Jason 1 and 2 Solar Radiation Pressure models

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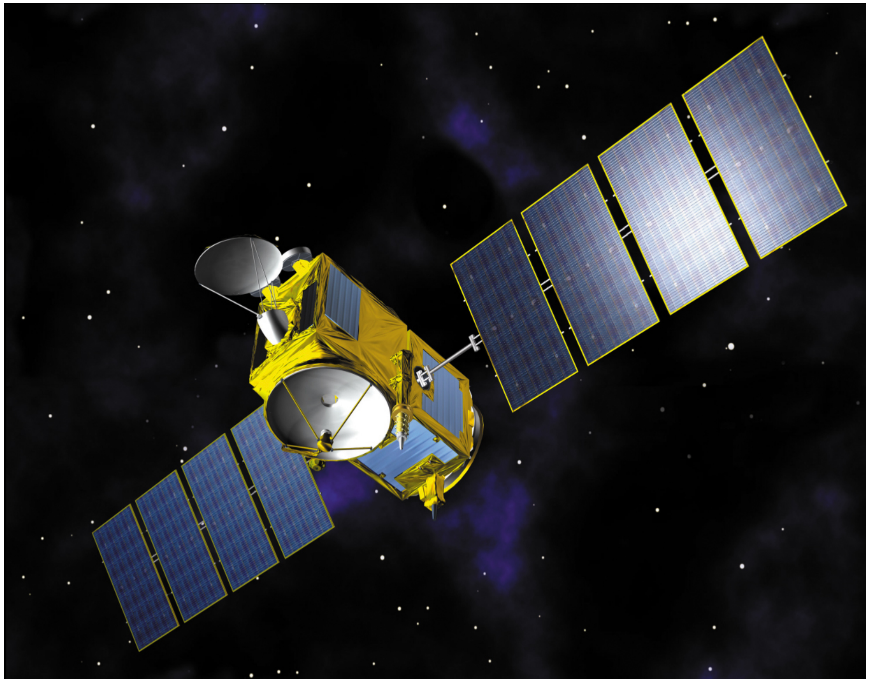


Jason radiation pressure models

Current POE model (see Aviso website):

- BW model, with true attitude (quaternions and solar array angle)

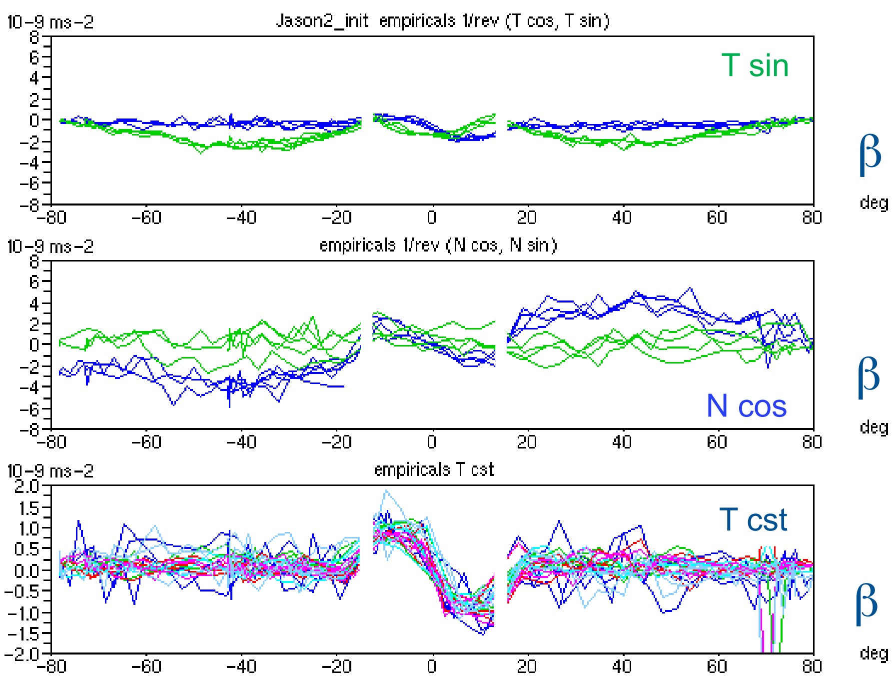
  solar array deviations from perfect sun pointing, 2 to 10 degrees (transverse effects)

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

- observed empirical accelerations (Jason 2, GPS, 30 hours arcs, cycles 61-87)

  1/rev along track and cross track, constant along track

  clear signatures function of sun angle β



order of magnitude :

$1\ 10^{-9}\ ms^{-2}$ <-> $0.1\ m^2$

Sensitivity analysis

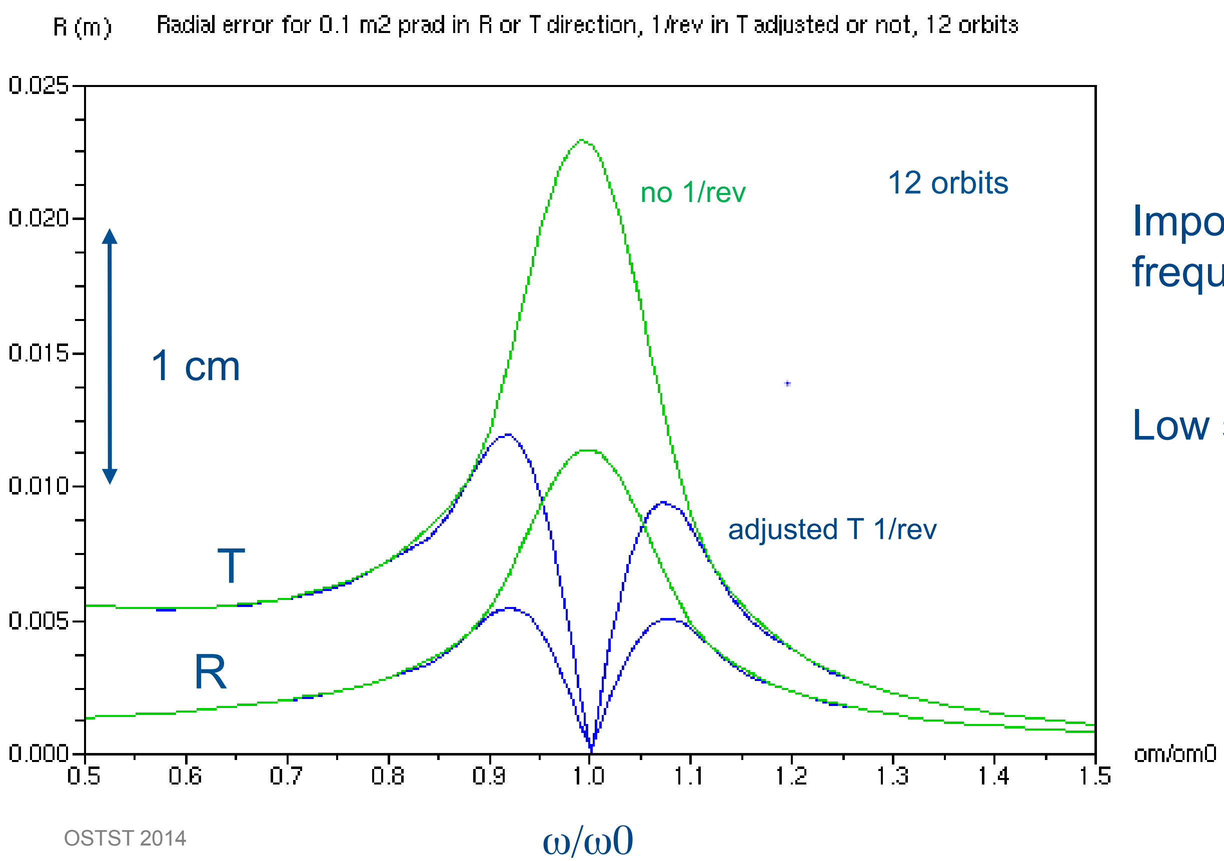
Radial performance function of possible perturbations

Sensitivity to periodic excitations

Radial orbit determination performance, with unknown periodic excitations and with standard parameters (empirical terms)

in plane : how do the T 1/rev terms (frequency $\omega 0$) mitigate the possible model errors ?

