An inter-agency comparison of non-gravitational force modeling for Sentinel-3A

D. Arnold 1, V. Girardin 1, A. Couhert 2, F. Mercier 2, H. Peter 3, S. Hackel 4, O. Montenbruck 4, A. Jäggi 1, J. Fernández Sánchez 5

1 Astronomical Institute, University of Bern, Switzerland
2 Centre National d’Etudes Spatiales, Toulouse, France
3 PosiTim UG, Seeheim-Jugenheim, Germany
4 German Space Operations Center, Wessling, Germany
5 GMV AD, Tres Cantos, Spain

COSPAR Scientific Assembly 2018
Pasadena, USA
July 16, 2018
Sentinel-3

- is an ESA Earth observation mission, part of the Copernicus Program
Introduction – Sentinel-3

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• currently consists of two satellites, Sentinel-3A (launched on February 16, 2016) and Sentinel-3B (launched on April 25, 2018)
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- requires precise and accurate orbit information (**requirement: 2-3 cm RMS in radial direction**)
- satellites are equipped with GPS and DORIS receivers and a Laser retro-reflector for **Precise Orbit Determination (POD)**
The Copernicus POD Quality Working Group (QWG)

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- consists of \(\sim10\) different agencies
The Copernicus POD Quality Working Group (QWG)

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- consists of ~10 different agencies
- provides orbit solutions obtained with different POD software packages for regular intercomparison
Motivation

- Sophisticated modelling of non-gravitational forces desired for Sentinel-3 to avoid degradation of orbit solutions due to (too many or too loosely constrained) empirical parameters.
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- This is mitigated depending on the degree of empirical orbit parametrization.
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Motivation

**Goal of study**: Compare modeled non-gravitational accelerations for Sentinel-3A (S3A) from different members of the POD QWG. The following groups have participated so far:

<table>
<thead>
<tr>
<th>Agency</th>
<th>POD Software</th>
</tr>
</thead>
<tbody>
<tr>
<td>Astronomical Institute, Univ. of Bern</td>
<td>AIUB  Bernese GNSS S/W</td>
</tr>
<tr>
<td>Centre National d’Etudes Spatiales</td>
<td>CNES  Zoom</td>
</tr>
<tr>
<td>Copernicus POD Service</td>
<td>CPOD  NAPEOS</td>
</tr>
<tr>
<td>German Space Operations Center</td>
<td>DLR   GHOST</td>
</tr>
<tr>
<td>EUMETSAT</td>
<td>EUM   NAPEOS</td>
</tr>
<tr>
<td>Technical University of Munich</td>
<td>TUM   Bernese GNSS S/W</td>
</tr>
</tbody>
</table>
First comparison:

- Each member used their POD software to compute the following non-gravitational accelerations (w/o estimating scaling factors) along a fixed S3A orbit for the three days 085, 170, and 250 of 2016 in the inertial and satellite-fixed coordinate frames:
  - Direct Solar Radiation Pressure (SRP)
  - Emitted and reflected Planetary Radiation Pressure (PRP)
  - Aerodynamic acceleration
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- Compare interpolated accelerations at a sampling of 10s
Satellite macro model

- 8-plate macro model, two plates (front and back of solar panel) are movable
Satellite macro model

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- Geometry and optical properties: s3a_macro_model_v2
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- Solar panel motion:
  - DLR assumes front panel normal vector into satellite-Sun direction at all times
  - Other groups assume $+y$ unit vector (rotation axis), panel normal vector and satellite-Sun vector in one plane (optimal orientation)
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- Attitude: CNES used theoretical attitude law, other groups quaternions
Comparison

Compare non-gravitational accelerations among different agencies in the order of size (3D amplitudes for S3A):

- Direct solar radiation pressure $\sim 100 \text{ nm/s}^2$
- Planetary radiation pressure (visual + IR) $\sim 30 \text{ nm/s}^2$
- Aerodynamic accelerations $\sim 5 \text{ nm/s}^2$
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## Solar radiation pressure modeling

<table>
<thead>
<tr>
<th></th>
<th>Earth model</th>
<th>Shadow model</th>
<th>Atm. refr.</th>
<th>Atm. abs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIUB</td>
<td>Oblated</td>
<td>Conical</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>CNES</td>
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<td>Conical</td>
<td>Yes</td>
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</tr>
<tr>
<td>CPOD</td>
<td>Spherical</td>
<td>Conical</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>DLR</td>
<td>Spherical</td>
<td>Conical</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>EUM</td>
<td>Spherical</td>
<td>Conical</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>TUM</td>
<td>Spherical</td>
<td>Cylindrical</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>
Solar radiation pressure

