Introduction of 2/rev harmonics in the empirical forces model for Sentinel altimetry satellites

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Perturbation Forces for Precise Orbit Determination

Gravitational Forces: earth gravity field, gravity perturbations (moon, sun, planets), ocean & solid earth tides

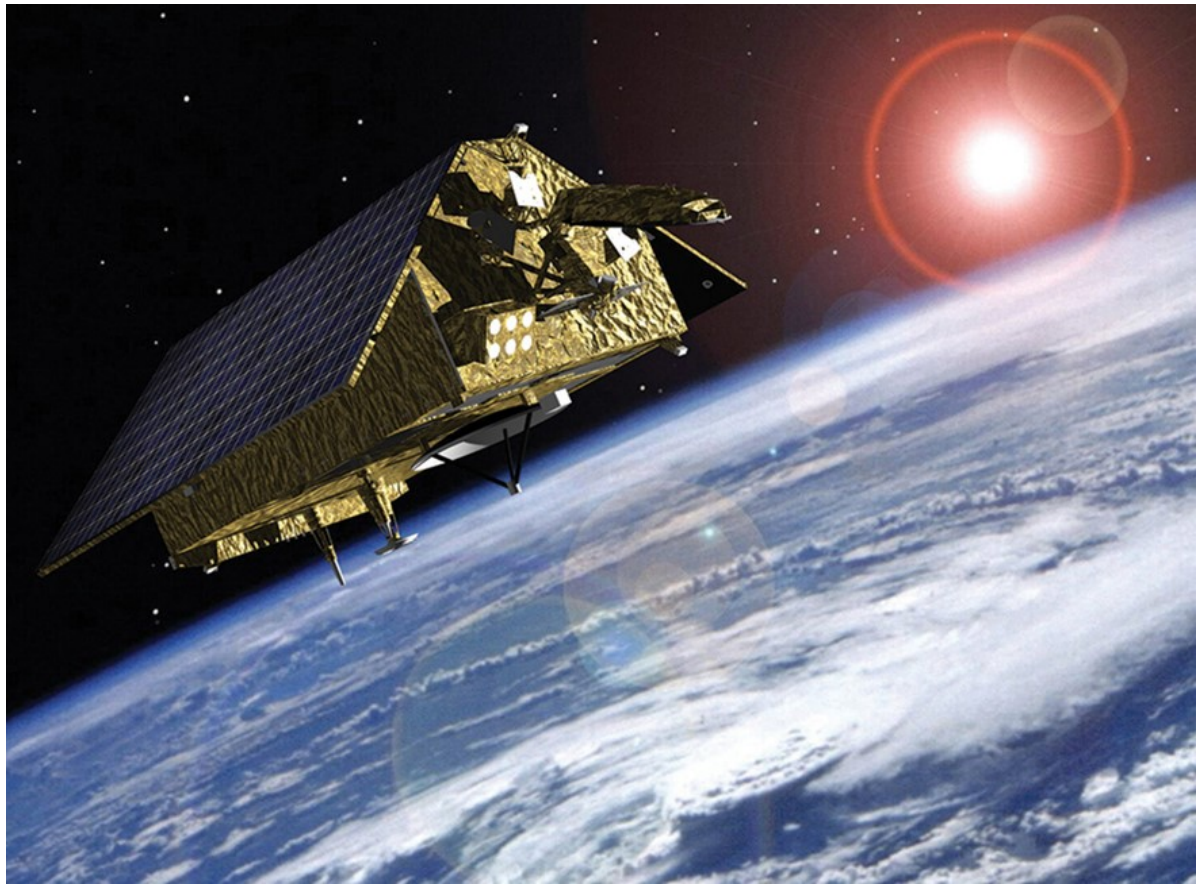
Forces on satellite: atmospheric drag, radiation pressure (direct solar radiation, albedo, earth IR radiation)

Sentinel-6 MF:

Pre-launch initial model

ESA's documentation model

Previous studies from CNES team showed a 2/rev contribution to the empirical forces for Sentinel-6 MF