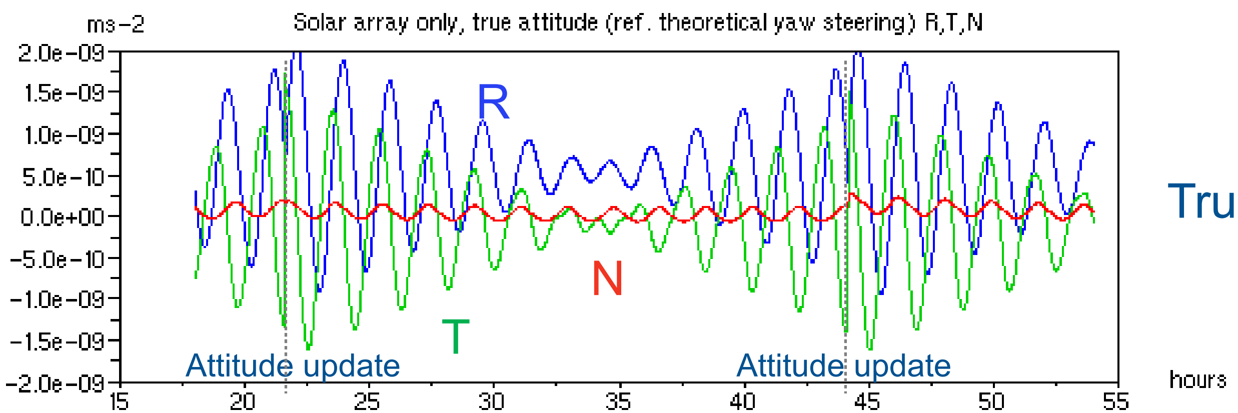
tests : R or T perturbation with frequency ω , 0.1m² absorbing surface (1 10^{-9} ms^{-2}), 12 orbits



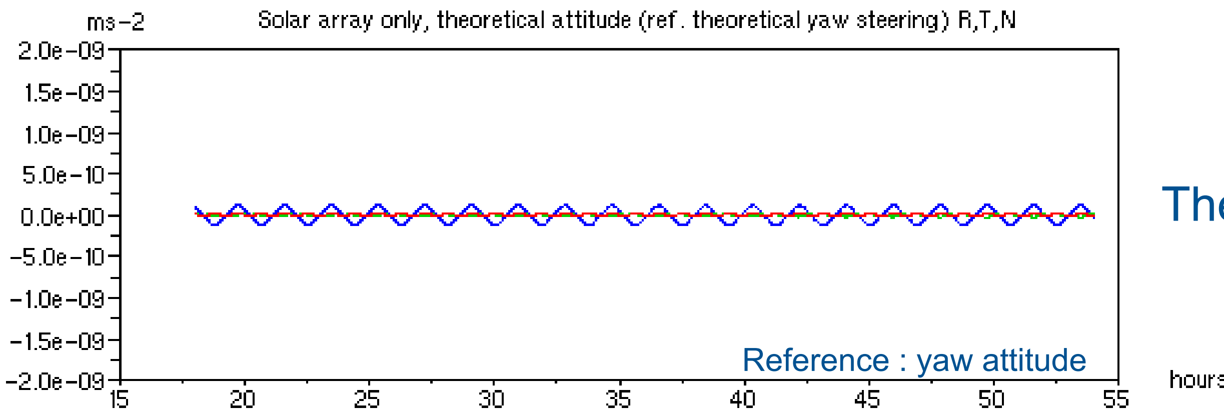
Important amplitude variations for frequencies close to $\omega 0$

Low sensitivity to harmonics ($\omega/\omega 0$ = 2,3…)

Solar array pointing effects, sun direction orthogonal to the orbit plane



True attitude



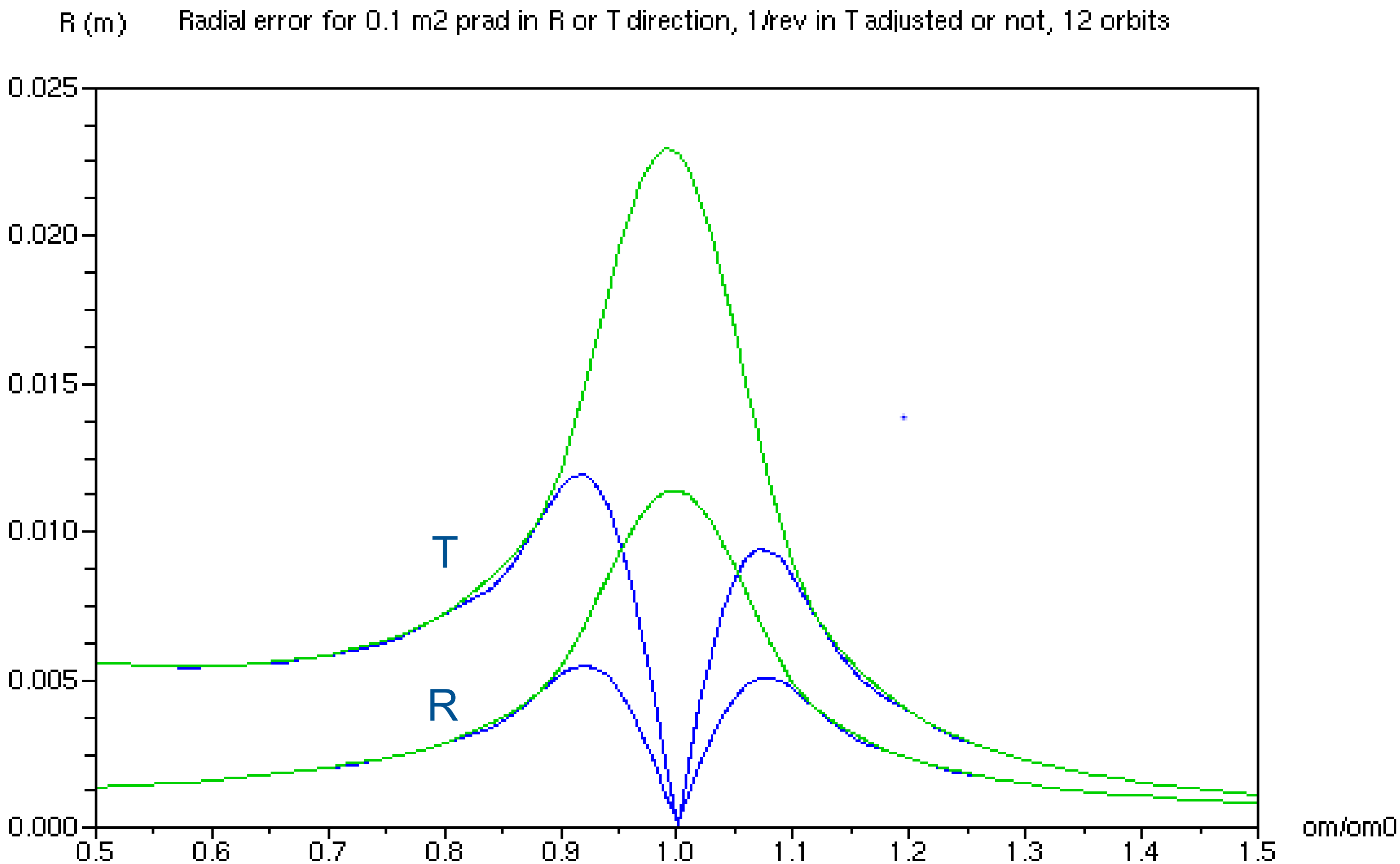
Theoretical attitude

R and T periodic accelerations of 1.5 10^{-9} ms^{-2}

- $\delta\omega$ equivalent to ½ orbit during 24 hours
- 24 hours 1/rev terms are not efficient : ~1 cm remaining effect in radial direction

A precise transverse model is needed for the solar array
0.15 10^{-9} ms^{-2} for 1 mm in radial (equivalent ~0.015 m^2 0.15 % of the total force)

