Geocenter estimates from 10 years of multi-mission LEO GNSS tracking

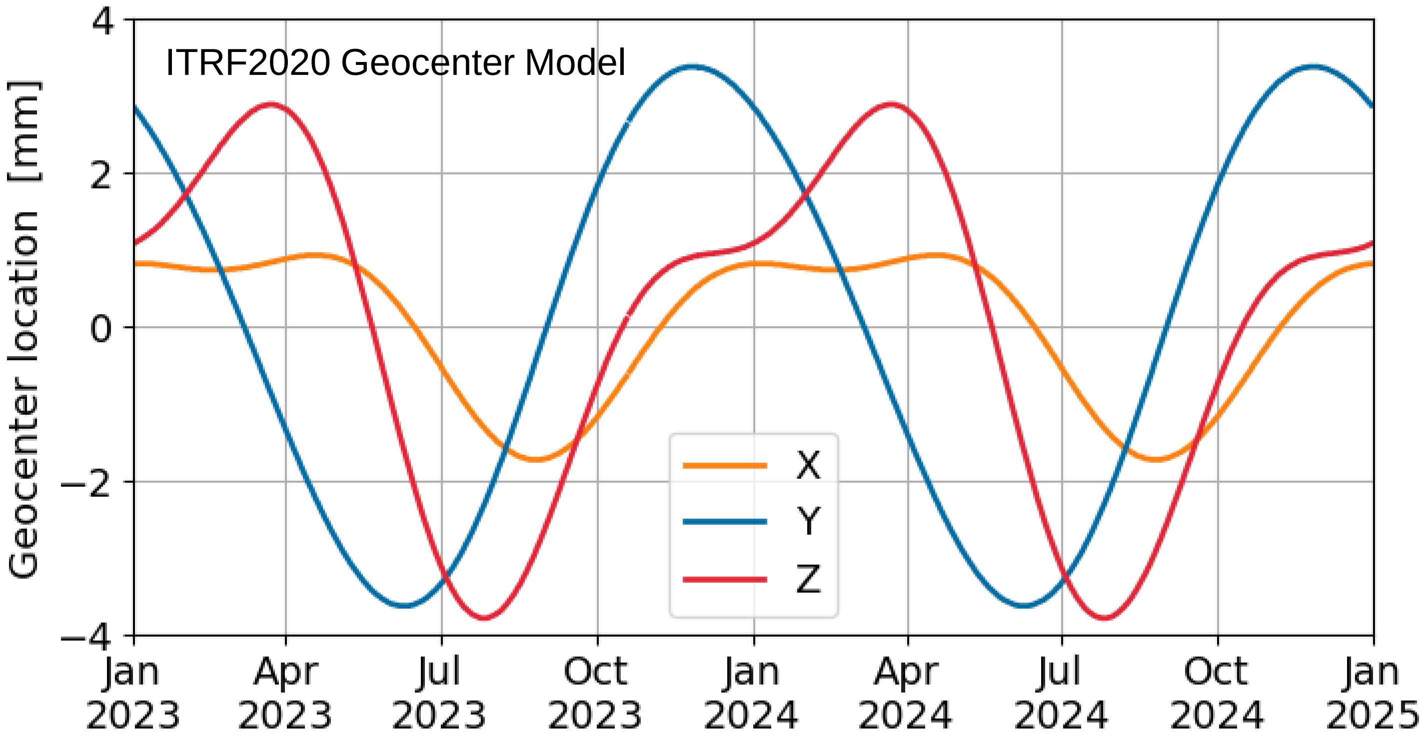
Peter Steigenberger, Bingbing Duan, Oliver Montenbruck

DLR

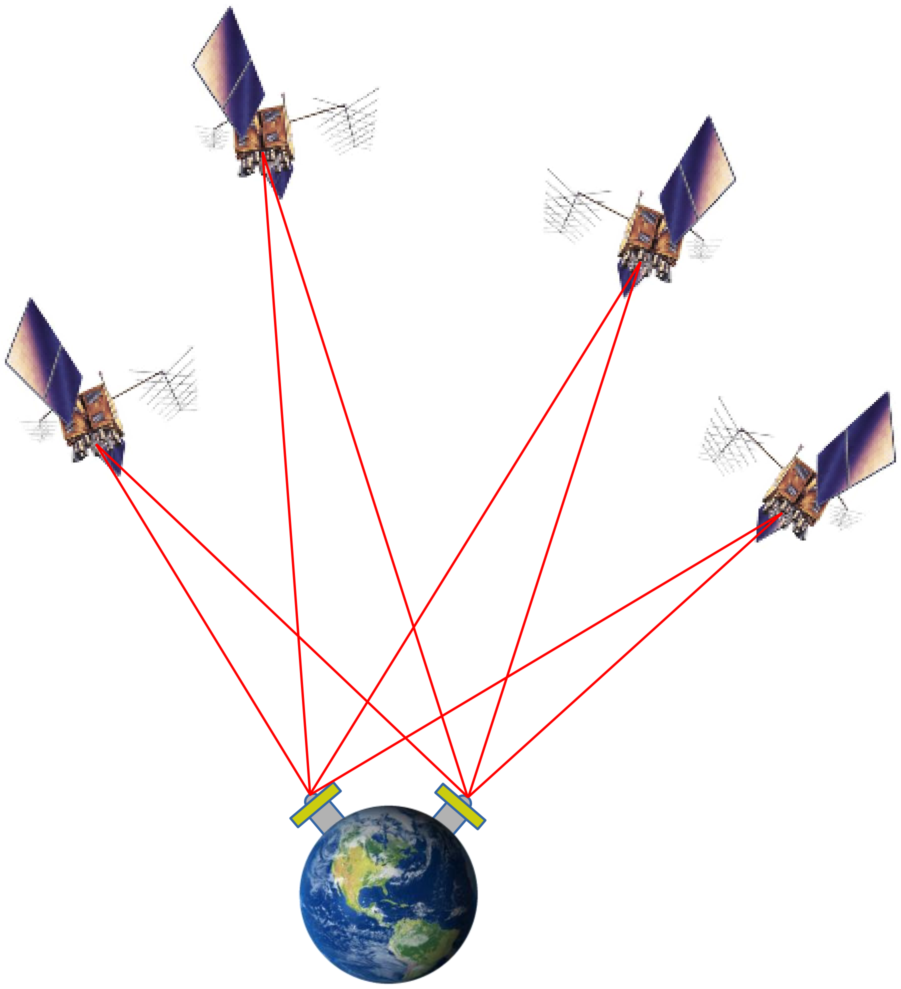
Introduction

- The origin of the ITRF is the **Center of Mass** of the total Earth system (CM)
- Geocenter motion: CM ⇔ CF
  - CF: **Center of Figure** of the crust of the Earth
- CF approximated by **Center of Network** (CN) used for GNSS orbit and clock determination

