Sentinel-6 radiation pressure model analysis

OSTST 2022, Venice, ITALY, 1st november 2022

Flavien Mercier (CNES) , Alexandre Couhert (CNES), John Moyard (CNES), Robert Cullen (ESA)

Introduction

Pre-launch SRP model from initial documentation
- some hypotheses on the geometry from various sources
- +- y cavities external surfaces (x and z) assumed totally diffuse
- solar array specularity equal to 0, unknown absorbed energy

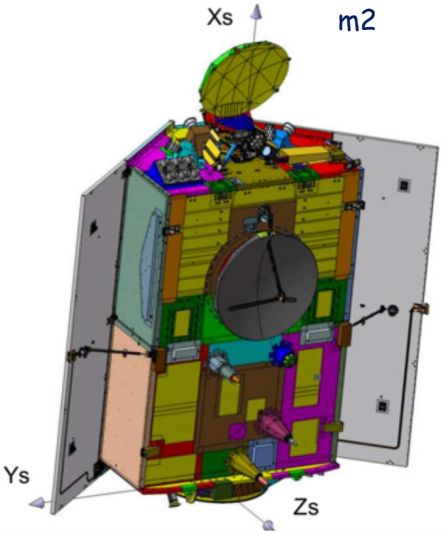
SRP model from updated documentation
(JC-TN-ESA-SY-0420-S6-POD-Context-2.1-20220122-No-ref.pdf)
- detailed materials information (12 panel model)
- new information on solar array (absorbed energy)
- better modelling hypotheses (thermal exchanges)

Comparisons of the two models (using in orbit observations : adjusted empiricals)

Update the new model using these in orbit results

Pre launch SRP model

-x	3.560	-1.	0.	0.	0.45	0.12	0.43	0.180	0.040	0.780
+x	3.620	1.	0.	0.	0.49	0.04	0.47	0.192	0.808	0.
GSa	8.670	0.	-0.6157	-0.7880	0.	0.14	0.86	0.	0.615	0.385
GSb	8.670	0.	0.6157	-0.7880	0.	0.14	0.86	0.	0.615	0.385
-z	3.170	0.	0.	-1.	0.44	0.02	0.54	0.114	0.627	0.259
+z	15.370	0.	0.	1.	0.35	0.08	0.57	0.066	0.724	0.210
	m2		normal		visible (Ks,Kd,Ka)			IR (Ks,Kd,Ka)		
					specular, diffuse, absorbed					



No specular effect on the Solar array
Ka is too important (cell efficiency ~10 %)

Different surfaces in +x or –x, dissymetry

Cavities surfaces added in +x and –x
the surfaces are not correct for drag modelling

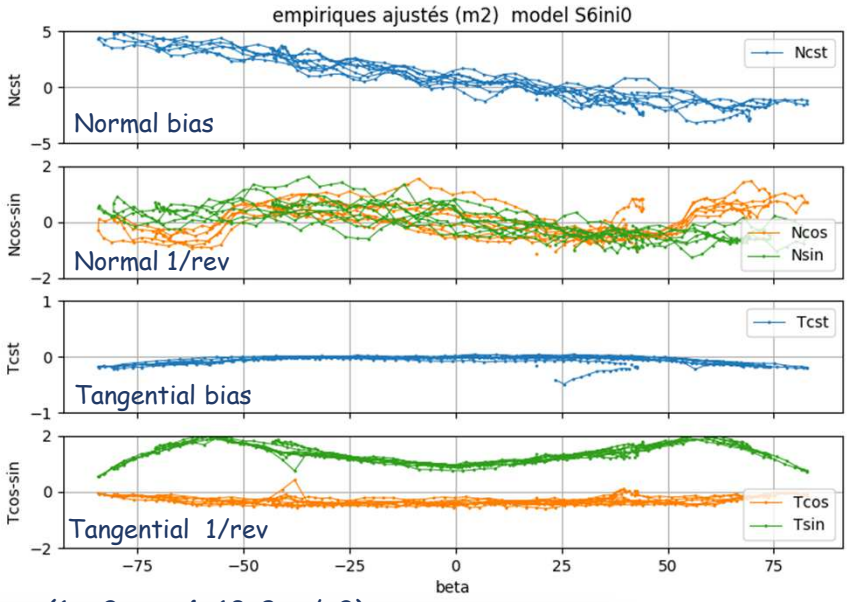
Cavities surfaces added on +z

Pre launch SRP model, flight results

Very important Normal bias

Normal 1/rev signatures

In plane behaviour not correct
the force is too small
(solar array ?, z surfaces ?)