Day 16/085, radial direction (status before May 2018):

-120 −100 −80 −60 −40 −20 0 20 40 60 0 50 100 150 200 250 300 350 Accelerations [nm/s^2] Minute of day 16/085

SRP acc. R

-19.51 ± 33.45
-22.58 ± 35.42
-20.89 ± 32.72
-23.46 ± 37.26
-19.95 ± 33.27
-29.39 ± 46.82

AIUB CNES CPOD DLR EUM TUM

TUM accelerations show significantly larger amplitudes
CNES and DLR show larger amplitudes (inst. re-emiss.?)
DLR accelerations larger (solar panel orientation?)
Solar radiation pressure

Day 16/085, radial direction (status before May 2018):

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Day 16/085, radial direction (status before May 2018):

![Graph showing solar radiation pressure accelerations for different agencies]

- AIUB
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- DLR
- EUM
- TUM

AIUB and TUM accelerations show significantly larger amplitudes.

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Solar radiation pressure

Day 16/085, along-track direction:

![Graph showing solar radiation pressure accelerations for different agencies.](image)

- AIUB: $-1.10 \pm 40.76$
- CNES: $-0.16 \pm 41.82$
- CPOD: $-0.84 \pm 40.45$
- DLR: $-0.24 \pm 44.45$
- EUM: $0.89 \pm 42.72$
- TUM: $-0.20 \pm 58.18$

TUM accelerations show significantly larger amplitudes. CNES and DLR show larger amplitudes (inst. re-emiss.?) and DLR accelerations are larger (solar panel orientation?).
Solar radiation pressure

Day 16/085, cross-track direction:

<table>
<thead>
<tr>
<th>Minute of day 16/085</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>AIUB</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>SRP acc. N</td>
</tr>
<tr>
<td>-27.79 ± 19.03</td>
</tr>
<tr>
<td>-28.42 ± 19.26</td>
</tr>
<tr>
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<tr>
<td>-27.86 ± 17.77</td>
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</table>

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AIUB CNES CPOD DLR EUM TUM
Solar panel orientation


![Graph showing SRP accelerations for different solar panel orientations](attachment:graph.png)

→ cannot explain the differences of the DLR SRP accelerations
Instantaneous re-emission

Acceleration of a flat area element $A$ due to absorbed ($\alpha$), diffusely reflected ($\delta$) and specularly reflected ($\rho$) radiation:

$$\vec{a}_{RP} = -\frac{\Phi}{c \cdot m} A \cos \theta \cdot \left[ (\alpha + \delta)\vec{e}_{\text{Sun}} + \frac{2}{3} \delta \vec{n} + 2 \rho \cos \theta \vec{n} \right],$$  \hspace{1cm} (1)

where

- $\Phi$ Solar flux
- $c$ Speed of light
- $m$ Satellite mass
- $\vec{e}_{\text{Sun}}$ Unit vector satellite-Sun
- $\vec{n}$ Area normal vector
- $\theta$ Angle between $\vec{e}_{\text{Sun}}$ and $\vec{n}$

and $\alpha + \delta + \rho = 1$. 
If the absorbed radiation is instantaneously re-radiated according to Lambert’s law, the following contribution needs to be added:

\[ \vec{a}_{RE} = -\frac{\Phi}{c \cdot m} A \cos \theta \cdot \frac{2}{3} \alpha \vec{n}, \]  

and the total radiation pressure acceleration amounts to

\[ \vec{a}_{RP} = -\frac{\Phi}{c \cdot m} A \cos \theta \cdot \left[ (\alpha + \delta) \left( \vec{e}_{Sun} + \frac{2}{3} \delta \vec{n} \right) + 2 \rho \cos \theta \vec{n} \right]. \]  

\[ (\alpha, \delta, \rho) \rightarrow (0, \alpha + \delta, \rho) \]
Instantaneous re-emission

Impact of instantaneous re-emission:

SRP acc. R

Minute of day 16/085

-100
deceleration
-80
deceleration
-60
deceleration
-40
deceleration
-20
deceleration
0
0
20
acceleration
40
acceleration
60
acceleration

-100
-80
-60
-40
-20
0
20
40
60
0
50
100
150
200
250
300
350

-19.51 ± 33.45
-21.73 ± 37.69

No re-emi.
Re-emi.

