GPS-Based Precise Orbit Determination of the Sentinel-6 MF and Sentinel-6B Missions

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Overview

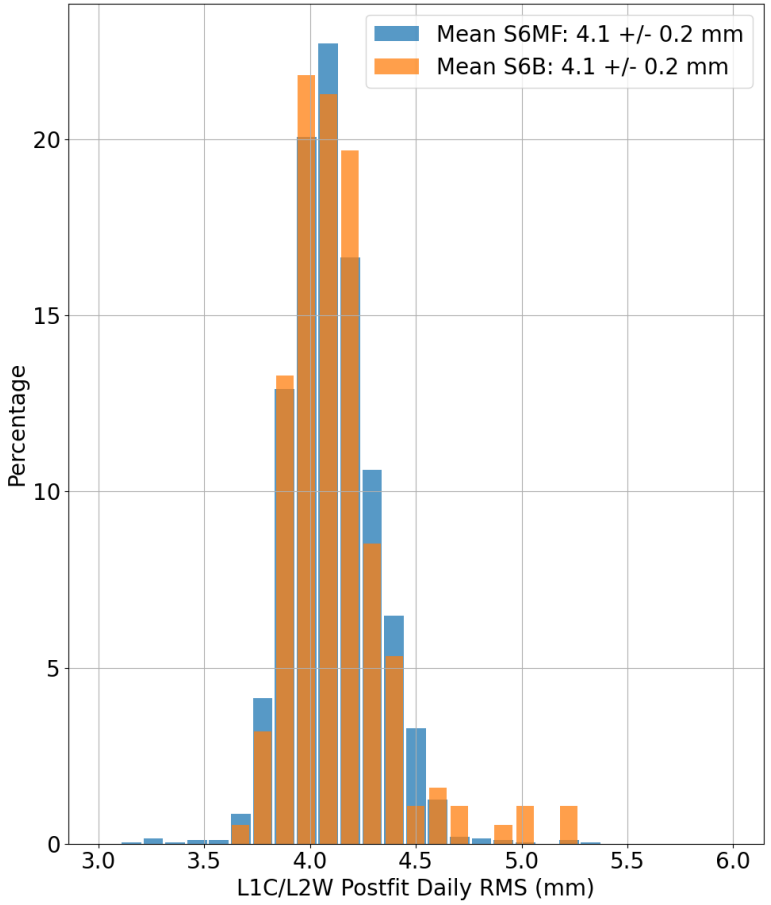
- Motivation
  - Evaluate the POD performance of Sentinel-6B relative to Sentinel-6MF
- Overview
  - Comparison of POD metrics
    - Post-fit residuals
    - Orbit overlaps
    - One-way SLR residual comparison
  - Comparison of PODRIX-TriG baseline
    - Implications for attitude and pre-launch metrology

