

Consistency of Galileo Satellite Antenna Phase Center Offsets

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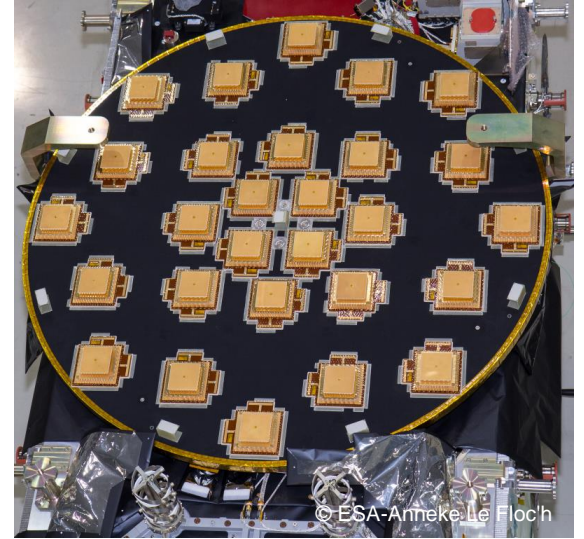
REFAG 2022



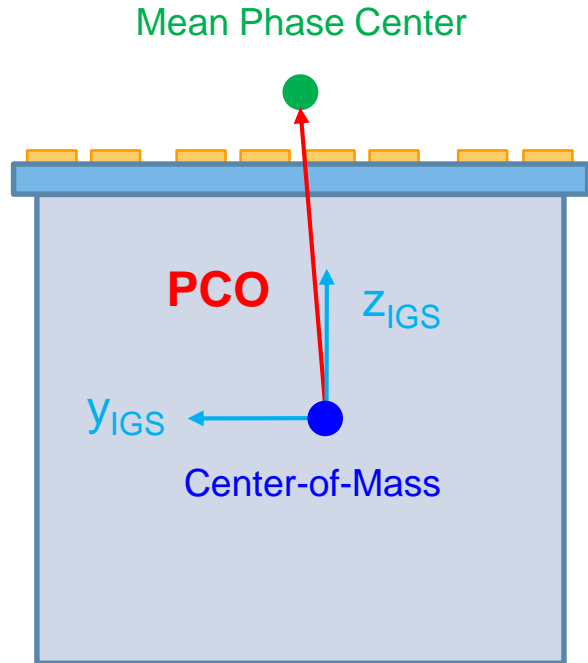
Knowledge for Tomorrow

Motivation

- Galileo satellite antenna phase center calibrations published by EUSPA
- E1/E5a used as default within IGS
- Growing number of E5b- and E6-capable receivers
- Inconsistencies in BDS-3 B1I/B3I and B1C/B2a antenna calibrations identified by Zajdel et al. (2022)
- Are the Galileo calibrations consistent?



Satellite Antenna Phase Center Offsets



- Current definition as used in [IGS ANTEX](#):