Intervals for the periodic excitations

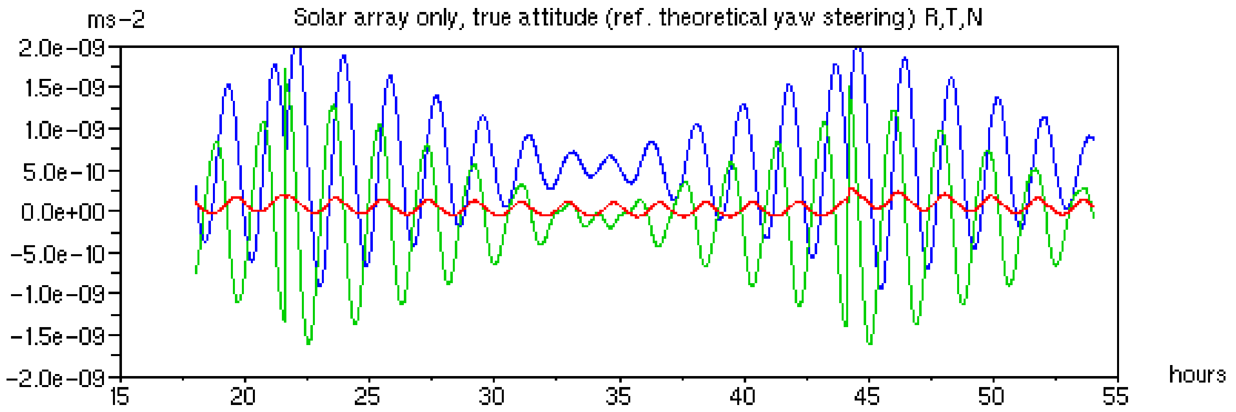


↔ subsolar point $\omega/\omega 0 \sim 0.002$

⟷ solar array transverse $\omega/\omega 0 \sim 0.05$

Summary : required precisions

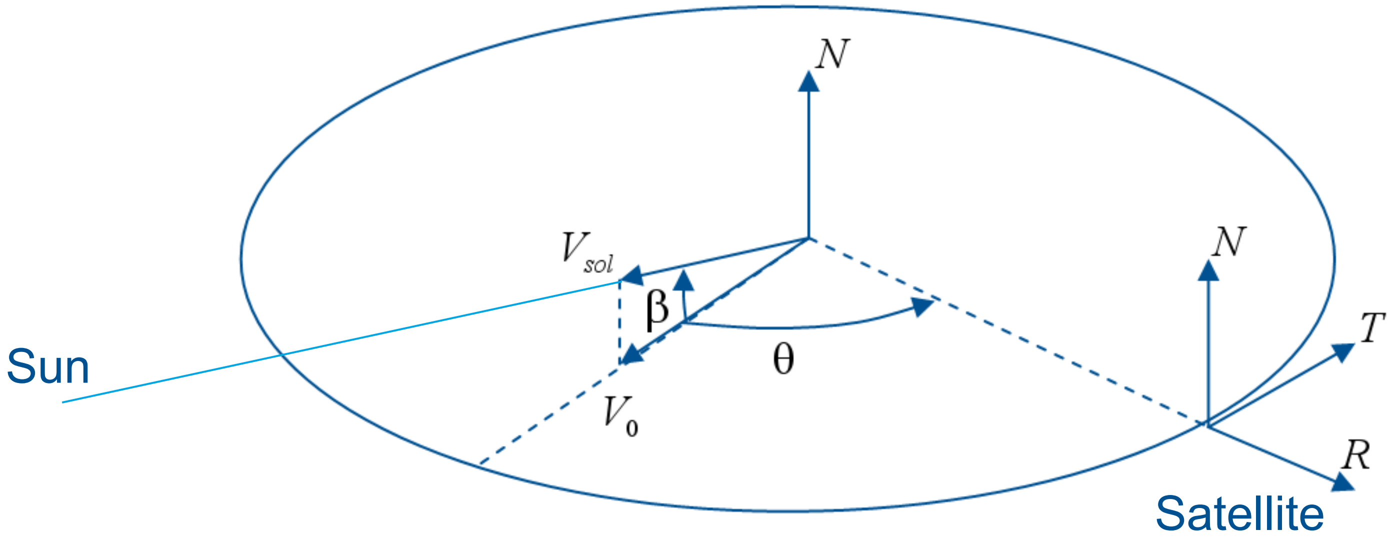
Solar array transverse effects (radial error 2 mm) :
precision 0.03 m^2 for 2°-10° mispointing



SRP model (radial error 2 mm) : 1/rev : max. 0.2 m^2 ($2\ 10^{-9}\ ms^{-2}$)
2/rev : max. 1 m^2

Attitude and frames

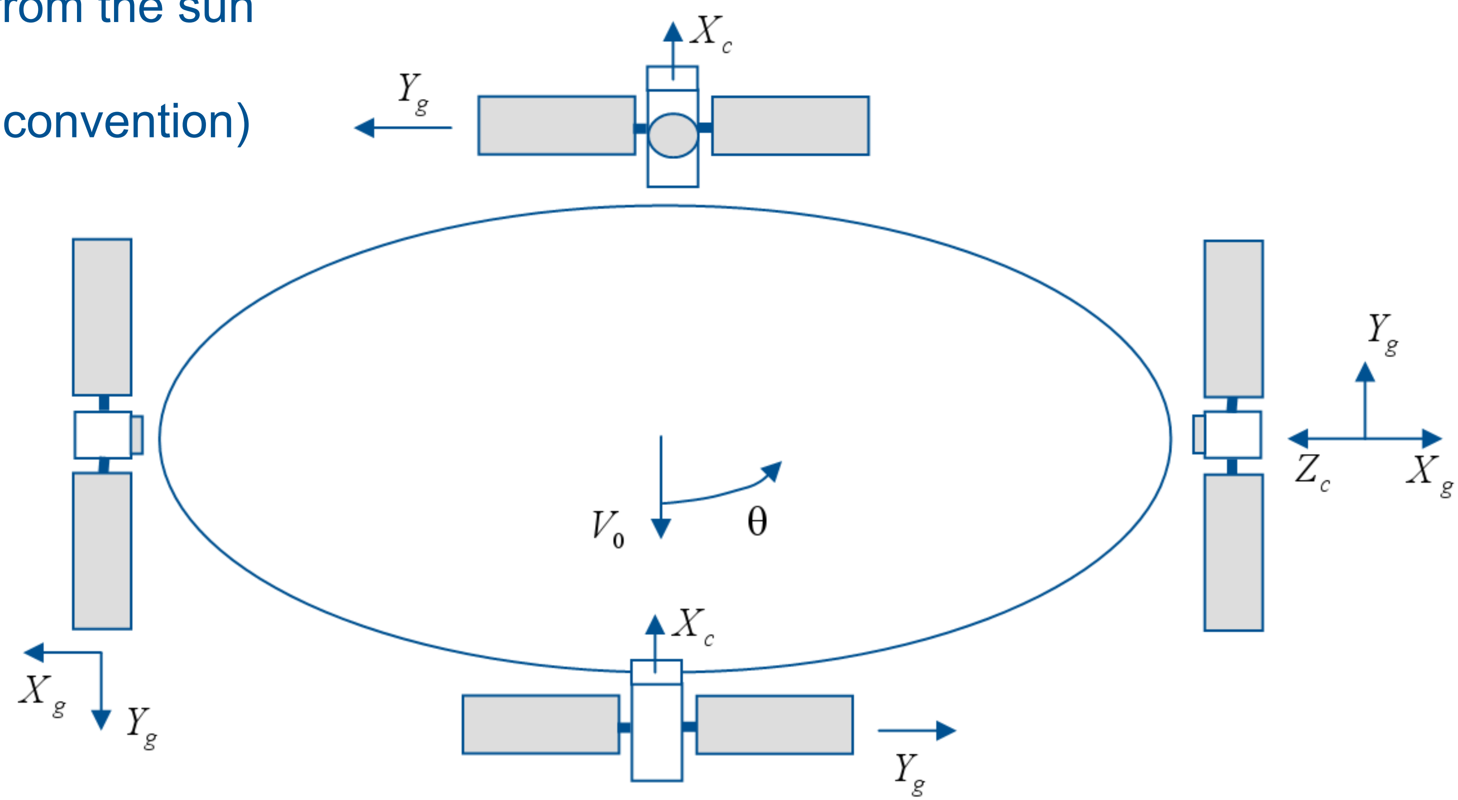
Geometry



θ : orbital angle (referenced to subsolar direction)
β : solar angle

Theoretical yaw steering, Rg frame

View from the sun
$\beta>0$
(GPS convention)