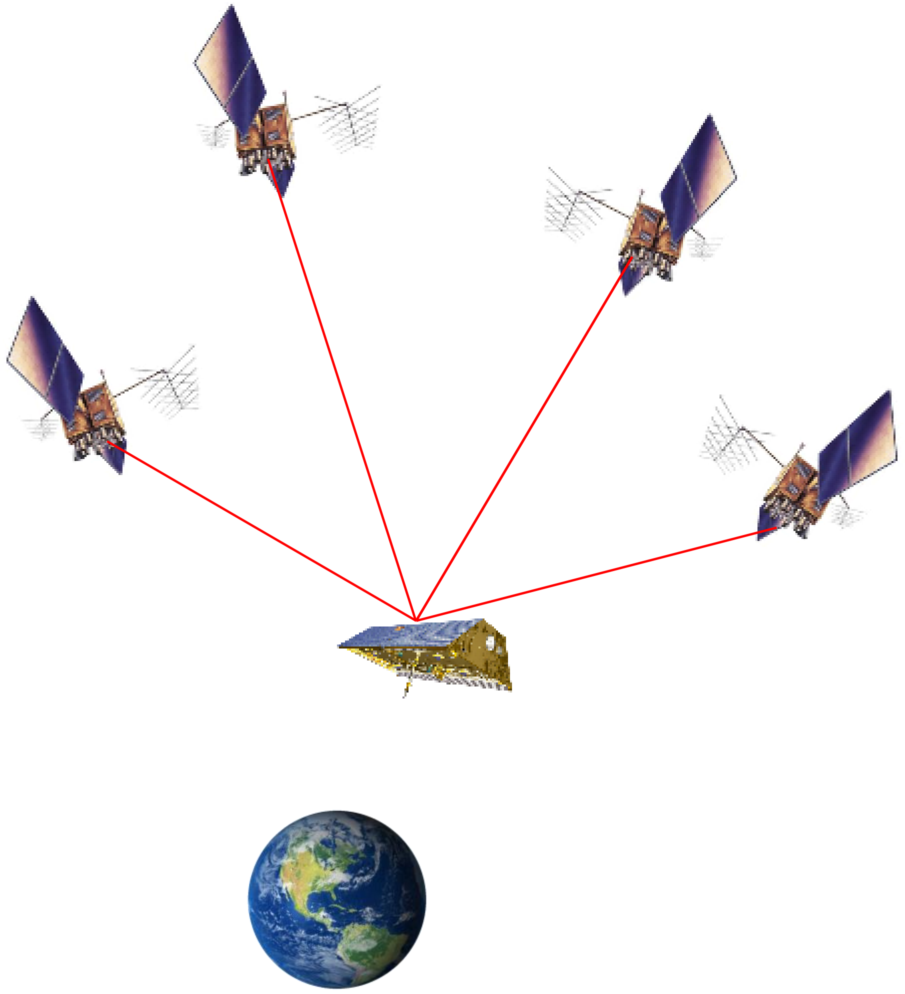
- Geocenter location
  CM ⇔ CN
- Low Earth Orbit (LEO) satellites are sensitive to geocenter motion



Parameter Estimation



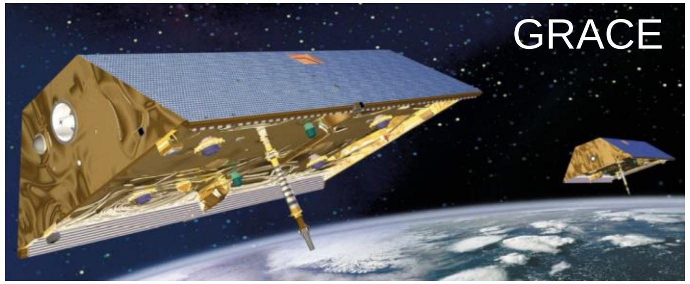
GNSS Orbit and clock products from global GNSS network refer to **Center of Network**

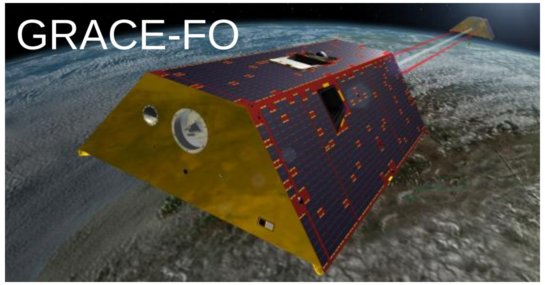


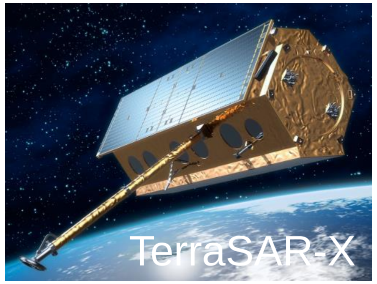
LEO orbit sensitive to **Center of Mass**
Estimation of geocenter location

