



DORIS AWG Meeting
Paris, France

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

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Session II: POD and other DORIS applications, 29 November 2023



Perturbation Forces for Precise Orbit Determination

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

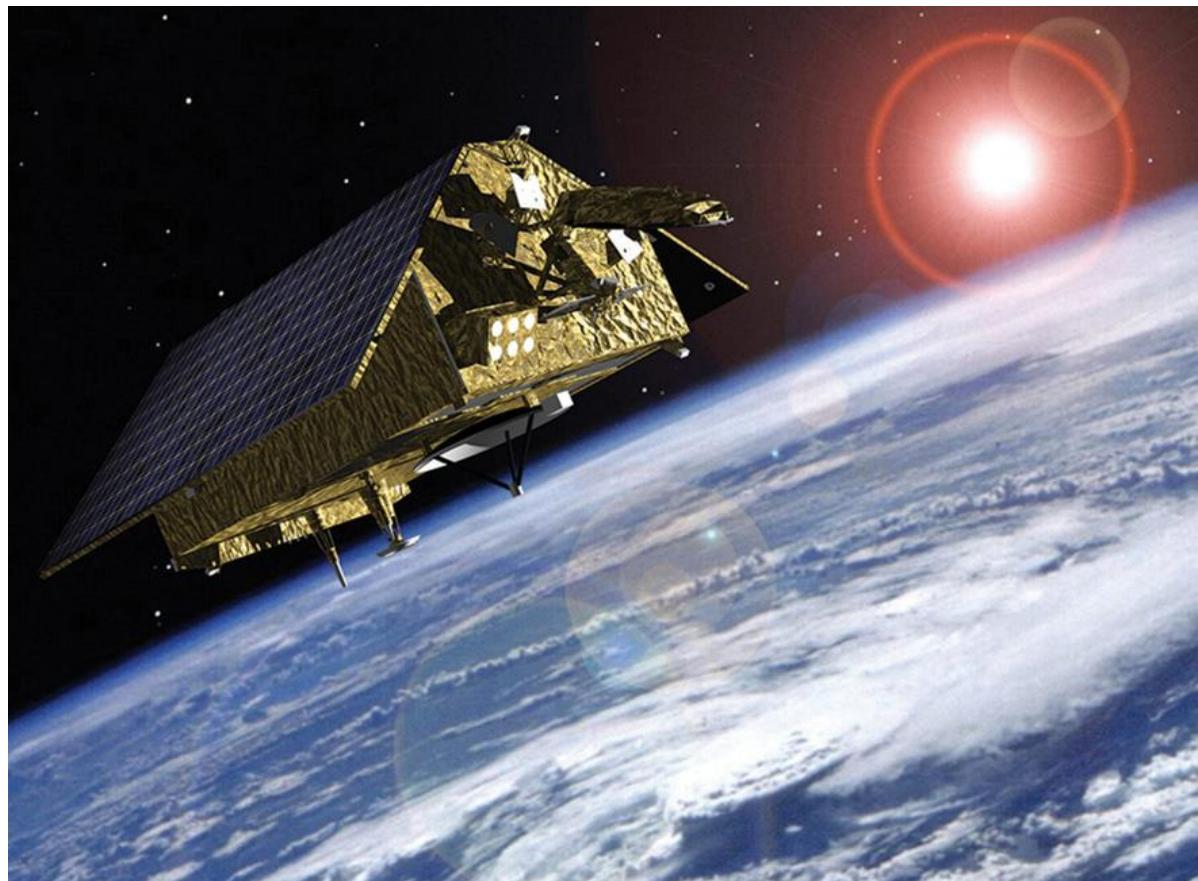
Forces on satellite: atmospheric drag, radiation pressure (direct solar radiation, albedo, earth IR radiation)

Sentinel-6 MF:

Pre-launch initial model

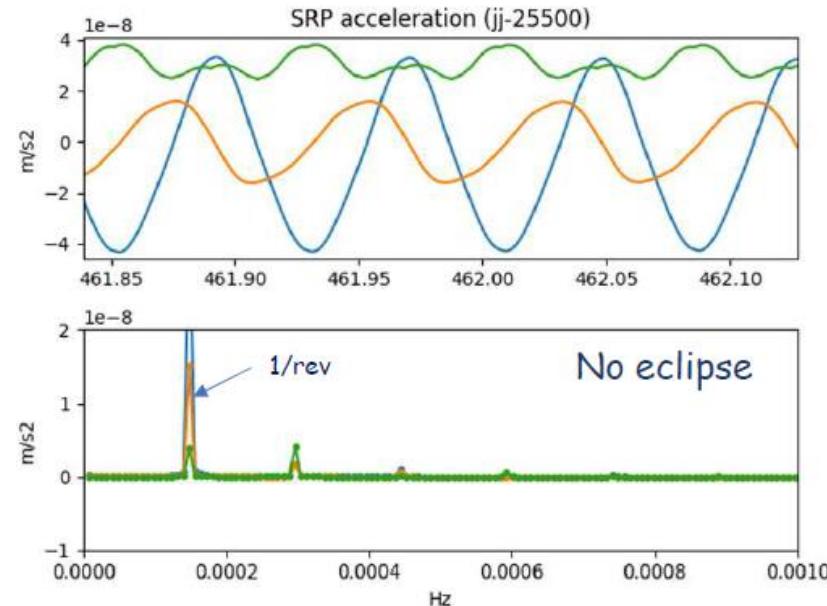
ESA's documentation model

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



Source : www.esa.int

Spectral analysis, radial displacement harmonics



R, T, N accelerations

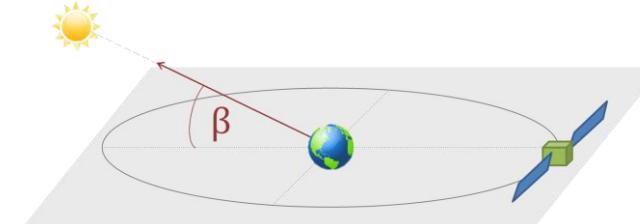
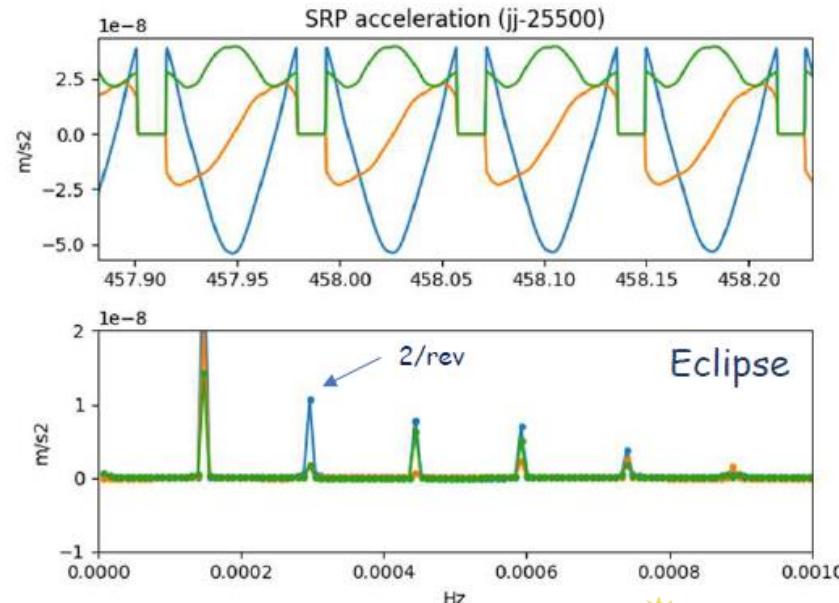
These two arcs are around the β value where eclipses begin (~55 degrees)

The SRP harmonics amplitudes are due to the eclipse transition

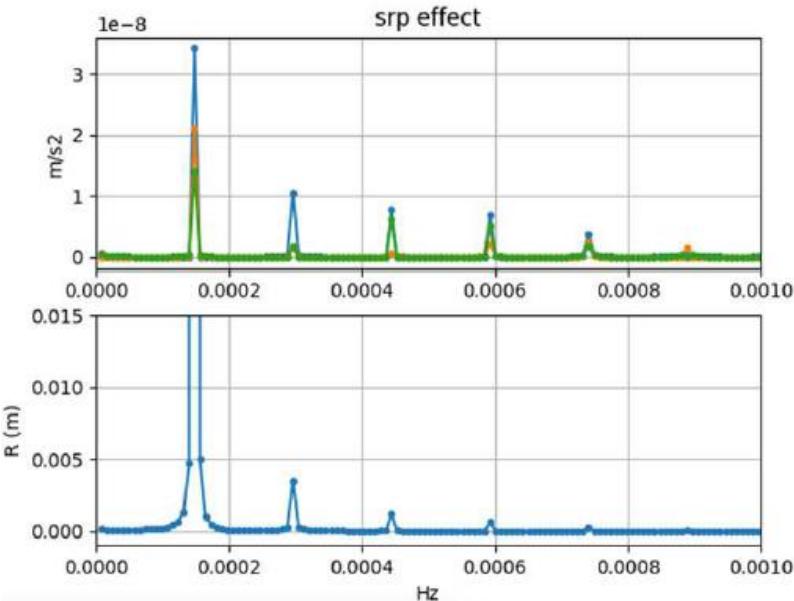


Sentinel-6 radiation pressure model analysis
OSTST 2022, Venice, POD Session

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



Spectral analysis, radial displacement harmonics



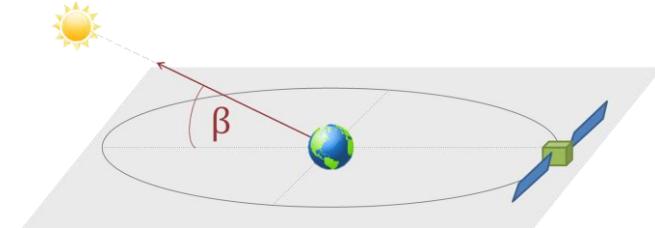
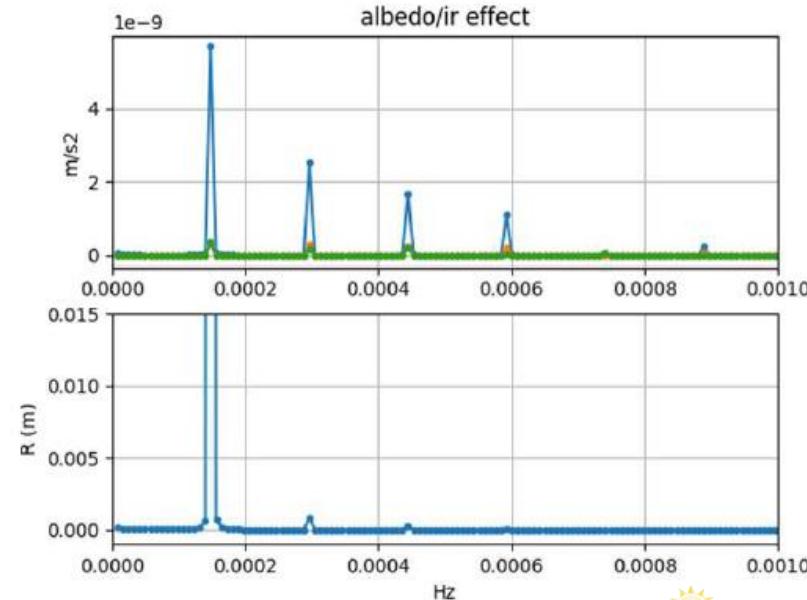
R , T , N accelerations, radial response, begin of eclipse period