PCO: vector from the center of mass to the mean phase center

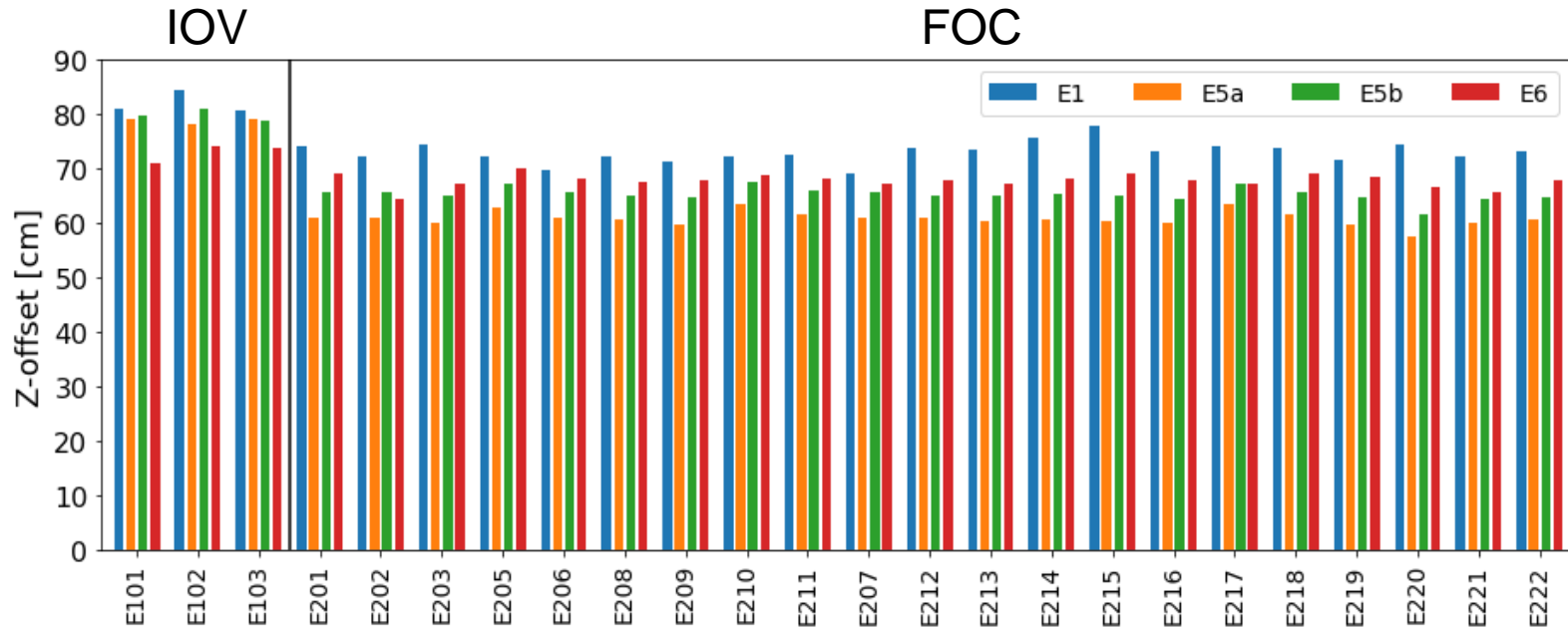
- Satellite antenna Z-PCOs are correlated with the terrestrial scale



Galileo Satellite Antenna Phase Center Offsets

Obtained from chamber calibrations

Available for E1, E5a, E5b, E5, E6

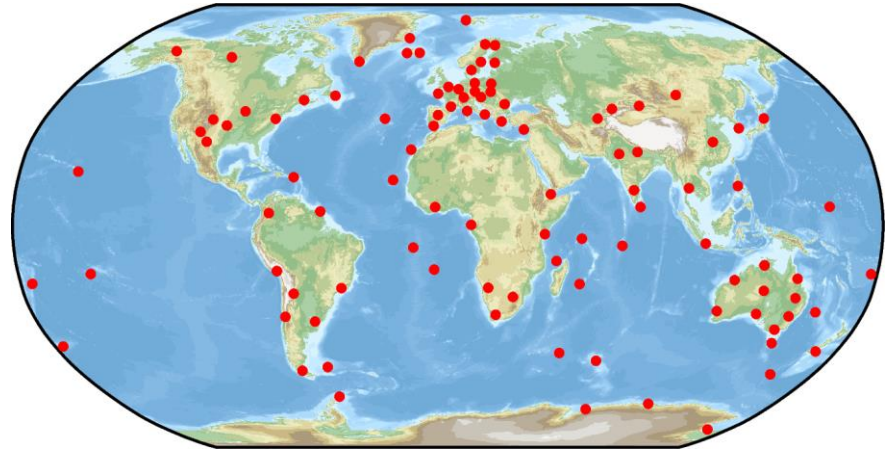


GNSS Data Processing

- Global GPS+Galileo solutions with NAPEOS
- Estimation of station coordinates, troposphere zenith delays, ERPs, clocks, orbits, PCOs
- ITRF2020 a priori coordinates
- 148 selected stations
- 1 July 2021 – 30 June 2022
- Ionosphere-free linear combinations of E1/E5a, E1/E5b, E1/E6