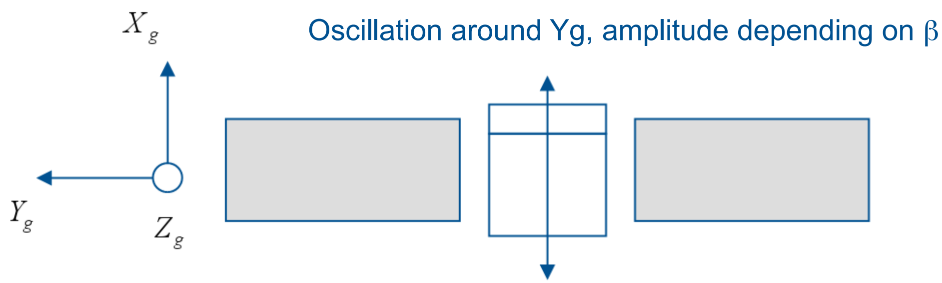


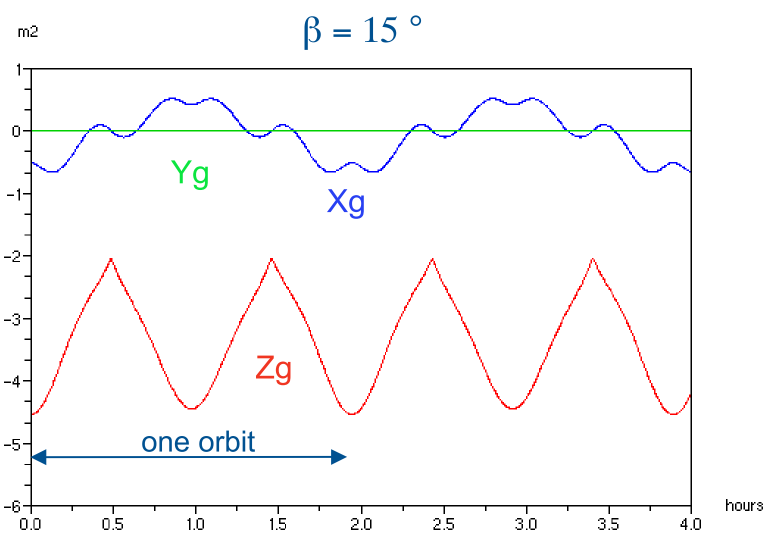
Subsolar point

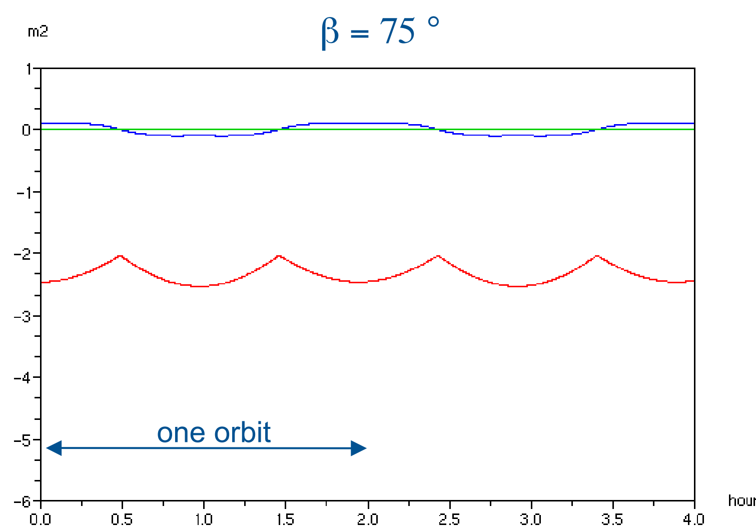
Solar array reference frame : Rg
Zg axis towards the sun, main acceleration is along Zg axis

accelerations are periodic functions of θ, the amplitudes depend on β
some interesting symmetries : for example, same accelerations on all axes for θ = 90 and -90 °
$a_i(\beta)$, $b_i(\beta)$ =0 for $\beta=90°$,i>=1

BW accelerations in Rg





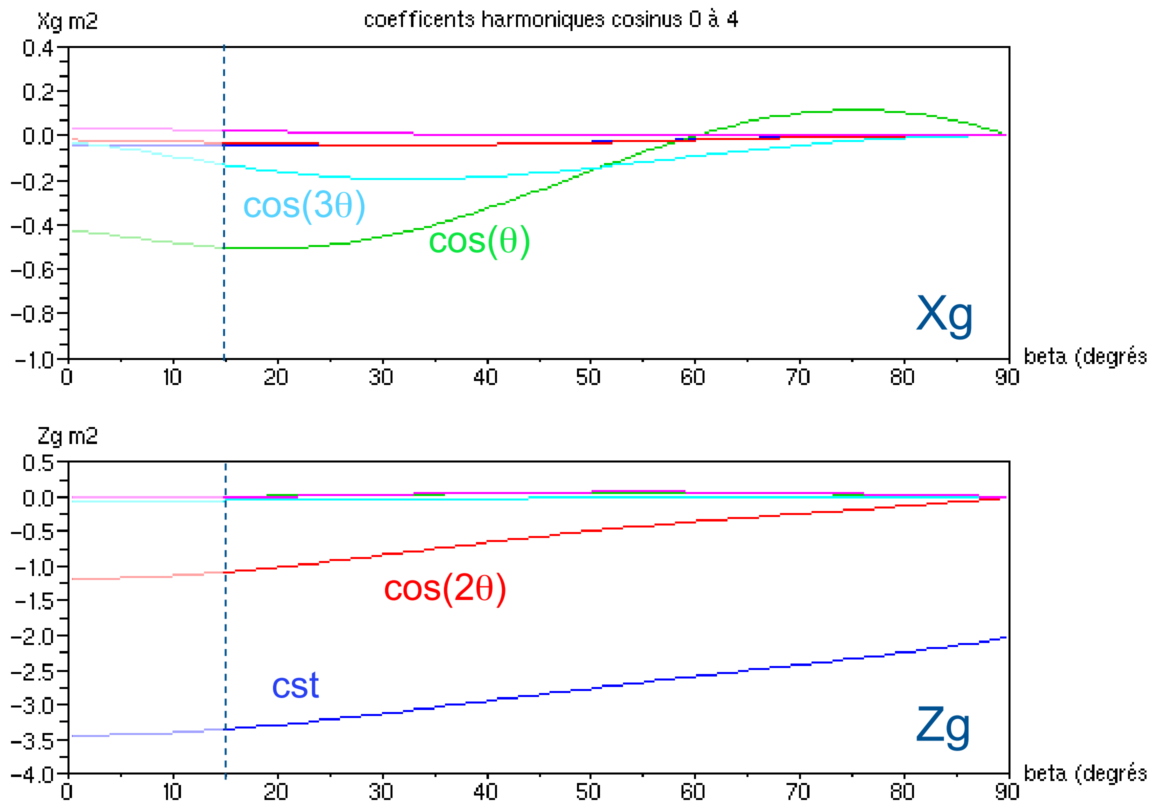


Central body BW model, theoretical yaw attitude

- Yg acceleration is null
- Xg and Zg, periodic accelerations, 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°
slow variations in β

→

Complete model :

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

see : *Empirical Solar Radiation Models for Altimeter Satellites* , F. Mercier, L. Cerri, OSTST 2013

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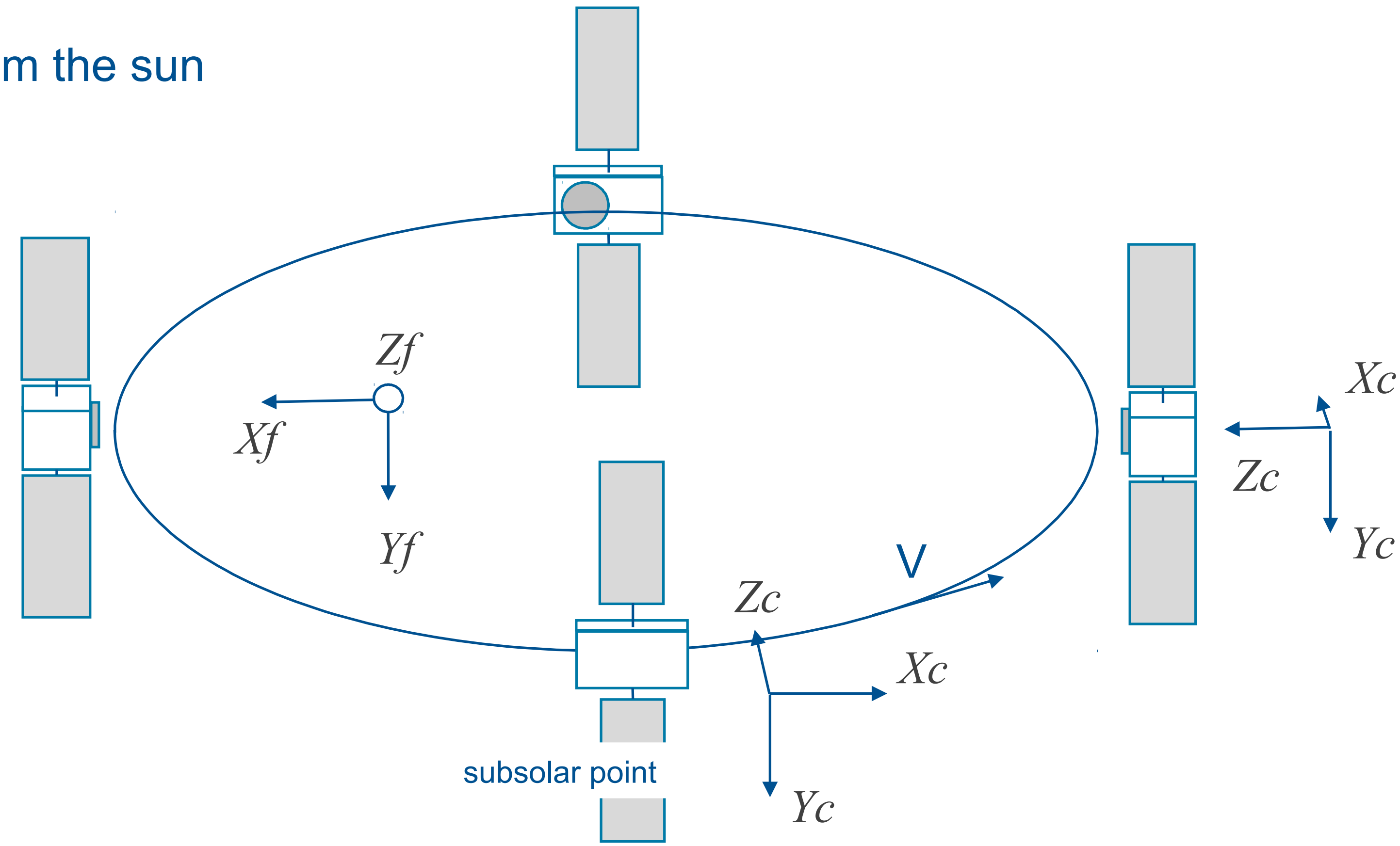
Reference frame Rf for fixed yaw