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

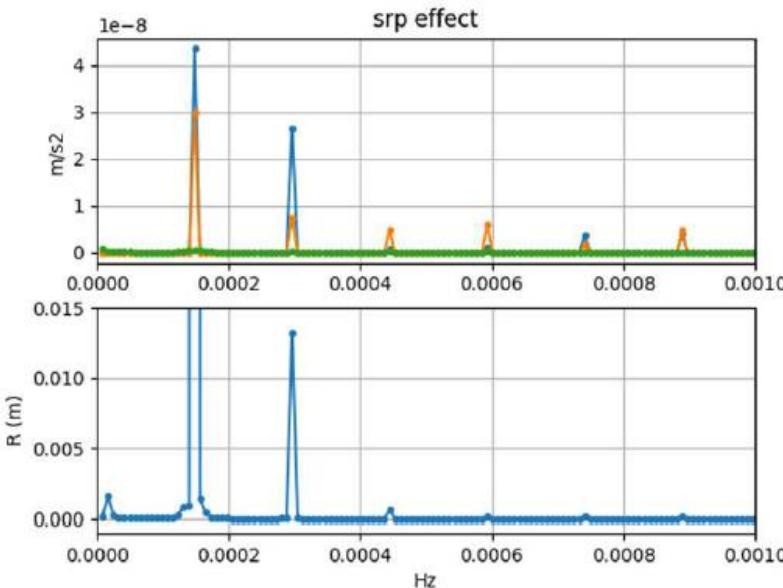


Sentinel-6 radiation pressure model analysis
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Source : Slides taken from
Mercier F., et al (2022)



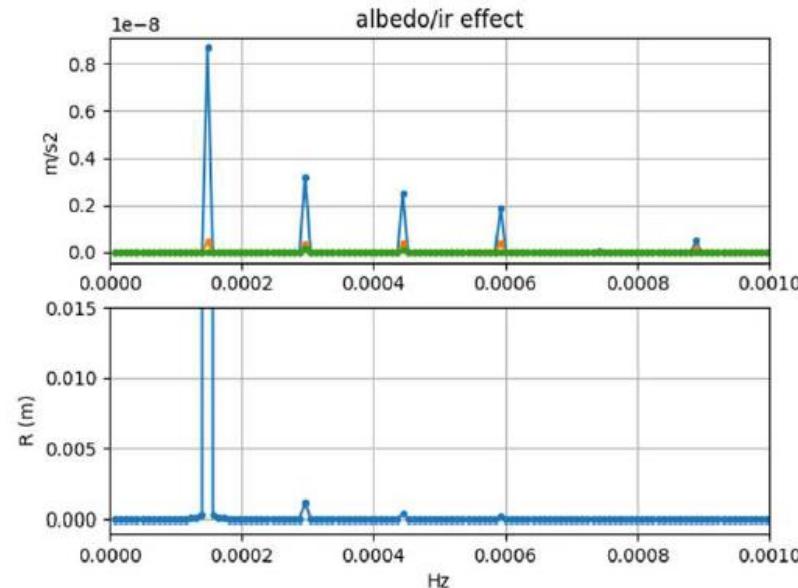
Spectral analysis, radial displacement harmonics



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

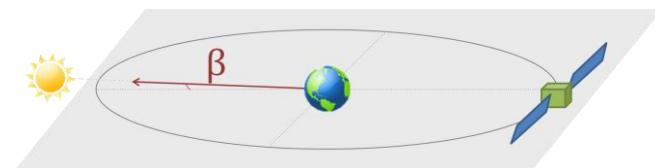
2/rev, main harmonic : here, the SRP contribution is higher (1.4 cm)
the albedo/ir response is negligible

