SOLAR RADIATION PRESSURE MODEL FOR ALTIMETER SATELLITES

ANALYSIS OF SARAL SURFACE ACCELERATIONS

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Solar Radiation Pressure (SRP):

Usual approach:

- Pre-launch model: constructed using thermo-optical description of the satellite (absorptivity $K_a$, specular refraction $K_s$ and diffuse refraction $K_d$) and thermal control

- Calibration by applying a global SRP coefficient identified during commissioning

- 1/rev empirical accelerations in T (along-track) and N (cross-track) direction (every 24h)
INTRODUCTION (2)

Empirical along-track accelerations (referenced : PSO=90°)

Objective :

- β-dependent patterns are observed\(^1\) : probably due to SRP mismodelling

- Improve SRP model

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\(^1\) “A review of some systematic errors observed in the Precision Orbit Determination of recent DORIS satellites”, Cerri & al. IDS Workshop 2012.
CONTENTS

● INTRODUCTION

● JASON 2 RESULTS

● SARAL ANALYSIS
  - OUT-OF-PLANE BEHAVIOUR
  - IN-PLANE BEHAVIOUR

● CONCLUSION
JASON 2 FINAL UPDATE

Empirical acceleration (reference : sub-solar point)

Jason 2 initial model, complete with initial solar array model

Jason 2 updated model with new solar array values

Courtesy of Flavien Mercier, see OSTST presentation on Wednesday (29/10/14)
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SARAL/AltiKa: Heliosynchronous orbit (i=98.55°)

Definition of $\beta$

Sub-solar point
Evolution of the sub-solar point

- Steady behaviour for most values of $\beta$
- Singularity when $\beta$ close to 90°, larger values for sub-solar point variations
- But OK $\Leftarrow$ no $\theta$ dependancy for RTN frame
INITIAL RESULTS (1)
EMPIRICAL 1/REV ACCELERATION ANALYSIS

Eclipses

Tcos & Tsin, referenced to sub-solar point (10-9 m/s²)

Ncos & Nsin, referenced to sub-solar point (10-9 m/s²)
INITIAL RESULTS (2)

$\beta$ - DEPENDANCY OF ALONG-TRACK EMPIRICAL ACCELERATION
• INTRODUCTION

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  - IN-PLANE BEHAVIOUR

• CONCLUSION
Normal bias:

A normal bias of 5 cm has been observed (equivalent magnitude: $5 \times 10^{-8} \text{ m/s}^2$)
May be due to CoM misalignment or SRP mismodelling
Corresponds to half of the cross-track SRP acceleration

* « Status of GDR orbits for ocean topography missions and prospects for future improvements » (Cerri & al., OSTST 2013)
OUT-OF-PLAN BEHAVIOUR (2)
EMPIRICAL 1/REV ACCELERATION ANALYSIS

Eclipse Periode
OUT-OF-PLAN BEHAVIOUR (3)  
NORMAL BIAIS

Estimation of bias

- Estimation of the bias that causes $2 \times 10^{-9}$ m/s² acceleration
  
  $$\text{Bias} \approx \frac{\text{amplitude}}{0.6} / \omega^2 = 2 \times 10^{-9} / 0.6 / 10^{-6} = 3.2 \text{ mm}$$

- Error due to SRP mismodelling can be up to 4 mm maximum:
  → observed bias comes from CoM mismodelling, not SRP mismodelling
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Along-track SRP acceleration:

- **Tsin**
  - Nominal $T_{\text{sin}}$ is a sinus
  - Actual $T_{\text{sin}}$ is mostly made of sinus

- **Tcos**
  - Nominal $T_{\text{cos}}$ is equal to 0
  - Actual $T_{\text{cos}}$ is small

Radial SRP acceleration:

- Similarly: mostly made of cosinus, with a small sinus

Empirical $1/\text{rev}$ along-track acceleration:

- Mostly sinus

\[ \theta = \frac{\pi}{2} \]
No systematic behaviour

- Different behaviour in winter and summer

**Tcos :**

- Should be small due to the symmetry of the satellite attitude

**Tsin :**

- $\beta < 75^\circ$: summer and winter curves don’t superimpose
- $\beta > 75^\circ$: lack of data and dispersion
IN-PLANE BEHAVIOUR (3)
INFLUENCE OF THE ATMOSPHERIC DRAG

- Similar signatures on drag values and empirical along-track amplitude
- Atmospheric drag may contribute to $T_{\text{empirical}}$ 1/rev acceleration
- Other effect? (attitude)
INTRODUCTION

JASON 2 RESULTS

SARAL ANALYSIS
- OUT-OF-PLANE BEHAVIOUR
- IN-PLANE BEHAVIOUR

CONCLUSION
CONCLUSION

JASON 1 and JASON 2

→ See OSTST presentation on Wednesday, 12:00

SARAL CROSS-TRACK BEHAVIOUR

• Observed cross-track bias cannot come from SRP model
• Cross-track current SRP model OK

SARAL IN-PLANE BEHAVIOUR

• Summer and winter behaviour inconsistent
• Model ok during summer (precision 10-9)
• During winter: important discrepancies in acceleration for the same beta value (high dispersion) and only one set of data

The current SRP model is satisfactory for GDR products
Possible improvement using more β cycles to mitigate drag effect
Thank you for your attention

Any questions?
Back-up slides
• Computation of the optical coefficients from the material property and the amount of each material on each side of Saral \cite{2}
• **New hypothesis**: MLI doesn’t absorb solar flux. All the incoming flux is reemitted in IR, (diffuse reemission)