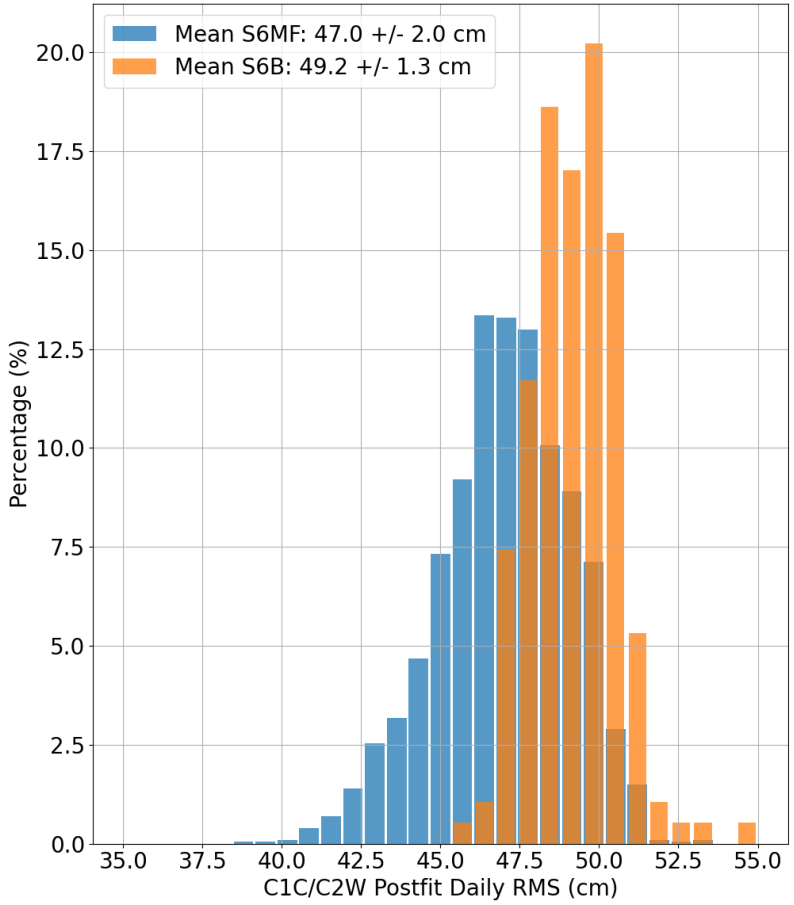
POD GNSS Post-fit Residuals

- Mean of all daily RMS statistics

	S6MF	S6B
L1C/L2W Carrier Phase	4.1 mm	4.2 mm
C1C/C2W Pseudorange	47.0 cm	49.2 cm

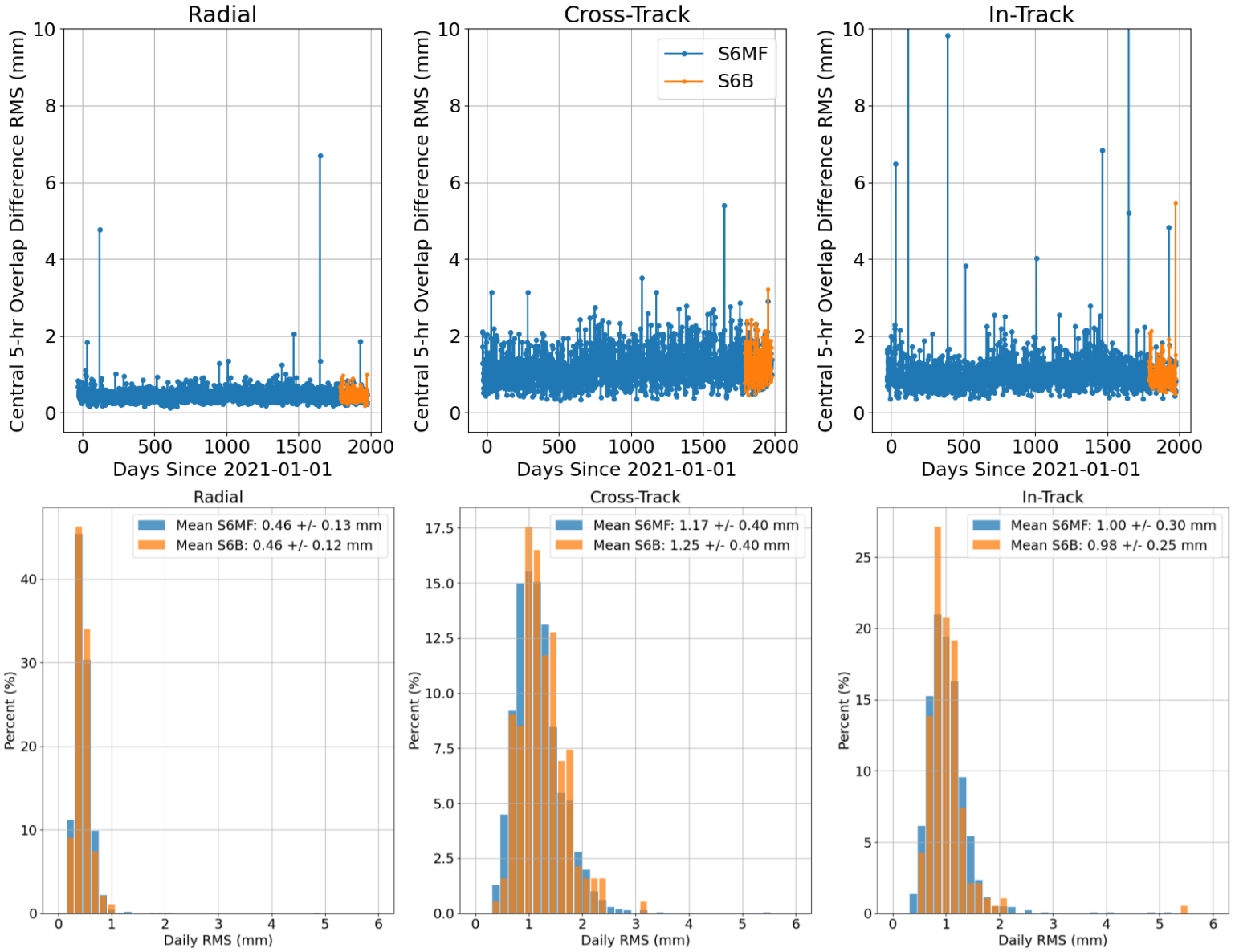
- Consistent S6MF and S6B daily phase residual RMS
- Daily code residual RMS slightly higher mean for S6B, but less daily variability
  - Perhaps related to smaller sample size and/or GPS flex power