higher harmonics : negligible



Sentinel-6 radiation pressure model analysis
OSTST 2022, Venice, POD Session

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



SRP harmonics amplitudes and beta angle

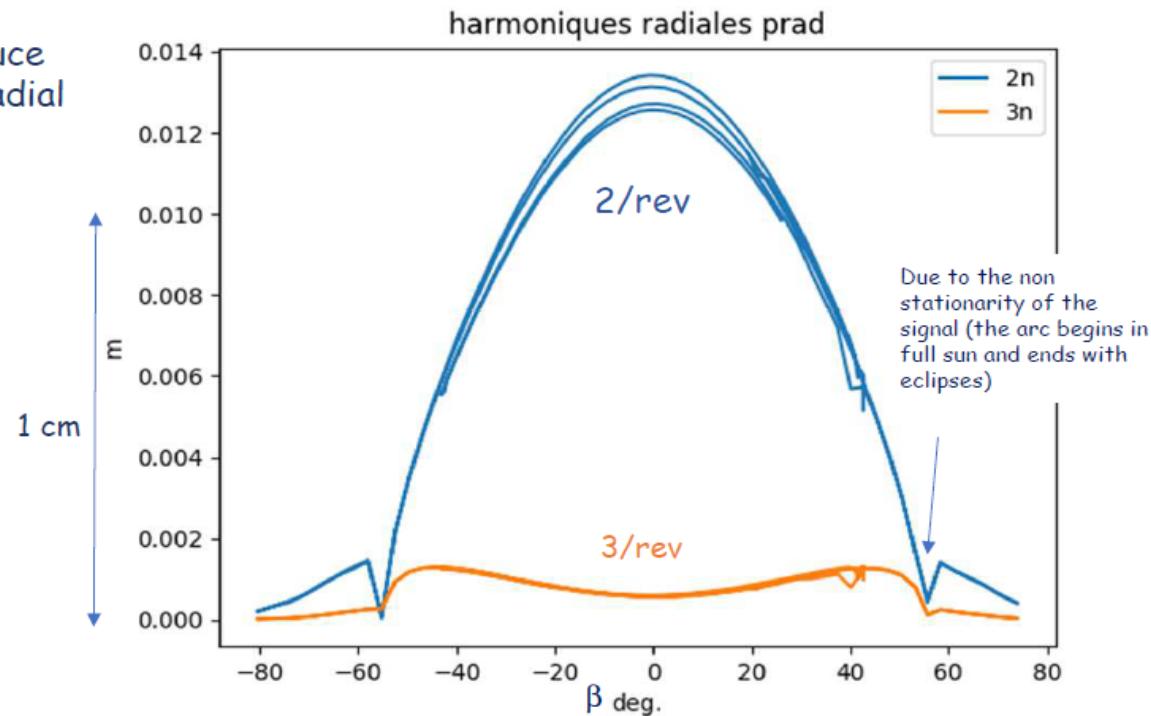
Radial 2/rev and 3/rev due to SRP acceleration :

10% error in the amplitude produce less than 1.5 mm at 2/rev in radial



Sentinel-6 radiation pressure model analysis
OSTST 2022, Venice, POD Session

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

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

- Introduction of 2/rev term in the empirical model



Source : www.space.com

Proposed empirical model

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

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

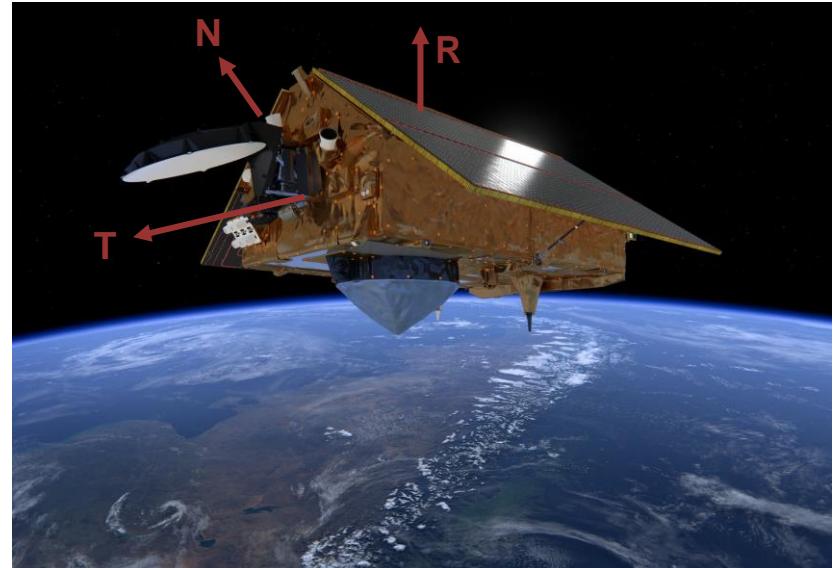


1 point / day

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

1 point / 2rev (G) or 1point (D)

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

Source : www.esa.int

Experiments:

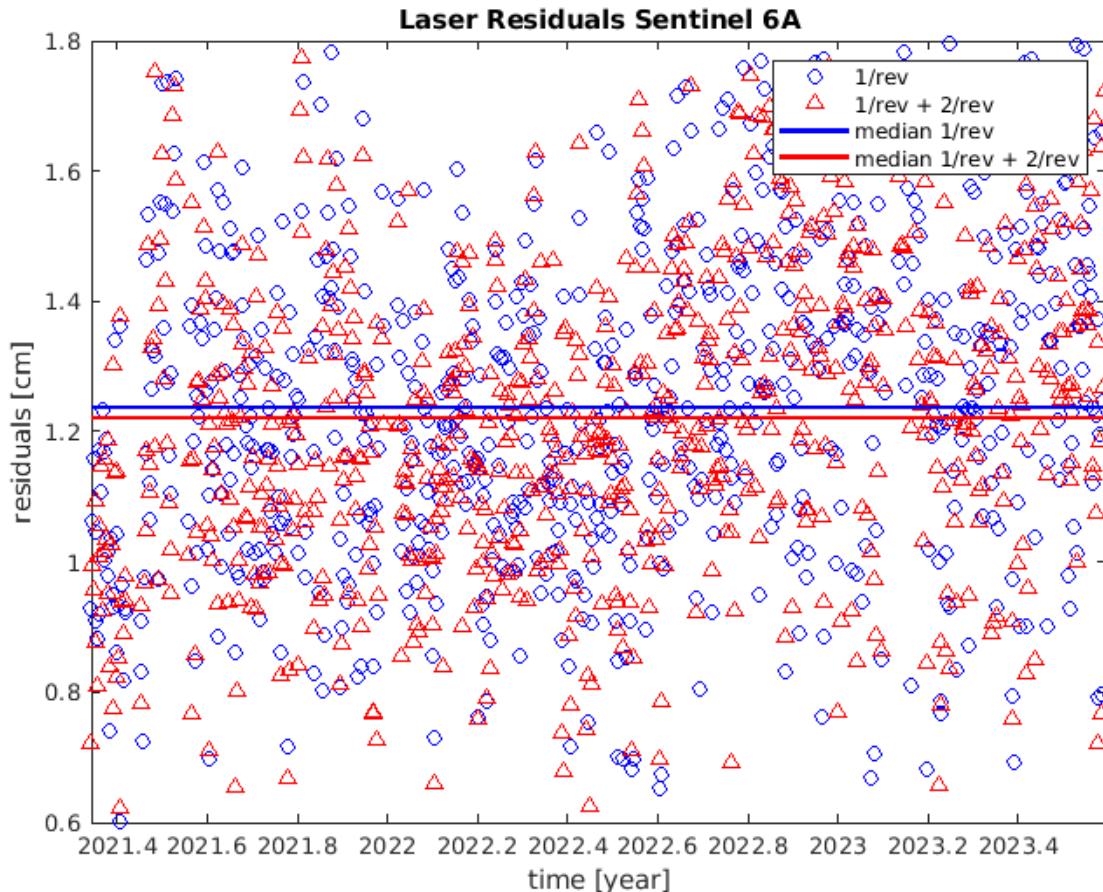
Sentinel 6A –MF : Cycles 18 -100 (21/08/18-23/02/21)