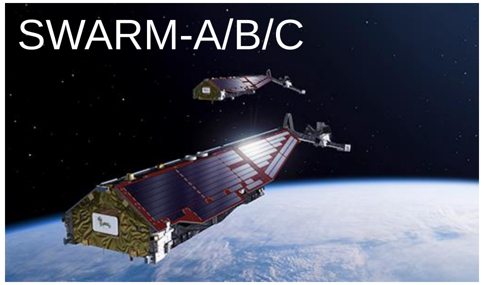
Images: NASA

LEO Missions

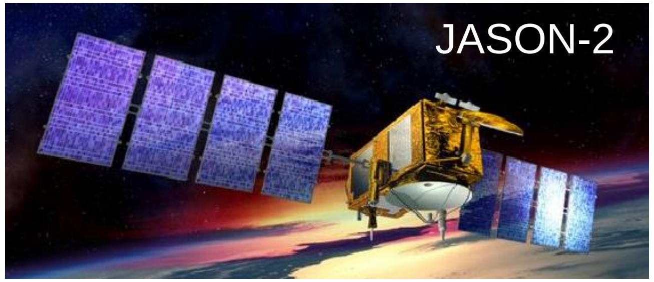


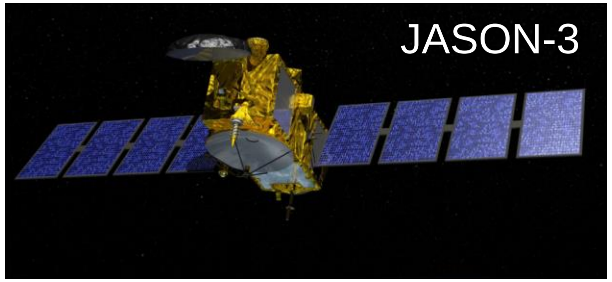


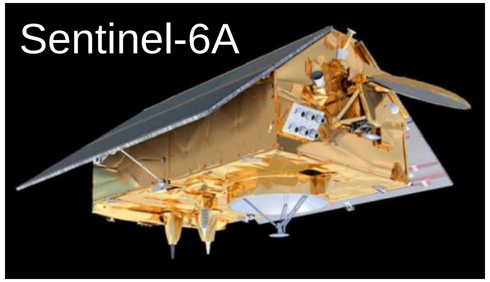




460 km
to
530 km



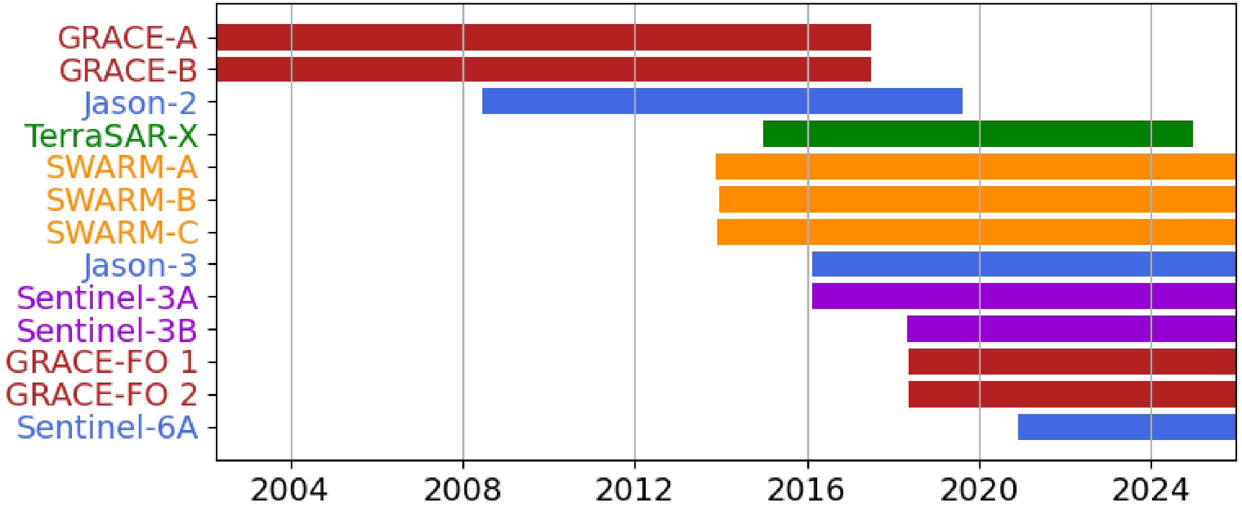


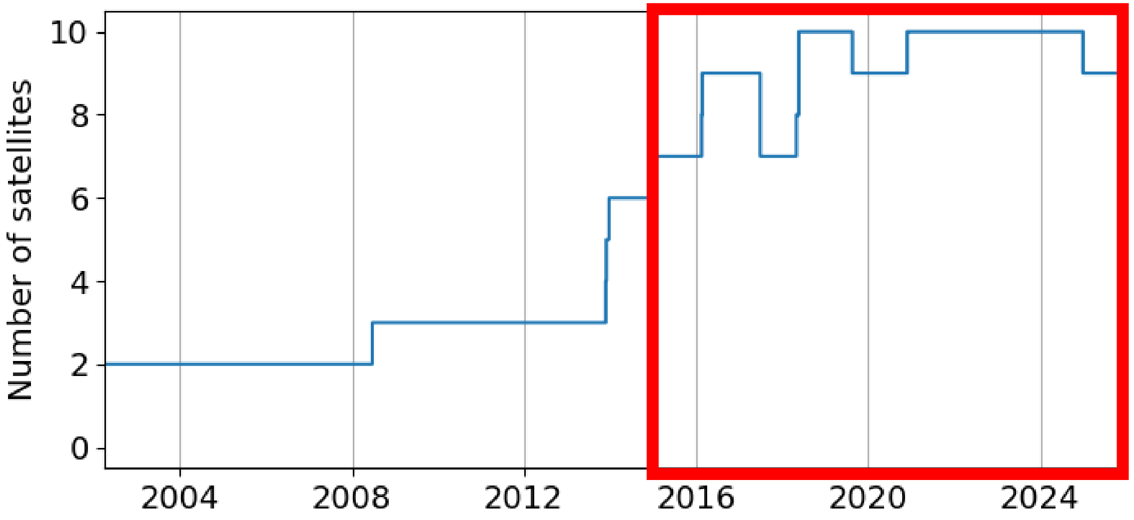


800 km

1336 km

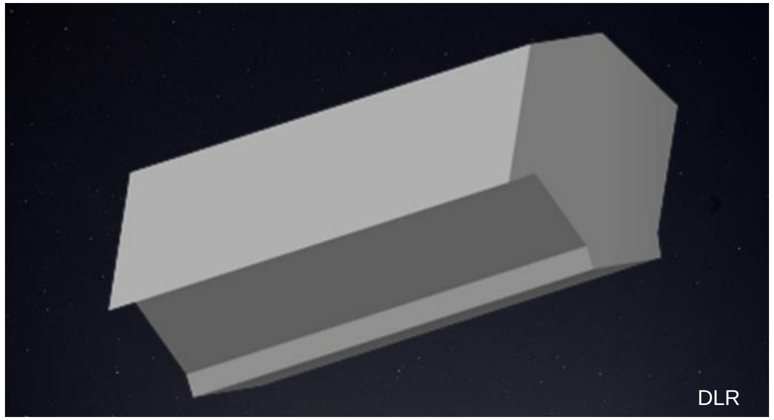
Images: CNES, DLR, ESA, NASA

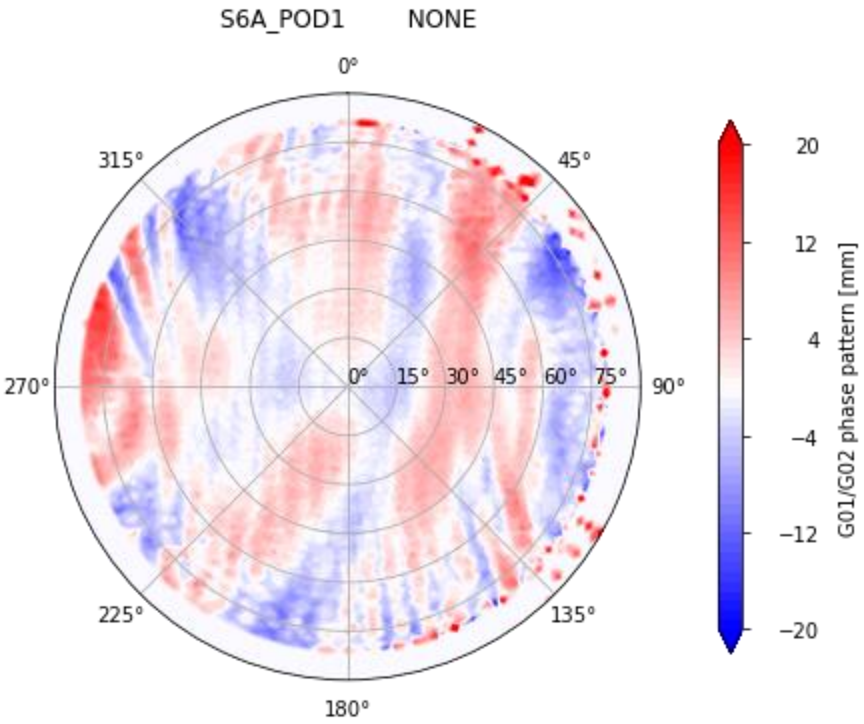




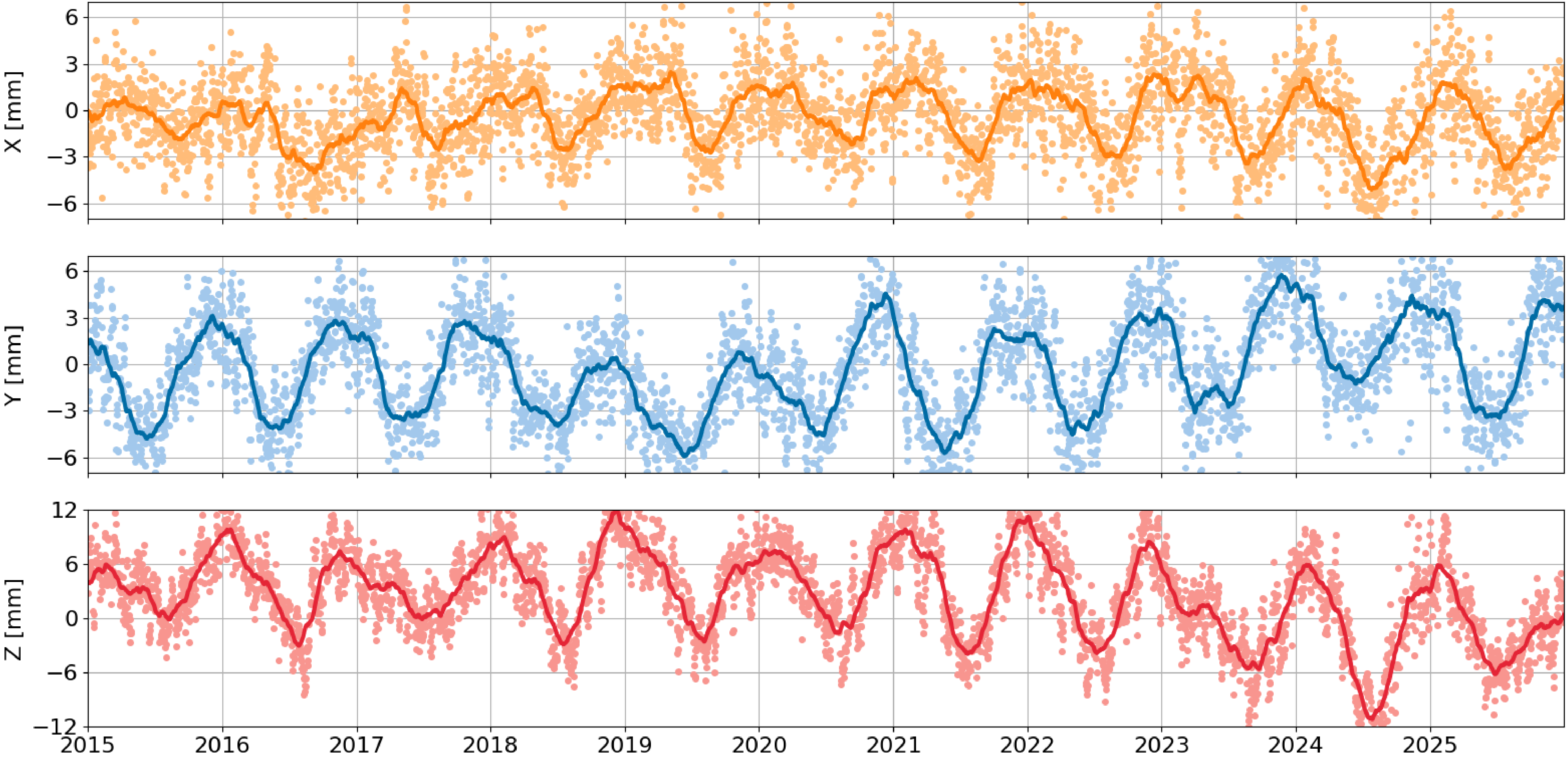
GPS Data Processing

- Reduced dynamic orbit determination with ambiguity fixing with DLR's GHOST software
- IGS repro3 and CODE operational orbit, clock and phase bias products
- Empirical tuning of box-wing models
- LEO-specific phase pattern estimation
- In general harmonized processing options
  - Horizontal wind model only for low satellites
  - Tighter constraints for higher satellites
- Estimation of daily geocenter locations