View from the sun
β>0



β>0 : Xc (satellite) along V, Yf=Yc, Xf=-Xc at subsolar point

β<0 : Xc (satellite) along –V (after flip) , Yf =-Yc , Xf =Xc at subsolar point

Zf towards the sun, the frame movement is continuous when the sun crosses the orbital plane (β=0)

Model update

Two steps :

Solar array update :

Ks,Kd,Ka coefficients adjusted to have good transverse accelerations with normal acceleration unchanged

Central part update :

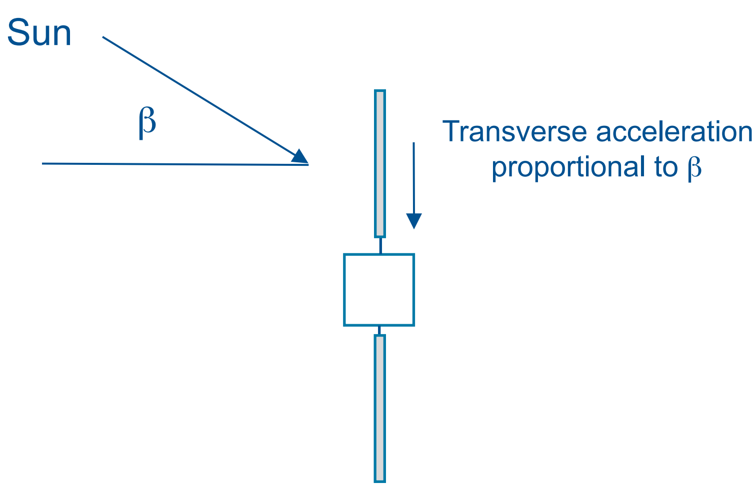
harmonic models defined for the two attitude cases

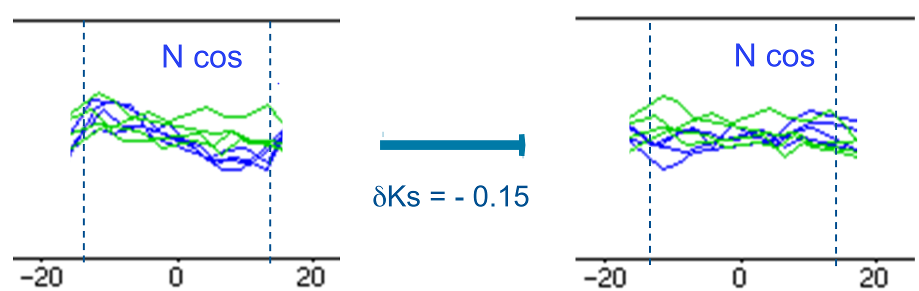
- fixed yaw
- yaw steering

Solar array transverse characteristics update (1)

Axis	m2	Normal direction	Ks	Kd	Ka
+SA	9.80	1.0	0.34	0.01	0.65
-SA	9.80	-1.0	0.00	0.30	0.70

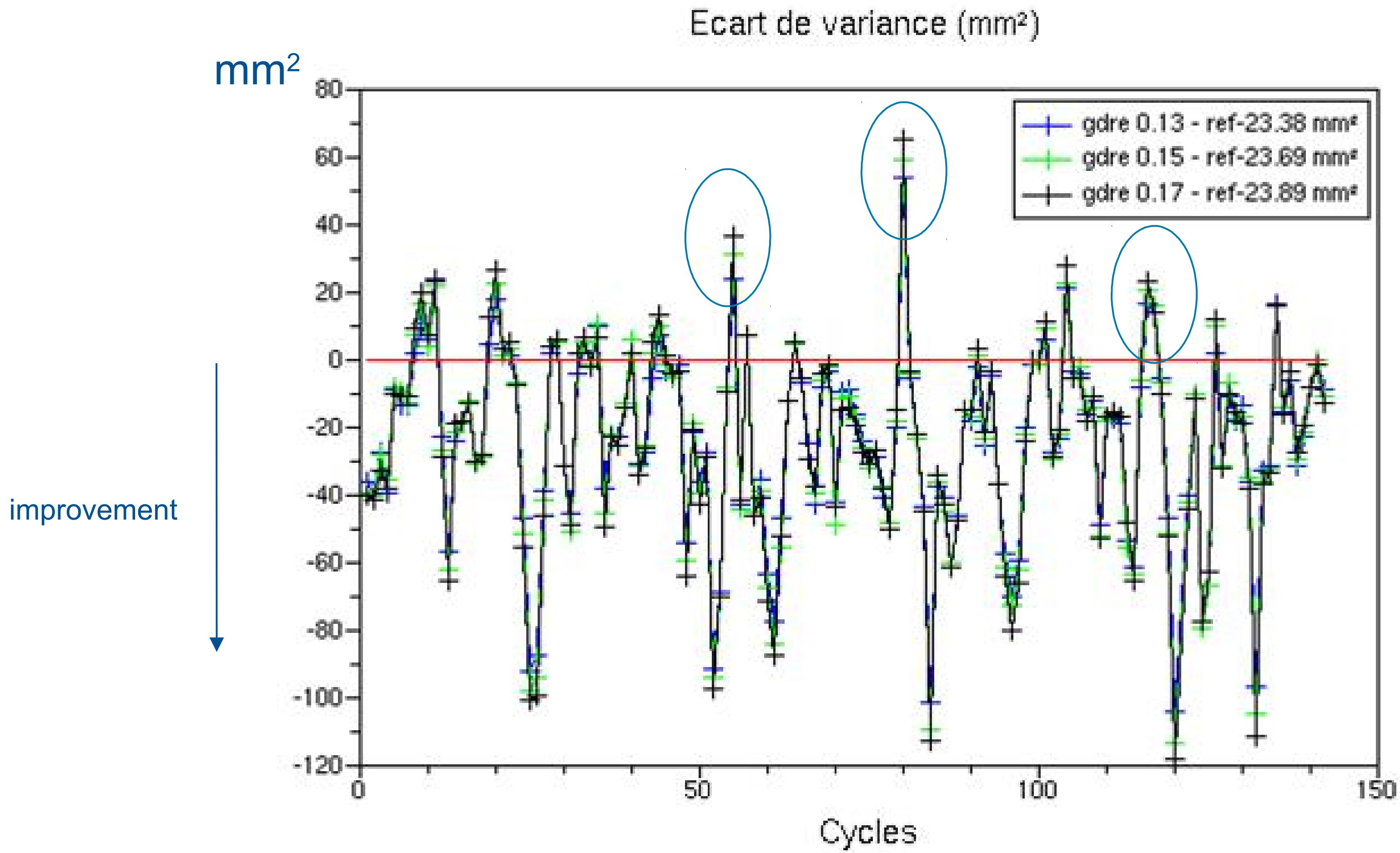
Initial guess : updated using fixed yaw normal behavior
variation of Ks and Ka with constraint 2*Ks+Ka unchanged





Ks around - 0.15 (Jason 1 and 2)
Tuned using altimeter crossovers criteria

Solar array correction, effect on crossovers comparison with gdrd



Sensitivity for Ks -0.13, -0.15, -0.17 are not very different (23 - 24 mm^2)