### Initial values (GDRD)

<table>
<thead>
<tr>
<th>Faces (ISRO frame)</th>
<th>$K_s$</th>
<th>$K_d$</th>
<th>$K_a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>+X</td>
<td>0.4000</td>
<td>0.2450</td>
<td>0.3550</td>
</tr>
<tr>
<td>-X</td>
<td>0.5450</td>
<td>0.1690</td>
<td>0.2860</td>
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<tr>
<td>+Y</td>
<td>0.5170</td>
<td>0.1720</td>
<td>0.3040</td>
</tr>
<tr>
<td>-Y</td>
<td>0.5200</td>
<td>0.1840</td>
<td>0.3020</td>
</tr>
<tr>
<td>+Z</td>
<td>0.2940</td>
<td>0.0760</td>
<td>0.6230</td>
</tr>
<tr>
<td>-Z</td>
<td>0.0780</td>
<td>0.0760</td>
<td>0.8370</td>
</tr>
</tbody>
</table>

### New values

<table>
<thead>
<tr>
<th>Faces (ISRO frame)</th>
<th>$K_s$</th>
<th>$K_d$</th>
<th>$K_a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>+X</td>
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<td>0.2820</td>
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<tr>
<td>-X</td>
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<td>0.4890</td>
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<tr>
<td>+Y</td>
<td>0.5280</td>
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<tr>
<td>-Y</td>
<td>0.5400</td>
<td>0.4130</td>
<td>0.0470</td>
</tr>
<tr>
<td>+Z</td>
<td>0.2940</td>
<td>0.1750</td>
<td>0.5310</td>
</tr>
<tr>
<td>-Z</td>
<td>0.0780</td>
<td>0.1580</td>
<td>0.7640</td>
</tr>
</tbody>
</table>

**smaller values of $K_a$**

**same values of $K_s$ for +Z side**

\[2\] « *Saral characteristics for DORIS calibration plan and POD processing*, Cerri & al
RMS of orbit differences for the two sets of $(K_s, K_d, K_a)$ parameters

- Very small in-plane orbit differences (absorbed by empirical 1/rev acceleration)
- Normal bias (not absorbed by parameterization)
• **Tcos**
  • $K_s$, $K_d$ and $K_a$ have no influence on Tcos (because Tcos cannot be SRP)

• **Tsin**
  • Same values around $\beta=90^\circ$ (because for $\beta=90^\circ$, there are no in-plane SRP accelerations, Tsin and Tcos are then only made of unmodelled forces)
  • Tsin still not a function of $\beta$
Dynamic response to a periodic perturbation

Radial (R) perturbation
- no 1/rev on T
- 1/rev on T

Along-track (T) perturbation
- no 1/rev on T
- 1/rev on T

For frequencies close to the orbital period $f_0$: radial error due to the perturbation is very small
For frequencies far from the orbital period ($0.9f_0$ and $1.1f_0$): radial error due to the perturbation is maximum

**SRP force spectrum**: close to the orbital period.
→ That’s why the orbit comparison of the two different models has very small RMS in radial and along-track directions.
Different sets of \((K_s, K_d, K_a)\) are considered

Difference between GDRD coefficients and sets coefficients:

<table>
<thead>
<tr>
<th>Set</th>
<th>(\Delta K_s)</th>
<th>(\Delta K_d)</th>
<th>(\Delta K_a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.25</td>
<td>0.0</td>
<td>-0.5</td>
</tr>
<tr>
<td>2</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>3</td>
<td>-0.25</td>
<td>0.0</td>
<td>0.5</td>
</tr>
</tbody>
</table>
When $\beta$ close to 90°
- Tsin and Tcos bias: jumps when $\beta$ close to 90

**Tcos**
- can’t come from nominal SRP: something else is absorbed

**Tsin**
- not a function of $\beta$
BACK UP SLIDES (7)
ESTIMATED ACCELERATION : DRAG, GDRD ORBITS

SARAL Atmospheric drag accelerations, (cycles 001 to 074) (m/s^2)

Radial

Tangential

Normal

CNES Julian Days
BACK UP SLIDES (8)
ESTIMATED ACCELERATION : SRP, GDRD ORBITS

SARAL Solar radiation pressure accelerations, (cycles 001 to 074) (m/s^2)

Radial

Tangential

Normal

CNES Julian Days
BACK UP SLIDES (10)
ESTIMATED ACCELERATION HILL: DRAG, GDRD ORBITS

SARAL Hill accelerations, (cycles 001 to 074) (m/s^2)

Tangential

Normal

CNES Julian Days
Winter

\[\beta = 90^\circ - 23^\circ - 8.55^\circ = 58.45^\circ\]

\[8.55^\circ \perp \text{to Saral orbital plane}\]

\[23^\circ\]

\[\text{Mean Earth rotation pole}\]

\[\text{Saral orbital plane}\]

\[\text{Equatorial plane}\]

Summer

\[\beta = 90^\circ - 23^\circ + 8.55^\circ = 75.55^\circ\]

\[8.55^\circ \perp \text{to Saral orbital plane}\]

\[23^\circ\]

\[\text{Mean Earth rotation pole}\]

\[\text{Saral orbital plane}\]

\[\text{Equatorial plane}\]

\[\beta\]

\[\text{Winter}\]

\[\text{Summer}\]

\[\text{Beta}\]

\[\text{Cycles}\]