Standard: POE-F

Processing GNSS-only / DORIS-only dynamic

0: no estimation, 1: estimation

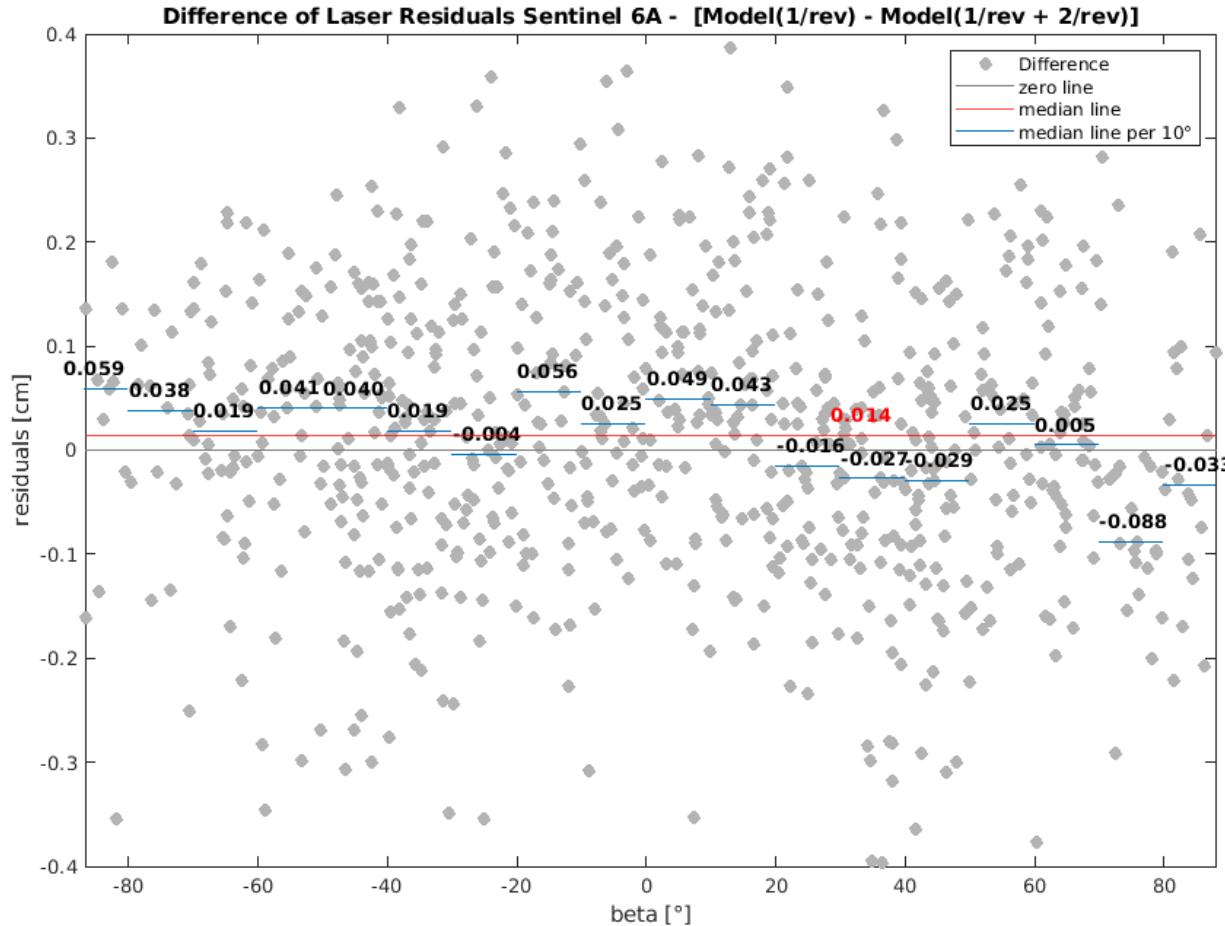
Results – Sentinel 6-MF, GPS-only



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, GPS-only



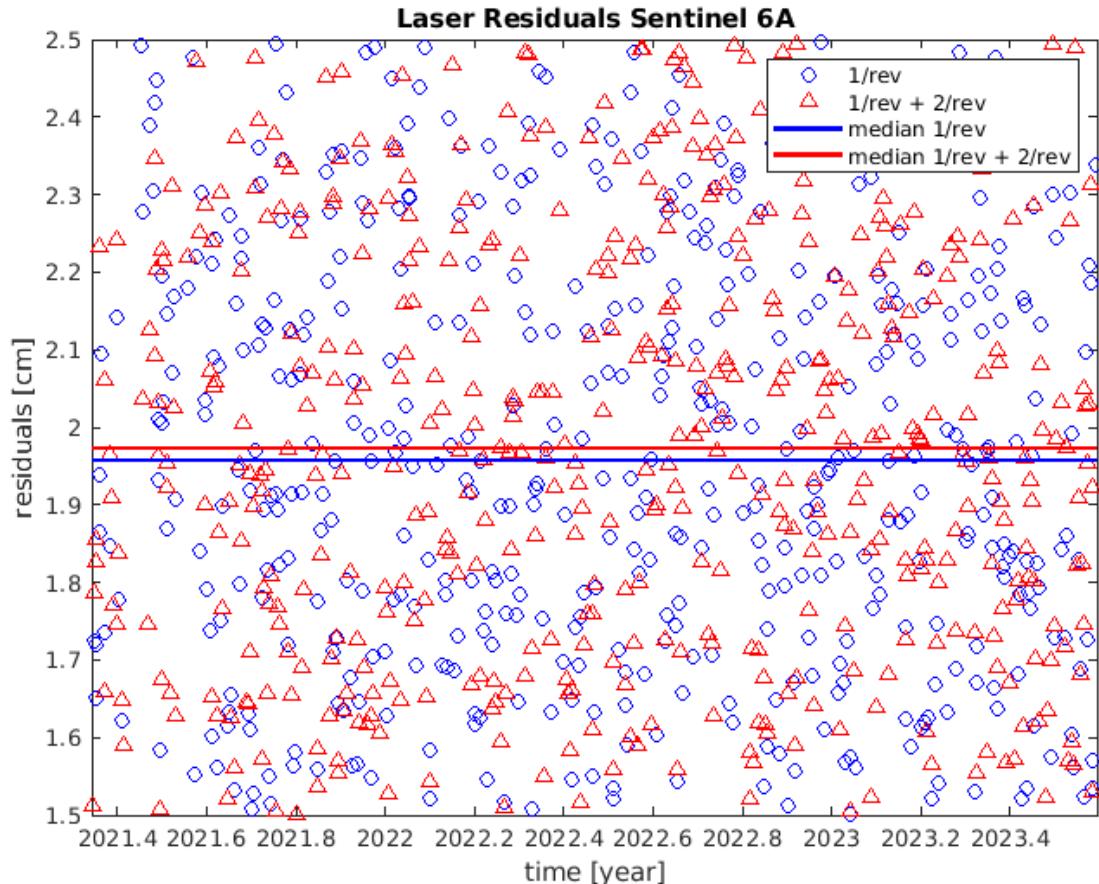
difference of residuals wrt. β angle

black values give the median of each $10^\circ \beta$ range

red line and value give the median of all residuals

- ✓ overall better residuals with the proposed model
- ✓ better estimation around small β angles $[-10^\circ, 10^\circ]$