Units : equivalent absorbing surface (1 m2 <--> 4. 10-9 m/s2)

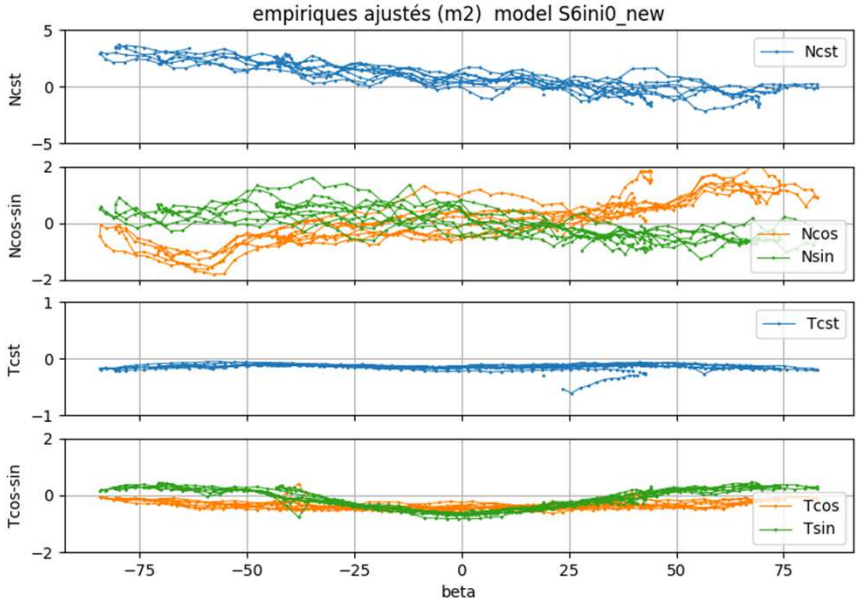
New SRP model, updated documentation

-x	3.35	-1.	0.	0.	0.50	0.50	0.	0.21	0.79	0.
+x	2.99	1.	0.	0.	0.50	0.50	0.	0.21	0.79	0.
GSa	8.65	0.	-0.6157	-0.7880	0.	0.80	0.20	0.	1.0	0.
GSb	8.65	0.	0.6157	-0.7880	0.	0.80	0.20	0.	1.0	0.
-z	2.61	0.	0.	-1.	0.45	0.55	0.	0.16	0.84	0.
+z	15.48	0.	0.	1.	0.35	0.65	0.	0.12	0.88	0.

Hypotheses :

- cavity effect in +z, totally diffuse
- +z surface, no absorbtion
- solar array absorbtion 20 %
- +-x surfaces covered with MLI, no absorbtion

New SRP model, flight results



Better in-plane results
important 1/rev Normal
Normal bias smaller

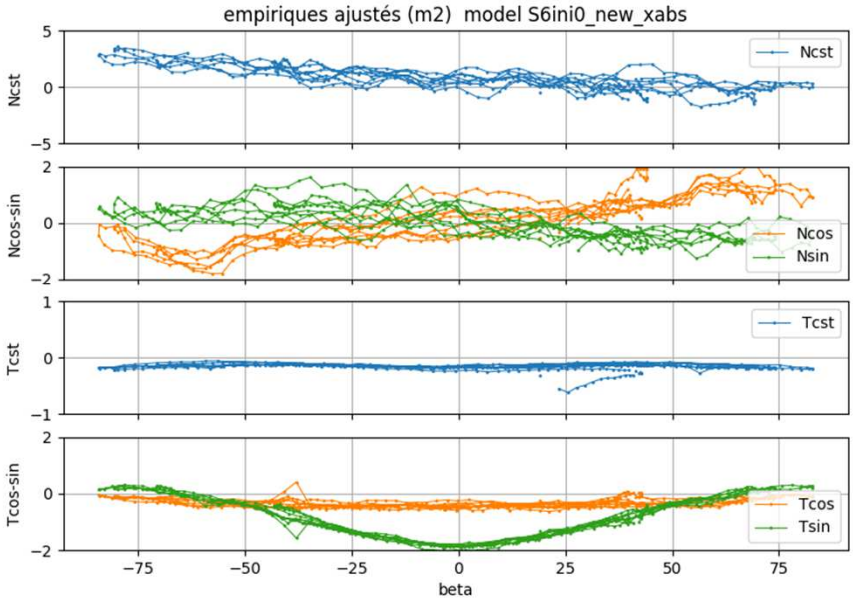
New SRP model, flight results, test x cavities