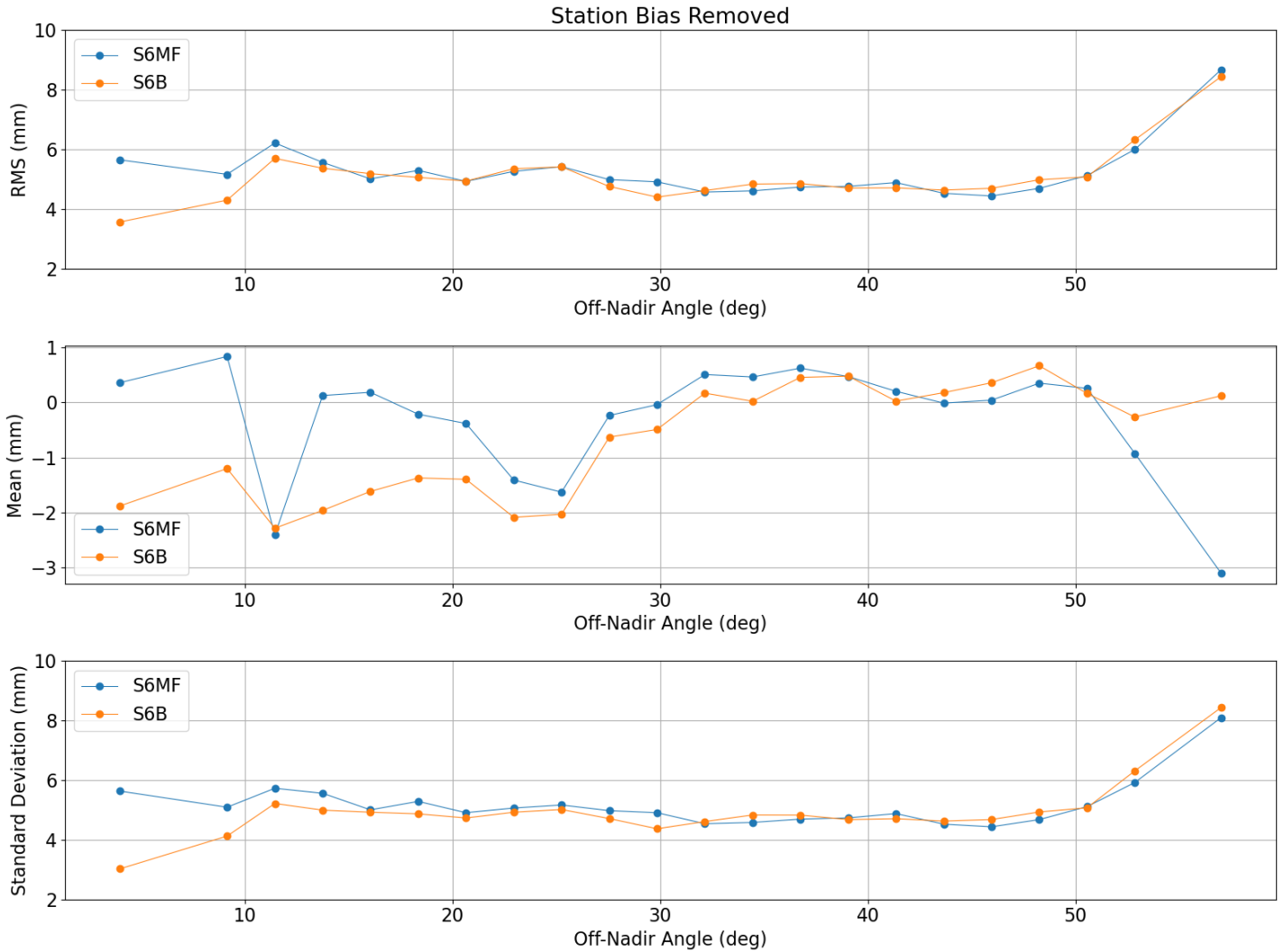
Orbit Overlaps

- 30-hour arcs result in 6-hour overlaps
  - Daily RMS statistics from overlap differences using central 5 hours
- Overall, S6MF and S6B overlap performance consistent
  - For both, cross-track overlaps have lowest precision
- Lessons learned from S6MF apply well to S6B



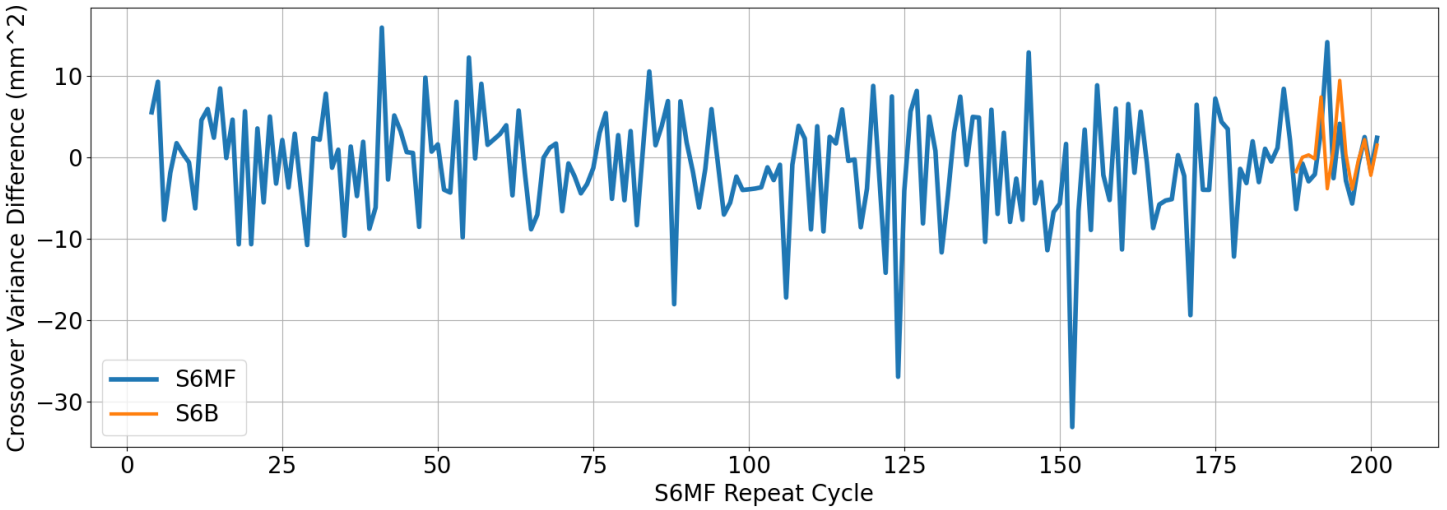
Sentinel-6MF/B One-Way SLR Residuals

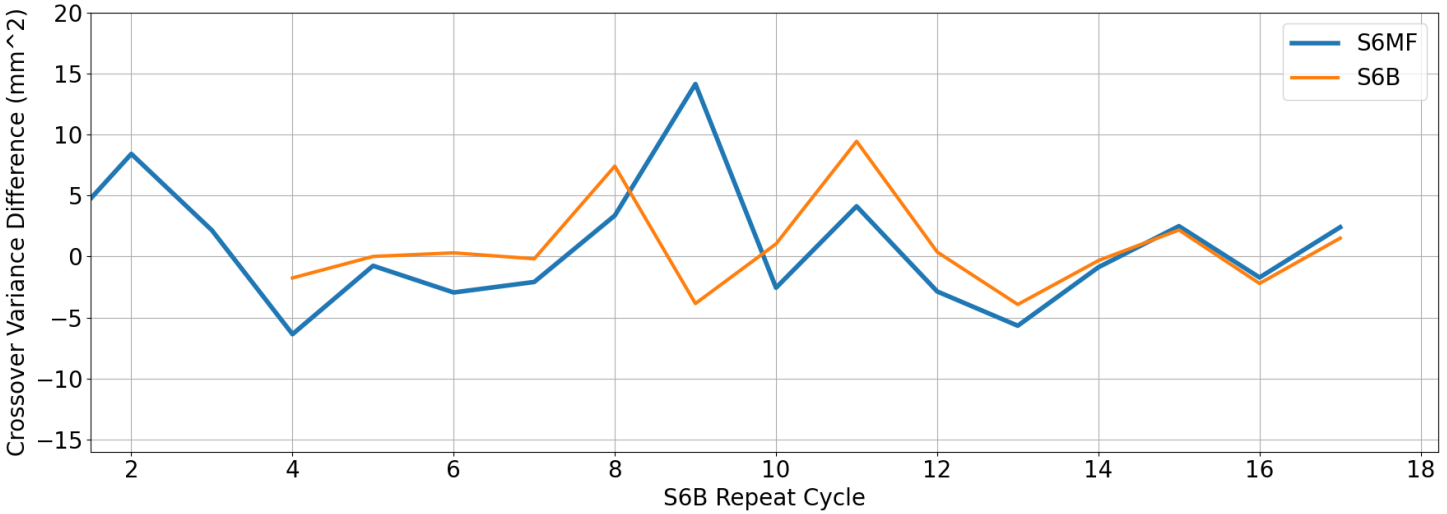
- Removal of a single station bias across entire mission
  - Mean across the entire mission
- Station positions from ITRF2020_u2024
  - Station seasonals and geocenter motion
- Limit S6MF to same stations and time span
  - 7 stations
  - S6MF: 15,841 observations
  - S6B 14,938 observations
- Very similar overall one-way RMS (~5.0 mm)
- Below 30-deg off nadir angle representative of radial accuracy
  - S6MF: 5.2 mm
  - S6B: 5.0 mm



