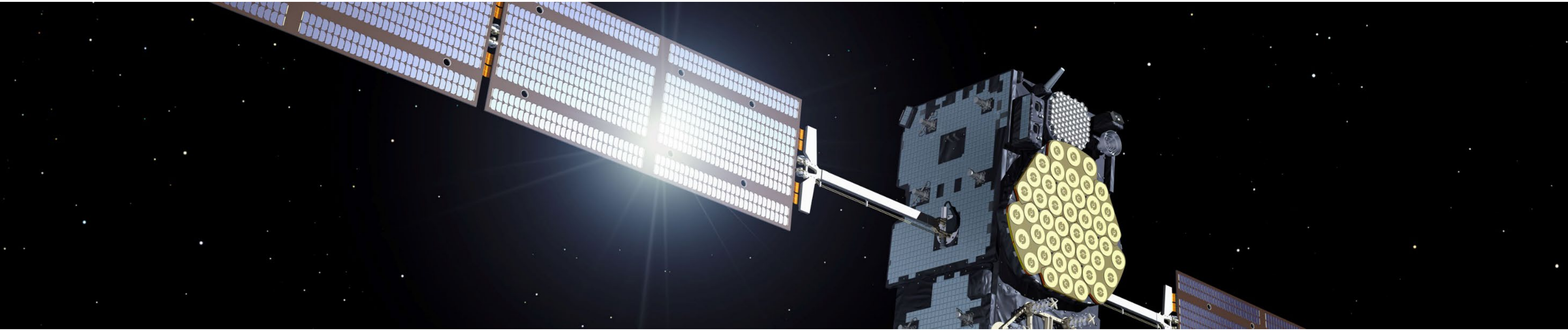
- **Galileo can deliver geocenter coordinates and Earth Rotation Parameters of the comparable quality to those of the GPS.** Moreover, the drift of the UT1-UTC values from the C04 values is 5 times smaller for the Galileo than for GPS

- Despite that, both GLONASS and Galileo comprise 3 orbital planes, **Galileo is not vulnerable to the same spurious signals as GLONASS**

- The artificial signal with a period close to **3.4 days is visible for the majority of the Galileo-derived parameters**. We identify this signal as a consequence of the combination of the Galileo revolution period and the solution length

- In case of Galileo, using hybrid SRP modelling, which includes both physical BOXWING model and empirical constant accelerations in DYB directions, **reduces the artificial signals in the time series of the Galileo-based parameters** i.e. the GCC and UT1-UTC and improves the consistency (ERP misclosures)

- The empirical parameters of ECOM2 model are correlated with the other estimated parameters such as the Z component of the GCC and UT1-UTC, which is clearly visible in the comparison of the formal errors for the subsequent series