Cavities model in +-x
add an absorbing surface

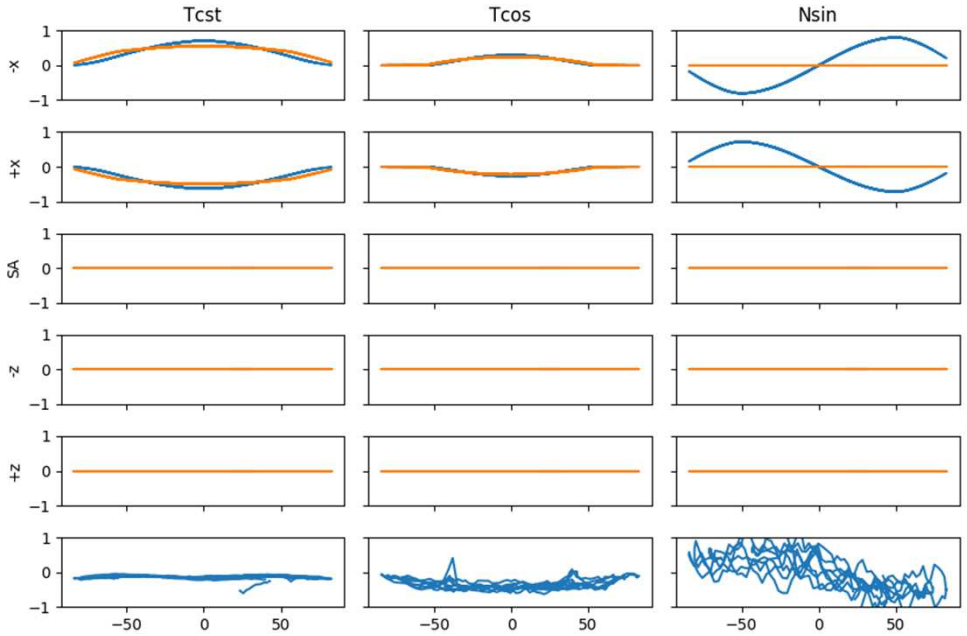
Not a good idea, the in-plane results are worse