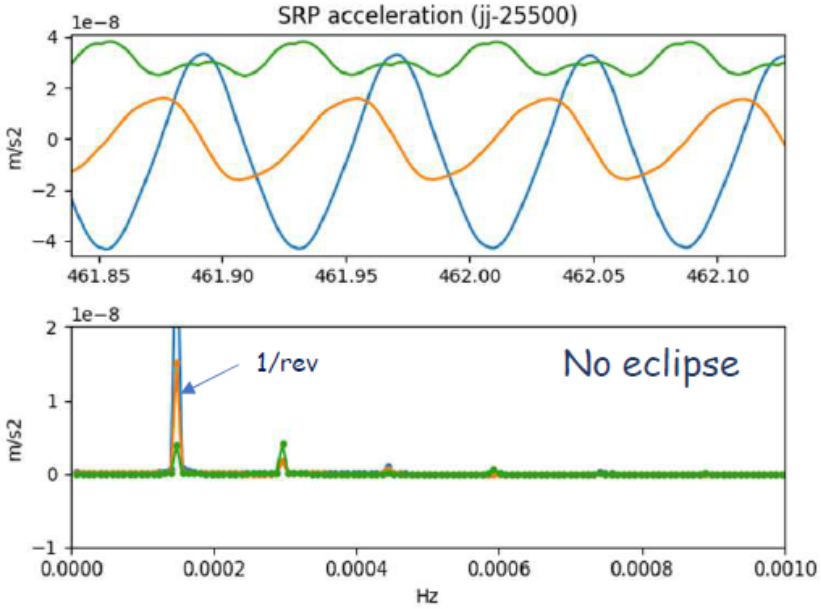


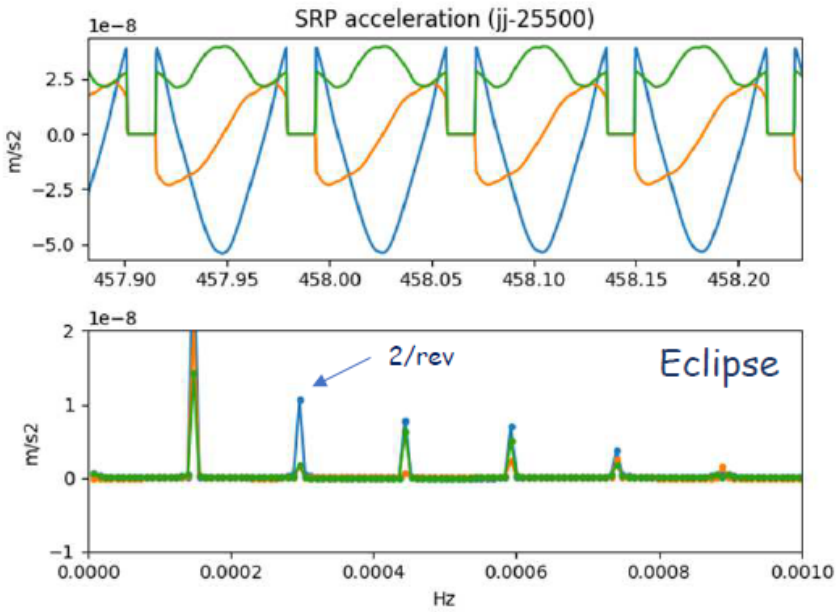
Source : www.esa.int

Sentinel-6 radiation pressure model analysis

OSTST 2022, Venice, POD Session

Spectral analysis, radial displacement harmonics





R, T, N accelerations

These two arcs are around the β value where eclipses begin (~55 degrees)

The SRP harmonics amplitudes are due to the eclipse transition

Source : Slides taken from Mercier F., et al (2022)