Station Selection

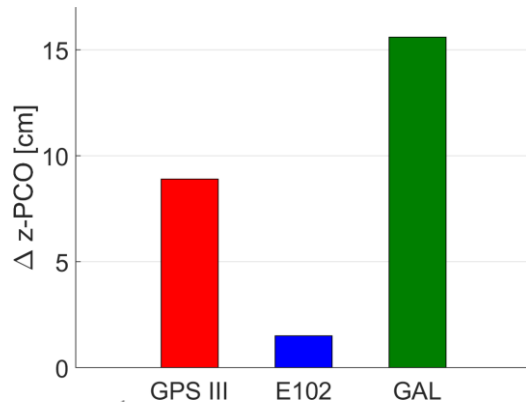
- Multi-frequency receiver antenna calibration
- Tracking of GPS L1/L2 and Galileo E1/E5a/E5b/E6
- Global distribution



ITRF2020 and igs20.atx Z-PCOs

ITRF2020 scale:

- Average of SLR and VLBI
- 0.15 ppb offset SLR/VLBI
- 0.68 ppb offset of IGS/GNSS solution at epoch 2015.0

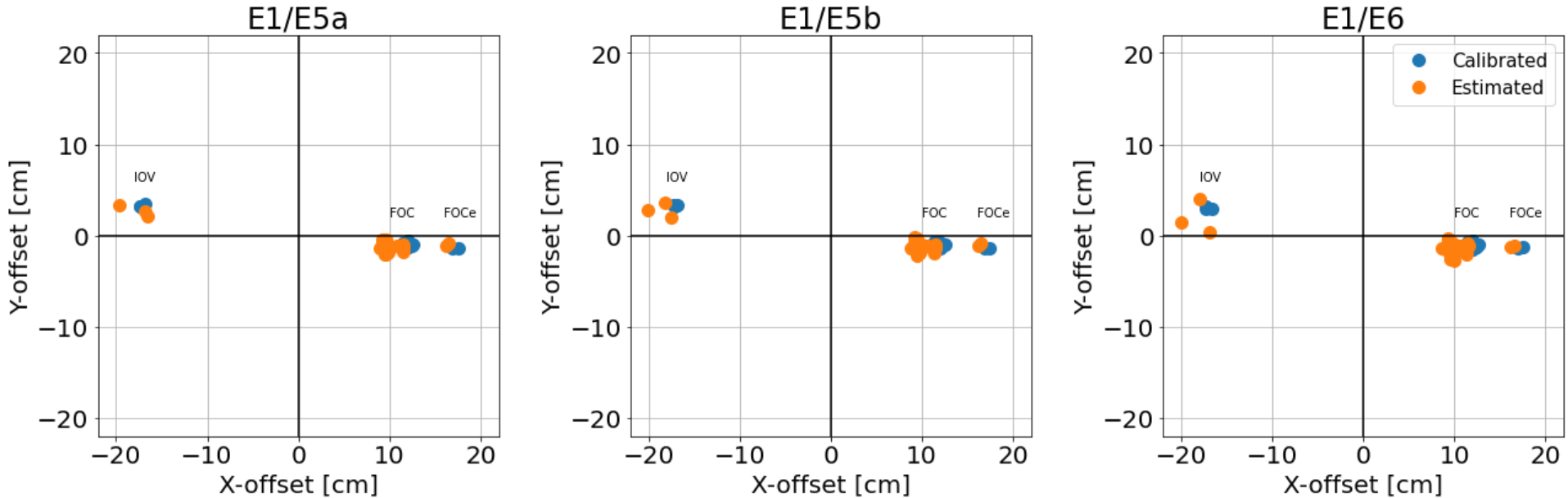


igs20.atx satellite antenna Z-PCOs

- Scale consistent with ITRF2020 at epoch 2015.0
- **Single offset** w.r.t. manufacturer values estimated for **GPS III**
- Other GPS L1/L2 Z-PCOs estimated from Repro3 time series
- **Offset** w.r.t. manufacturer values estimated for Galileo IOV satellite **E102**
- **Single offset** w.r.t. manufacturer values estimated for **other Galileo satellites**