Diffuse characteristics (instead of absorbing) even worse

No effect on the Normal axis



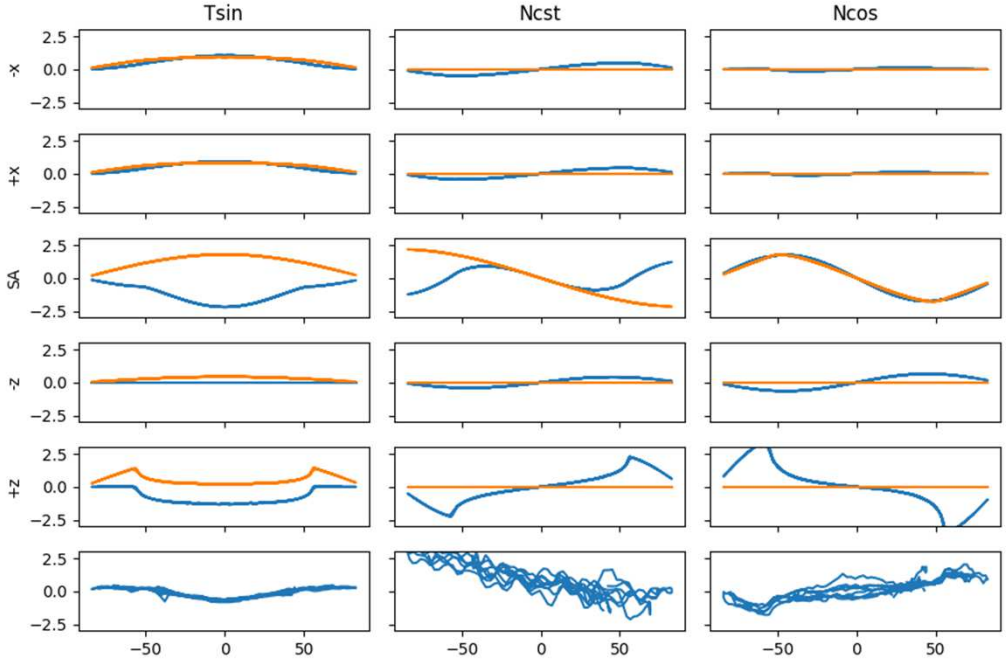
New SRP model, partial derivatives



Specular coeff.
Diffuse coeff.

Update Ks on
the +-x surfaces to
improve Nsin

New SRP model, partial derivatives



Specular coeff.
Diffuse coeff.

Update Ks on the +z surface to correct Ncos

First update

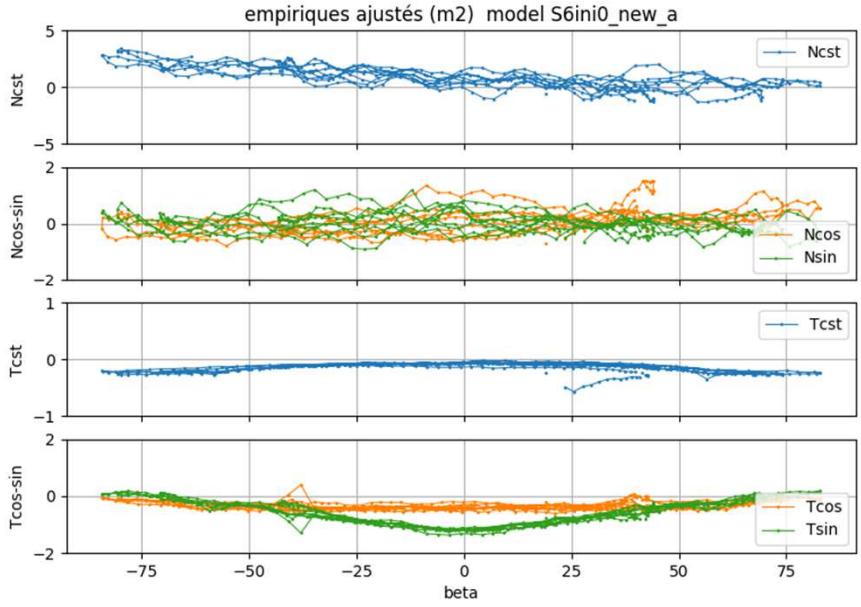
Changes :