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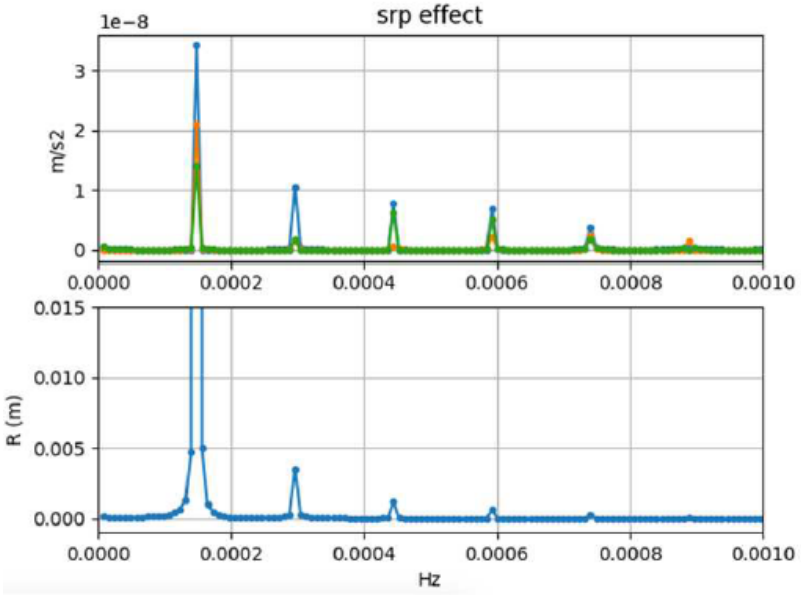
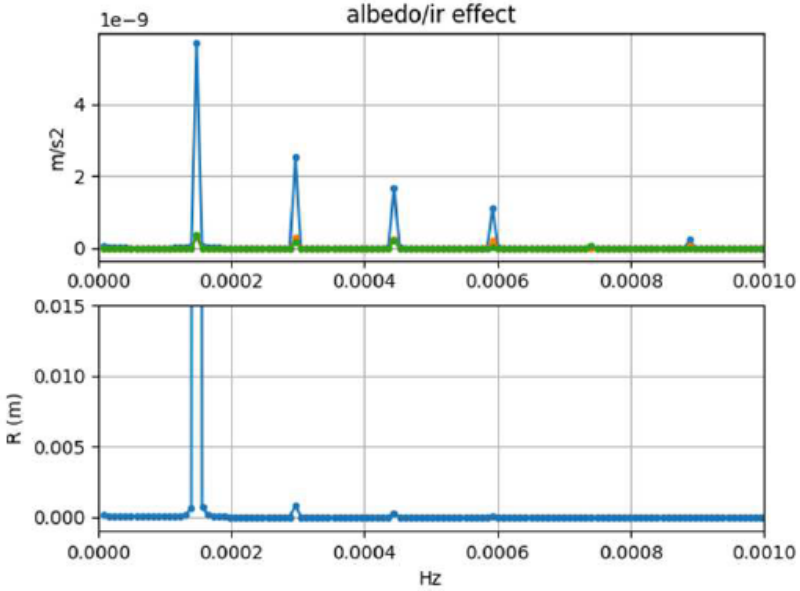
Spectral analysis, radial displacement harmonics





R, T, N accelerations, radial response, begin of eclipse period

2/rev, main harmonic : here, the SRP contribution is below 5 mm amplitude
the albedo/ir response is negligible

Source : Slides taken from Mercier F., et al (2022)

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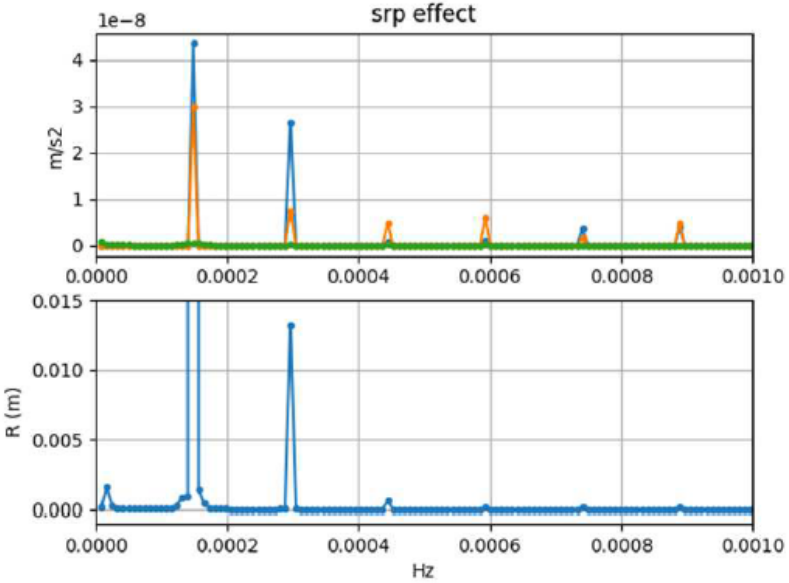
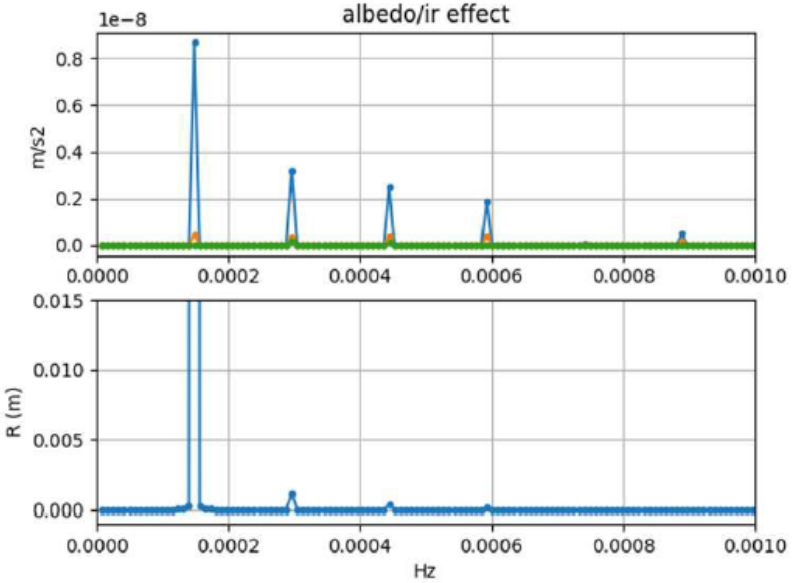
Spectral analysis, radial displacement harmonics





