Empirical Solar Radiation Models for Altimeter Satellites

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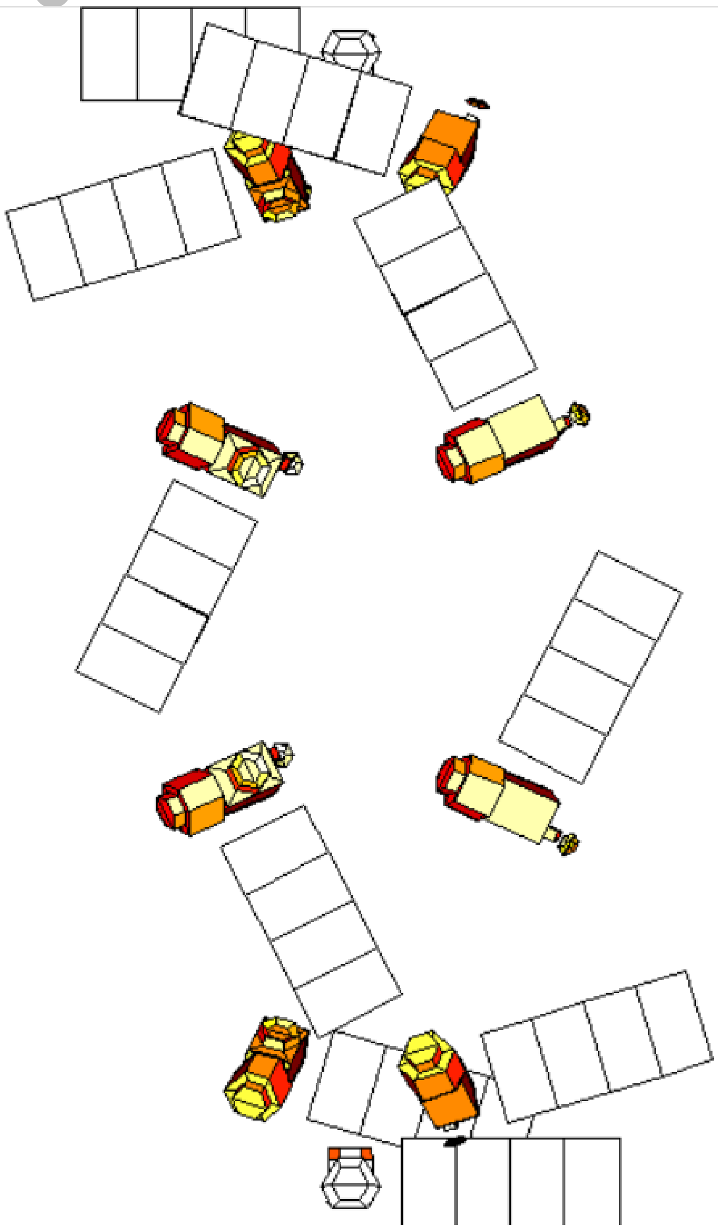
Radiation pressure models



Radiation pressure models : current approach

construction of a refined radiation pressure model

precise geometry, materials characteristics

ray tracing method for incoming fluxes

diffuse emissions on radiators (thermal control), antenna radiation

simplified model for orbit determination

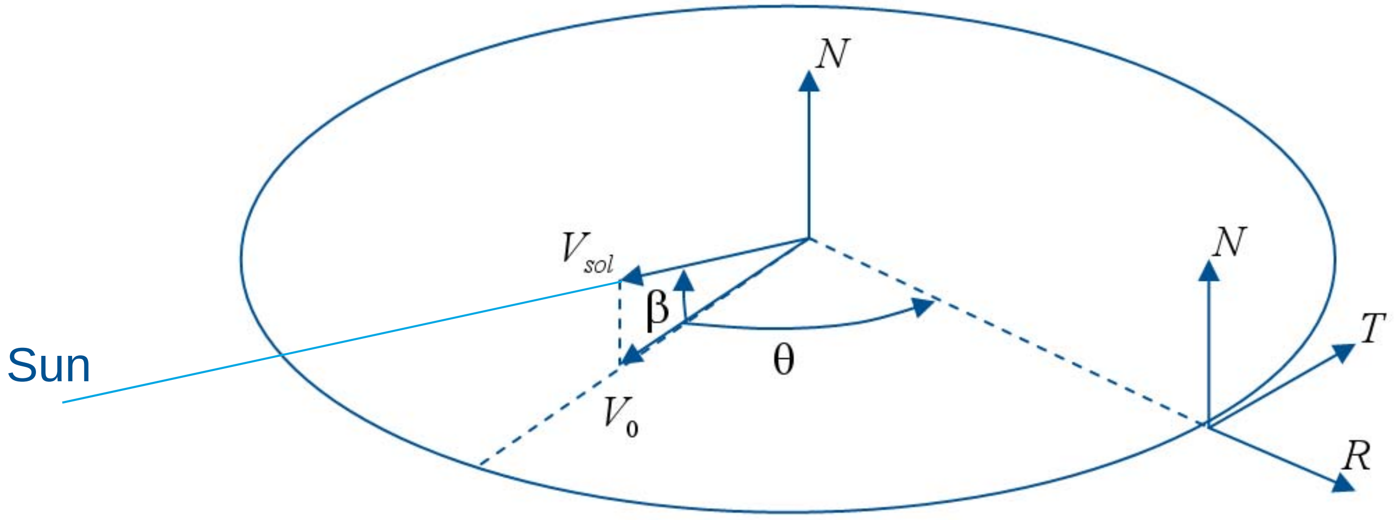
… for efficient computation of the surface forces

adjusted 'box and wings' models

or use of interpolation tables

use (if possible) the complete attitude definition, including solar array pointing

Geometry



θ : orbital angle (referenced to subsolar direction)

β : solar angle

Radiation pressure models

Relevant parameters to accommodate SRP errors in orbit determination :

- Global scale coefficients of the solar radiation pressure model

- Partial update of few macromodel coefficients

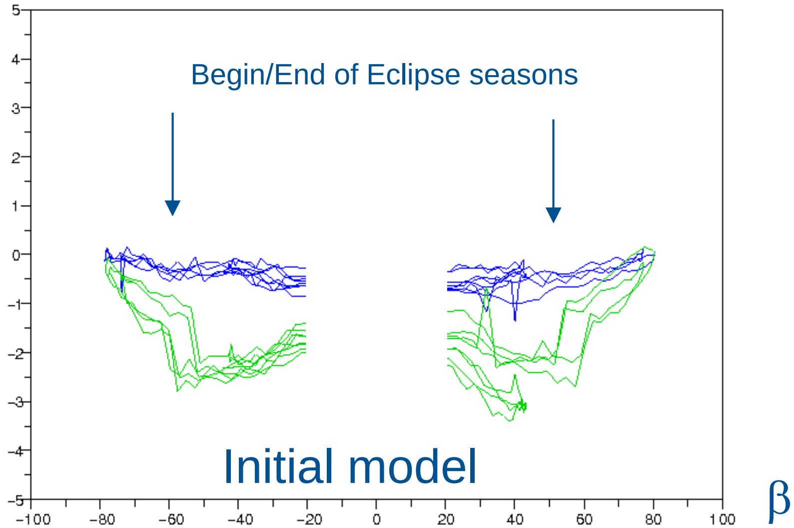
- Empirical forces

  1/rev along track and cross track, constant along track (or drag)

  analysis of the empirical forces as functions of sun angle β : **systematic signatures**

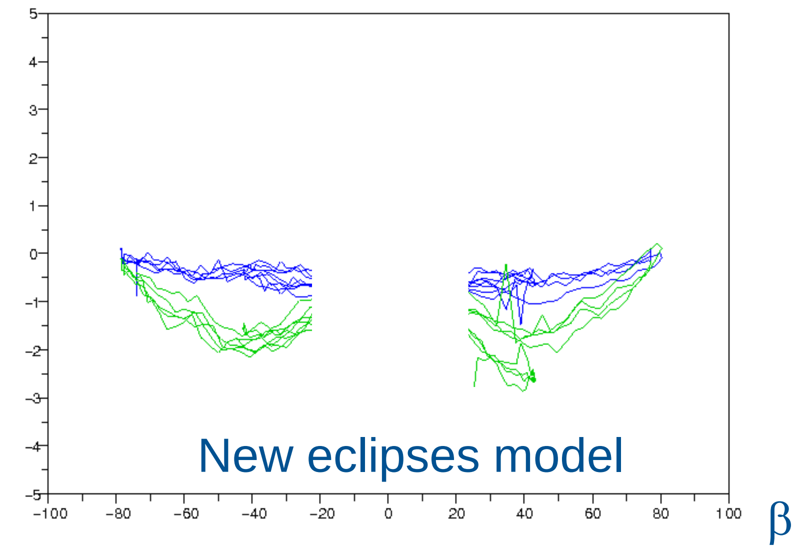
Empirical forces signatures, yaw steering cases