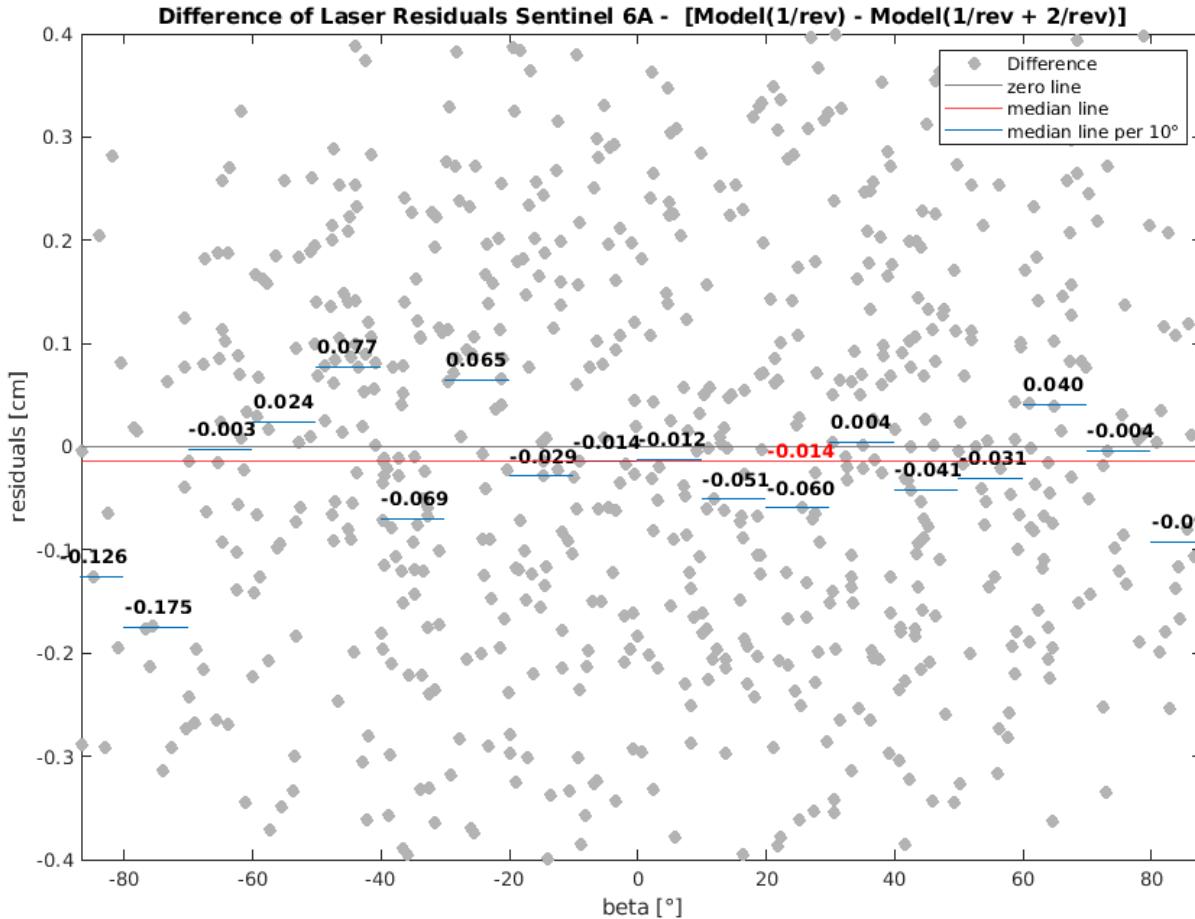
Results – Sentinel 6-MF, DORIS-only



1 value laser residual / day
median 1/rev=1,96cm
median 1/rev + 2/rev=1,97cm

- ✗ no improvement
- ✗ but negligible difference for median values

Results – Sentinel 6-MF, DORIS-only



difference of residuals wrt. β angle

black values give the median of each $10^\circ \beta$ range

red line and value give the median of all residuals

- ✗ no relation between improvements and β angle values
- ✗ no sufficient observability for adjustment of the parameters in a dynamic processing

Conclusions – Future Work

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

Bigger improvement during eclipse seasons for GNSS processing

No improvements seen for DORIS-only dynamic processing



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

More tests will also include reduced dynamic processings of GNSS-only, DORIS-only and GNSS+DORIS

THANK YOU !

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Sources

Carrou JP. (1986), Zoom software: error analysis and accurate orbit restitution at CNES. In: Bhatnagar KB (ed) Space dynamics and celestial mechanics. Springer, Dordrecht, pp 381–398

Morrow R. (2008), Satellite Altimetry https://www.aviso.altimetry.fr/fileadmin/documents/kiosque/education/Rose_cours1_2008.pdf

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] ids-doris.org/images/slideshow/slide4.jpg

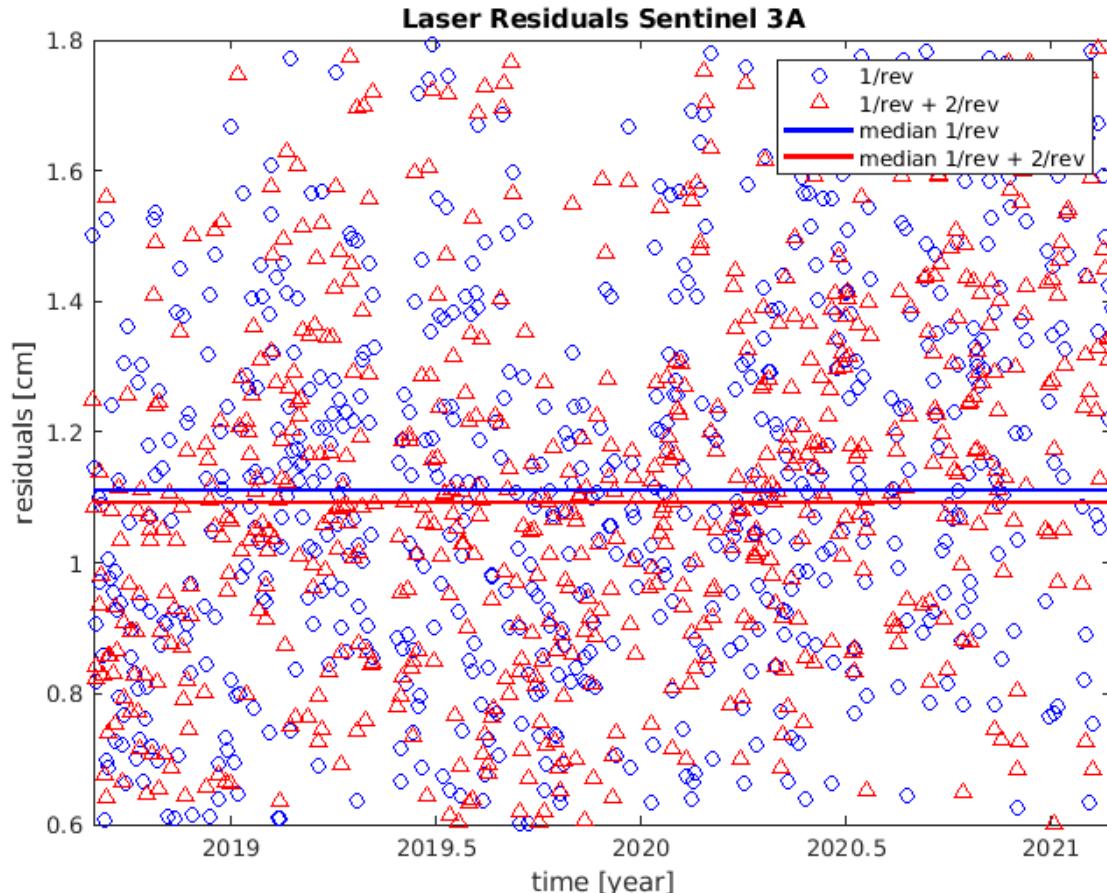
[2] www.esa.int/Space_in_Member_States/France/Dernier_coup_d_aeil_sur_le_satellite_Sentinel_6