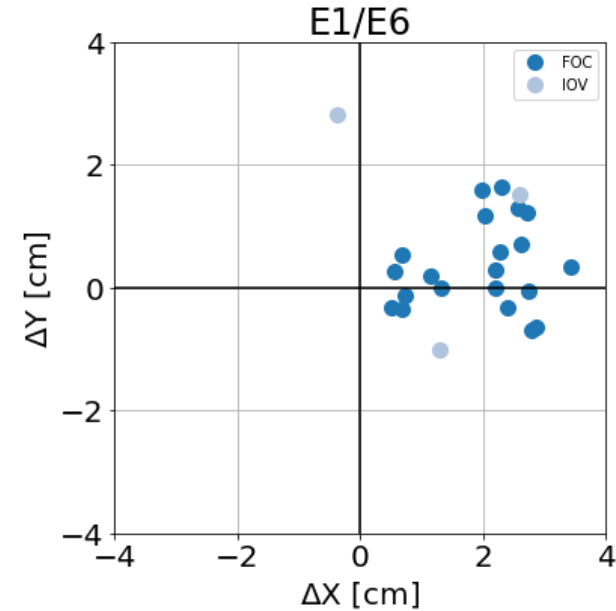
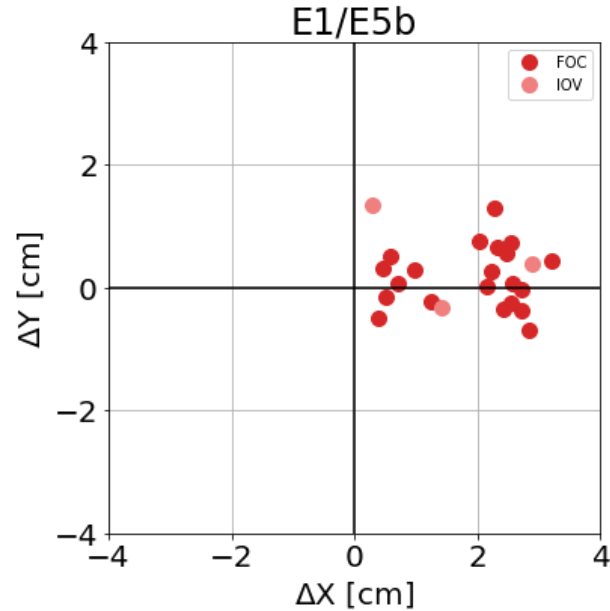
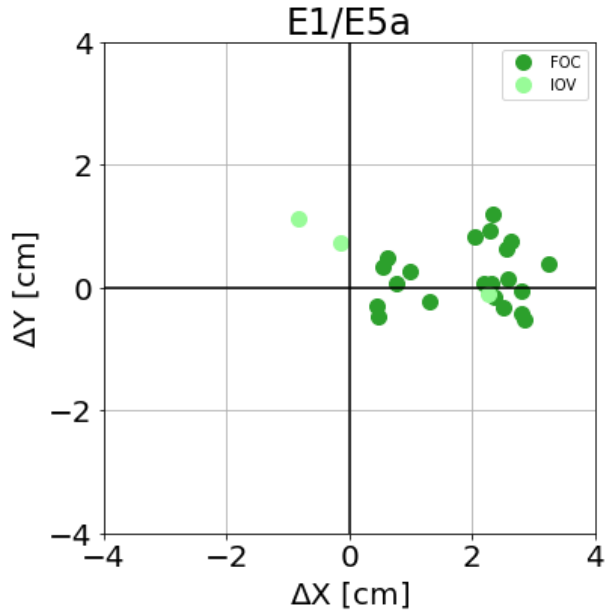
Horizontal Galileo PCOs