R, T, N accelerations, radial response, β value close to 0 (sun close to the orbital plane)

2/rev, main harmonic : here, the SRP contribution is higher (1.4 cm)
the albedo/ir response is negligible

higher harmonics : negligible

Source : Slides taken from Mercier F., et al (2022)

Sentinel-6 radiation pressure model analysis

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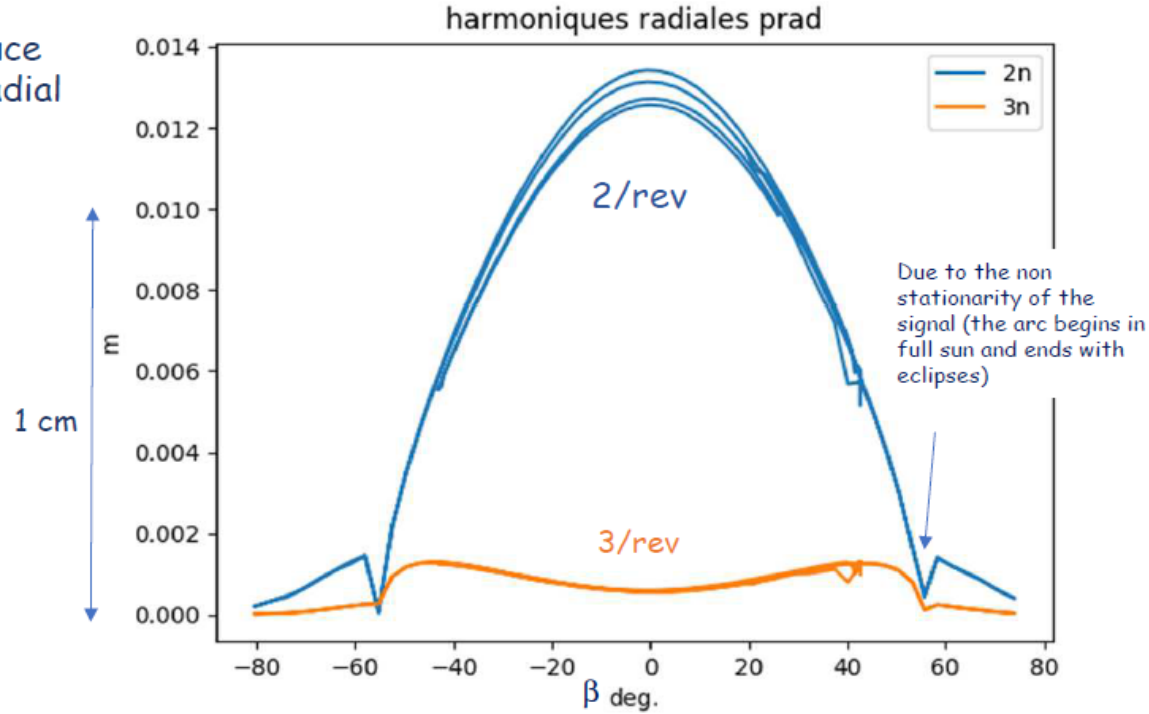
SRP harmonics amplitudes and beta angle

Radial 2/rev and 3/rev due to SRP acceleration :

10% error in the amplitude produce less than 1.5 mm at 2/rev in radial (~1.5 cm for the complete model see preceding slide)



Source : Slides taken from Mercier F., et al (2022)

Conclusions from previous studies

CNES POD Team showed a contribution to the radial acceleration spectrum producing 2/rev harmonics during eclipse transitions (mainly due to SRP), dependency on β angle

Proposal of introduction of 2/rev term

$$F = \underbrace{A\cos\omega t + B\sin\omega t + C}_{\text{1/rev}} + \underbrace{D\cos 2\omega t + E\sin 2\omega t}_{\text{2/rev}}$$

- Introduction of 2/rev term in the empirical model

Source : www.space.com

Proposed empirical model

$$F = \underbrace{A\cos\omega t + B\sin\omega t + C}_{1/rev} + \underbrace{D\cos 2\omega t + E\sin 2\omega t}_{2/rev}$$