10-9ms-2 Tangential, cos and sin



Jason-2 example, Along track (daily estimate of 1/rev)

10-9ms-2 Tangential, cos and sin



Correction of
atmospheric absorption/refraction effects

Phase reference : subsolar point
acceleration order of magnitude 2 10-9 ms^{-2} equivalent to 0.2 m^2 (total absorption)

Current ‘box and wings’ Jason model

Applied since GDR-C standards (with 0.97 scale coefficient for Jason-1)

Axis	m2	Normal direction			Ks	Kd	Ka
X	1.65	1.0			0.09	0.28	0.21
-X	1.65	-1.0			0.43	0.21	0.01
Y	3.00		1.0		1.19	-0.01	-0.01
-Y	3.00		-1.0		1.20	-0.00	-0.00
Z	3.10			1.0	0.24	0.40	0.33
-Z	3.10			-1.0	0.32	0.37	0.27
+SA	9.80	1.0			0.34	0.01	0.65
-SA	9.80	-1.0			0.00	0.30	0.70

Remarks : +SA towards the sun (solar array)

adjusted on a precise model
(Ks+Kd+Ka not constrained on central part to have correct surfaces)

Different attitude descriptions

Ideal Yaw-steering attitude : Z satellite towards earth,
Y satellite orthogonal to sun direction (same as GPS)

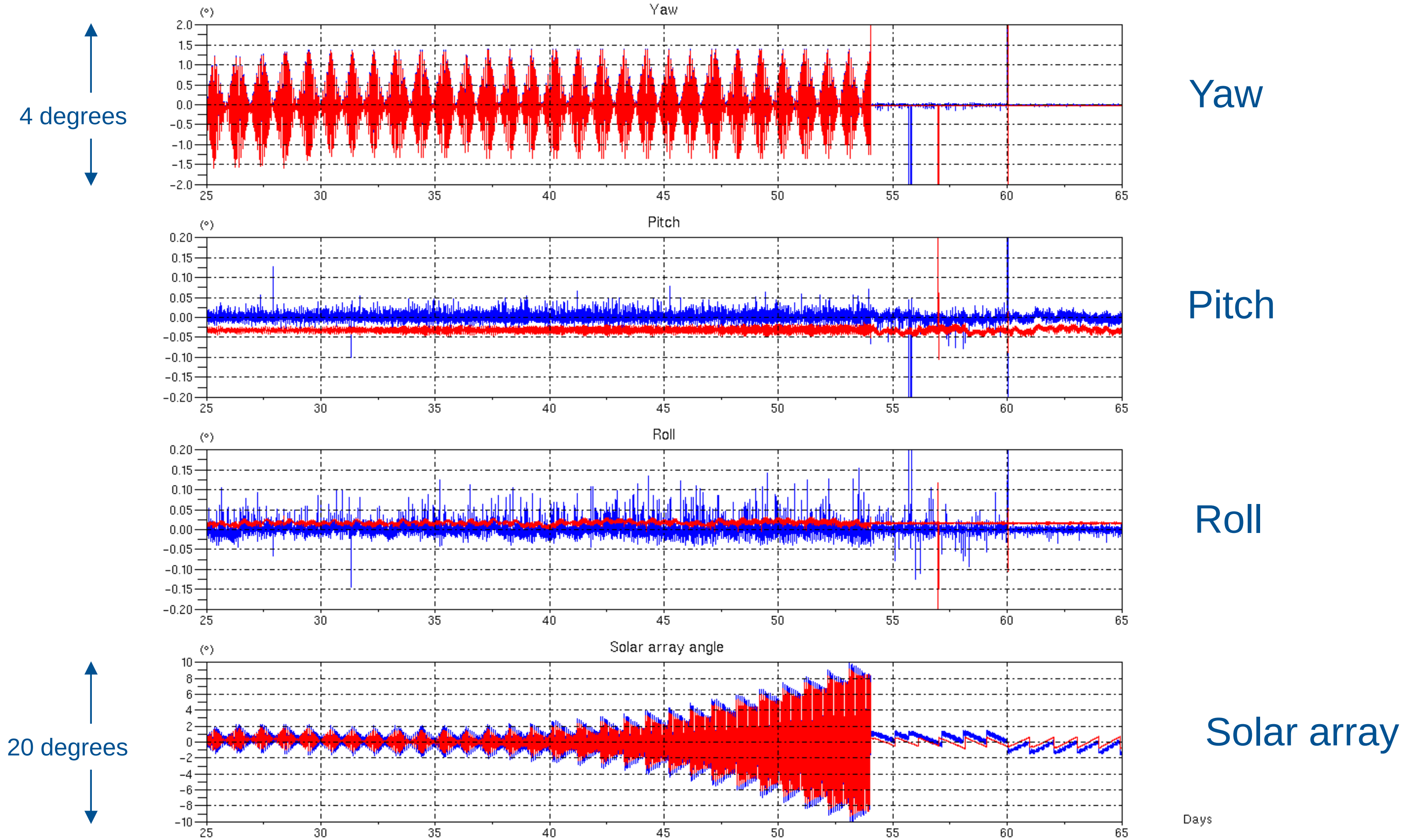
Topex/Jason theoretical attitude : similar to the above yaw case, with limitations on rates (important effect for small β values)

True attitude : close to the theoretical attitude
but : obtained by daily adjusted expressions
corresponding accelerations are not well represented by 1/rev empiricals

→ Verify acceleration differences for these three models
is it possible to use 1/rev, 2/rev .. in θ terms to mitigate ?

Remark : $|\beta|<15$ ° fixed-yaw attitude , other definitions for the model
(this case is not detailed in the following slides)

Observed Jason 1 and 2 attitude

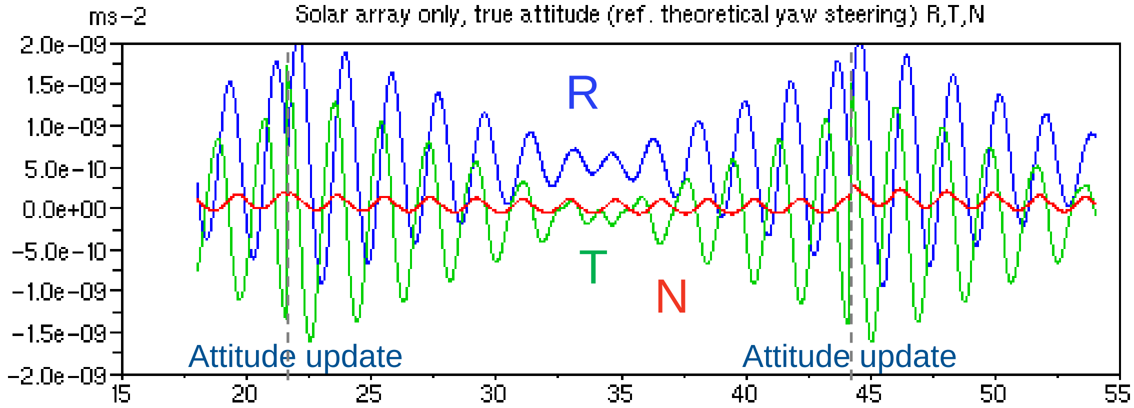


Comparison of true and Jason theoretical attitude (Jason 1 and Jason 2 during tandem)

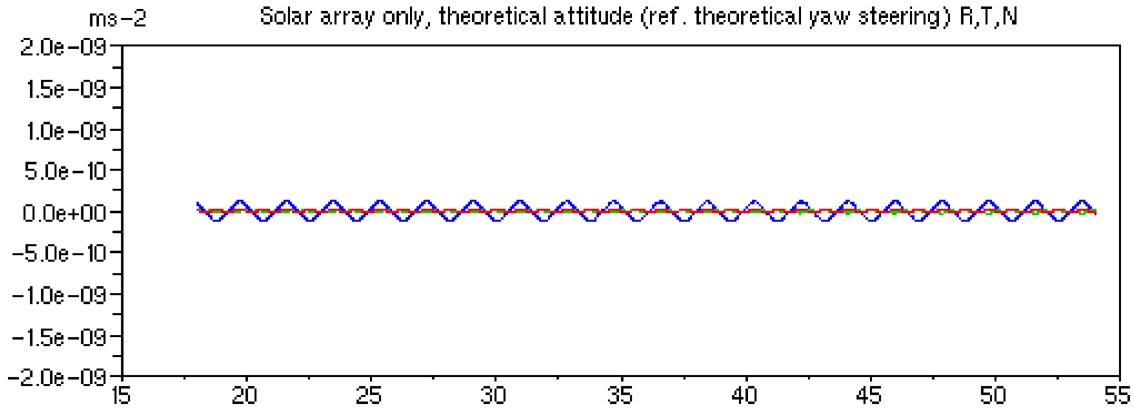
L. Cerri et al. *Precision Orbit Determination Standards for the Jason Series of Altimeter Missions*. MAR GEODESY.