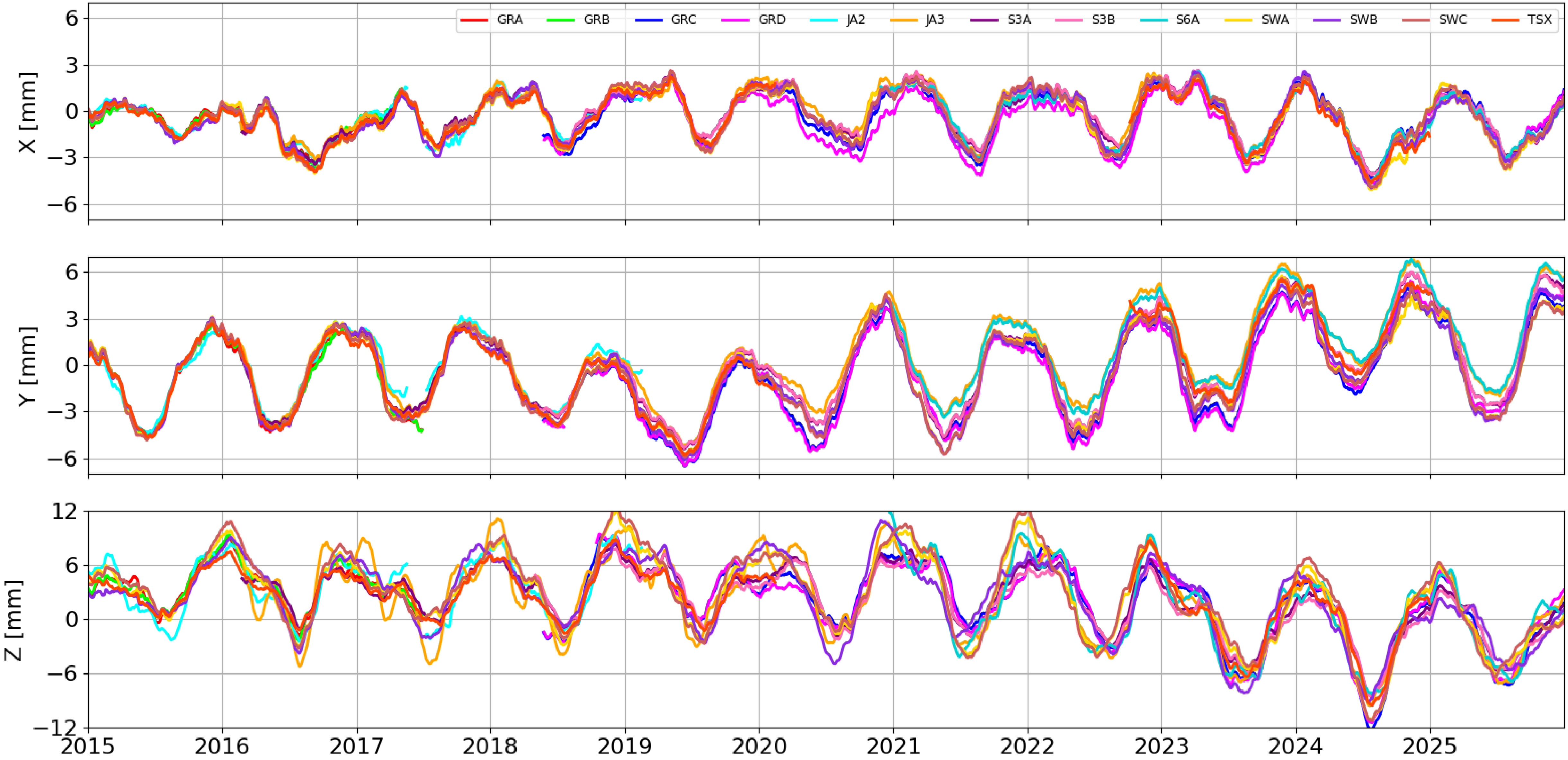




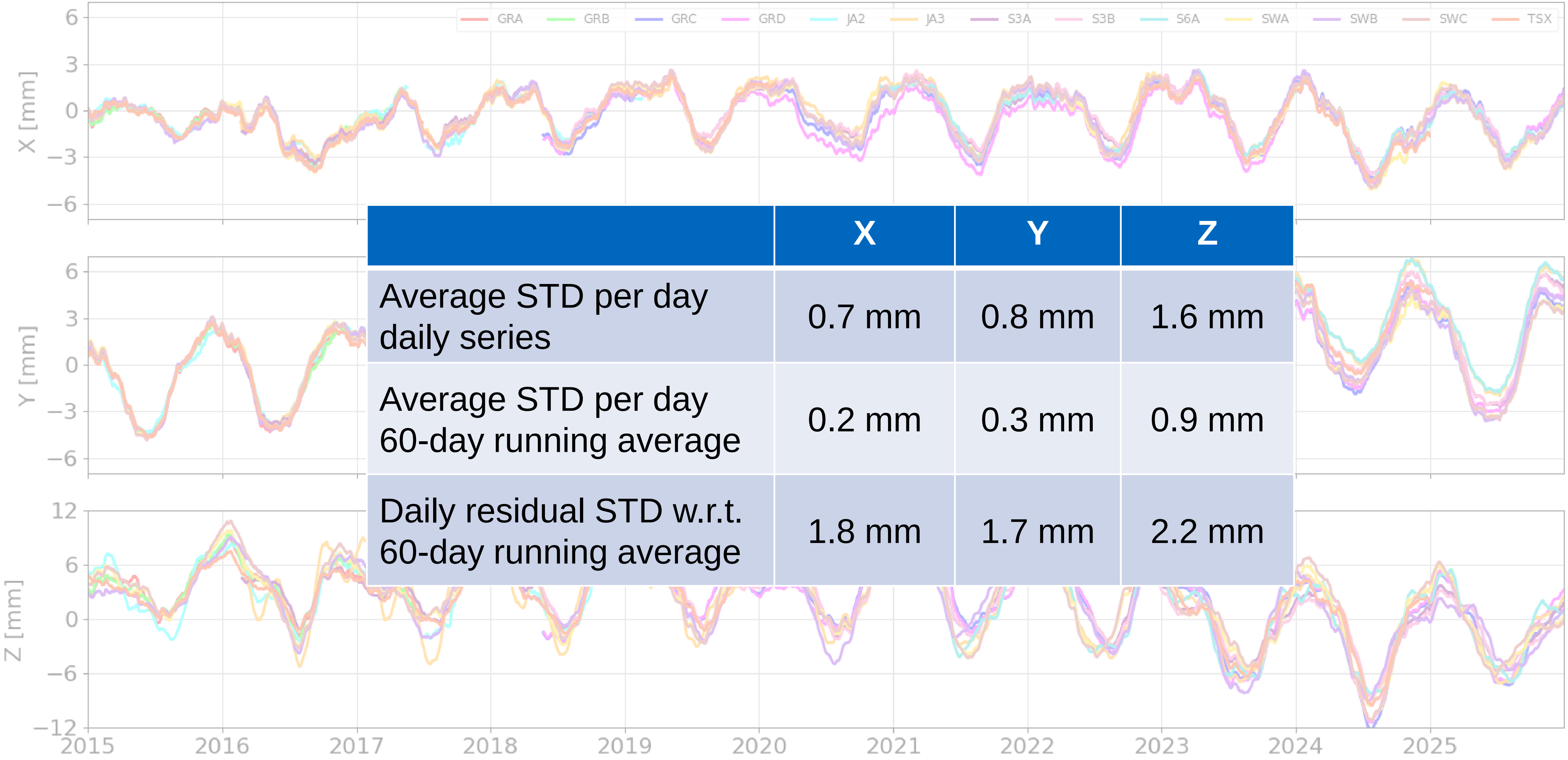
LEO Geocenter Location: Daily Estimates SWARM-A