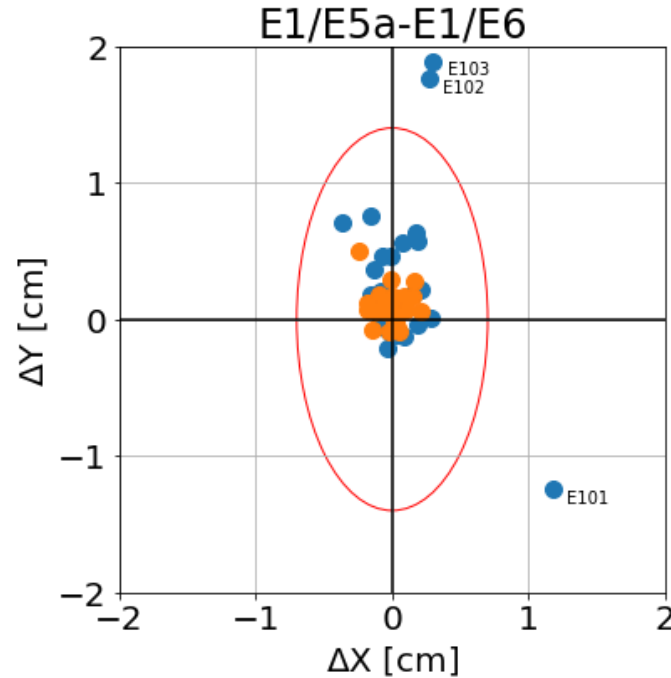
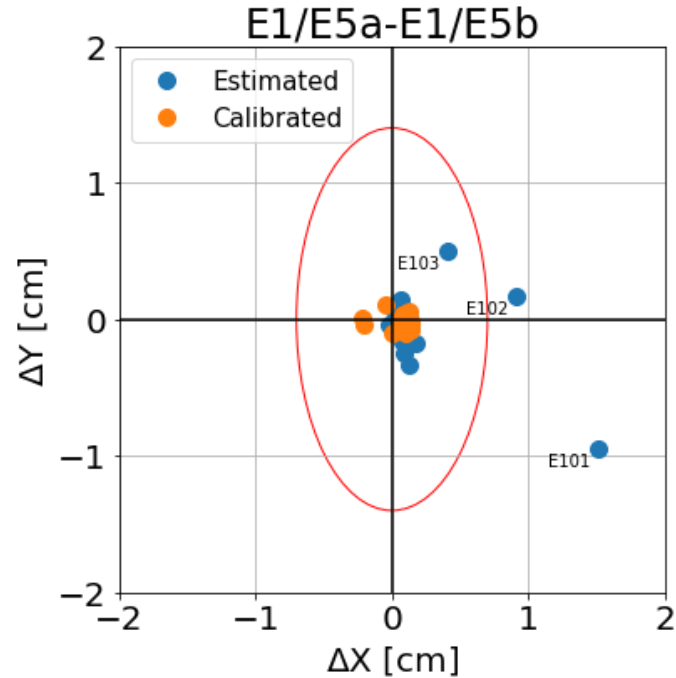
IOV: In-Orbit Validation FOC: Full Operational Capability FOCe: FOC in eccentric orbit (E201 and E202)