Example : accelerations, β ~80 °, solar array contribution

Impact of attitude law on solar array SRP acceleration



True attitude – Ideal Yaw



Jason theoretical attitude – Ideal Yaw

R and T accelerations of 2.0 10^{-9} ms^{-2} at frequencies close to orbital frequency

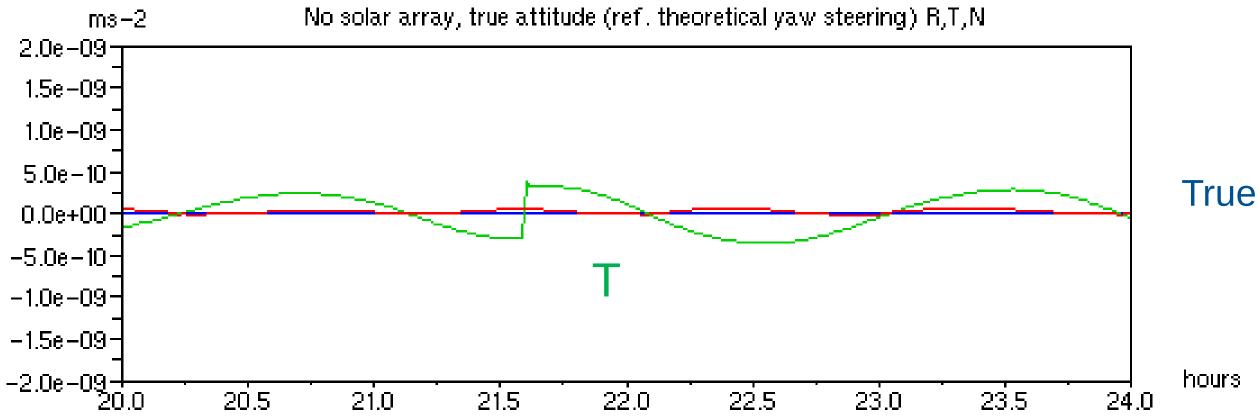
for complete attitude case, not correctly cancelled by θ 1/rev terms

these T and R accelerations are due to transverse effects on the solar array

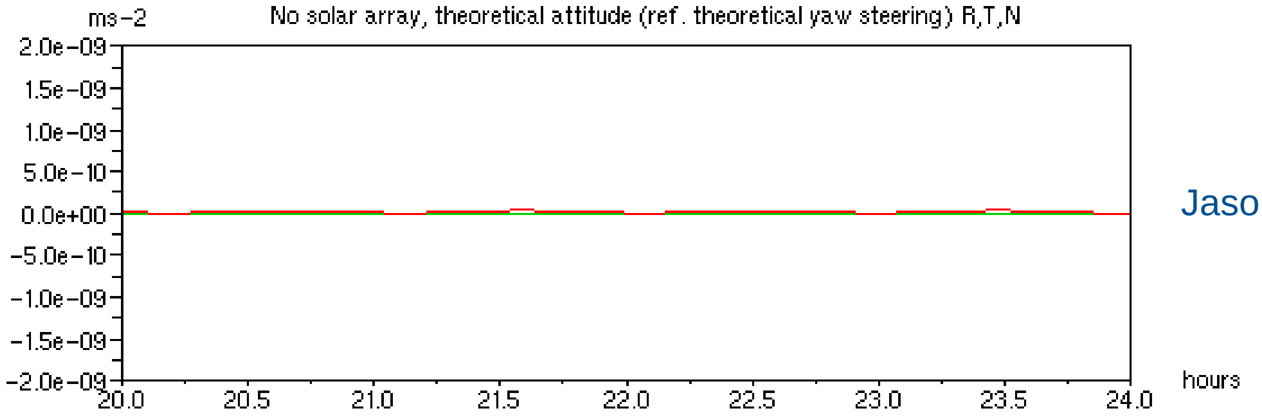
(solar array is ~parallel to orbital plane for high β values)

Example : β ~80 °, central part contribution

Impact of attitude law on 6-plate central box SRP acceleration



True attitude – Ideal Yaw

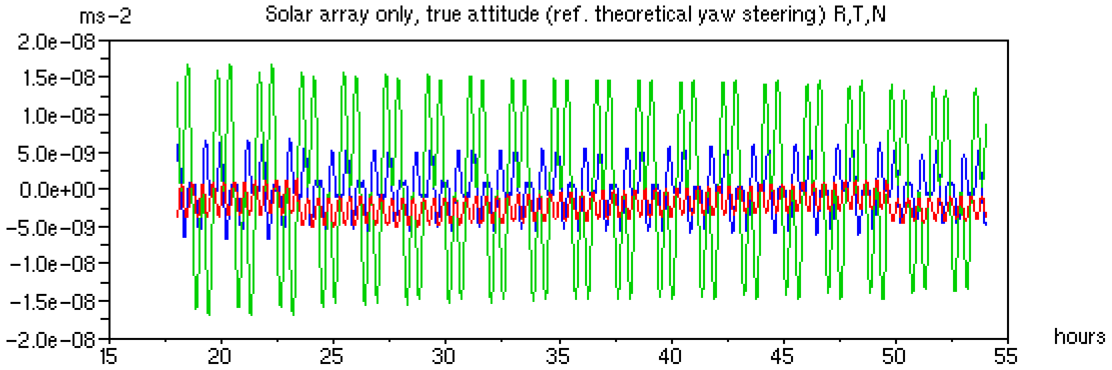


Jason theoretical attitude – Ideal Yaw

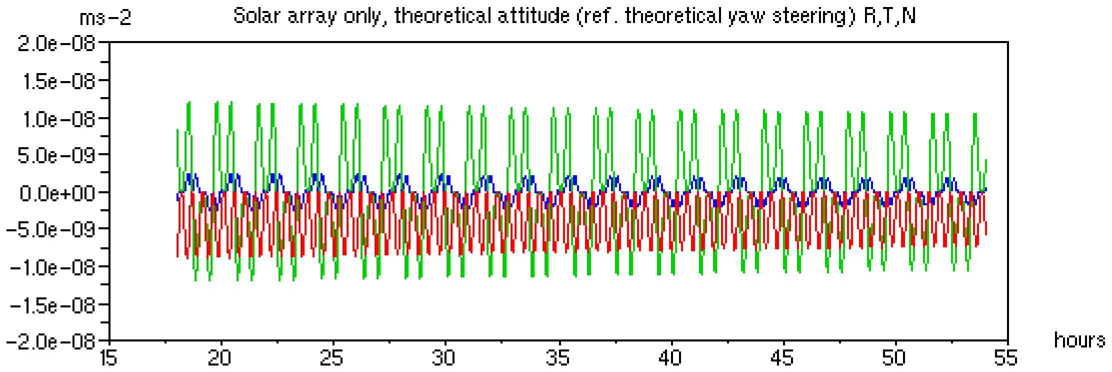
Similar effect, 10 times smaller than the solar array contribution