Crossovers

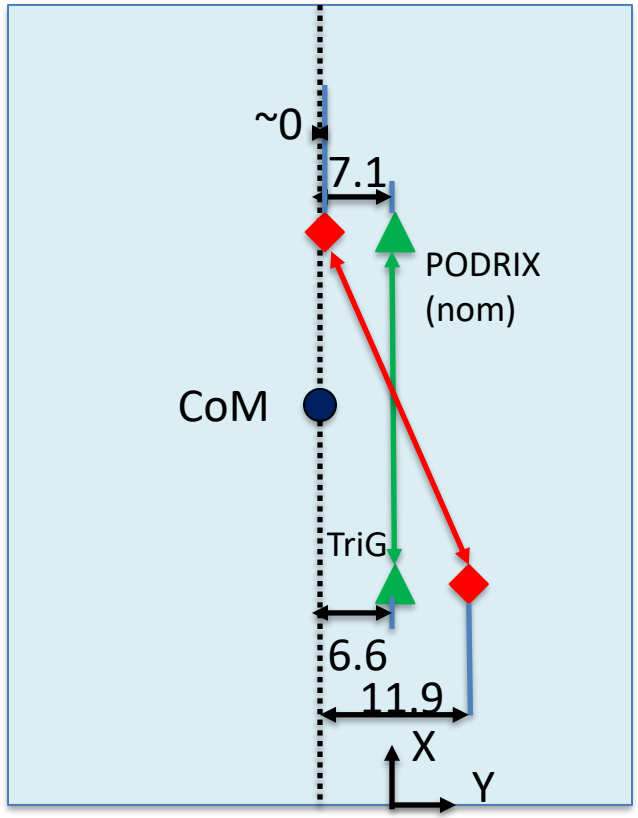
- Plots show sea surface height (SSH) crossover variance difference
  - Lower is less variance than NTC product orbit
- Crossover variance is very similar to product orbit (POE-G)
- Mean crossover variance difference within 1mm^2 for both S6MF and S6B





Baseline - Introduction

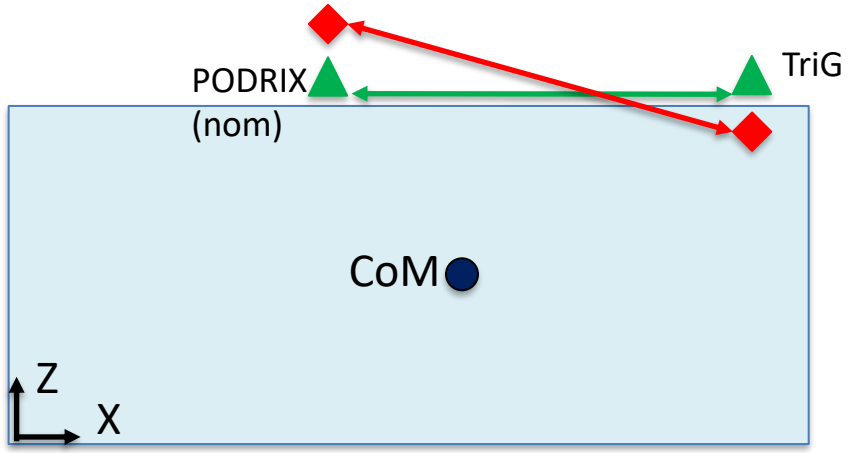
- Two active GNSS receivers on S6MF
  - PODRIX receiver with RUAG antenna
    - Nominal and redundant.
    - Primary GNSS POD
    - GPS + Galileo
  - TriG receiver with RUAG antenna
    - Single-string
    - Aimed towards supporting radio occultation measurements, including POD antenna
    - GPS only
- Provides unique opportunity to validate spacecraft attitude using short baseline GPS solutions
- For S6MF, anomalous Y offsets observed for each antenna by multiple groups (e.g., CNES, DLR, JPL) led to discovery and correction of a yaw-bias.



S6MF Yaw-bias

Baseline - Introduction

- Confident that the observed baseline is real
  - Can we also observe a possible pitch bias from baseline z-offset?
- Common mode errors that **don't** affect the estimated baseline
  - Center of Mass location
  - Sentinel-6 orbit errors
  - GPS Transmitter orbit and clock errors
  - Transmitter antenna calibrations
  - Ionosphere delay
- Errors that **do** affect the baseline
  - Attitude errors
  - Antenna reference point
  - Receiver antenna phase center errors (as measured)
  - Local multipath