Modeling of instantaneous re-emission is very likely one of the main reasons for the larger DLR accelerations in normal direction. Surprisingly, CNES (which also models inst. re-emission) does not show larger cross-track accelerations.
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Instantaneous re-emission: Updates

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- Newly provided accelerations now show smaller amplitudes:
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**SRP acc. T**

- AIUB
- CNES
- CPOD
- DLR
- EUM
- TUM
- TUM new

-1.10 ± 40.76
-0.16 ± 41.82
-0.84 ± 40.45
-0.24 ± 44.45
0.89 ± 42.72
-0.20 ± 58.18
-0.19 ± 45.88
Instantaneous re-emission: Updates

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```
Accelerations [nm/s^2]

<table>
<thead>
<tr>
<th>Minute of day 16/085</th>
<th>AIUB</th>
<th>CNES</th>
<th>CPOD</th>
<th>DLR</th>
<th>EUM</th>
<th>TUM</th>
<th>TUM new</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-27.79 ± 19.03</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>-28.42 ± 19.26</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>-26.08 ± 18.47</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>150</td>
<td>-31.56 ± 21.33</td>
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<td></td>
<td></td>
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<td>200</td>
<td>-27.86 ± 17.77</td>
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<tr>
<td>250</td>
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<tr>
<td>300</td>
<td>-31.20 ± 21.10</td>
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<tr>
<td>350</td>
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</tbody>
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```
Instantaneous re-emission: Updates

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Instantaneous re-emission: Updates

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- Newly provided SRP accelerations:

![Graph showing SRP accelerations](image-url)
- CPOD recently updated their radiation pressure modeling to account for instantaneous re-emission
- Newly provided SRP accelerations:

![Graph showing SRP accelerations for different agencies](image-url)
• CPOD recently updated their radiation pressure modeling to account for instantaneous re-emission

• Newly provided SRP accelerations:

$$\text{SRP acc. T} = -0.84 \pm 40.45$$  
$$\text{SRP acc. T} = -0.92 \pm 43.95$$
Instantaneous re-emission: Updates

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![Graph showing SRP accelerations](image)

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![Graph showing SRP accelerations](image)
Instantaneous re-emission: Updates

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### Planetary radiation pressure modeling

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<tr>
<th></th>
<th>Earth model</th>
<th>Radiation model</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIUB</td>
<td>Grid $2.5^\circ \times 2.5^\circ$</td>
<td>CERES</td>
</tr>
<tr>
<td>CNES</td>
<td>Ring segments</td>
<td>Knocke et al., 1988</td>
</tr>
<tr>
<td>CPOD</td>
<td>Grid $5^\circ \times 5^\circ$</td>
<td>CERES</td>
</tr>
<tr>
<td>DLR</td>
<td>Ring segments</td>
<td>CERES, approx.</td>
</tr>
<tr>
<td>EUM</td>
<td>Grid $5^\circ \times 5^\circ$</td>
<td>CERES</td>
</tr>
<tr>
<td>TUM</td>
<td>Grid $10^\circ \times 10^\circ$</td>
<td>CERES</td>
</tr>
</tbody>
</table>

- **“Ring segments”:** concentric rings with sectors around satellite foot point (3 rings with 4, 8, and 12 sectors for DLR and 15 rings with 15 sectors for CNES).
- **“CERES, approx.”**: a 2nd order polynomial in latitude and a periodic function in time is used to approximate the CERES grid values.
Planetary radiation pressure

Day 16/085, radial direction (status before May 2018):

![Graph showing accelerations over time for various agencies.](image)
Planetary radiation pressure

Day 16/085, radial direction (status before May 2018):

PRP acc. R

TUM accelerations are noisy and show larger amplitude

- AIUB
- CNES
- CPOD
- DLR
- EUM
- TUM

11.29 ± 5.19
12.25 ± 5.44
11.50 ± 5.42
17.18 ± 6.94
11.35 ± 5.41
16.01 ± 8.15
Planetary radiation pressure

Day 16/085, radial direction (status before May 2018):

- TUM accelerations are noisy and show larger amplitude
- DLR accelerations show offset

<table>
<thead>
<tr>
<th>Agency</th>
<th>Acceleration [nm/s²]</th>
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</thead>
<tbody>
<tr>
<td>AIUB</td>
<td>11.29 ± 5.19</td>
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<tr>
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**Planetary radiation pressure**

Day 16/085, along-track direction:

![Graph showing accelerations over time for different agencies](image)