Example : β ~18 °, solar array contribution

Impact of attitude law on solar array SRP acceleration



True attitude – Ideal Yaw

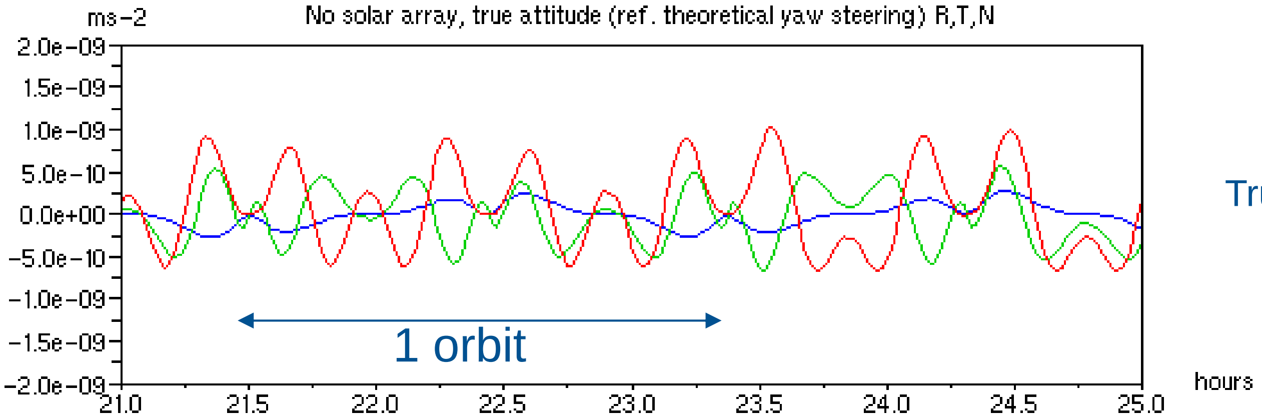


Jason theoretical attitude – Ideal Yaw

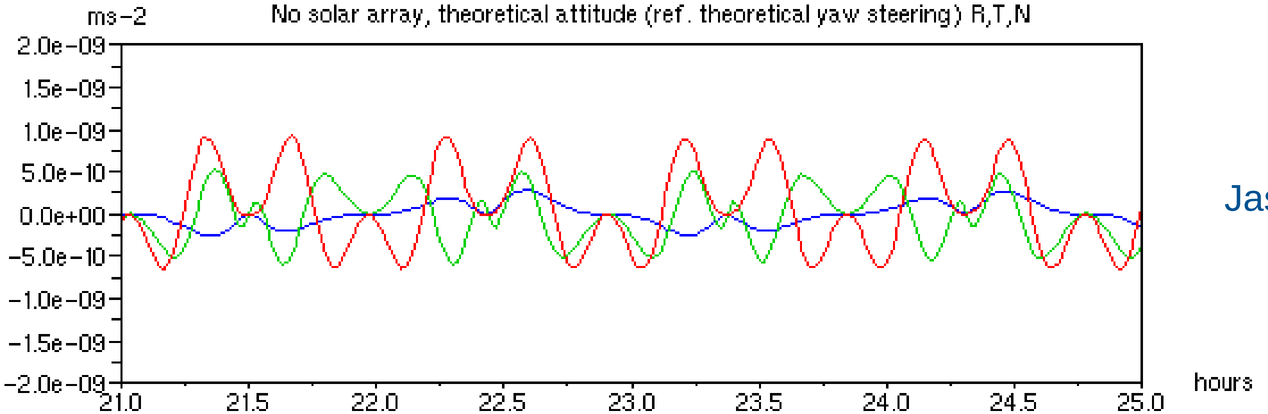
important differences between ideal yaw, and Jason laws (true or theoretical)
- with 1/rev terms and higher harmonics
- also clear attitude jumps at updates

Example : β ~18 °, central part contribution

Impact of attitude law on 6-plate central box SRP acceleration



True attitude – Ideal Yaw



Jason theoretical attitude – Ideal Yaw

Central part contribution 10 times smaller than solar array

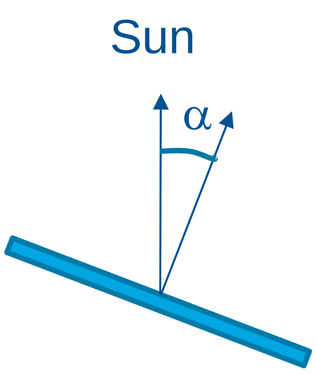
1/rev term ~ 1.0 10^{-10} ms^{-2} , higher rank harmonics have little contribution to orbit error

Models choice : solar array

A precise model is needed for the solar array accelerations

Standard plate model with Ks,Kd,Ka and exact pointing

must be used with the correct orientation (true attitude law)
optical coefficients must be updated for transverse behavior
(deviations with respect to the sun direction may reach 10 degrees)
tuned model represents also thermal radiation effects (diffuse emission)
must be representative up to 10 degrees mispointing



How to update in a simple way ?
Transverse diffuse and specular effects are not separable (α remains small)

simultaneous update of specular part and absorbed part
total force is unchanged : 2*Ks+Ka = 0

Models choice : central part

The central part may be empirically modeled (or corrected)

- attitude misrepresentation effects are much smaller than for the solar array
- a precise model is not possible (antennas, various shapes, shadows, thermal behavior)

Construction of a model in the sun-pointed frame (referred to as ***Rg***)

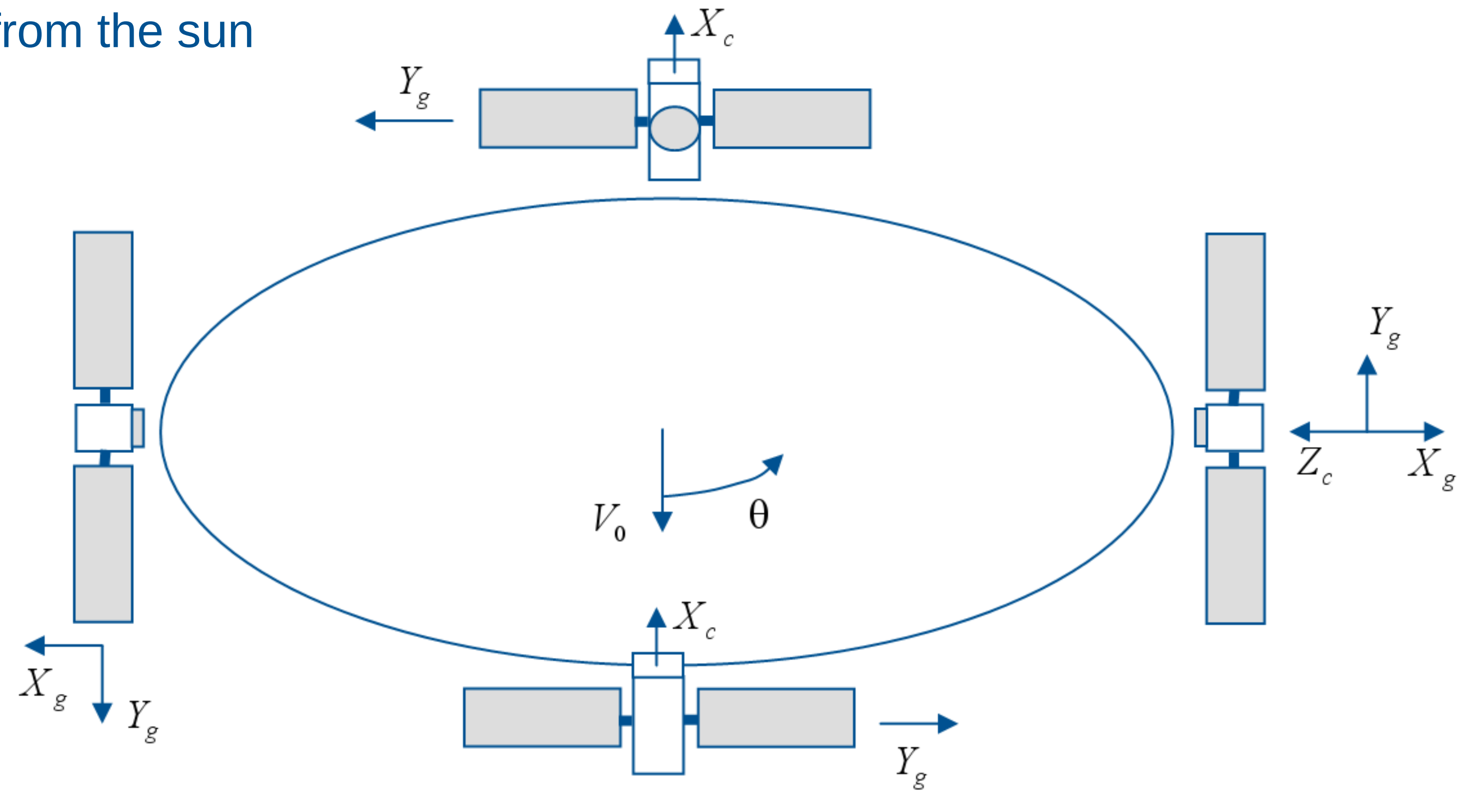
- represents all radiation effects on the central part including thermal radiation effects
- represents the difference between theoretical yaw attitude and true attitude

Rg frame : Xg,Yg,Zg reference frame, assuming a perfect yaw attitude
Yg solar array rotation axis in the ideal yaw case
Zg towards the sun

This reference frame is used at IGS for GPS satellite empirical accelerations for SRP modelling

Theoretical yaw steering, Rg frame

View from the sun



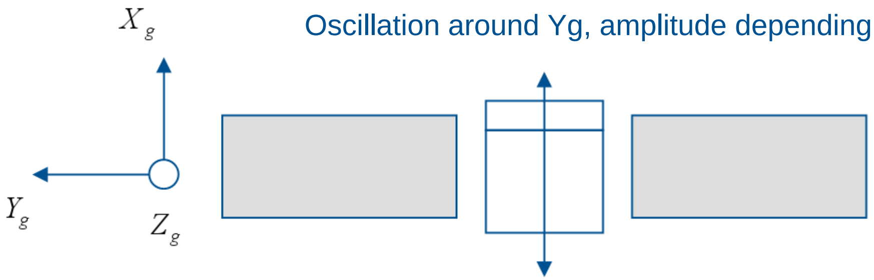
Subsolar point

Solar array reference frame : Rg
Zg axis towards the sun, main acceleration is along Zg axis