Horizontal PCOs: Differences Estimated and Calibrated



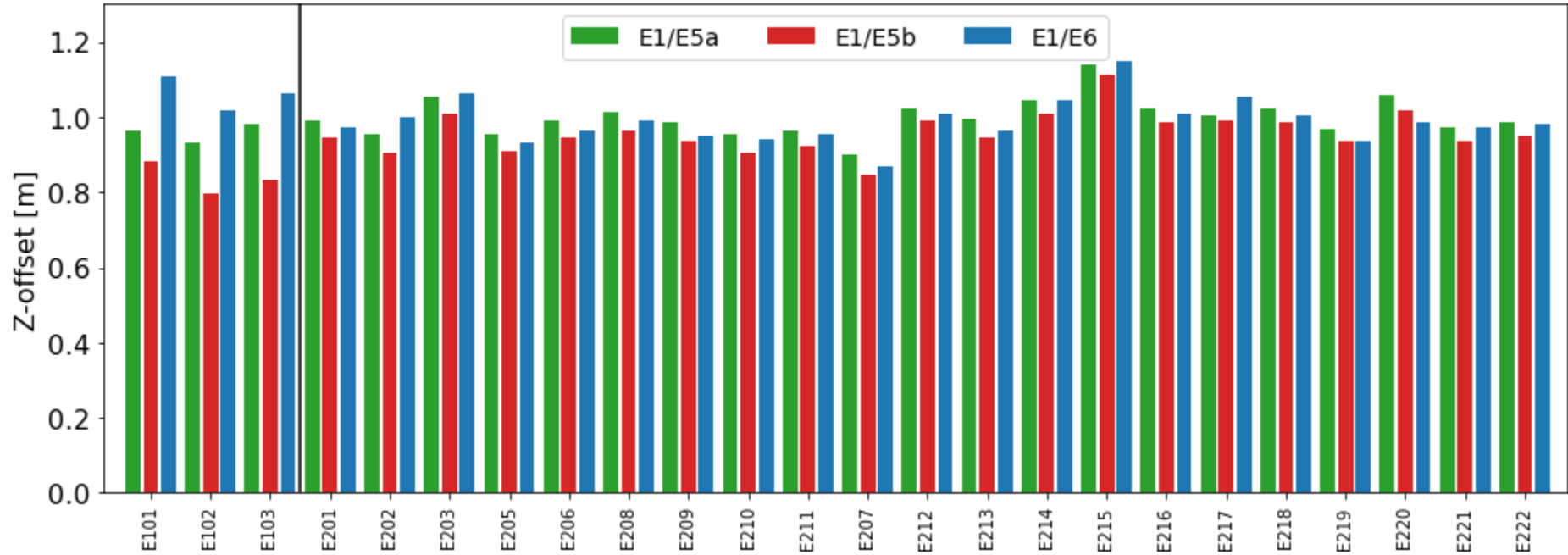
Horizontal PCOs: Differences Linear Combinations