# *Thank you for your attantion*

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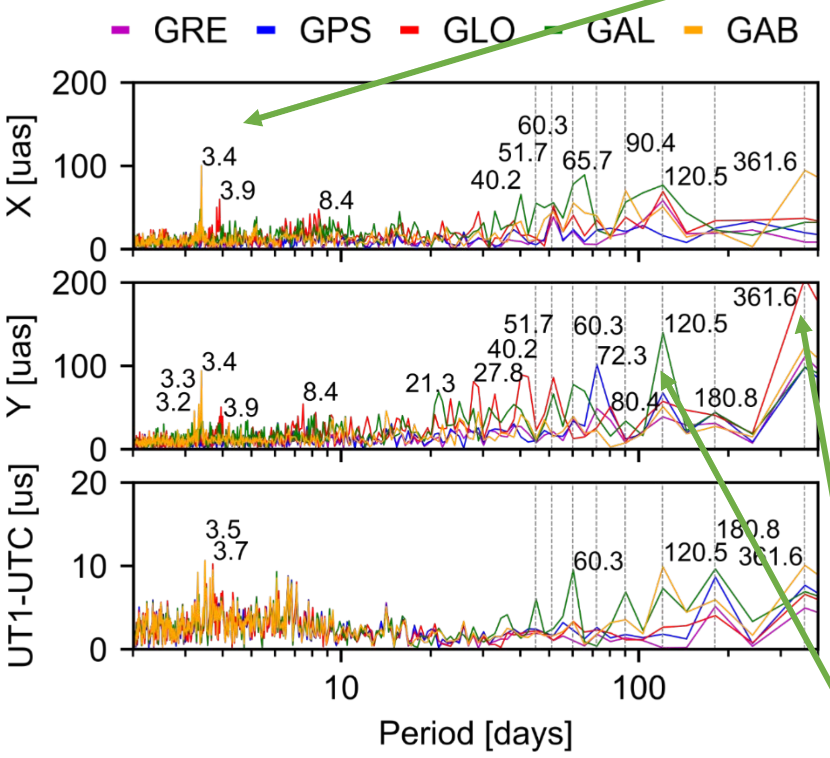
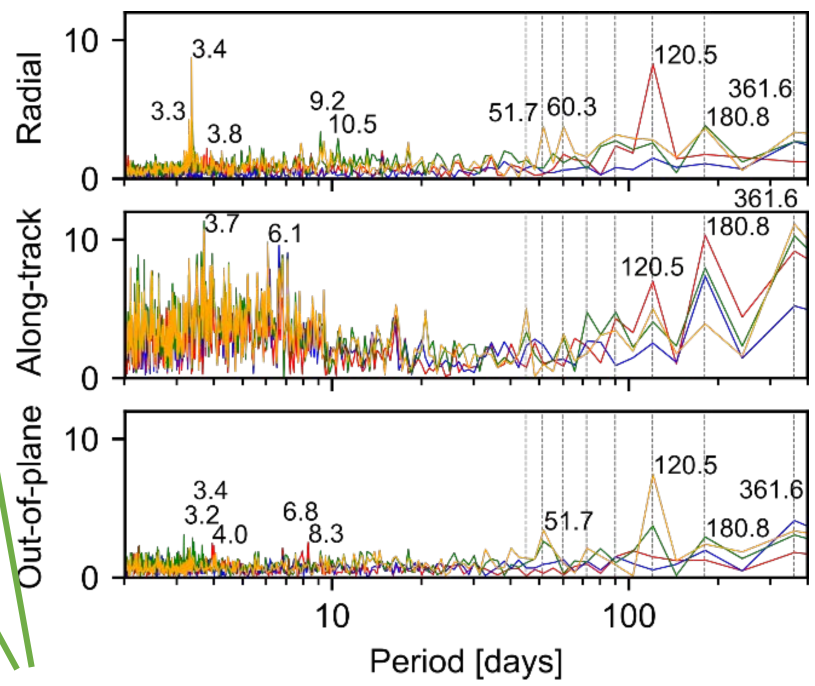
# ERP misclosures vs. Orbit misclosures



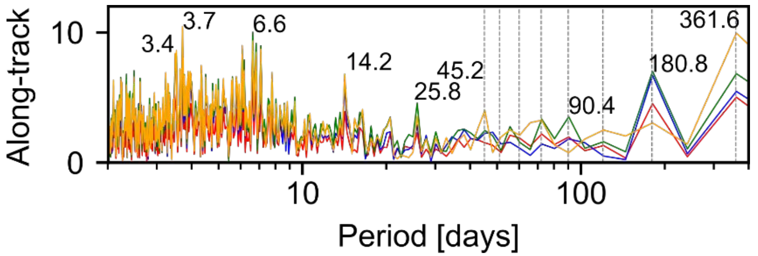

Inertial Reference System




Inertial – Earth-Fixed

Impact of the ERP

No impact on radial




Minor impact on the out-of plane

- The spectrum analysis of the ERP misclosures shows a signal with a **period close to ~3.3-3.4** days for Galileo-based estimates
- Each system shows the periodic signal for the misclosures of the Y pole coordinate at different frequencies
- Most of the **harmonic periods for GAL solution disappear when using the hybrid model for SRP modelling**
- The largest impact is visible for the along-track component, while the radial direction is roughly unchanged. The largest peaks are visible for the 1 and ½ cpy as well as for the 14.2 and 25.8 days with the amplitude of up to 10 mm

# ECOM