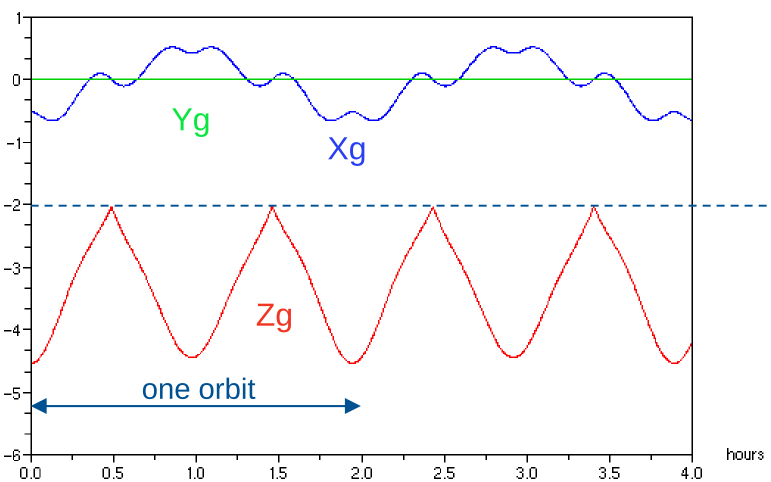
accelerations are periodic functions of θ
some interesting symmetries : for example, **same accelerations on all axes for θ = 90 and -90 °**

Characteristics of accelerations in Rg

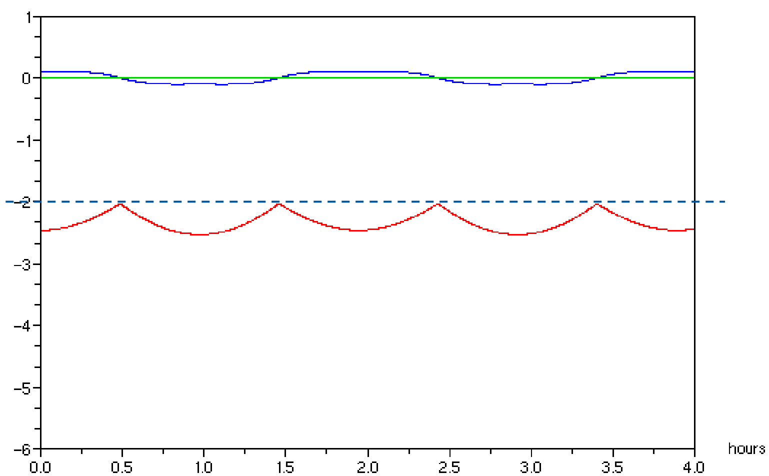
Oscillation around Yg, amplitude depending on β



$\beta = 15°$



$\beta = 75°$

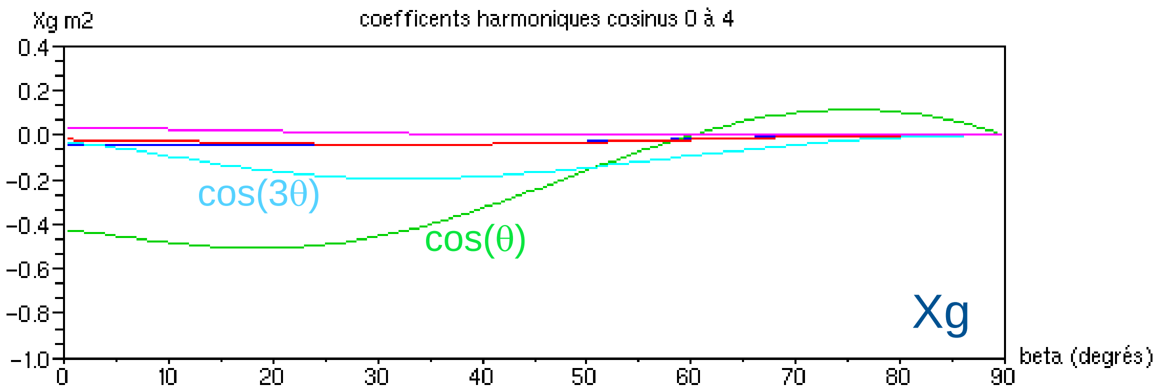


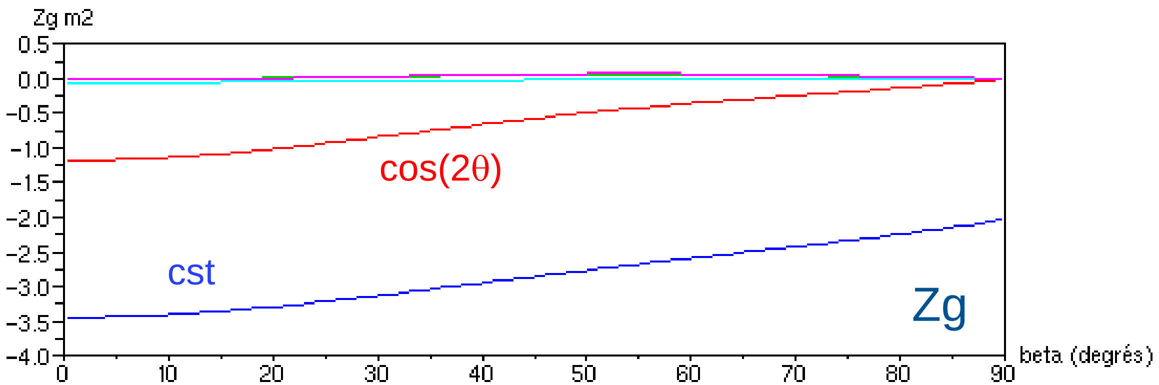
Central body model, yaw attitude

- Yg acceleration is null
- Xg and Zg accelerations periodic, with harmonics amplitudes vary with β
- Zg : bias, cos(θ) (small), cos(2θ) , …

→ harmonic components functions of β

Accelerations components in Rg





BW model, with yaw reference attitude :

- even terms only
- only terms in θ and 2θ have significant effects
- all harmonics are null at β=90°
- variations in β can be represented with low degree polynomials

→

Complete model :

- terms up to second harmonic
- null harmonics at β=90°
- polynomial β expression

Model definition, identification

Construction of the normal equations

- 1.5-day arcs, gps measurements
- reference solar array with complete attitude law , box=0
- 15 parameters
- specular and absorption coefficients for solar array
- empirical forces (inclusion in normal equations allows rapid quality check)

Cycles 61 to 87 (Jason 2)

Identification of polynomial coefficients $a_0 + a_1(u^2 - 1) + 4a_2u^2(u^2 - 1)$

$(u = \frac{\beta}{\beta_0}, \beta_0$ corresponds to 90 °) $a_0 = 0$ for periodic terms

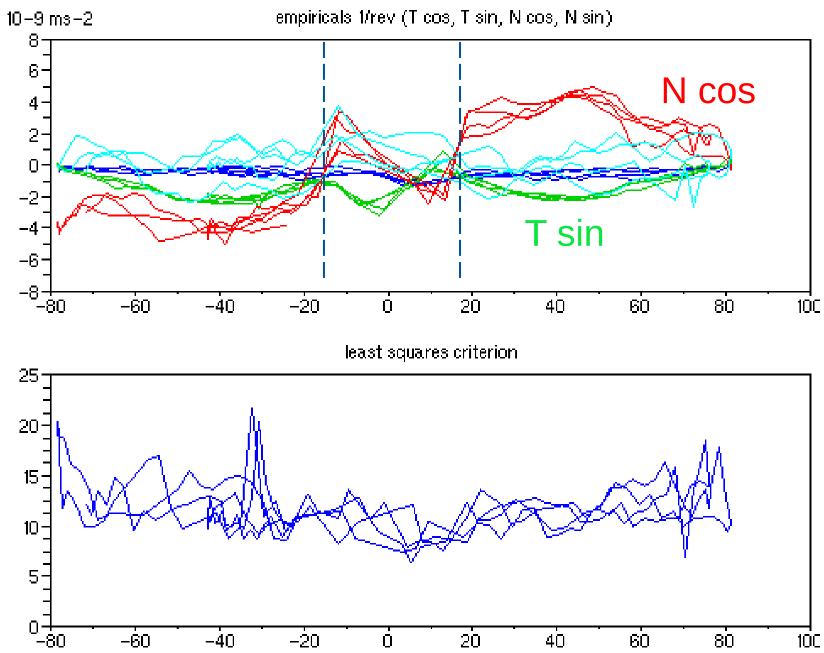
A priori values from 'BW' model with theoretical yaw