1 point / day

	1/rev cos	1/rev sin	const.
R	0	0	0
T	1	1	0
N	1	1	1

1 point / 2rev

	2/rev cos	2/rev sin	const.
R	0	0	0
T	0	0	1
N	0	0	0

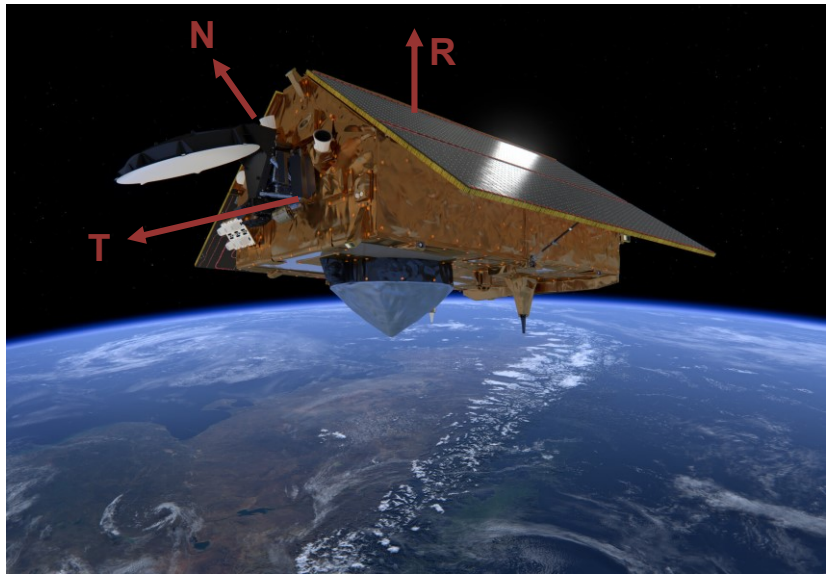
1 point / day

	1/rev cos	1/rev sin	const.
R	0	0	0
T	1	1	0
N	1	1	1

1 point / 2rev

	2/rev cos	2/rev sin	const.
R	**1**	**1**	0
T	0	0	**0**
N	0	0	0

0: no estimation, 1: estimation

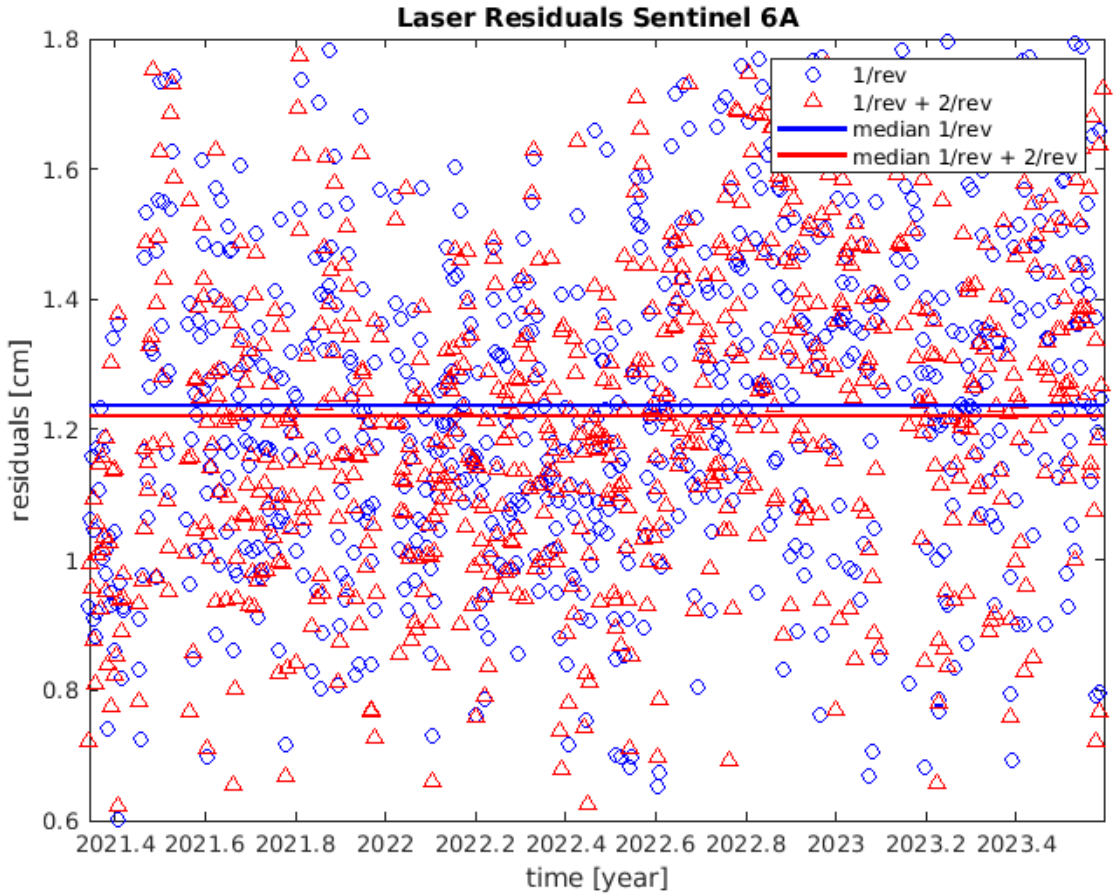