LEO Geocenter Location: 60-day Running Average

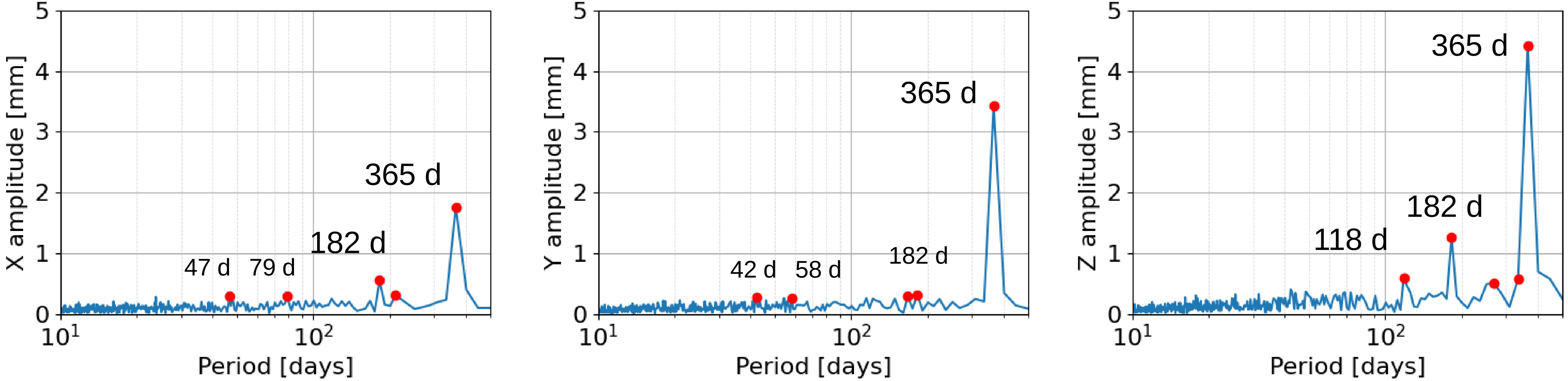


LEO Geocenter Location: 60-day Running Average



	X	Y	Z
Average STD per day daily series	0.7 mm	0.8 mm	1.6 mm
Average STD per day 60-day running average	0.2 mm	0.3 mm	0.9 mm
Daily residual STD w.r.t. 60-day running average	1.8 mm	1.7 mm	2.2 mm

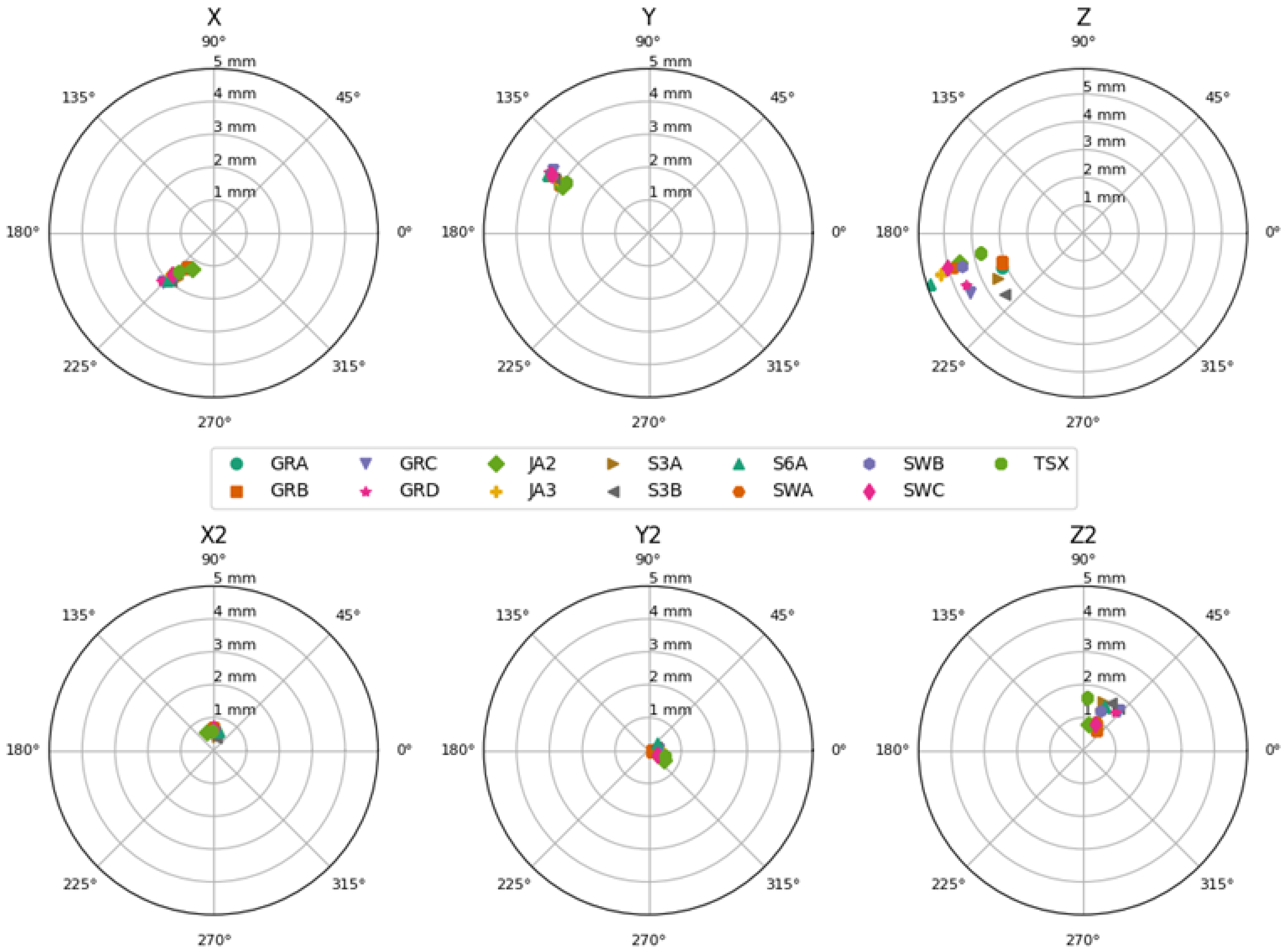
Spectral Analysis of Daily LEO Averages



Seasonal Fit:

$$o + d \cdot t + A_1 \cdot \cos\left[2\pi(t - t_0) - \varphi_1\right] + A_2 \cdot \cos\left[4\pi(t - t_0) - \varphi_2\right]$$