5 adjusted components in Rg frame (subset of the 15 parameters)
Xg cos and sin, Zg constant, cos and sin

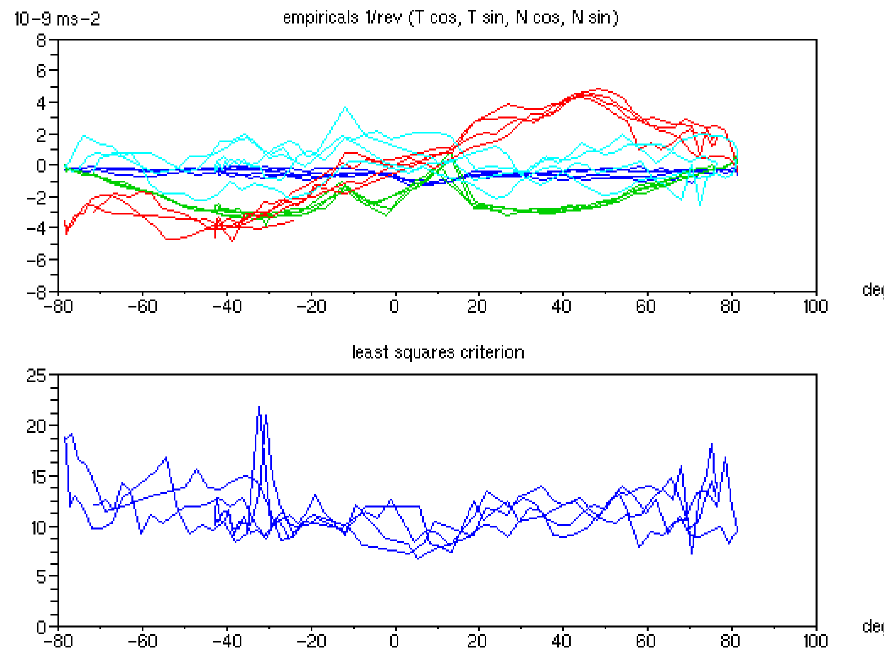
Adjusted solar array (2 coefficients)

Effect of solar array correction

Initial model



Initial model + GS correction



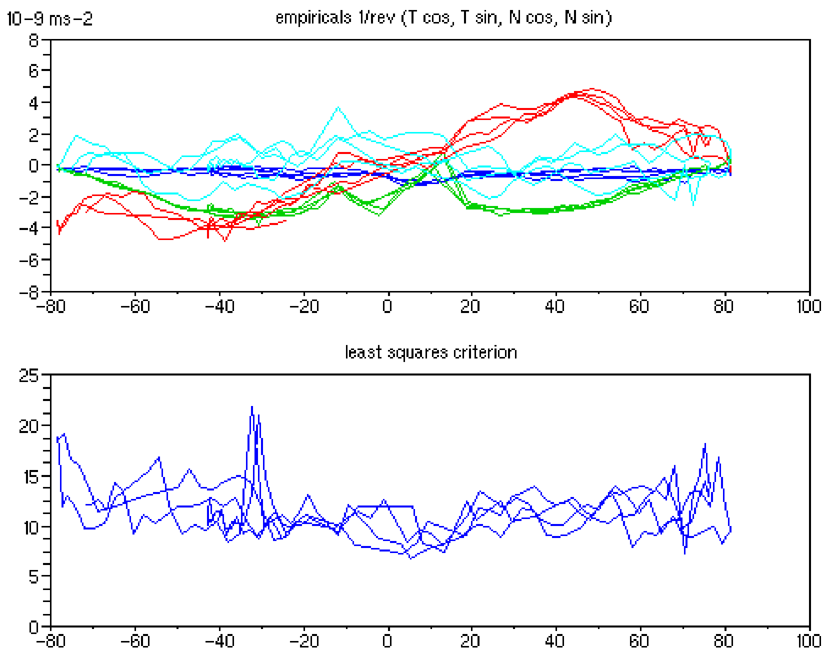
No sensitivity on the empirical accelerations during yaw steering

Important N effect in fixed yaw (transverse component relative to solar array)

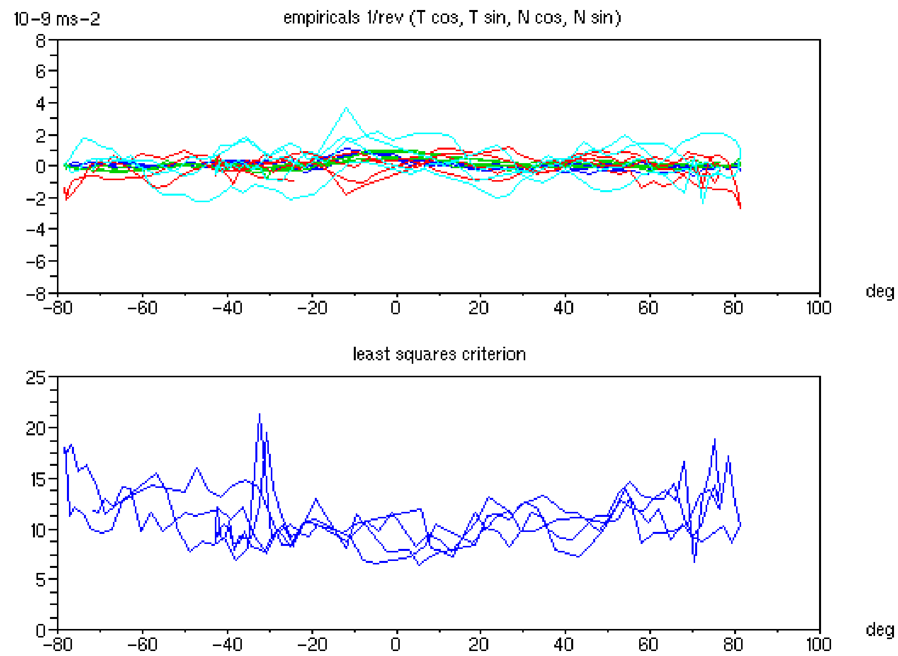
Solar array modifications : δKs -0.15 and δKa +0.3

Model correction

Initial model + GS correction

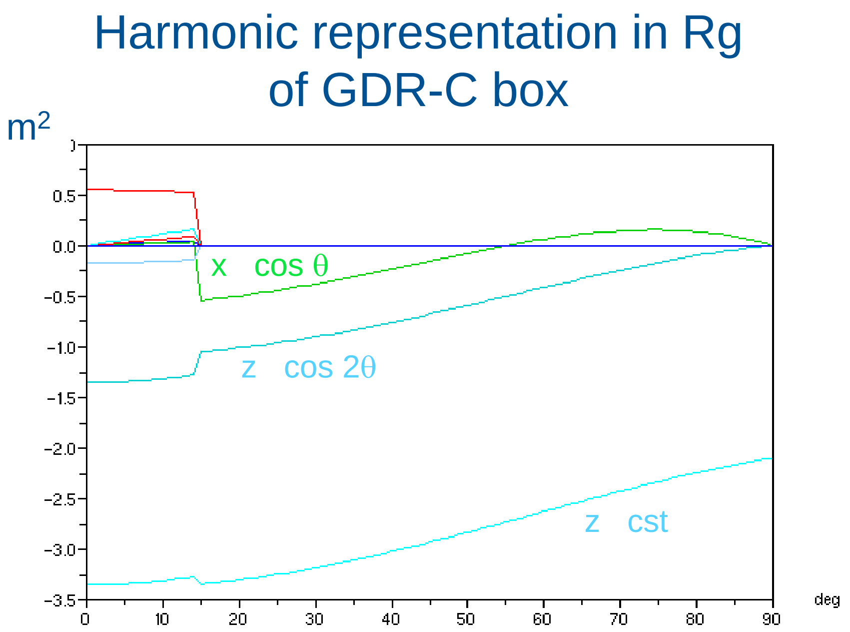


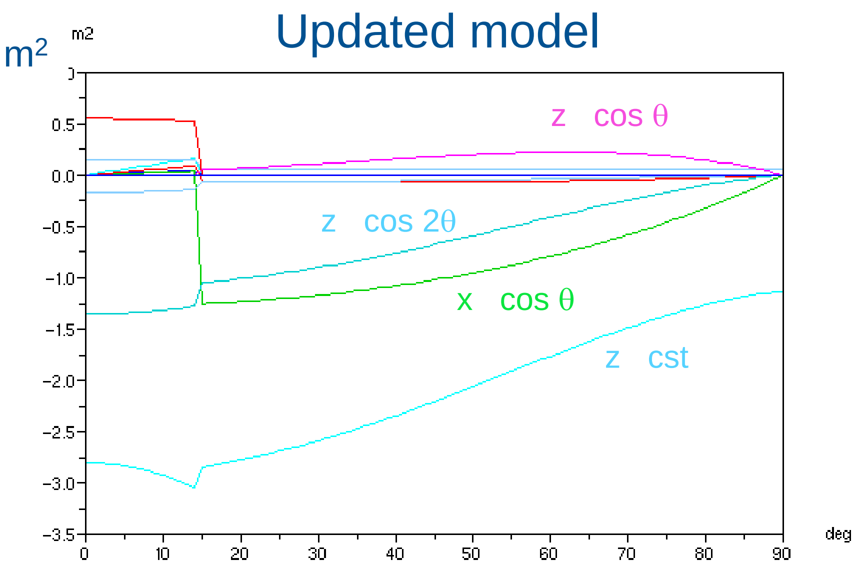
Initial model + GS correction + Harmonic model coefficients