Source : www.esa.int

Experiments:
Sentinel 6A –MF : Cycles 18 -100 (21/08/18-23/02/21)
Sentinel 3A : Cycles 100-201 (05/05/21-06/08/23)

Standard: POE-F
Processing GNSS dynamic

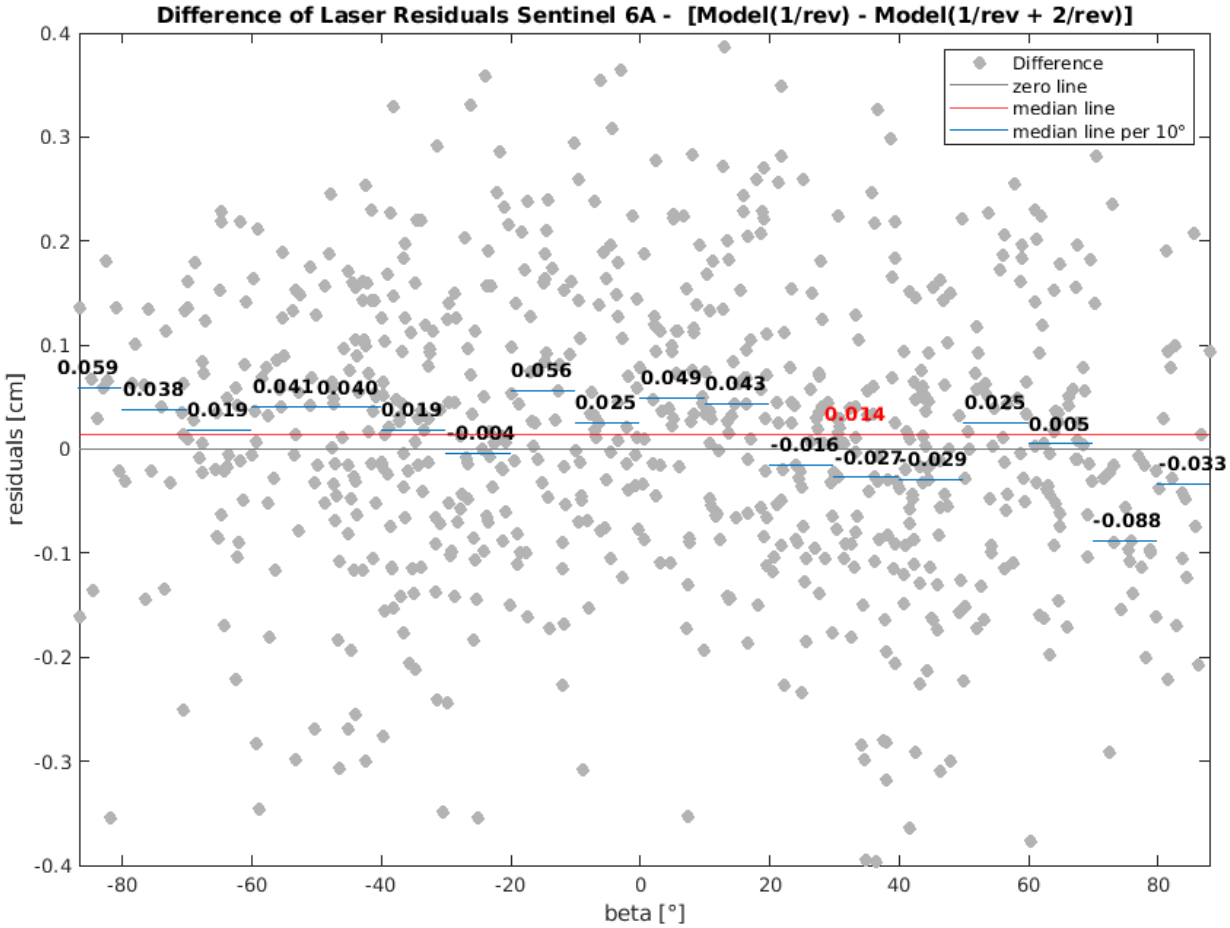
Results – Sentinel 6-MF



1 value laser residual / day
median 1/rev=1,24cm
median 1/rev + 2/rev=1,22cm

- ✓ overall better residuals with the proposed model
- ✓ but negligible improvement