-0.17 systematically degrades highest values

→ chosen value -0.15

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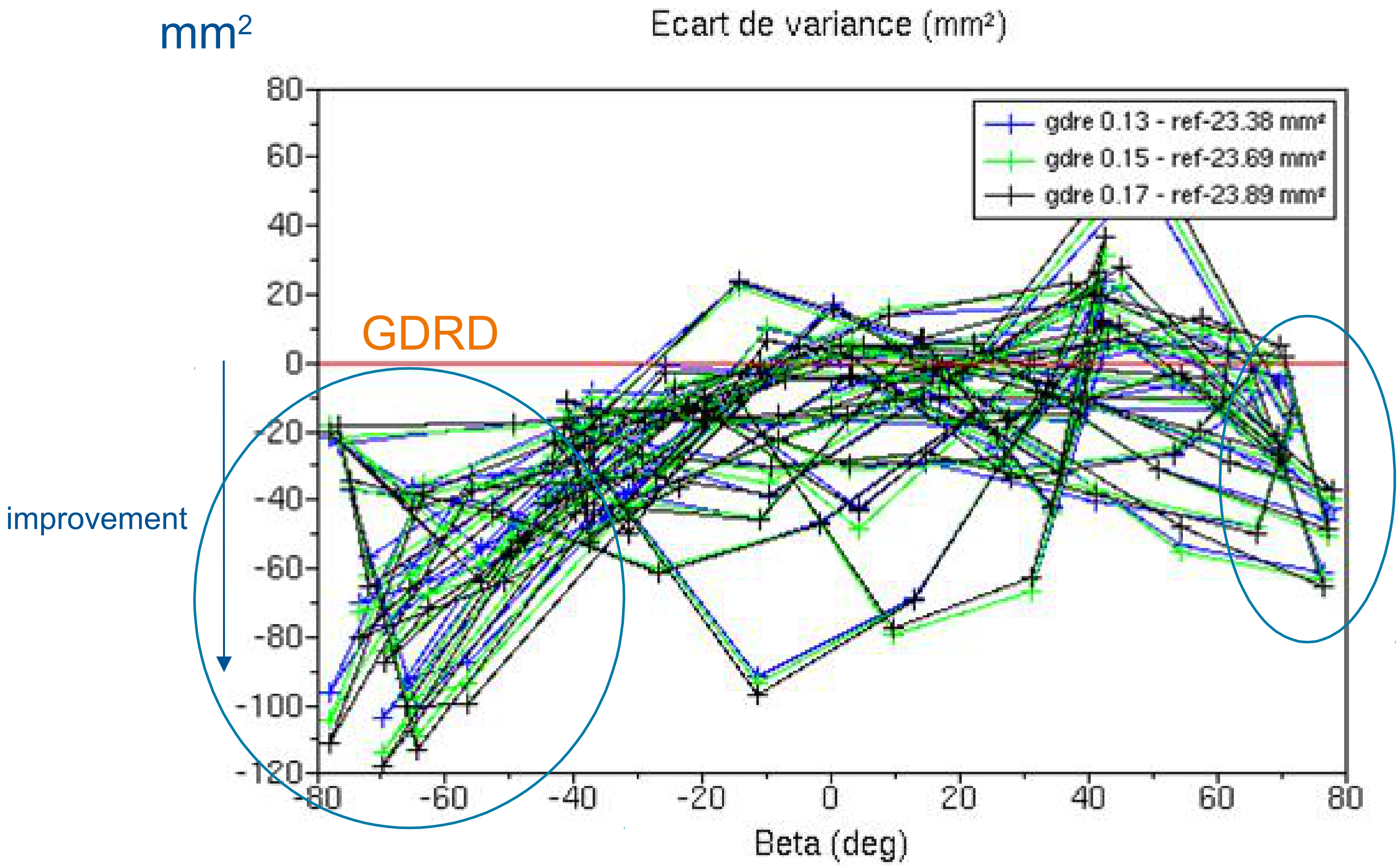
Solar array correction, effect on crossovers comparison with gdrd, as function of beta

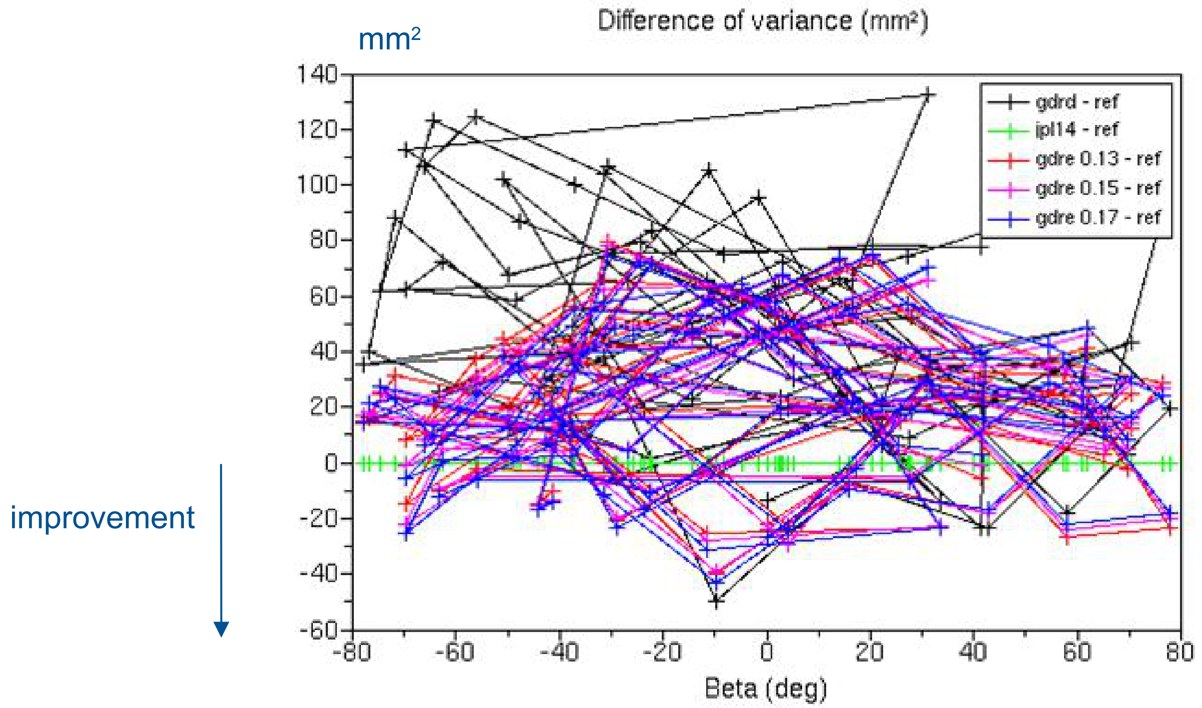


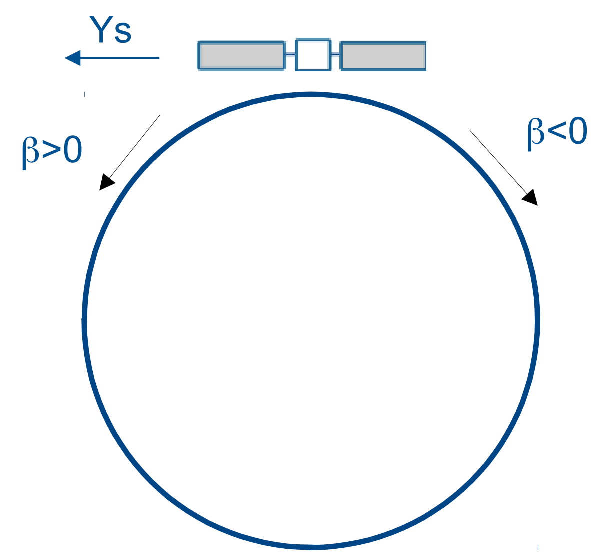
Comparison with GDRD, symmetry ?

Systematic improvement for $\beta<0$ and for high β values

Beta dependency of crossovers, comparison with JPL

Comparison with JPL orbits : gdrd errors were not symmetric





Effect of solar array correction on the crossover residuals

gdrd results depend from the direction of rotation around the sun direction

new model improves the performance for $\beta < 0$, w.r.t. gdrd

structure is now symmetric, when compared to jpl

Model update

Two steps :

Solar array update :

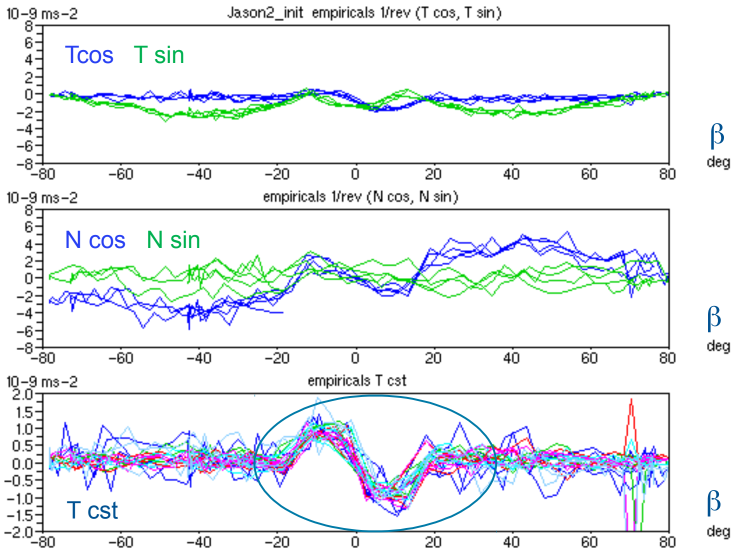
Ks,Kd,Ka coefficients adjusted to have good transverse accelerations with normal acceleration unchanged

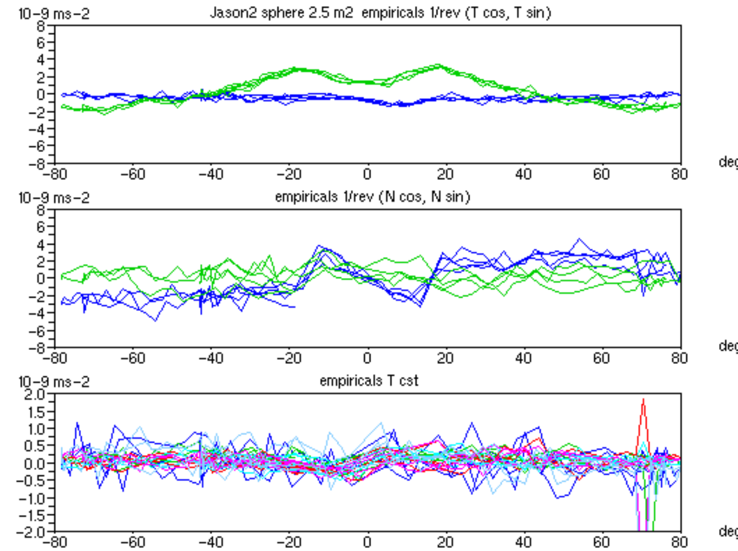
Central part update :

harmonic models defined for the two attitude cases

- fixed yaw
- yaw steering

Simple model : Zg constant term (sphere)