Central part empirical model adjustment

Jason 1 updated model characteristics





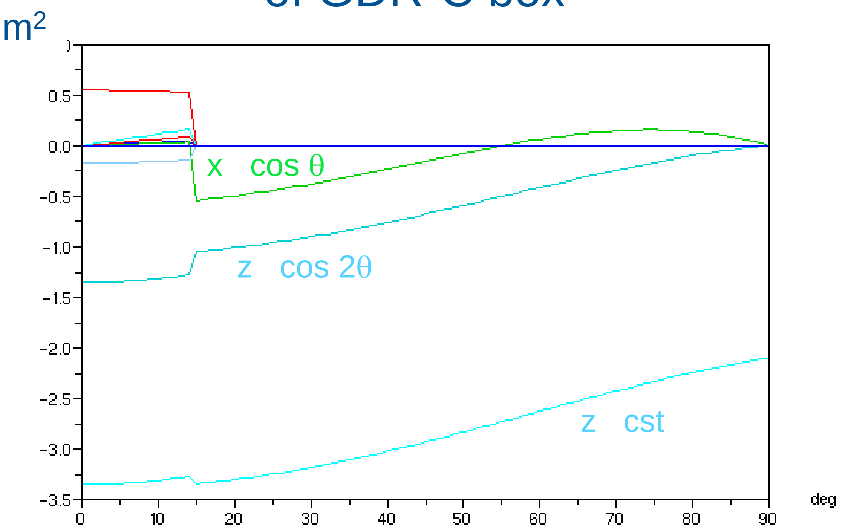
The updated model remains close to the initial one
(z cst, z cos, x cos were adjusted without constraints)

The x and z sin contributions are small (symmetric satellite and sun-orientation)

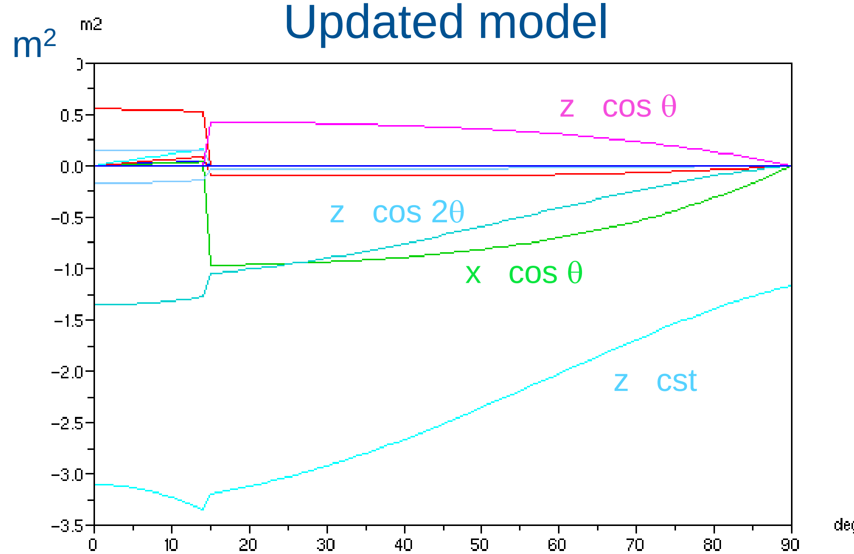
The z cos term reflects a dissymmetry between Earth and anti-Earth faces

Jason 2 updated model characteristics

Harmonic representation in Rg of GDR-C box



Updated model

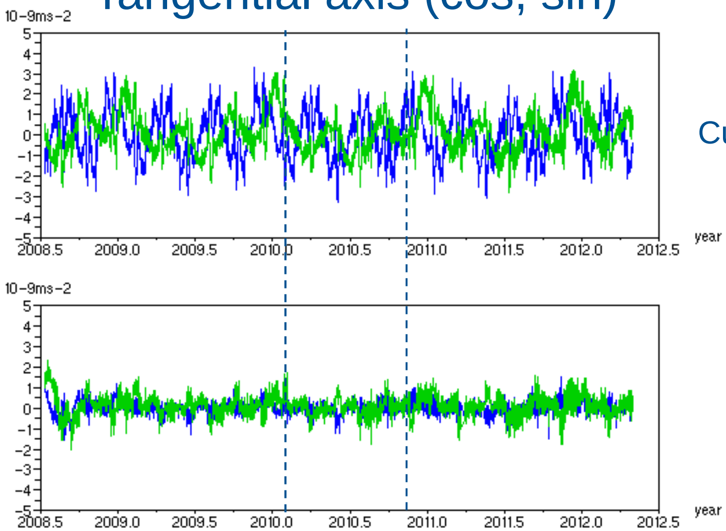


Jason 2 and Jason 1 updated models are very similar

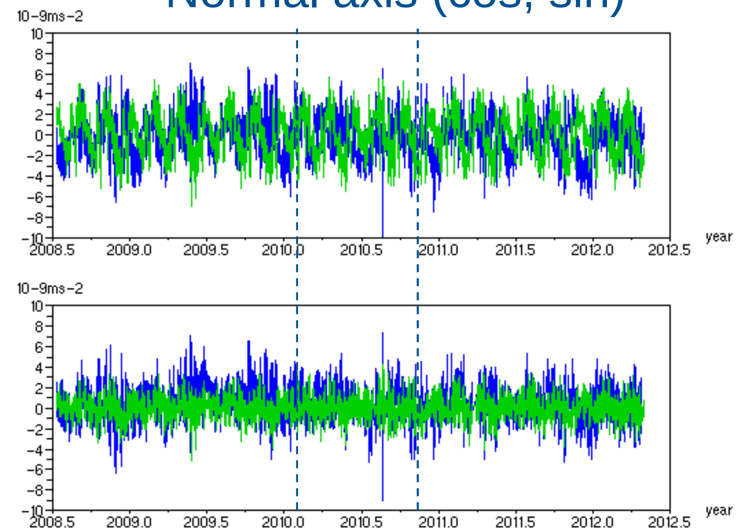
Jason 2 POD performances (1)

Empirical 1/rev terms

Tangential axis (cos, sin)



Normal axis (cos, sin)