Pre-launch Metrology
Post-Launch GNSS Measurements

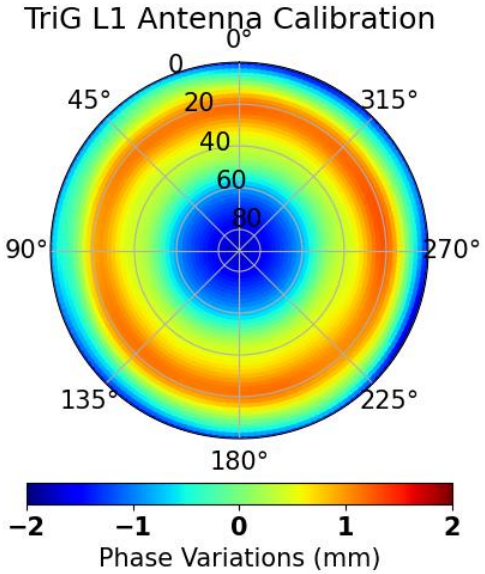
Pre-Launch Antenna Calibrations

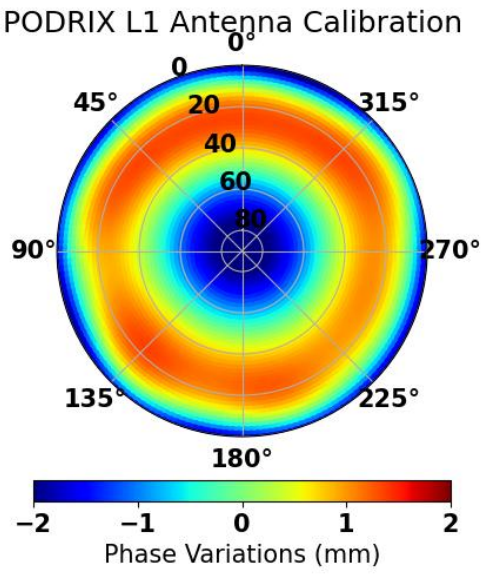
- Fixed center of mass to antenna reference point (ARP)

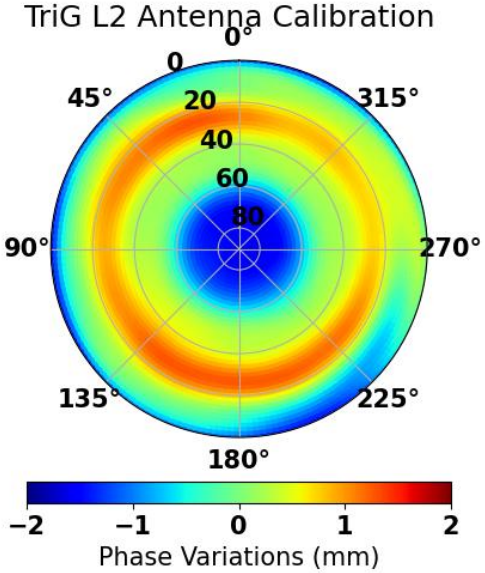
	Body-X (mm)	Body-Y (mm)	Body-Z (mm)
TriG	-930.852	6.779	-1133.413
PODRIX	944.160	6.990	-1118.440

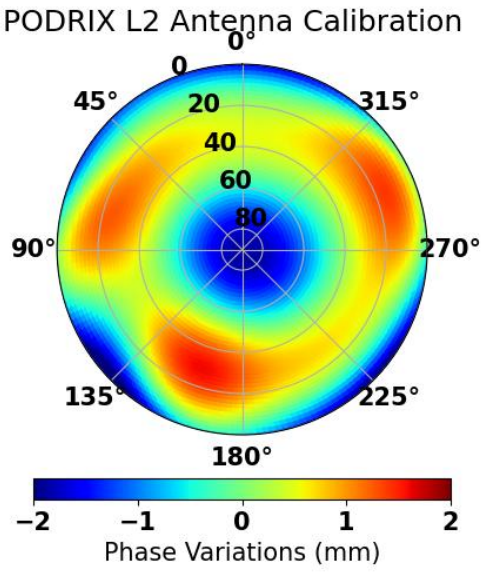
- Phase center offset (PCO) to ARP
  - Offsets computed using elevation dependent weighting of the pre-launch anechoic chamber measurements
  - Rotated into body frame

	Body-X (mm)	Body-Y (mm)	Body-Z (mm)
TriG-L1	0.584	0.625	-100.193
TriG-L2	0.633	0.466	-105.573
PODRIX-L1	0.035	0.220	-100.328
PODRIX-L2	0.220	0.018	-105.016