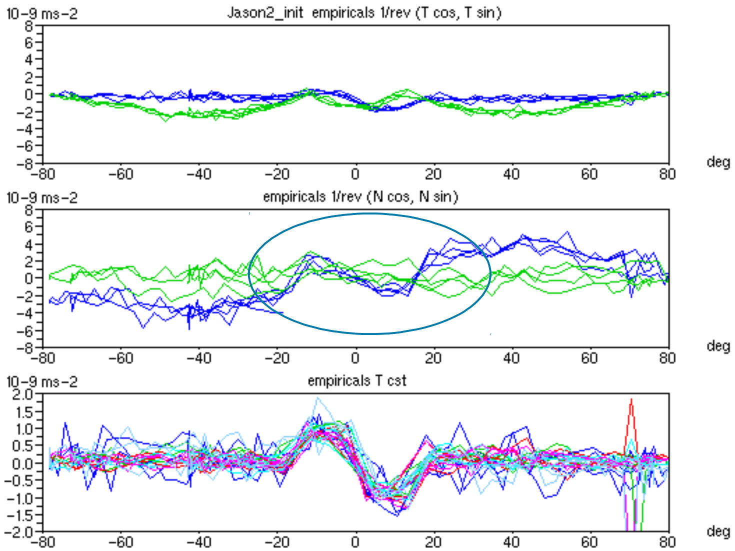
Jason 2 initial model, complete
with initial solar array model

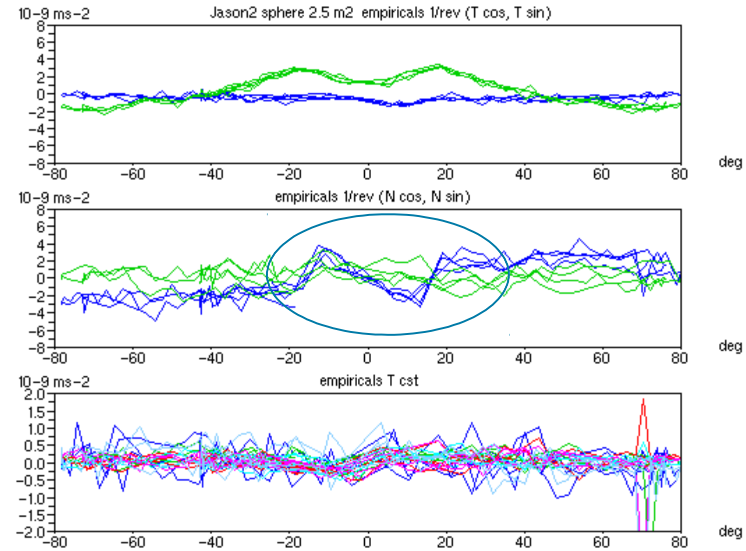
Jason 2 : 2.5 m2 Zg term (sphere)
with initial solar array model

- the important along track error is not present with the simple model due to a sin(θ) term in Zg (dissymmetry term between θ=90° or -90°)

- no significant along track bias (possible 'Y-bias' thermal radiation effect….)

Simple model : Zg constant term (sphere)





Jason 2 initial model, complete
with initial solar array model

Jason 2 2.5 m2 Zg term (sphere)
with initial solar array model

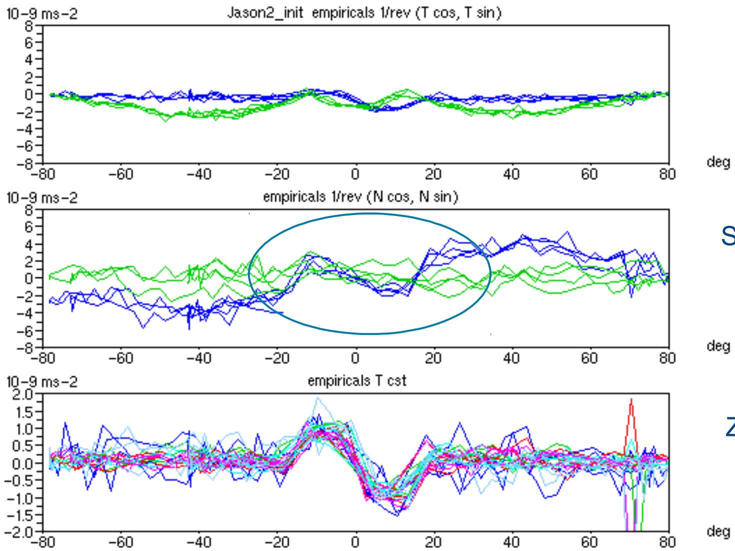
- the important along track error vanishes when using the simple model
  due to a sin(θ) term in Zg (dissymmetry term between θ=90° or -90°)

- no significant along track bias (possible 'Y-bias' thermal radiation effect….)

- important Normal cos(θ) term
  fixed case : updating of solar array transverse behavior

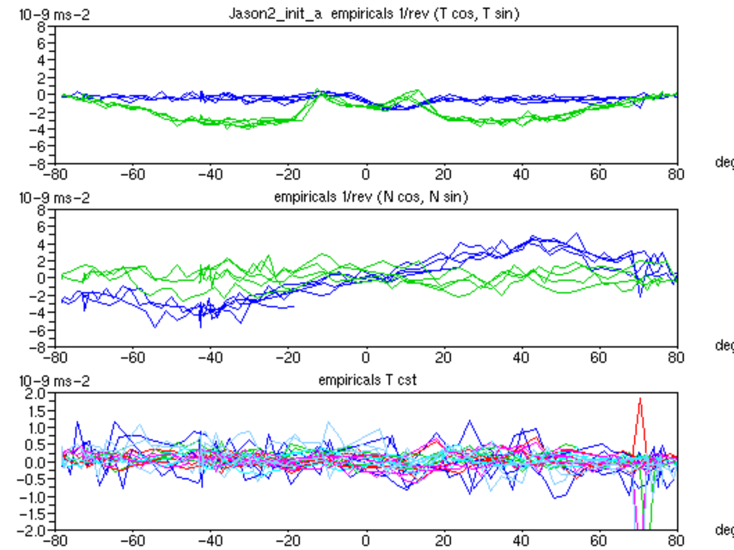
- similar results on Jason 1

Zg modification, solar array update



Solar array update

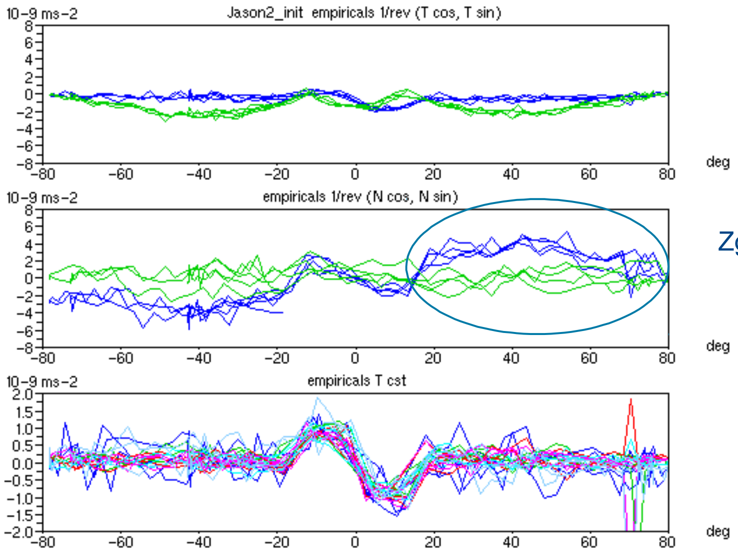
Zg sine suppressed



Jason 2 initial model, complete
with initial solar array model

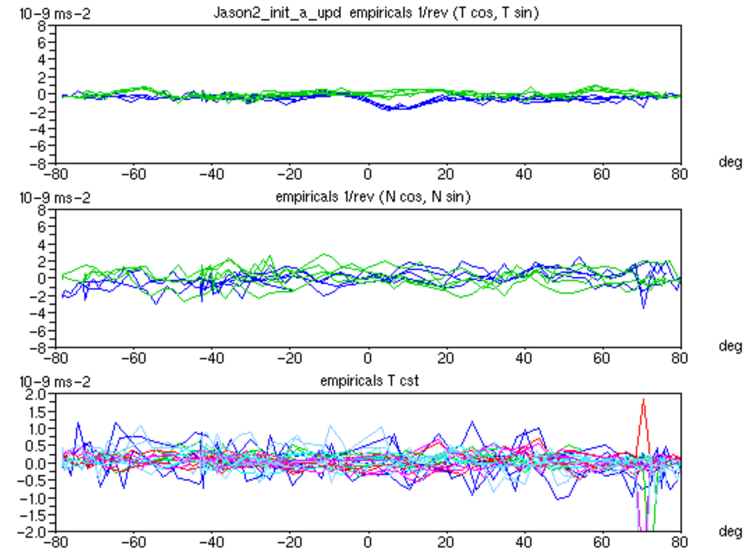
Jason 2 initial model, corrected
- no sz term (sine along Zg)
- solar array dKs -0.15, dKa +0.30