[7] www.space.com/sentinel-jason-earth-observation-satellite-named-nasa-scientist.html

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

Backup Slides

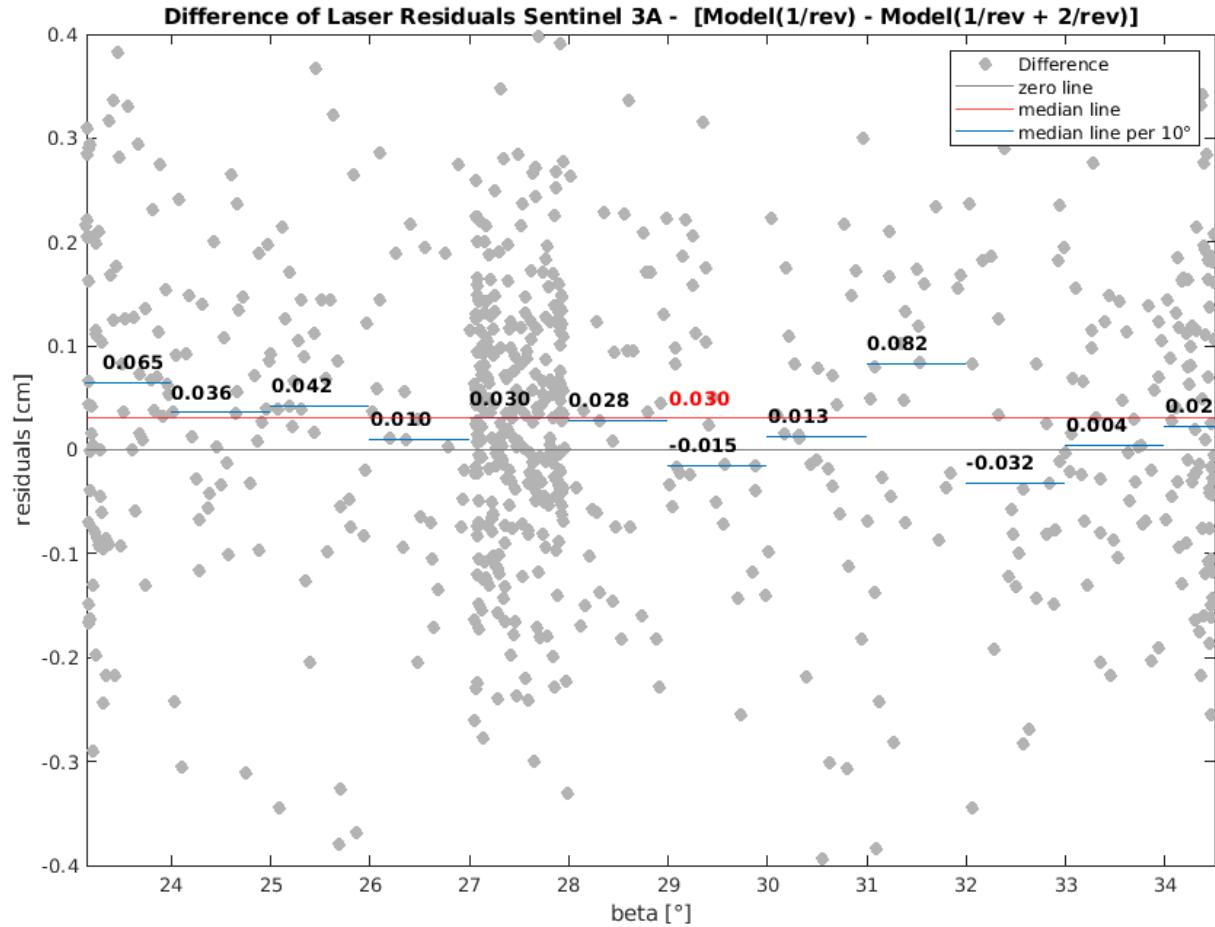
Results – Sentinel 3A, GPS-only



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, GPS-only



difference of residuals wrt. β angle

black values give the median of each $10^\circ \beta$ 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°]