Mean formal errors of PCO estimates

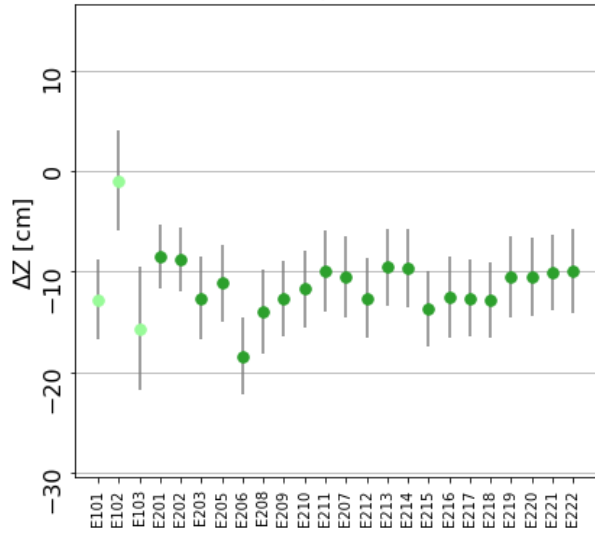


Estimated Galileo Z-PCOs

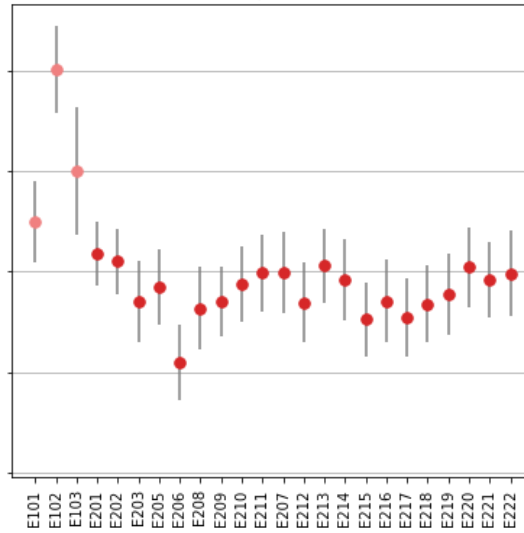


Z-PCOs: Differences Estimated and Calibrated

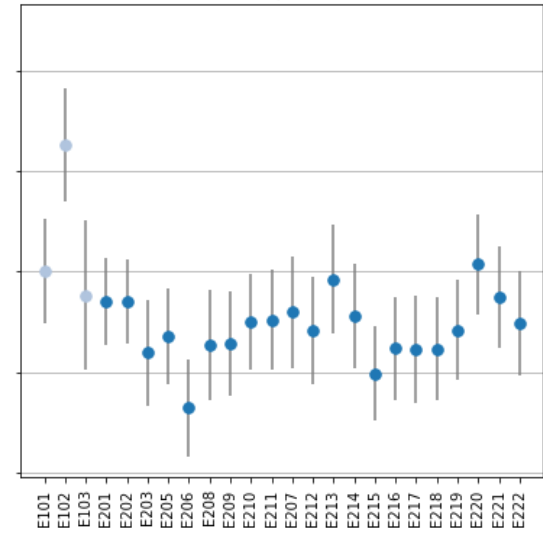
E1/E5a



E1/E5b



E1/E6



Mean PCO and Scale Differences

Semi-analytical relation between PCO and station height change:

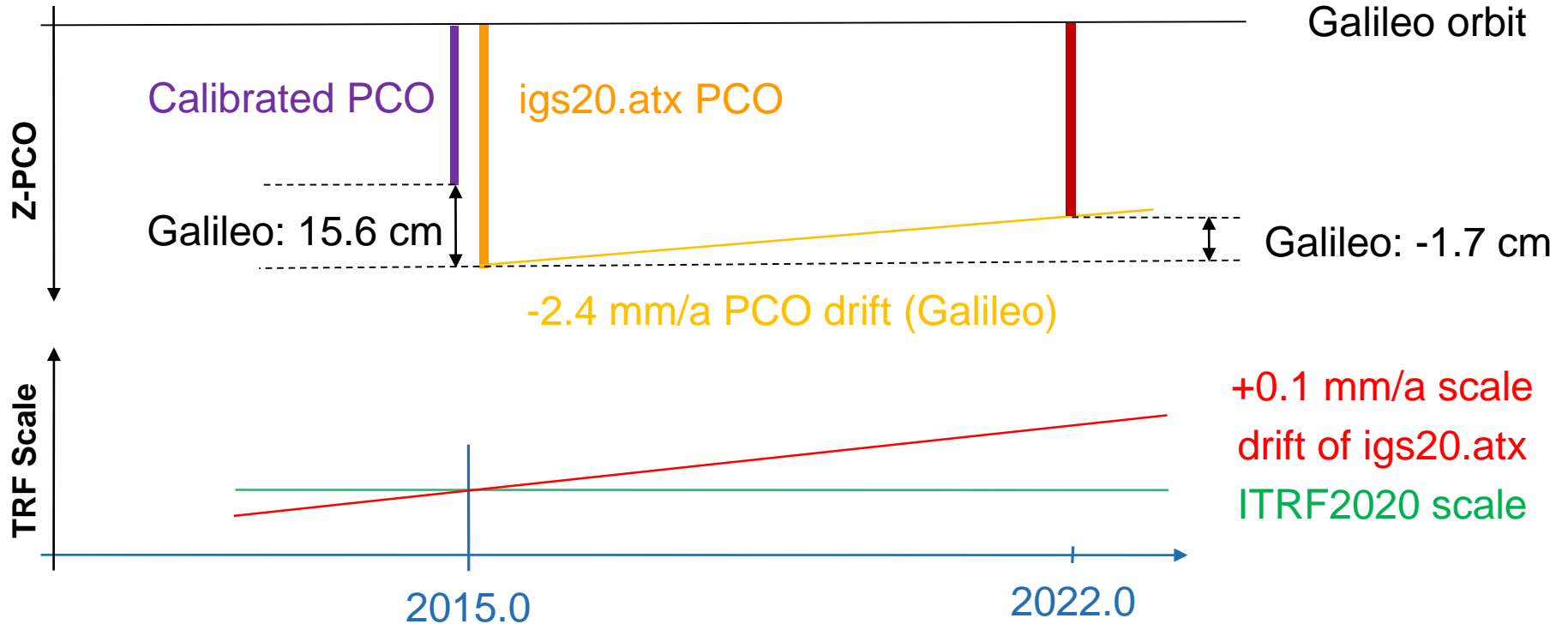
$$\alpha = \frac{\Delta h}{\Delta z_{\text{PCO}}} = -0.041 \quad \text{for Galileo orbit height and } 10^\circ \text{cutoff angle}$$