- **PRP acc. T**
  - AIUB
  - CNES
  - CPOD
  - DLR
  - EUM
  - TUM

- **Accelerations [nm/s^2]**
  - Minute of day 16/085
  - TUM accelerations are noisy and show larger amplitude
  - DLR accelerations show offset
  - CNES and DLR accelerations show less fine structure (coarser Earth model)

- **Values:**
  - AIUB: 0.02 ± 1.32
  - CNES: 0.02 ± 1.34
  - CPOD: 0.06 ± 1.43
  - DLR: 0.01 ± 1.57
  - EUM: 0.04 ± 1.42
  - TUM: 0.09 ± 2.97
Planetary radiation pressure

Day 16/085, cross-track direction:

Graph showing acceleration data for different agencies:

- AIUB
- CNES
- CPOD
- DLR
- EUM
- TUM

- TUM accelerations are noisy and show larger amplitude.
- DLR accelerations show offset.
- CNES and DLR accelerations show less fine structure (coarser Earth model).
- DLR accelerations show larger amplitudes.

Acceleration values:

0.03 ± 1.53
−0.30 ± 1.10
−0.01 ± 1.24
0.36 ± 1.85
0.01 ± 1.21
0.33 ± 2.56
Planetary radiation pressure

Day 16/085, cross-track direction:

DLR accelerations show larger amplitudes

CNES and DLR accelerations show less fine structure (coarser Earth model)

PRP acc. N

Minute of day 16/085

0.03 ± 1.53
−0.30 ± 1.10
−0.01 ± 1.24
0.36 ± 1.85
0.01 ± 1.21
0.33 ± 2.56

AIUB
CNES
CPOD
DLR
EUM
TUM
Impact of instantaneous re-emission:

Modeling of instantaneous re-emission is very likely one of the main reasons for the offset in DLR accelerations in radial direction. Surprisingly, CNES (which also models inst. re-emission) does not show the same acceleration offset in radial direction.
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PRP: Updates

- TUM is using a grid to model Earth surface, but only one mean direction for PRP. Employed grid resolution of 10 deg seems insufficient.
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![Graph showing PRP accelerations](image-url)
PRP: Updates

- CPOD recently updated their radiation pressure modeling to account for instantaneous re-emission
PRP: Updates

- CPOD recently updated their radiation pressure modeling to account for instantaneous re-emission
- Newly provided PRP accelerations:

![Graph showing PRP accelerations](image)

- AIUB
- CNES
- CPOD
- DLR
- EUM
- TUM
- TUM new
- CPOD new

Accumulated values:

- AIUB: 11.29 ± 5.19
- CNES: 12.25 ± 5.44
- CPOD: 11.50 ± 5.42
- DLR: 17.18 ± 6.94
- EUM: 11.35 ± 5.41
- TUM: 16.01 ± 8.15
- TUM new: 13.84 ± 5.27
- CPOD new: 13.89 ± 6.39
- CPOD recently updated their radiation pressure modeling to account for instantaneous re-emission
- Newly provided PRP accelerations:

![Graph showing PRP accelerations](image)

<table>
<thead>
<tr>
<th>Accelerations [nm/s²]</th>
<th>Minute of day 16/085</th>
<th>PRP acc. T</th>
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Institutions: AIUB, CNES, CPOD, DLR, EUM, TUM, TUM new, CPOD new.
### Aerodynamic acceleration modeling

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- All groups except EUM and TUM model aerodynamic lift accelerations.
- Aerodynamic accelerations offer the largest potential for differences: many different atmospheric models, different proxies, many differences in modeling of gas-surface interaction, ...
## Aerodynamic acceleration modeling

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- Aerodynamic accelerations offer largest potential for differences: many different atmospheric models, different proxies, many differences in modeling of gas-surface interaction, ...
Aerodynamic accelerations

Day 16/085, radial direction:

Aerodynamic acc. R

Minute of day 16/085

-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
0 50 100 150 200 250 300 350

Accelerations [nm/s^2]

0.02 ± 0.33
0.01 ± 0.41
0.00 ± 0.15
0.01 ± 0.15
0.00 ± 0.04
−0.00 ± 0.00

AIUB CNES CPOD DLR EUM TUM

EUM and TUM do not model lift
AIUB and CNES show larger amplitudes (density models?)
EUM acceleration smaller
CNES and TUM accelerations show larger amplitudes
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Aerodynamic accelerations

Day 16/085, radial direction:

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Aerodynamic accelerations

Day 16/085, radial direction:

AIUB and CNES show larger amplitudes (density models?)