Satellite-specific Seasonal Fits



Annual amplitude STD

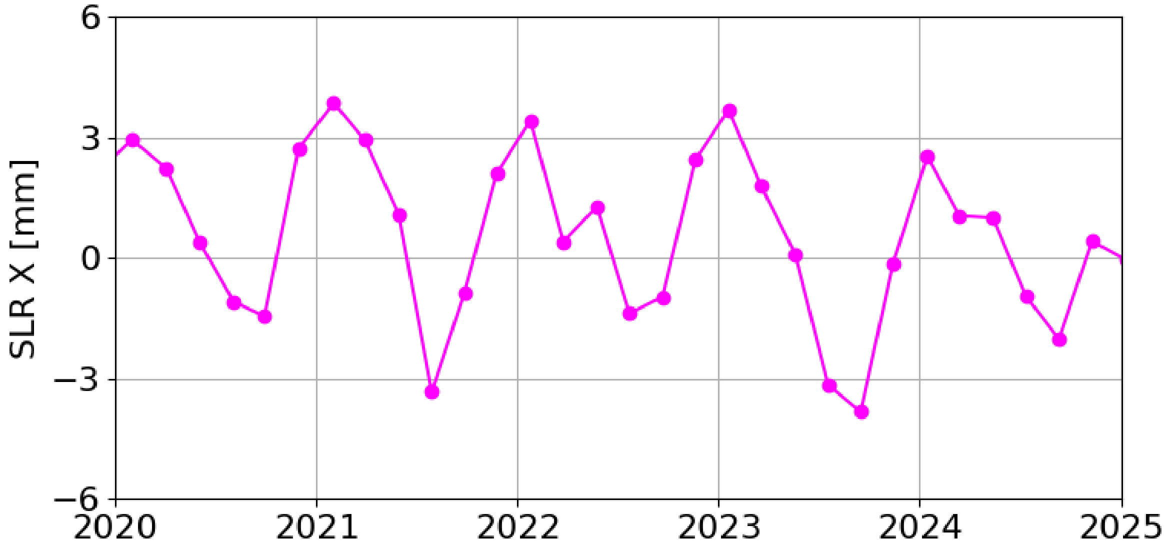
X	Y	Z
0.3 mm	0.2 mm	0.8 mm

Annual phase STD

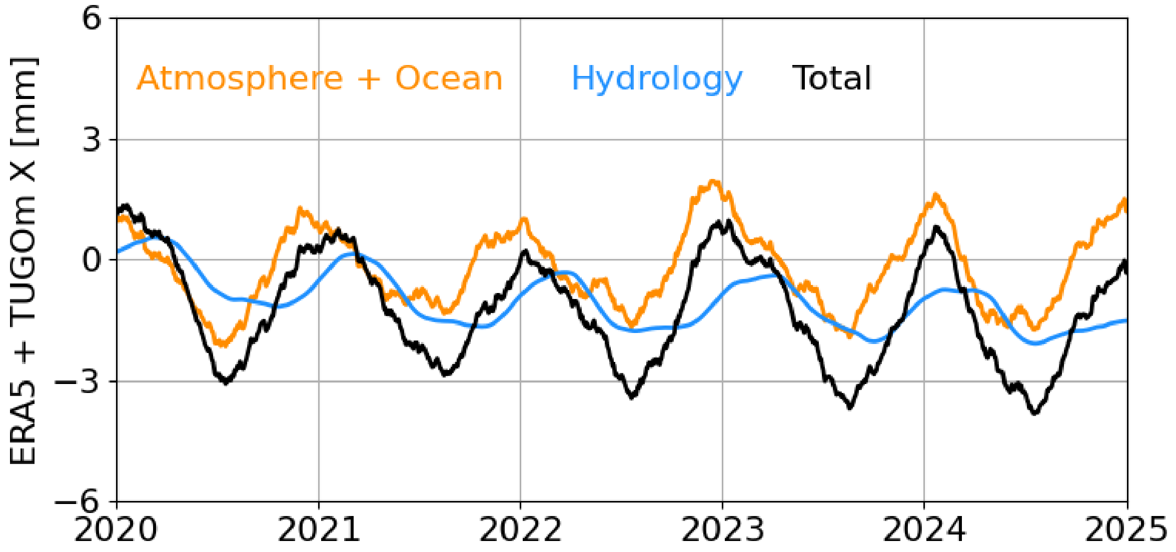
X	Y	Z
4.6°	1.2°	7.2°

Comparison with SLR and Geophysical Models (1)

Satellite Laser Ranging (SLR)



Geophysical Models



CSR Texas:

http://loading.u-strasbg.fr/geocenter.php

Detrended 60-day estimates from LAGEOS-1 and -2

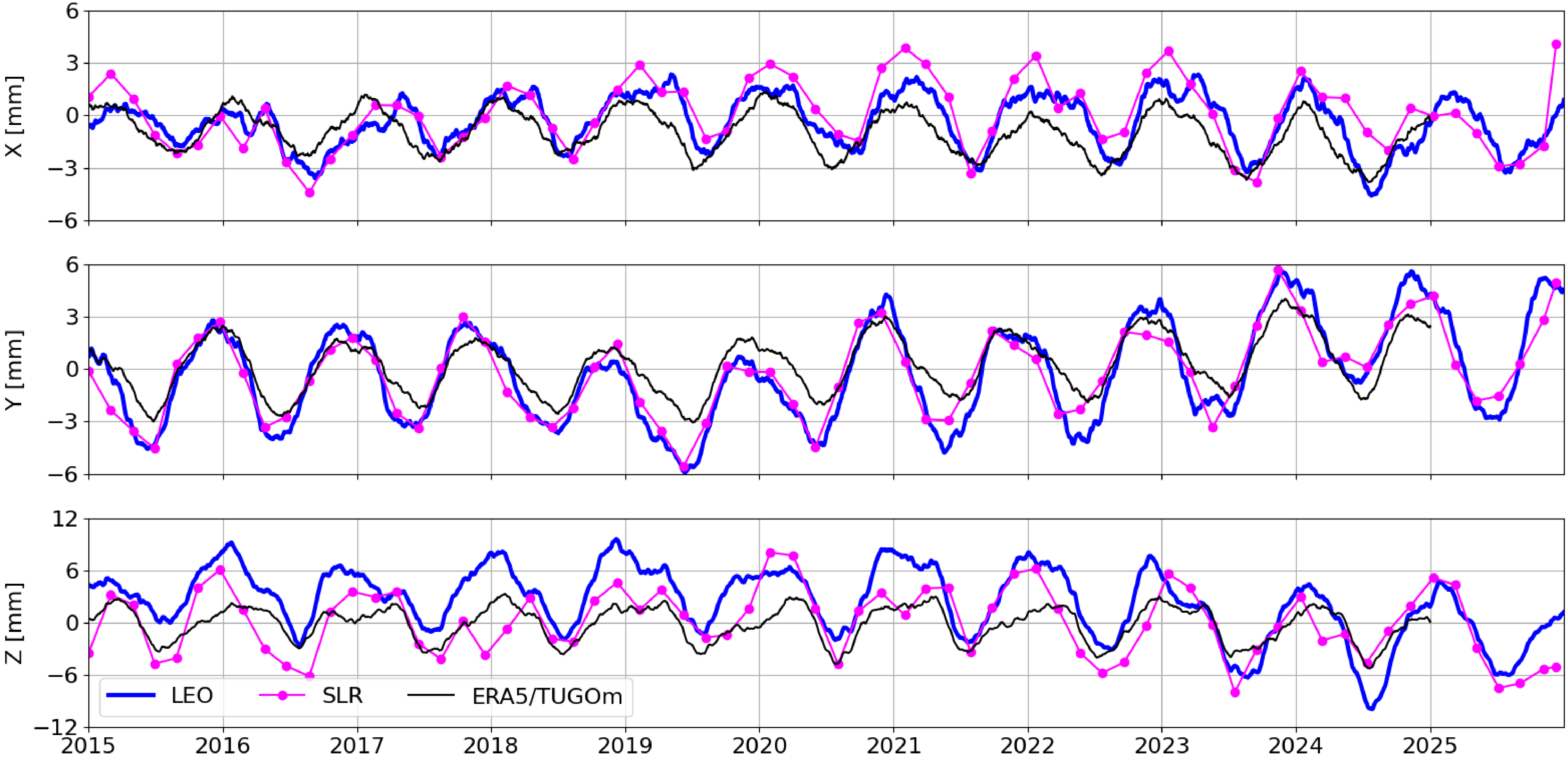
EOST Loading Service:

http://loading.u-strasbg.fr/geocenter.php

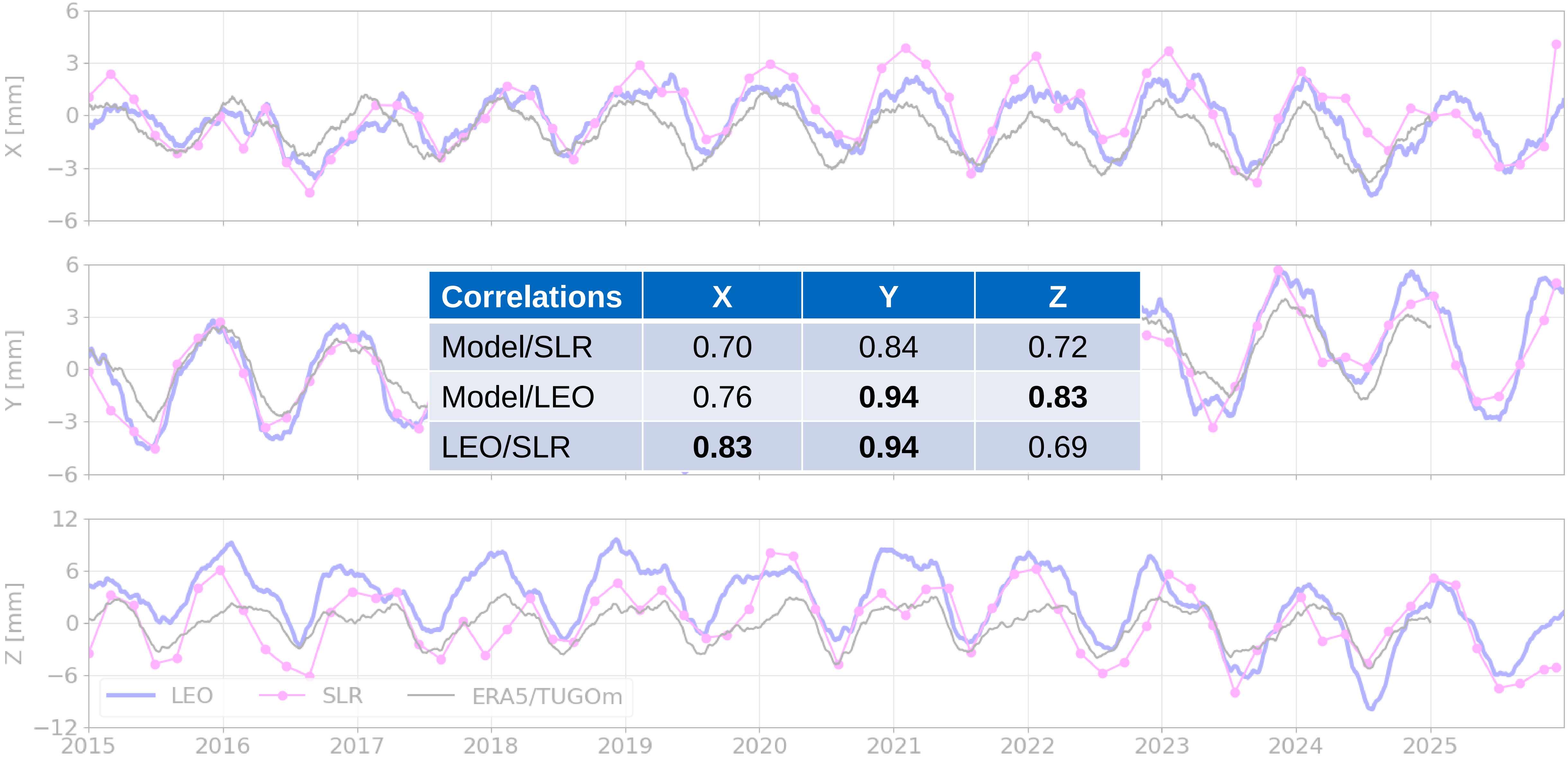
Atmosphere and ocean: ERA5 + TUGOm

Hydrology: ERA5 Land

Comparison with SLR and Geophysical Models (2)

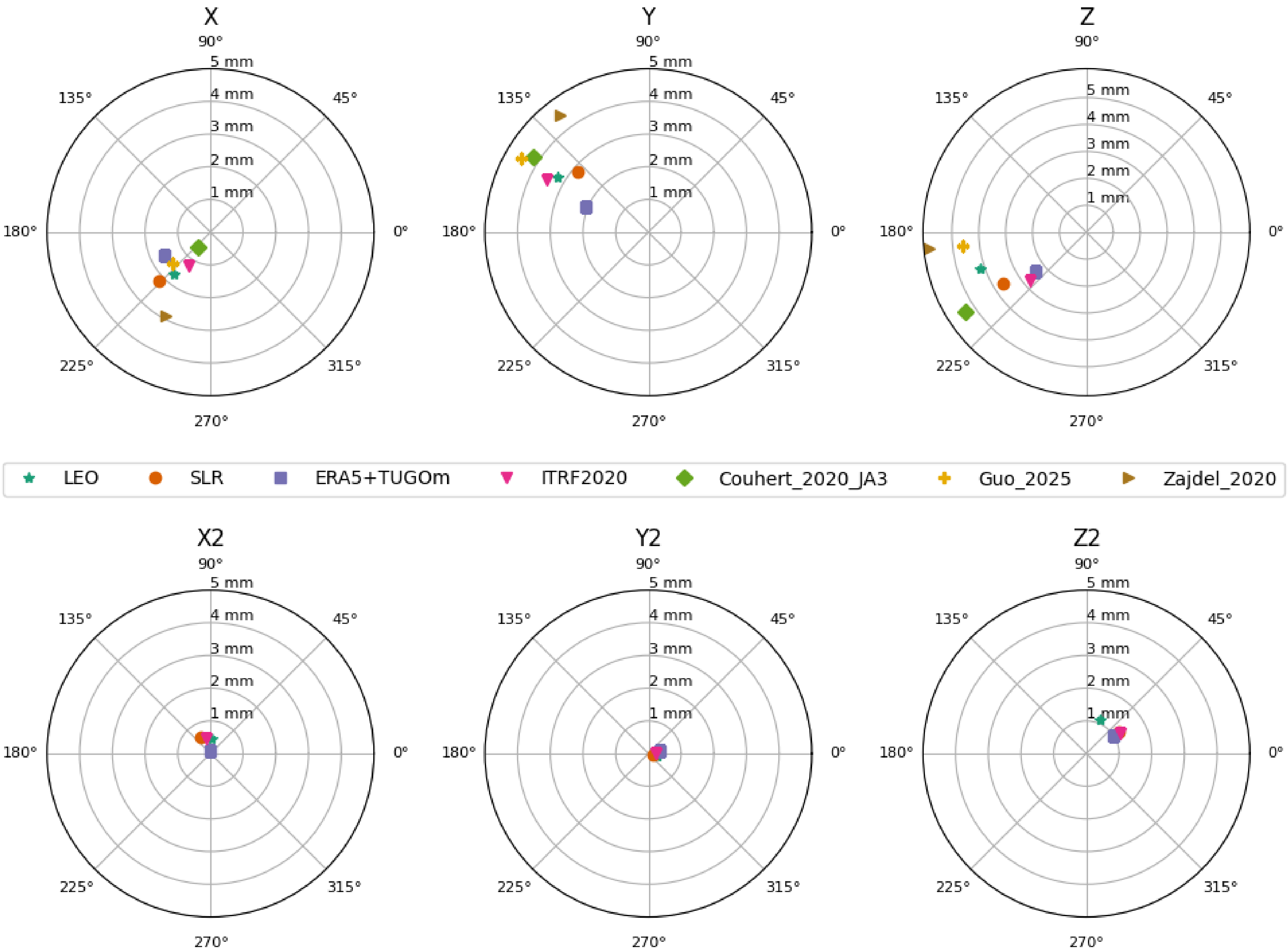


Comparison with SLR and Geophysical Models (2)



Correlations	X	Y	Z
Model/SLR	0.70	0.84	0.72
Model/LEO	0.76	**0.94**	**0.83**
LEO/SLR	**0.83**	**0.94**	0.69