Ks, Ka on +x and –x surfaces

+z totally diffuse

No more N 1/rev signatures

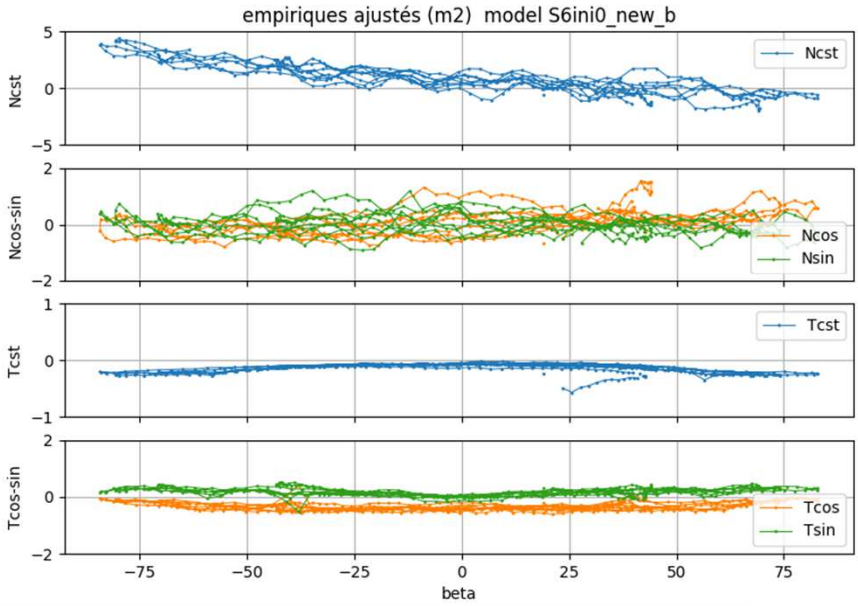
T sin increase at small beta



Second update

Changes :

- Ks, Ka on +x and –x surfaces
- +z totally diffuse
- Ks on solar array



This improves Tsin, but
N cst remains important

Final model

-x	3.35	-1.	0.	0.	0.50	0.50	0.	0.21	0.79	0.
+x	2.99	1.	0.	0.	0.50	0.50	0.	0.21	0.79	0.
GSa	8.65	0.	-0.6157	-0.7880	0.	0.80	0.20	0.	1.0	0.
GSb	8.65	0.	0.6157	-0.7880	0.	0.80	0.20	0.	1.0	0.
-z	2.61	0.	0.	-1.	0.45	0.55	0.	0.16	0.84	0.
+z	15.48	0.	0.	1.	0.35	0.65	0.	0.12	0.88	0.

Ks,Ka modification for surfaces +x and –x
solar array characteristics, specular modified
+z surface fully diffuse

-x	3.35	-1.	0.	0.	0.20	0.80	0.	0.21	0.79	0.
+x	2.99	1.	0.	0.	0.80	0.20	0.	0.21	0.79	0.
GSa	8.65	0.	-0.6157	-0.7880	0.30	0.50	0.20	0.	1.0	0.
GSb	8.65	0.	0.6157	-0.7880	0.30	0.50	0.20	0.	1.0	0.
-z	2.61	0.	0.	-1.	0.45	0.55	0.	0.16	0.84	0.
+z	15.48	0.	0.	1.	0.	1.00	0.	0.	1.00	0.

Remark : this model absorbs the incoming energy only via the solar array, correct for energy balance, in reality, there are more complex exchanges between the external panels and the cavity

Discussion

Updating the model using information on the 1/rev accelerations is efficient but still some anomalies :

- the in plane and out of plane behaviour cannot be simultaneously corrected
- very important Normal bias

This approach does not garantee an improvement in the radial direction (altimetry)

Error estimation : radial accelerations spectrum

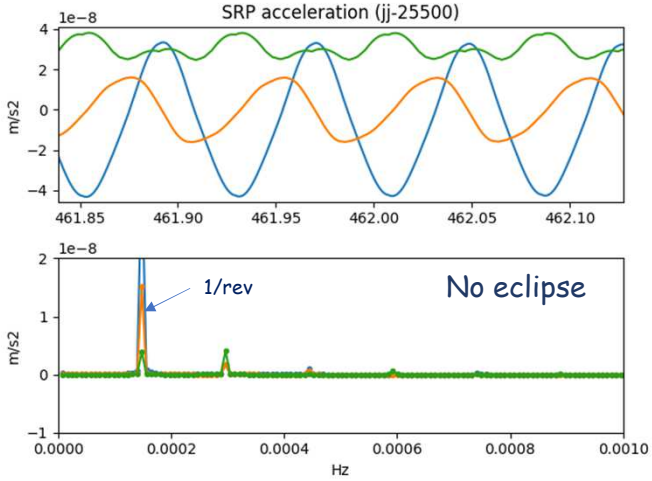
- no eclipse : mainly 1/rev, higher harmonics have negligible effects