Final update (Jason 2)



Zg update

Zg and Xg update

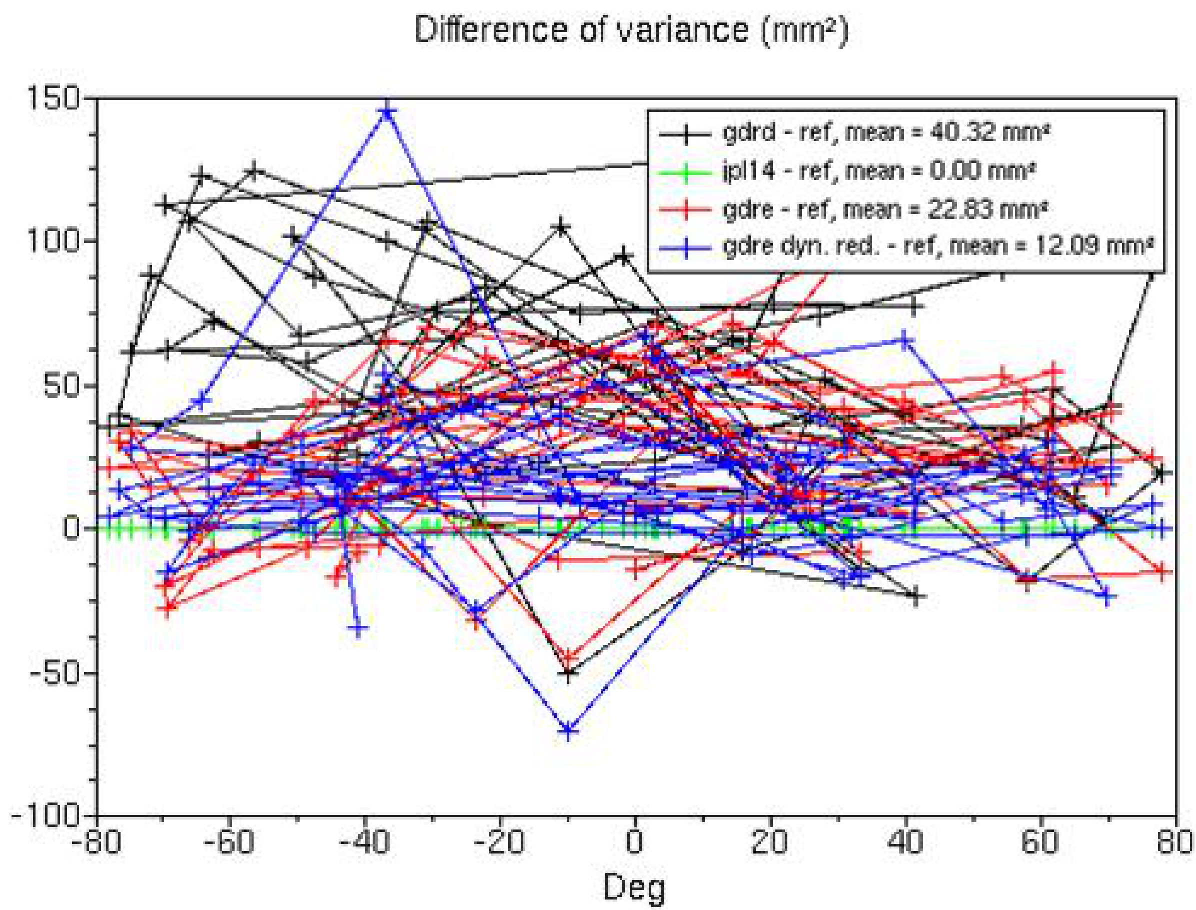


Jason 2 initial model, complete
with initial solar array model

Jason 2 initial model, corrected
- no sz term (sine along Zg)
- solar array dKs -0.15, dKa +0.30
- cst z (Zg constant) update
  fixed yaw and yaw steering
- cst y (‘Y-bias’) update
  yaw steering only
- cst x, cx, sx update, with constraints
  yaw steering only

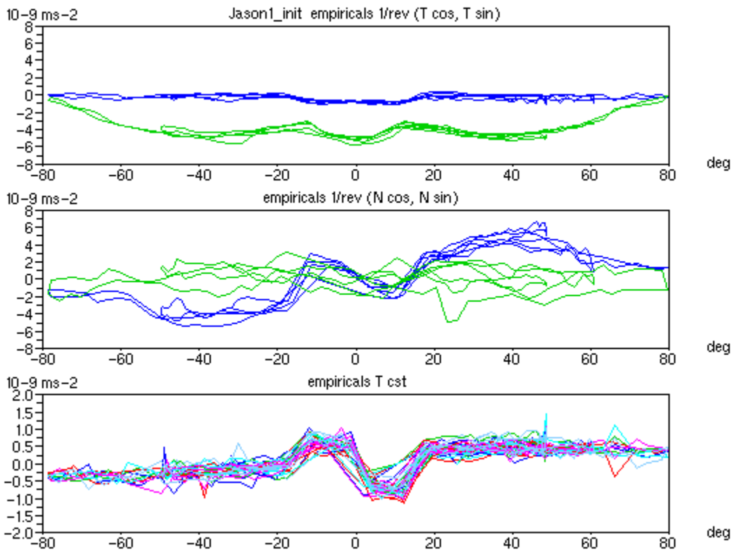
Complete performance, altimeter crossover

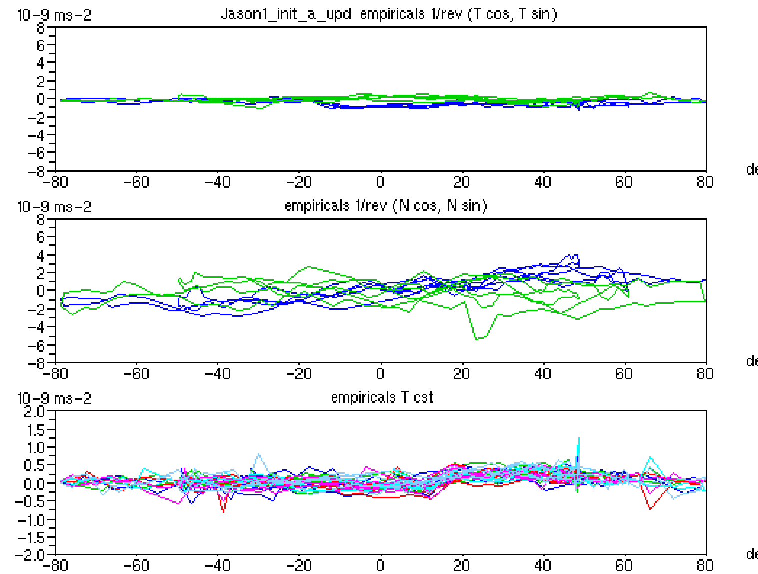
gdrd
JPL (reference)
gdre, new srp model dynamic
gdre, new srp model red. dynamic



New central part model doesn't change the radial performance
New solar array model improves clearly the performance
Reduced dynamic solutions : possible improvements for intermediate β values

Final update (Jason 1)





Jason 1 initial model, complete
with initial solar array model

Jason 1 initial model, corrected
- no sz term (sine along Zg)
- solar array dKs -0.15, dKa +0.30
- cst z (Zg constant) update
  fixed yaw and yaw steering
- cst y ('Y-bias') update
  yaw steering only
- cst x, cx, sx update, with constraints
  yaw steering only

Jason 1 and 2 : similar behavior
- same initial model
- same solar array model (9.8 m^2)
  dKs -0.15, dKa +0.30
- different updated Zg terms
  (1.86 – 2.53 for Jason 1 1.55 - 2.35 for Jason 2)
- N cos for Jason 1 not yet completely removed (1-2 10^{-9} ms^{-2})
- small Y-bias for Jason 1
  (0.00 for Jason 2 and 0.04 for Jason 1)

Conclusion

SRP model and empirical 1/rev Tangential accelerations

- 1/rev terms are necessary
- SRP required precision ~0.2 m2 (orbital period)
  1.0 m2 (higher harmonics)
  (effect of β variations, subsolar angle movement, eclipses)

Pointing error effects

- frequency band of excitation outside the 1/rev filtering band
  (mainly solar array transverse acceleration)
- solar array model update, use of quaternions and rotation angle

Harmonic models for satellite body (Jason 1 and Jason 2)

- 1/rev empirical accelerations minimized from $4\ 10^{-9}\ ms^{-2}$ to less than $1\ 10^{-9}\ ms^{-2}$

Radial performance improvement (crossovers) w.r.t. gdrd

- 40 to 100 mm^2
- for high $|\beta|$ values
- for $\beta<0$