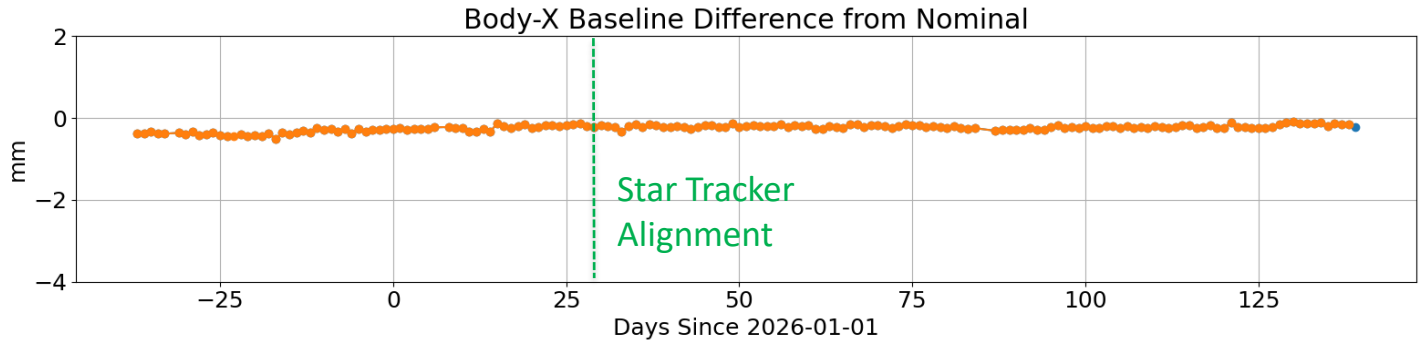


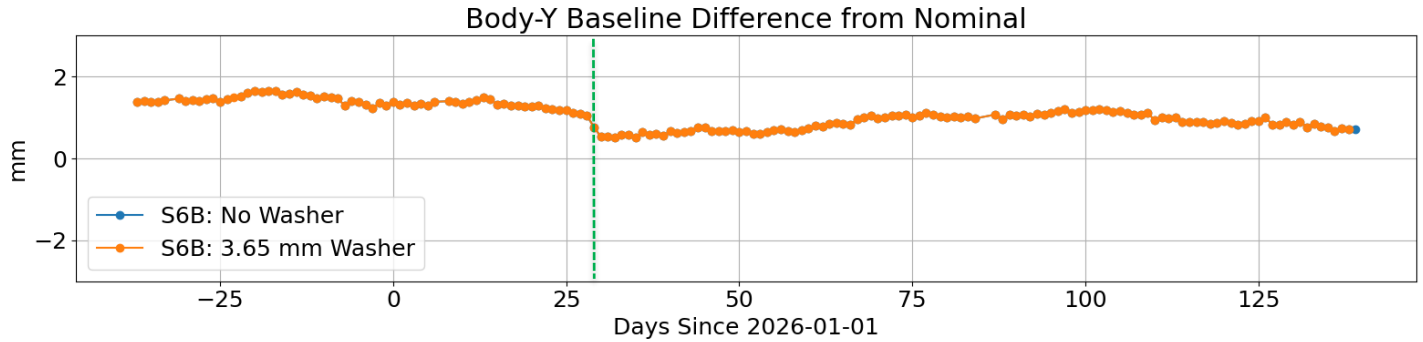
Sentinel-6B L1 Baseline Body Offsets

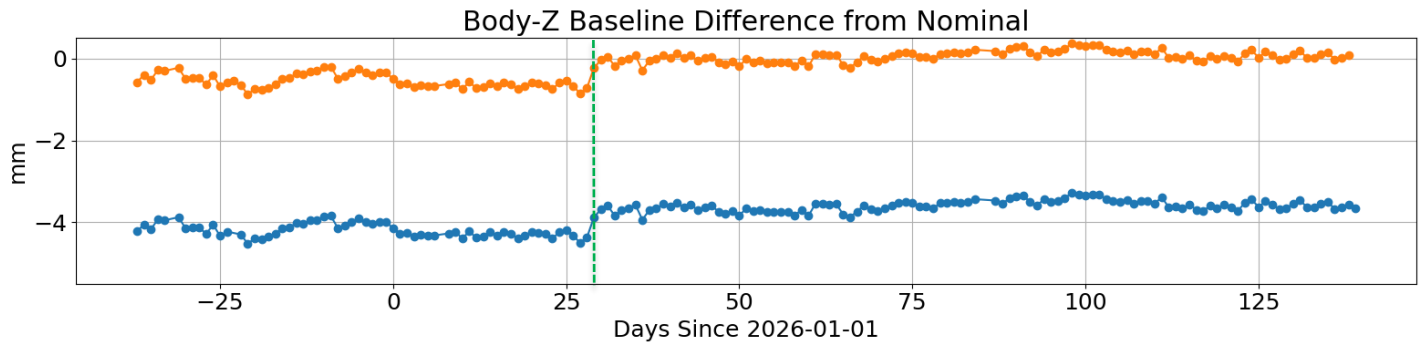
- Estimation Strategy
  - Single Frequency (L1)
  - Pre-launch antenna calibration
  - Fix PODRIX receiver clock
  - Fix orbit solution
  - Estimate TriG clock and GNSS clocks
- Possibly a 3.65 mm washer for PODRIX antenna that has not been accounted for?
  - Possibility brought up during CPOD Working Group Meeting
  - TriG antenna washer is known and included in metrology
- Mean baseline offsets from nominal after star tracker alignment +/- std

	Body-X (mm)	Body-Y (mm)	Body-Z (mm)
No Washer	-0.21 +/- 0.05	0.87 +/- 0.19	-3.594 +/- 0.12
With Washer	-0.21 +/- 0.05	0.87 +/- 0.19	0.06 +/- 0.13

- After star tracker alignment, the relative z-offset becomes zero only when applying z-offset that includes PODRIX antenna washer