Aerodynamic acc. R

Minute of day 16/085

AIUB  CNES  CPOD  DLR  EUM  TUM

0.02 ± 0.33
0.01 ± 0.41
0.00 ± 0.15
0.01 ± 0.15
0.00 ± 0.04
−0.00 ± 0.00
Aerodynamic accelerations

Day 16/085, along-track direction (largest):

-5
-4.5
-4
-3.5
-3
-2.5
-2
-1.5
-1
-0.5
0
0 50 100 150 200 250 300 350

Minute of day 16/085

Aerodynamic acc. T

AIUB CNES CPOD DLR EUM TUM

-3.04 ± 0.91
-2.64 ± 1.05
-2.90 ± 1.02
-2.71 ± 0.89
-1.67 ± 0.46
-2.42 ± 0.95

EUM and TUM do not model lift

AIUB and CNES show larger amplitudes (density models?)

EUM acceleration smaller

CNES and TUM accelerations show larger amplitudes

AIUB and CNES accelerations show larger amplitudes
Aerodynamic accelerations

Day 16/085, along-track direction (largest):

- EUM acceleration smaller
- CNES and TUM accelerations show larger amplitudes

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AIUB and CNES show larger amplitudes (density models?)

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CNES and TUM accelerations show larger amplitudes

AIUB and CNES accelerations show larger amplitudes
Aerodynamic accelerations

Day 16/085, cross-track direction:

Aerodynamic acc. N

Minute of day 16/085

-0.01 ± 0.39
0.03 ± 0.41
-0.00 ± 0.18
0.02 ± 0.21
0.00 ± 0.08
0.03 ± 0.10

AIUB and CNES show larger amplitudes (density models?)
EUM acceleration smaller
CNES and TUM accelerations show larger amplitudes
Aerodynamic accelerations

Day 16/085, cross-track direction:

AIUB and CNES accelerations show larger amplitudes
Aerodynamic acceleration modeling

- Further tests needed to better disentangle impact of different density models/wind models
  - Even if different groups use the same models, different results are likely (e.g., due to different usage of proxies)
    - Option: Compare densities along an orbit
- For Sentinel-3 the aerodynamic accelerations are rather small.
  - Option: Compare, e.g., for Swarm
- For comparison of different atmospheric models in LEO POD see presentation PSD.1-0008-18 *Non-gravitational forces acting on spacecraft: impact of different atmospheric models on LEO orbits* by V. Girardin, Monday, 16th July 2018, 12:40, R101
Conclusions

• Overall, the different agencies of the Copernicus POD QWG agree rather well on the modeled non-gravitational accelerations for Sentinel-3A
• SRP accelerations rather identical (at least up to scaling factor)
• Aerodynamic accelerations rather diverse, but so are the employed models
• Difference between the two employed solar panel orientations not critical
• Instantaneous re-emission explains part of the SRP and PRP differences
• TUM could revise and change their settings to better agree with the other groups
Outlook

- Check impact of different radiation data and Earth modelings
- Check impact of different atmospheric models
- For further comparisons of aerodynamic accelerations:
  - Use as unified models as possible (density models, HWM)
  - Compare densities along an orbit
  - Maybe use another LEO with higher aerodynamic accelerations (e.g., Swarm)
- Thermal radiation?
Thank you
Environment

- In 2016 the orbital altitude of S3A was around 800 km
Environment

- In 2016 the orbital altitude of S3A was around 800 km
- Beta angle:
• In 2016 the orbital altitude of S3A was around 800 km
• TEC:
Solar radiation pressure

Days 16/170 and 16/250:

![Graph showing SRP accelerations for different organizations (AIUB, CNES, CPOD, DLR, EUM, TUM) on days 16/170 and 16/250. The graph includes acceleration values such as -20.69 ± 33.47, -23.38 ± 35.43, -21.63 ± 33.50, -24.55 ± 37.51, -23.01 ± 33.13, -30.16 ± 46.34, and comments on organizations' performance.]
Solar radiation pressure

Days 16/170 and 16/250:

![Solar radiation pressure graph](image)

- $-19.02 \pm 32.83$
- $-21.78 \pm 34.92$
- $-20.25 \pm 32.30$
- $-22.66 \pm 36.90$
- $-21.48 \pm 33.15$
- $-28.31 \pm 46.00$
Solar radiation pressure