Current model

New model

Adjusted period

Adjusted period

Systematic effects are fully removed

Model has identical performances outside the adjusted period

Different behavior at the beginning of life

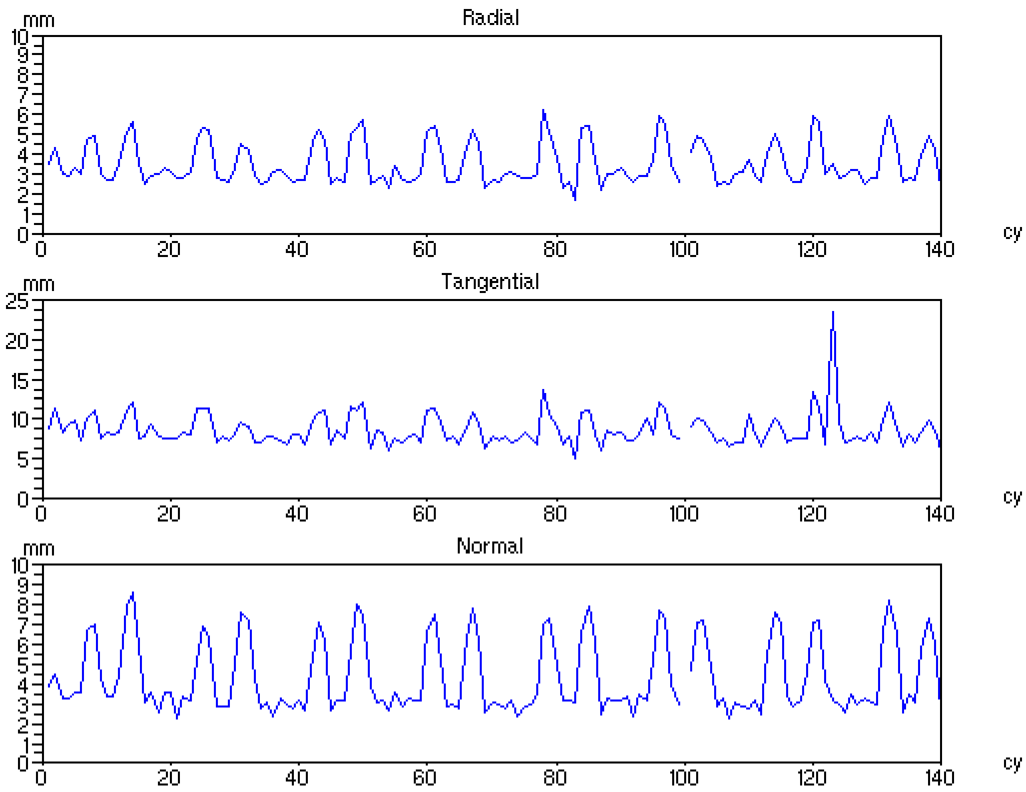
Jason 2 POD performances (2)

rms R,T,N orbit differences, new model and current model

Radial

Tangential

Normal



Radial effect is between 3 and 5 mm, important for high β values

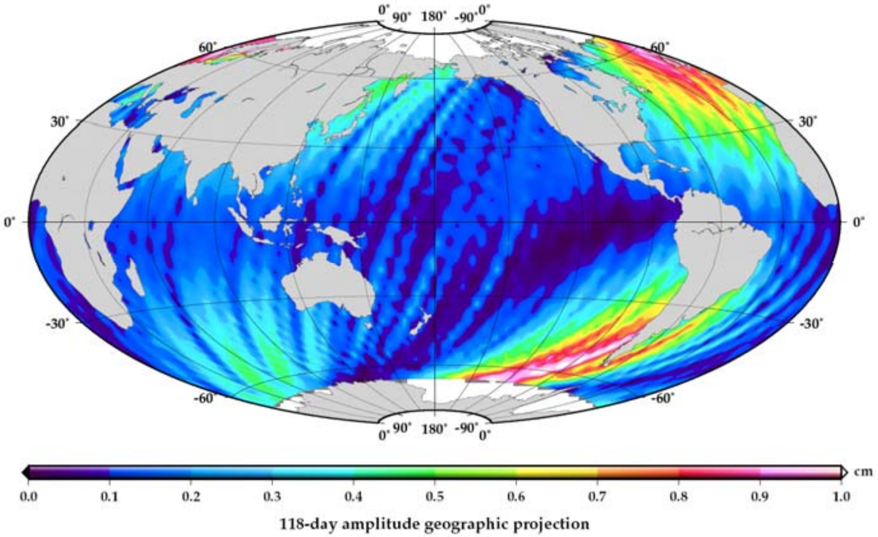
Jason 2 POD performances (4)

effect of the radiation model update on radial orbit differences

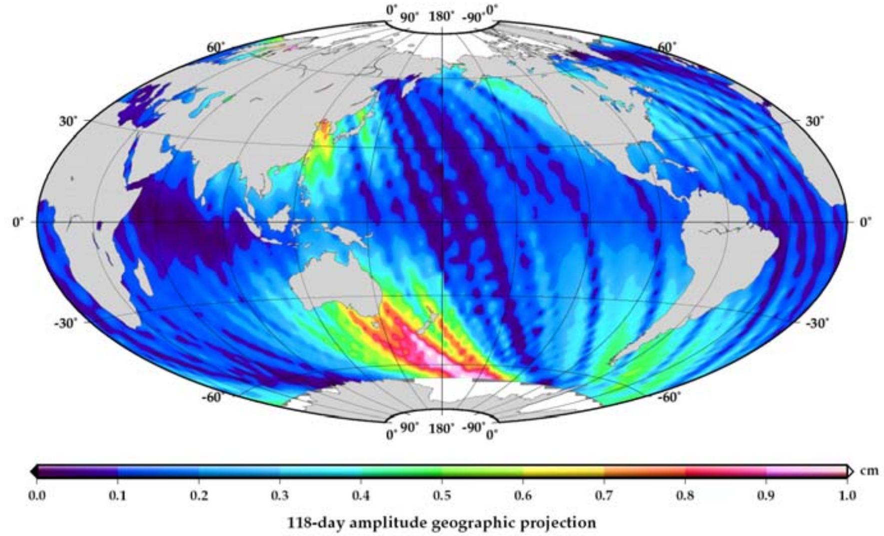
main component is at 120 days

Amplitude of the 120-day signal in the radial orbit differences

Ascending



Descending



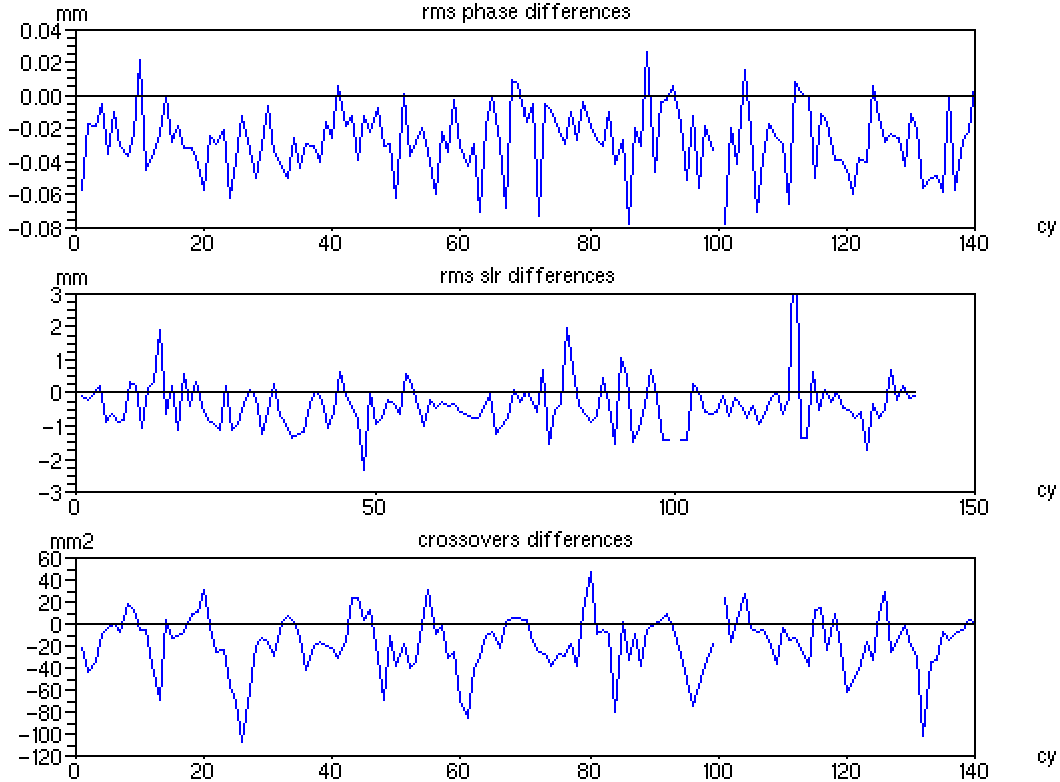
Jason 2 POD performances (3)

Improvements (negative value means improvement)

Phase

SLR

Crossovers



Small but systematic improvements on all metrics

Conclusions for Jason

The solar array must be represented with the true pointing

- pointing errors relative to sun, up to 10 degrees
- empirical 1/rev terms cannot represent the difference between true and theoretical pointing
- updated to have correct transverse accelerations

The central part can be modeled empirically

- pointing errors are smaller than for the solar array … and surface as well!
- empirical model expressed as θ harmonics in Rg frame (angle relative to subsolar point, axes aligned to Sun and solar array)
- Simple polynomial representation in β for the harmonics coefficients

Updated model, using ~10 months of data, tested over mission lifespan

- new coefficients for solar array, to use with correct pointing
- empirical model for central part, expressed in Rg frame

Systematic improvement of the quality of the orbits

Prospects

Other applications and developments

- Efficient SRP models are very important for Doris-only dynamic solutions (IDS)

- extension to other satellites ongoing, evidence of systematic signatures in empirical accelerations (Cryosat, Saral, HY2A, …)