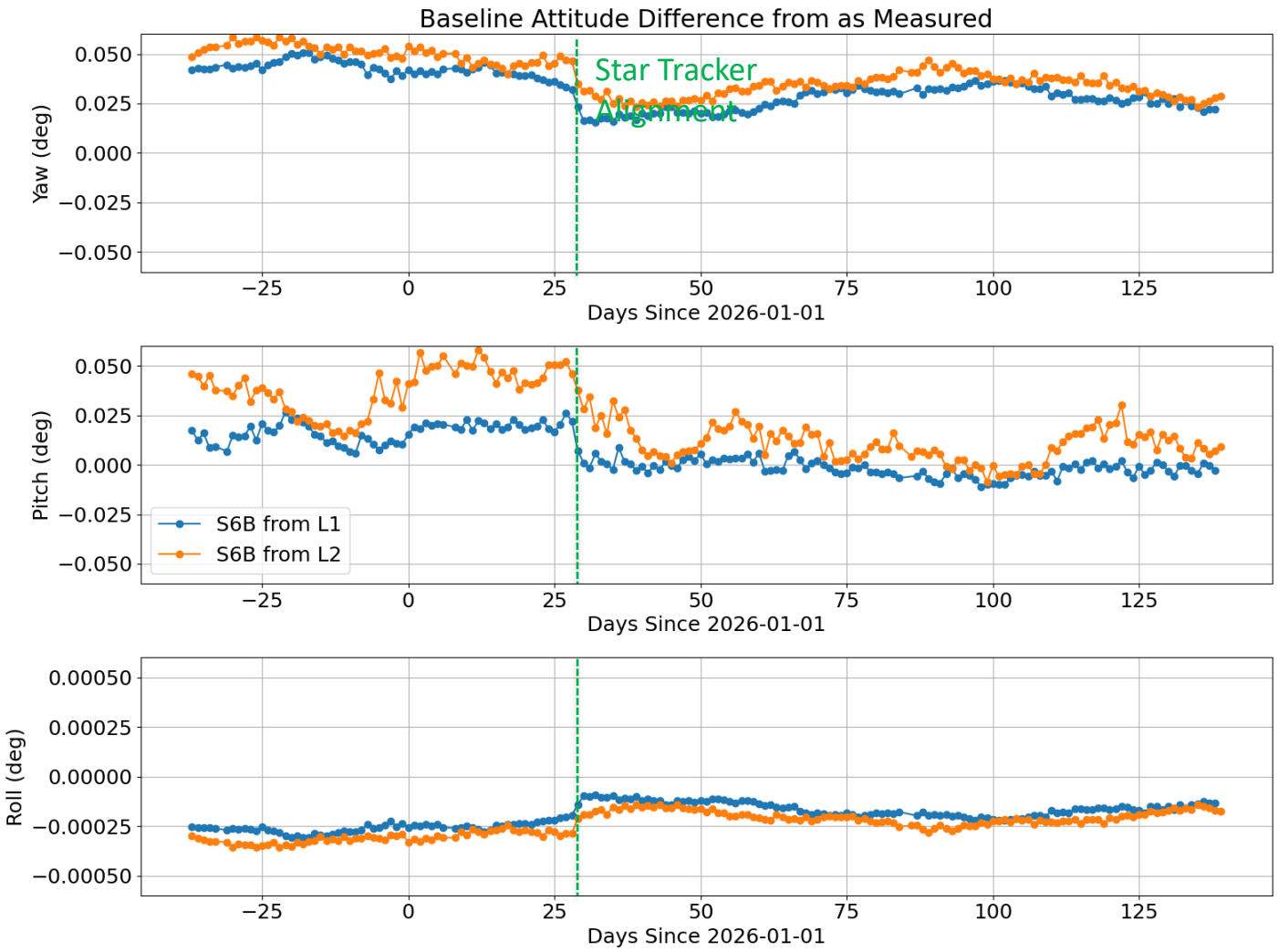




Sentinel-6B Yaw, Pitch, and Roll

- Estimates of the attitude errors using both L1 and L2
- Applying PODRIX washer to both L1 and L2
- Star tracker alignment reduces the estimated attitude error
- Pitch bias near zero when the washer offset is applied to the PODRIX ARP for both L1 and L2
- Mean attitude error +/- std (after star tracker alignment)

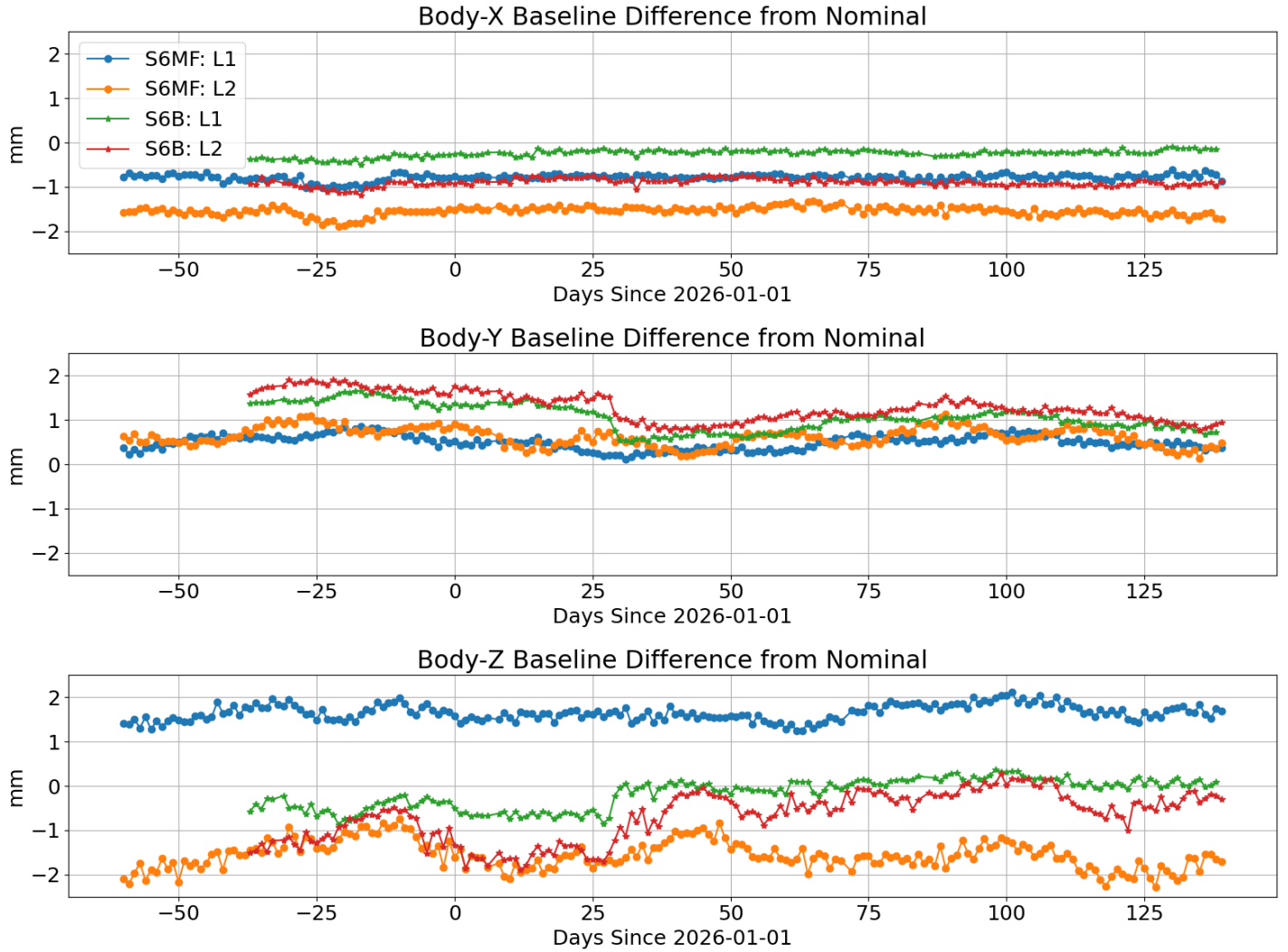
	Yaw (deg)	Pitch (deg)	Roll (deg)
L1	0.027 +/- 6e-3	-0.002 +/- 0.004	-1.6e-4 +/- 4e-5
L2	0.033 +/- 6e-3	0.010 +/- 0.009	-2.0e-4 +/- 3e-5



Comparisons to Sentinel-6 MF

- L1 and L2 baseline applying the PODRIX 3.65 mm washer for both S6MF and S6B
- Similar differences in Body-X and -Y for S6MF and S6B
- Body-Z offset is both larger for S6MF
  - Still smaller with washer than without
  - S6MF L1 Body-Z: -1.97 mm without washer