Results – Sentinel 6-MF



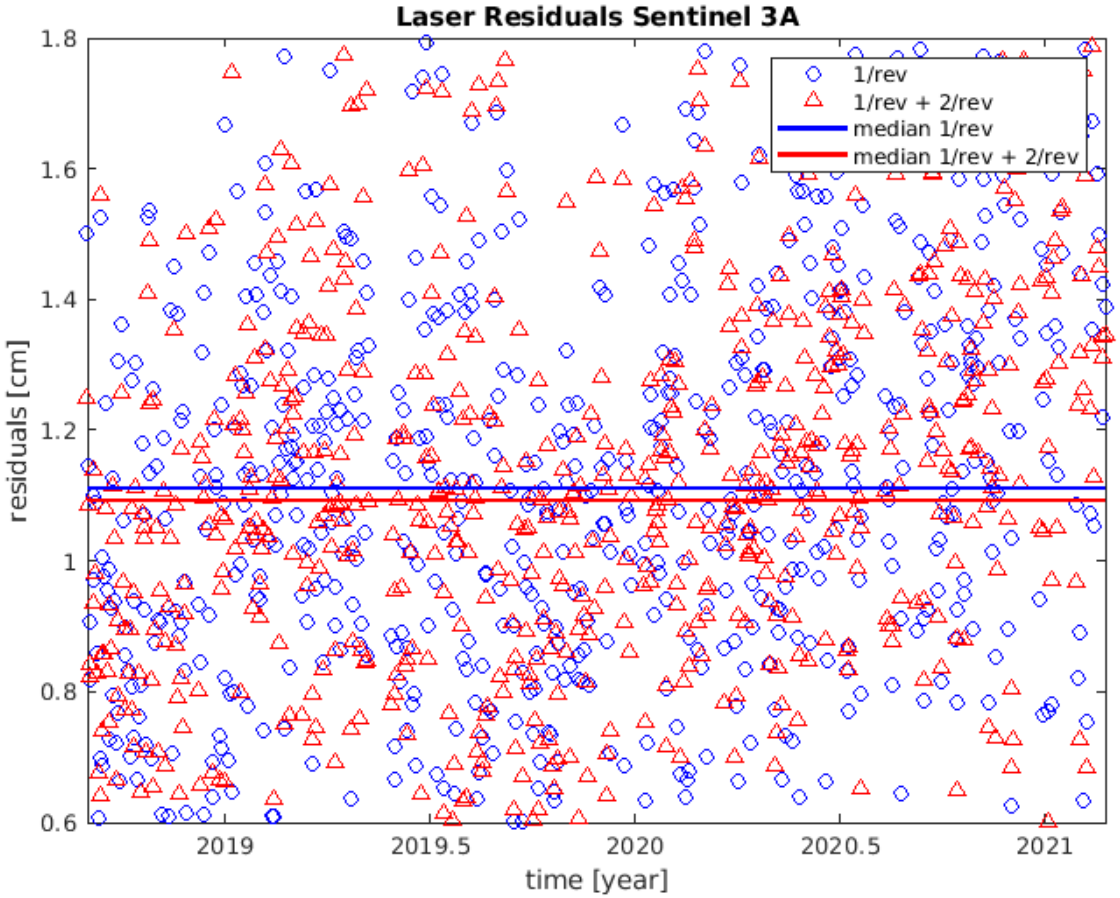
difference of residuals wrt. β angle

black values give the median of each 10° β range

red line and value give the median of all residuals

- ✓ overall better residuals with the proposed model
- ✓ better estimation around small β angles [-10° 10°]