Days 16/170 and 16/250:

![Graph showing solar radiation pressure accelerations for various agencies.]
Solar radiation pressure

Days 16/170 and 16/250:
Solar radiation pressure

Days 16/170 and 16/250:

![Graph showing solar radiation pressure accelerations for different agencies. The graph displays a time series of accelerations in force per unit mass over the minutes of day 16/170. The accelerations are indicated for different agencies: AIUB, CNES, CPOD, DLR, EUM, and TUM. The values shown are as follows:

- AIUB: $-19.70 \pm 13.98$ nm/s$^2$
- CNES: $-21.58 \pm 15.06$ nm/s$^2$
- CPOD: $-20.24 \pm 14.17$ nm/s$^2$
- DLR: $-22.57 \pm 15.74$ nm/s$^2$
- EUM: $-20.17 \pm 14.20$ nm/s$^2$
- TUM: $-29.41 \pm 20.46$ nm/s$^2$]
Solar radiation pressure

Days 16/170 and 16/250:

![Graph showing SRP accelerations for different agencies from AIUB, CNES, CPOD, DLR, EUM, TUM.](image)

- AIUB: $-24.27 \pm 17.02$
- CNES: $-25.51 \pm 17.59$
- CPOD: $-23.56 \pm 16.79$
- DLR: $-27.87 \pm 19.08$
- EUM: $-24.33 \pm 16.55$
- TUM: $-33.75 \pm 23.24$
Planetary radiation pressure

Days 16/170 and 16/250:

![Graph showing accelerations in nm/s² over time]

- AIUB
- CNES
- CPOD
- DLR
- EUM
- TUM

- PRP acc. R:
  - 11.70 ± 6.23
  - 12.23 ± 6.04
  - 12.00 ± 6.36
  - 17.24 ± 7.95
  - 12.03 ± 6.29
  - 16.07 ± 9.18
Planetary radiation pressure

Days 16/170 and 16/250:

![Graph showing accelerations over time for different agencies](image)
Planetary radiation pressure

Days 16/170 and 16/250:

The chart above shows the acceleration due to planetary radiation pressure (PRP) over a period of time for different agencies: AIUB, CNES, CPOD, DLR, EUM, and TUM. The accelerations are given in nm/s² and are indicated at specific minute markers.

- AIUB: -0.03 ± 1.49
- CNES: -0.03 ± 1.31
- CPOD: 0.03 ± 1.45
- DLR: -0.01 ± 1.75
- EUM: -0.03 ± 1.46
- TUM: -0.00 ± 2.88
Planetary radiation pressure

Days 16/170 and 16/250:

![Graph showing the Planetary Radiation Pressure (PRP) accelerations for different agencies (AIUB, CNES, CPOD, DLR, EUM, TUM) over the minute of day 16/250. The graph displays the accelerations in nm/s² and shows the range of the values for each agency.](image)
Planetary radiation pressure

Days 16/170 and 16/250:

![Graph showing PRP accelerations](image)

- AIUB
- CNES
- CPOD
- DLR
- EUM
- TUM
Planetary radiation pressure

Days 16/170 and 16/250:

![Graph showing planetary radiation pressure accelerations for different agencies from 0 to 350 minutes of day 16/250.](image)

- AIUB
- CNES
- CPOD
- DLR
- EUM
- TUM

PRP acc. N:

- 0.03 ± 1.40
- −0.28 ± 1.11
- 0.03 ± 1.24
- 0.33 ± 1.71
- 0.10 ± 1.33
- 0.32 ± 2.52

The graph shows the accelerations in [nm/s²] for PRP over the minute of day 16/085. The accelerations are plotted for two orientations: Correct and Sun. The data points are 11.29 ± 5.19 for Correct and 11.30 ± 5.20 for Sun. The graph indicates that the impact of solar panel orientation is negligible (as for SRP).

![Graph showing PRP acceleration over time for Correct and Sun orientations]

Impact negligible (as for SRP)
Scaling factors

- If SRP accelerations differ only by a scaling factor (same for all components), they will not impact the POD if scaling factor is estimated
- E.g., estimate scaling factors and biases to fit accelerations to AIUB accelerations:
Scaling factors

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- E.g., estimate scaling factors and biases to fit accelerations to AIUB accelerations:

![Graph showing accelerations over time](image-url)
Scaling factors

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- E.g., estimate scaling factors and biases to fit accelerations to AIUB accelerations:

\[
\text{DLR} \times 0.891 + 0.058
\]