| Linear combination | ΔZ PCO [cm] | | Scale difference [ppb/mm] | | | |
|--------------------|---------------------|-------|---------------------------|-----|------|-----|
| | All | FOC | All | | FOC | |
| E1/E5a | -11.4 | -11.6 | 0.73 | 4.7 | 0.75 | 4.8 |
| E1/E5b | -10.2 | -11.9 | 0.66 | 4.2 | 0.77 | 4.9 |
| E1/E6 | -14.5 | -15.7 | 0.93 | 5.9 | 1.01 | 6.4 |

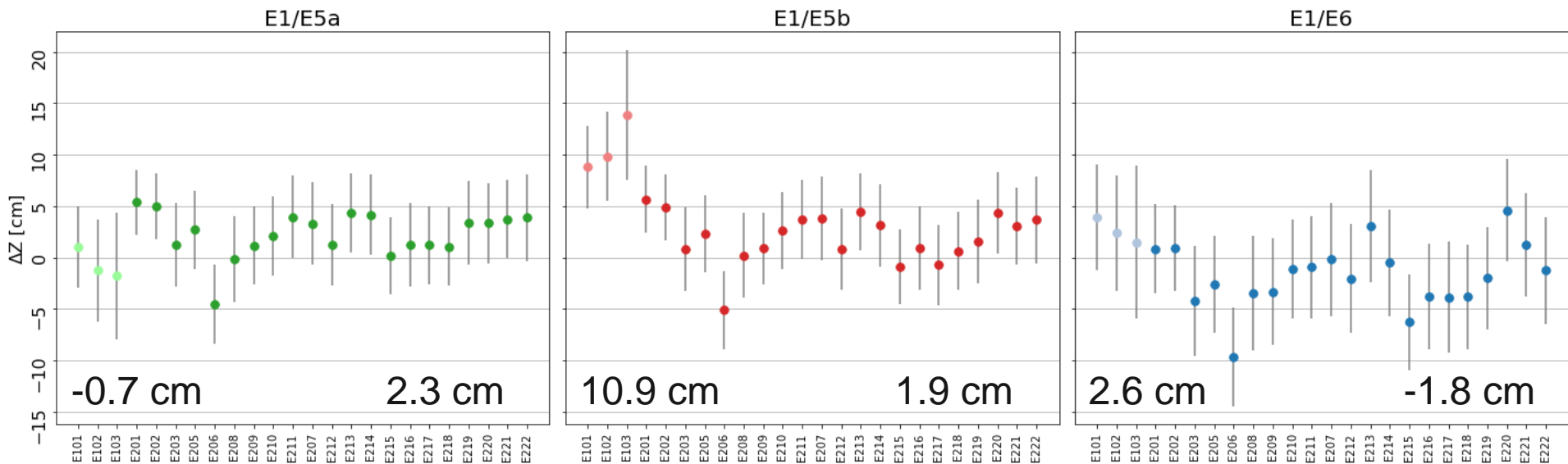


Consistency with igs20.atx (1)

estimated PCO,
ITRF2020 scale fixed



Consistency with igs20.atx (2)



$$\Delta S_{\text{FOC}}: -0.9 \text{ mm} \hat{=} -0.15 \text{ ppb} \quad -0.8 \text{ mm} \hat{=} -0.12 \text{ ppb} \quad 0.7 \text{ mm} \hat{=} 0.12 \text{ ppb}$$



Summary and Outlook

Horizontal PCO estimates

- agree within their estimation precision with the ground calibrations for FOC
- Small discrepancy for IOV

Z-PCO estimates

- 10-16 cm discrepancy w.r.t. calibrations
 - ± 2 cm discrepancy w.r.t. igs20.atx
- E1/E5a and E1/E5b FOC scale pretty consistent at 0.03 ppb level
 - 0.25 ppb FOC difference for E1/E6
 - Increased differences for IOV, in particular for E1/E5b
 - Consistency of different frequencies better by a factor of two compared to BDS-3
 - Multi-frequency applications (raw approach, ambiguity resolution, ...)