Geocenter Location: Annual and Semi-annual Terms



Couhert et al. (2020)
Jason-3

Guo et al. (2025):
4 LEO + Ground network

Zajdel et al. (2020)
GPS+GLO+GAL

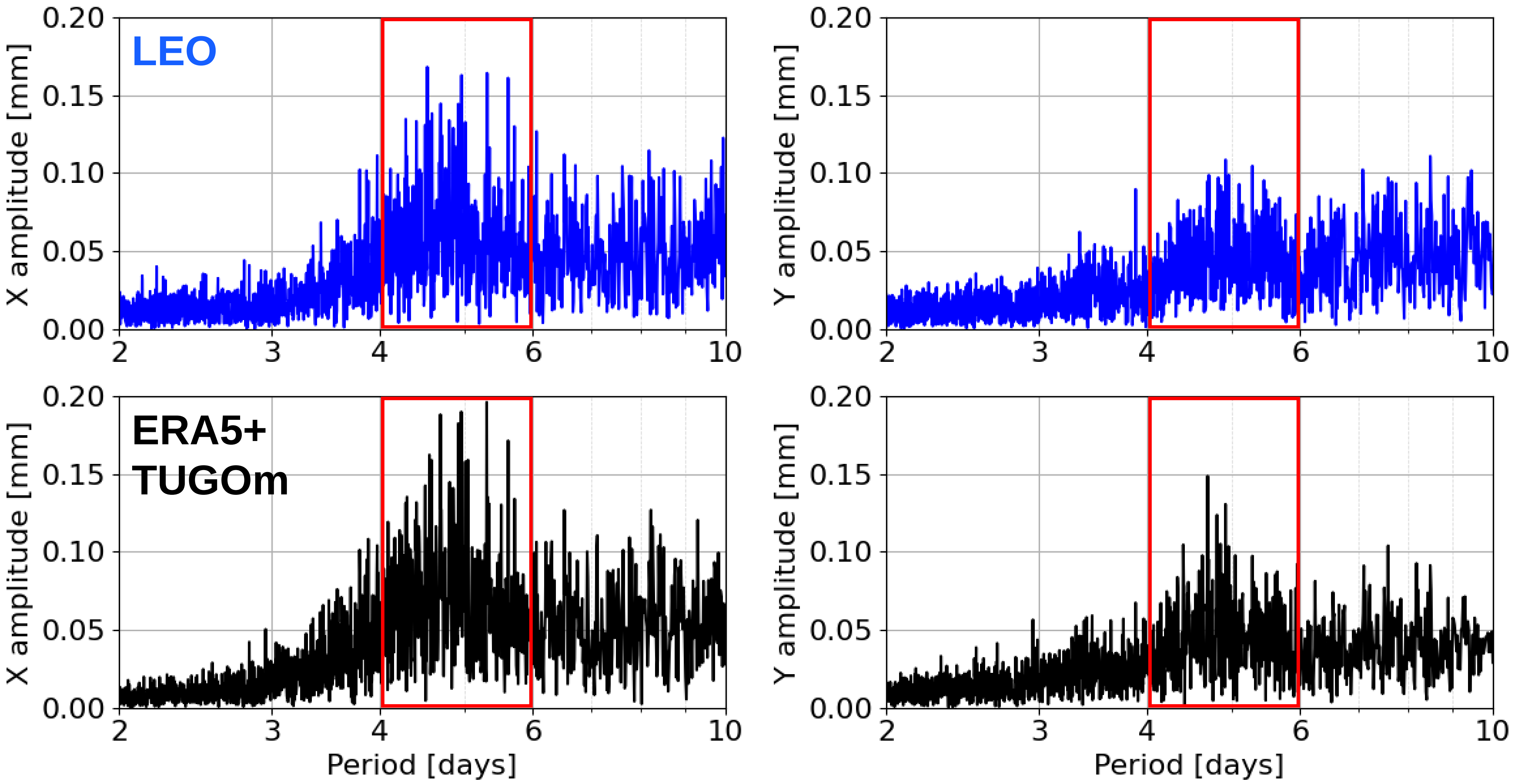
Annual amplitude STD

X	Y	Z
0.7 mm	0.9 mm	1.2 mm

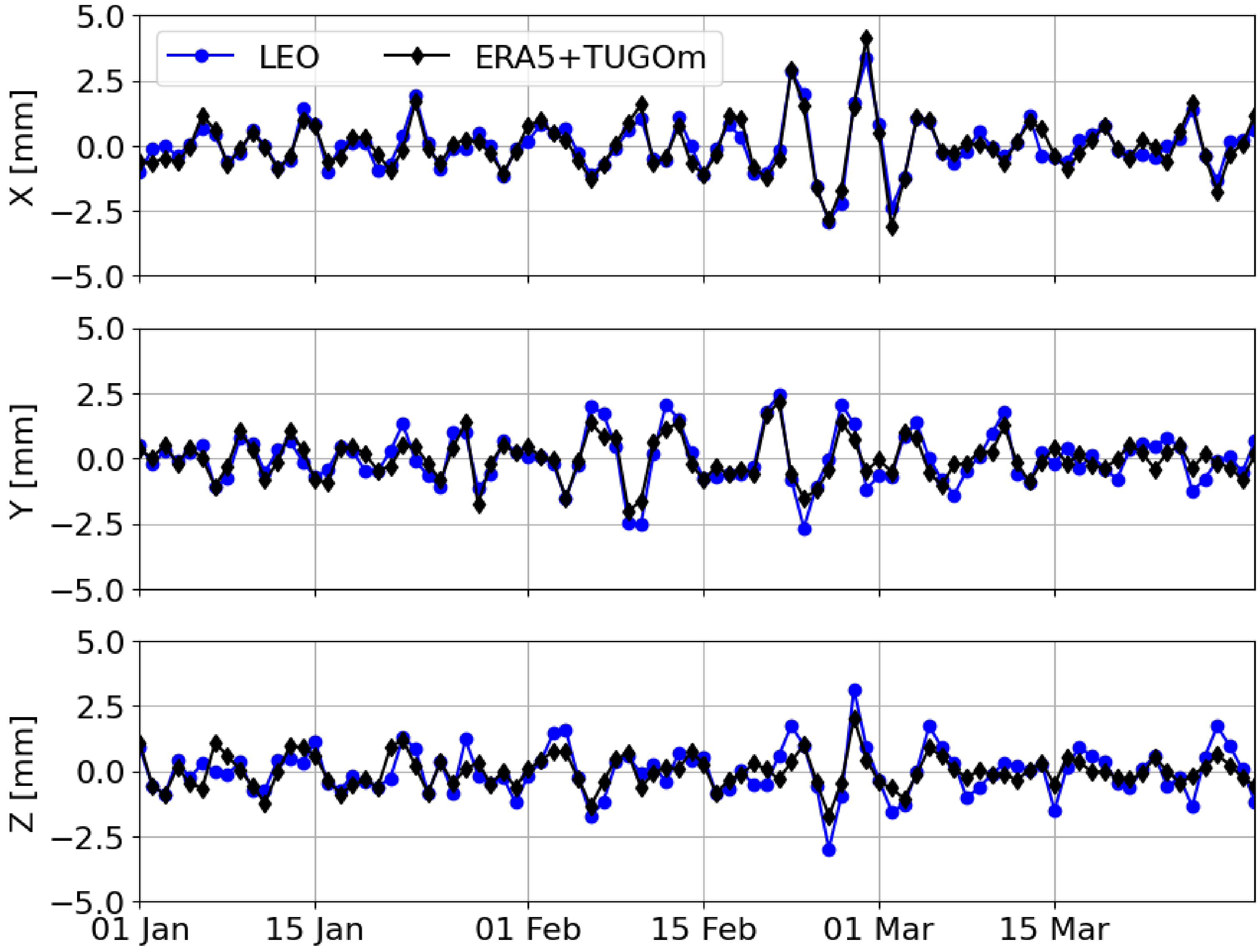
Annual phase STD

X	Y	Z
10.7°	9.4°	13.5°

Short-Period Variations (1)



Short-Period Variations (2)



LEO data:

- Highpass filtering 10 days cutoff

ERA5+TUGOm

- Bandpass filtering with 1.5 and 10 days cutoff
- Median down-sampling to 1 day

Correlations

X	Y	Z
0.92	0.85	0.74

Summary

- Estimation of geocenter location from 11 years GPS tracking of 13 LEO satellites
- Very high consistency of diverse LEO missions at different orbital heights and configurations: better than 1 mm
- Good agreement with SLR at annual and even longer time scales
- Common signals at periods of 4-6 days with geophysical models
- Future work
  - Further analysis of few-days variations
  - Extension of TerraSAR-X series
  - Inclusion of Jason-1 and CHAMP to complement early years