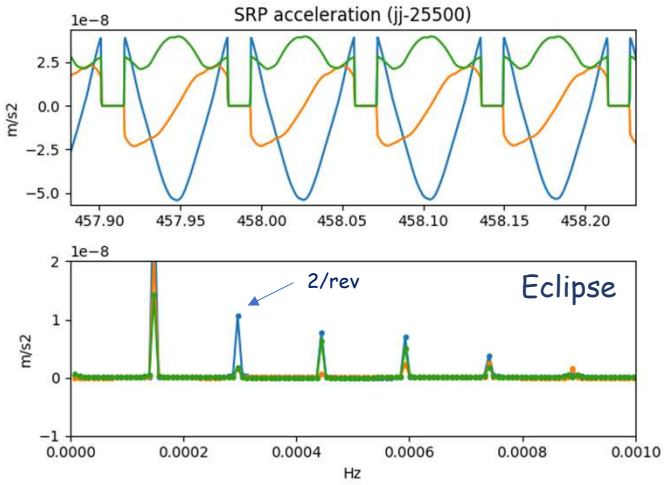
- eclipse : most important contributions are from the eclipse transitions, producing 2/rev, 3/rev … harmonics

  the amplitude of the SRP acceleration around the eclipses must be correct (mainly due to +z)

  --> the model should not have significant changes in adjusted 1/rev when eclipses begin (around 55 degrees)

Spectral analysis, SRP harmonics



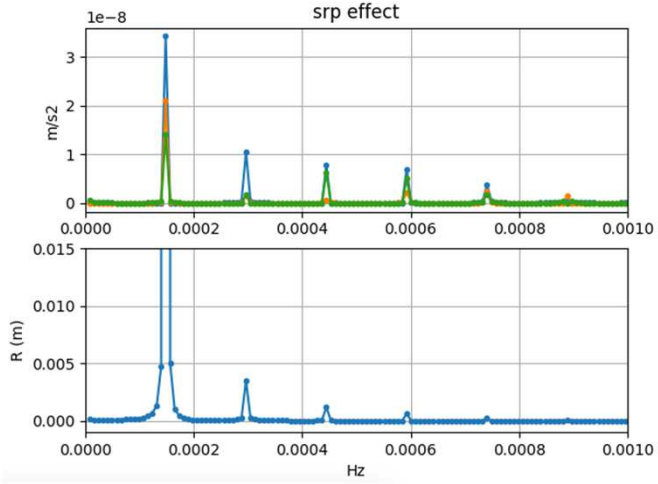


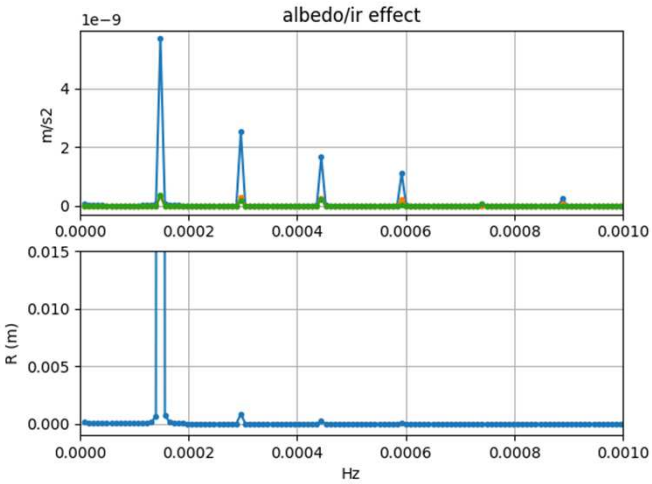
R, T, N accelerations

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

The SRP harmonics amplitudes are due to the eclipse transition

Spectral analysis, radial displacements harmonics (1)

