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

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COSPAR Scientific Assembly 2018
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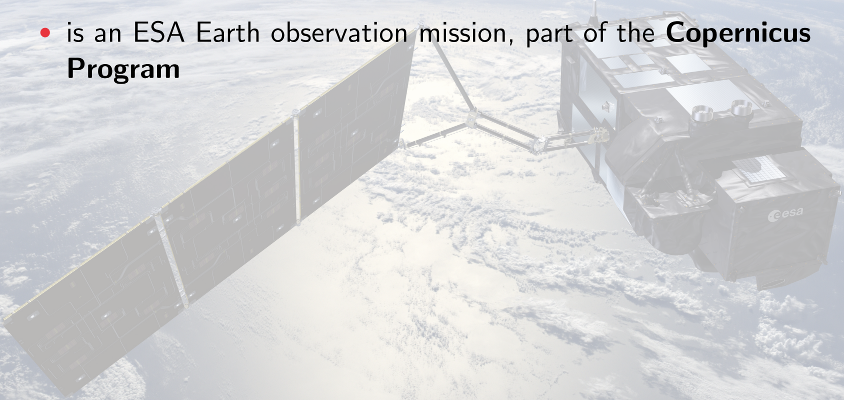
Introduction – Sentinel-3

Sentinel-3

- is an ESA Earth observation mission, part of the **Copernicus Program**



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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)**

Introduction – POD QWG

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- provides orbit solutions obtained with different POD software packages for regular intercomparison

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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:

Agency		POD Software
Astronomical Institute, Univ. of Bern	AIUB	Bernese GNSS S/W
Centre National d'Etudes Spatiales	CNES	Zoom
Copernicus POD Service	CPOD	NAPEOS
German Space Operations Center	DLR	GHOST
EUMETSAT	EUM	NAPEOS
Technical University of Munich	TUM	Bernese GNSS S/W

Methods

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)
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- Compare interpolated accelerations at a sampling of 10 s

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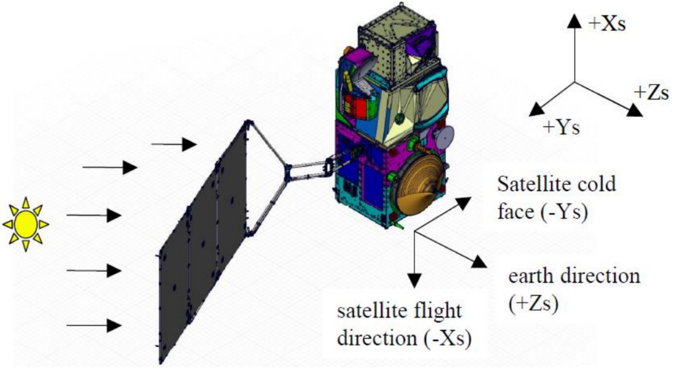

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- Attitude: CNES used theoretical attitude law, other groups quaternions

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Planetary radiation pressure (visual + IR)

~ 30 nm/s^2

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Direct solar radiation pressure

~ 100 nm/s^2

↓

Planetary radiation pressure (visual + IR)

~ 30 nm/s^2

↓

Aerodynamic accelerations

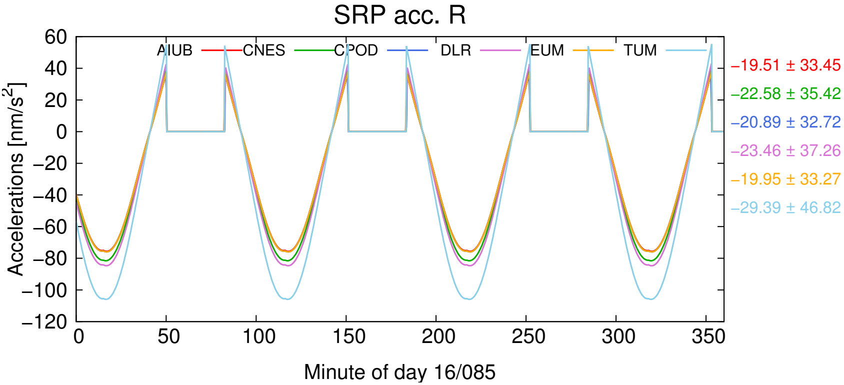
~ 5 nm/s^2

Solar radiation pressure modeling

	Earth model	Shadow model	Atm. refr.	Atm. abs.
AIUB	Oblated	Conical	No	No
CNES	Oblated	Conical	Yes	No
CPOD	Spherical	Conical	No	Yes
DLR	Spherical	Conical	No	No
EUM	Spherical	Conical	No	No
TUM	Spherical	Cylindrical	No	No