	Body-X (mm)	Body-Y (mm)	Body-Z (mm)
S6MF: L1	-0.77 +/- 0.05	0.46 +/- 0.15	1.68 +/- 0.19
S6MF: L2	-1.53 +/- 0.09	0.58 +/- 0.21	-1.59 +/- 0.29
S6B: L1	-0.21 +/- 0.05	0.87 +/- 0.19	0.06 +/- 0.13
S6B: L2	-0.89 +/- 0.07	1.09 +/- 0.18	-0.35 +/- 0.30

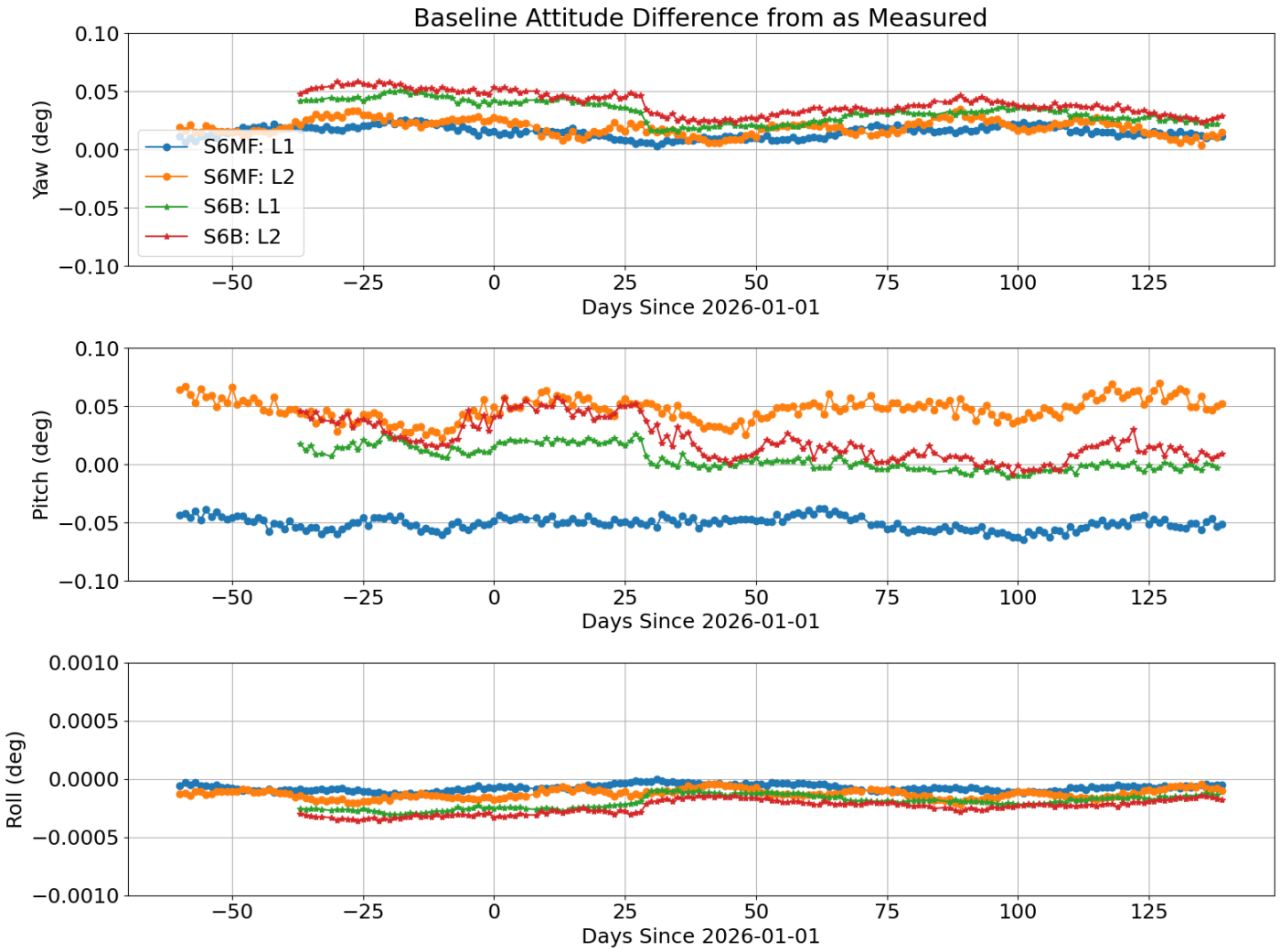


Comparisons to Sentinel-6 MF

- Mean attitude error +/- std (after star tracker alignment)

	Yaw (deg)	Pitch (deg)	Roll (deg)
S6MF: L1	0.014 +/- 0.005	**-0.051** +/- 0.006	6.9e-5 +/- 3e-5
S6MF: L2	0.018 +/- 0.006	**0.048** +/- 0.009	-1.2e-4 +/- 4e-5
S6B: L1	0.027 +/- 0.006	-0.002 +/- 0.004	-1.6e-4 +/- 3e-5
S6B: L2	0.033 +/- 0.006	0.010 +/-0.009	-2.0e-4 +/- 3e-5

- Resulting pitch bias for S6MF is larger than for S6B
- From before, possible sources for z-offset discrepancy
  - Attitude errors
  - Antenna reference point
  - Receiver antenna phase center errors (as measured)
  - Local multipath
- There appears to be an inconsistency with the metrology or attitude between S6MF and S6B



Summary

- S6MF and S6B show very good consistency in post-fit RMS, orbit overlaps, SLR residuals, and SSH crossovers
- Dual receiver setup on S6MF/B allows for very precise recovery of the baseline between them
- Baseline estimates support the addition of a 3.65 mm washer to the PODRIX
  - Completely removes the estimated pitch bias on S6B
  - S6B has good agreement between L1 and L2
  - S6MF is not consistent between L1 and L2 body-z
  - May indicate an inconsistency between S6MF and S6B in either the pre-launch metrology or a possible pitch error for S6MF
- Thank you for your attention!

Baseline vs Temperature

- Variability in body-x is related to temperature
- Possibly due to thermal expansion of the spacecraft