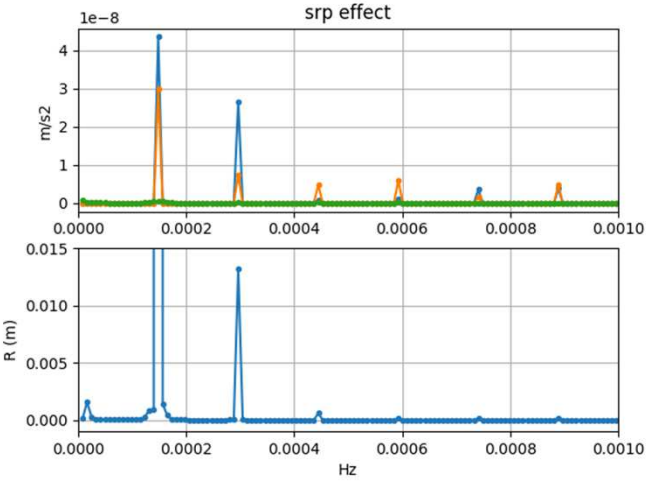


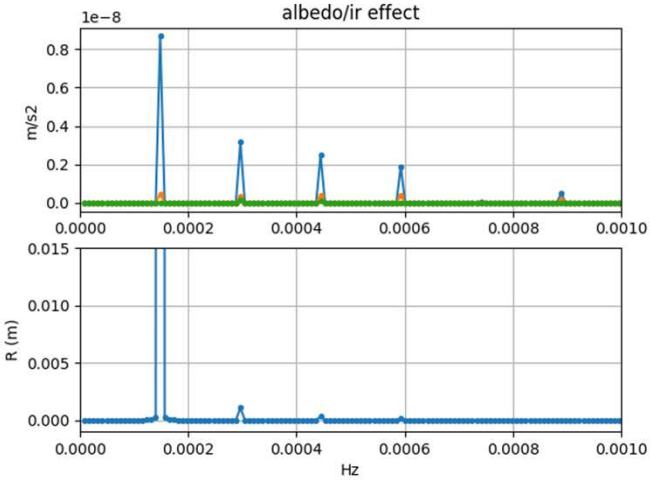


R, T, N accelerations, radial response, begin of eclipse period

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

Spectral analysis, radial displacements harmonics (2)





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

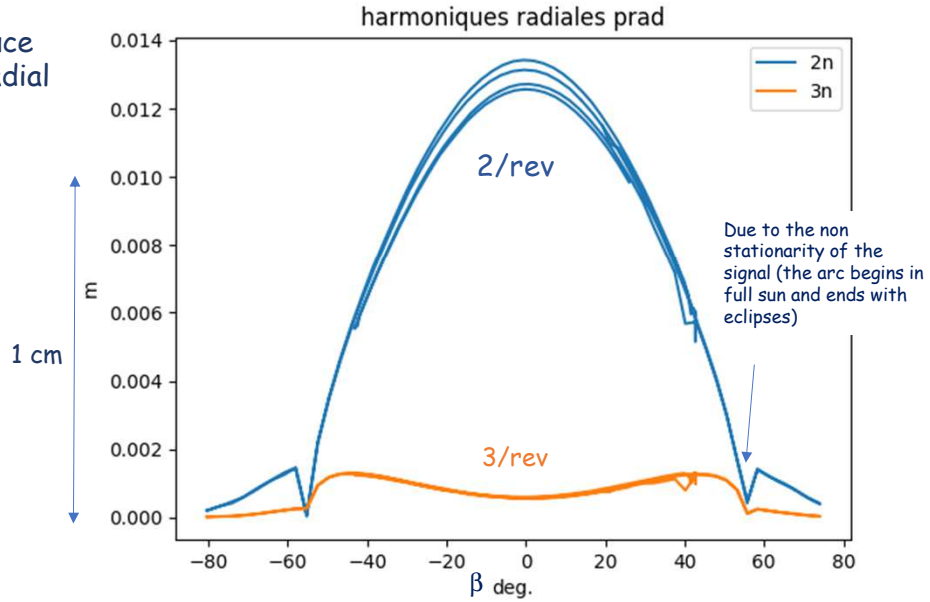
2/rev, main harmonic : here, the SRP contribution is higher (1.4 cm)
the albedo/ir response is negligible

higher harmonics : negligible

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)



Conclusion

The new model (from the last version of the documentation) behaves correctly,
better than the pre-flight model for the in-plane behaviour

This model is not correct for the normal bias
improvements needed :
- better modelling of the solar array energy exchanges (external panels)
- how to handle the +-y cavities in a simple model ?

Error analysis
the Albedo/IR harmonics effects are negligible (2/rev, …)
the 2/rev term is the main contributor of the SRP to the radial performance
(1/rev errors are handled by the empiricals)
this term is important for the eclipse cases, for high β values

The current model is simple (6 surfaces), but needs an empirical constant normal bias per arc
the remaining 1/rev errors stay below 1 m2 equivalent acceleration (4. 10-9 m/s2)