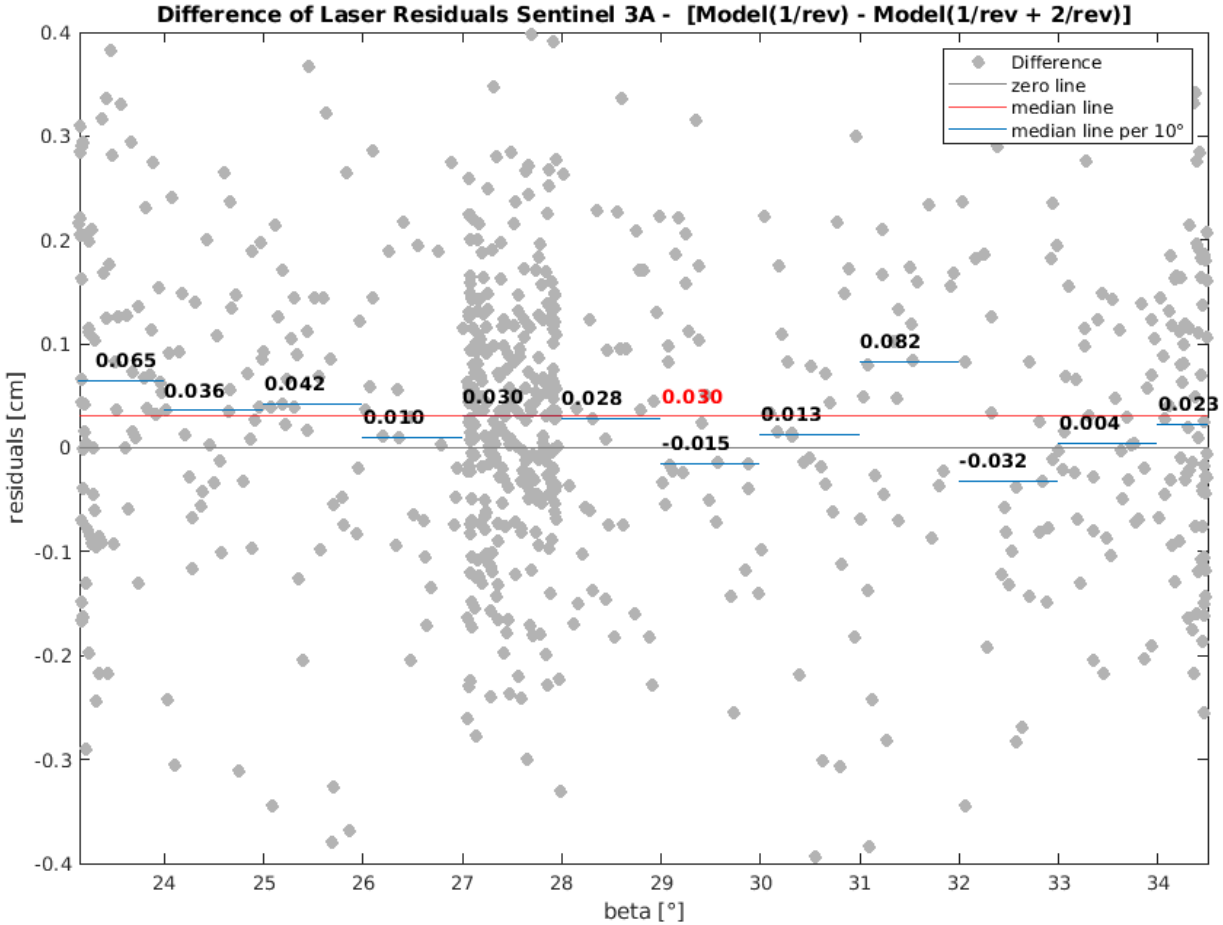
Results – Sentinel 3A



1 value laser residual / day
median 1/rev=1,11cm
median 1/rev + 2/rev=1,09cm

- ✓ overall better residuals with the proposed model
- ✓ but negligible improvement

Results – Sentinel 3A



difference of residuals wrt. β angle

black values give the median of each 10° β range

red line and value give the median of all residuals

- ✓ overall better residuals with the proposed model
- ✓ better estimation around smaller β angles with higher eclipse periods [23° 25°]

Conclusions – Future Work

Estimation of 2/rev empirical forces in the radial direction showed a small improvement on the SLR residuals

Bigger improvement during eclipse seasons (for Sentinel 6A-MF) and longer eclipse periods (for Sentinel 3A)

The CNES POD team will perform more tests to improve the parameters of these 2/rev terms.

More tests will also include DORIS-only dynamic and DORIS/GNSS dynamic processings

THANK YOU !

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Mercier F., Couhert A., Moyard J., Cullen R. (2022), Sentinel-6 radiation pressure model analysis, OSTST 2022 presentation, Venice, https://ostst.aviso.altimetry.fr/fileadmin/user_upload/OSTST2022/Presentations/POD2022-Sentinel_6_radiation_pressure_model_analysis.pdf

Images

[1] cpaess.ucar.edu/meetings/ostst-2023

[2] www.esa.int/Space_in_Member_States/France/Dernier_coup_d_aeil_sur_le_satellite_Sentinel_6

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[8] www.esa.int/Applications/Navigation/Galileo_enhancing_Sentinel-6_s_sea_level_monitoring_mission