Solar radiation pressure

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



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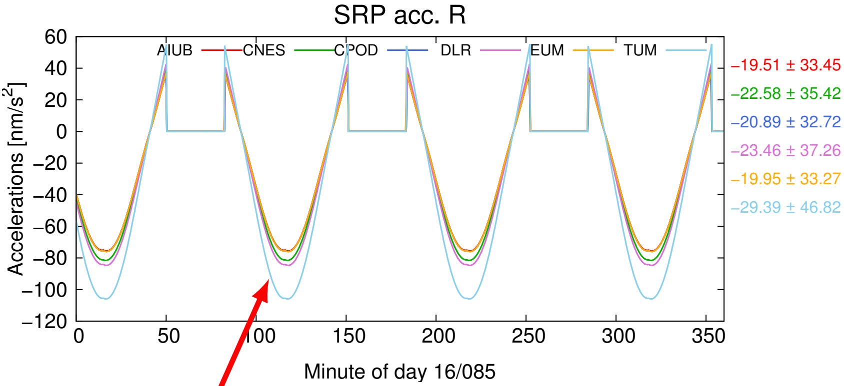

TUM accelerations show significantly larger amplitudes

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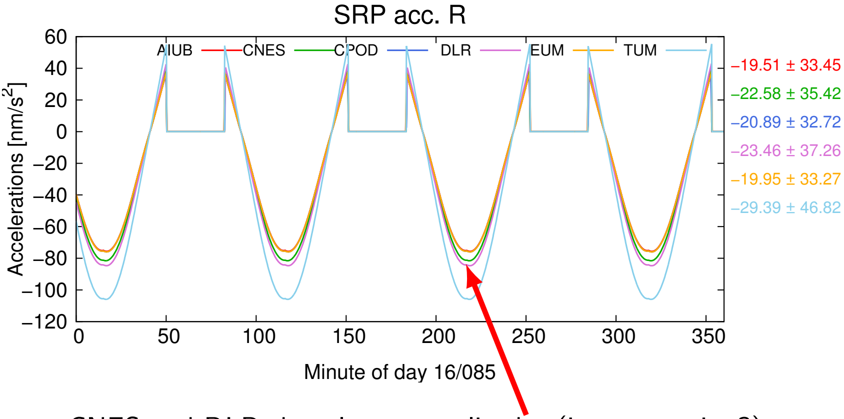
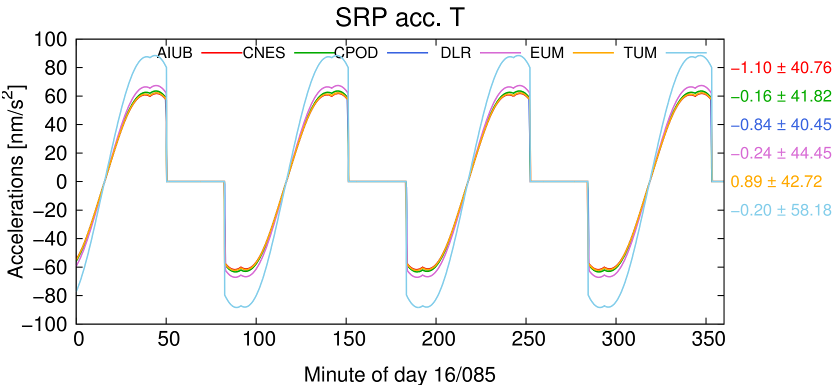


CNES and DLR show larger amplitudes (inst. re-emiss.?)

Solar radiation pressure

Day 16/085, along-track direction:



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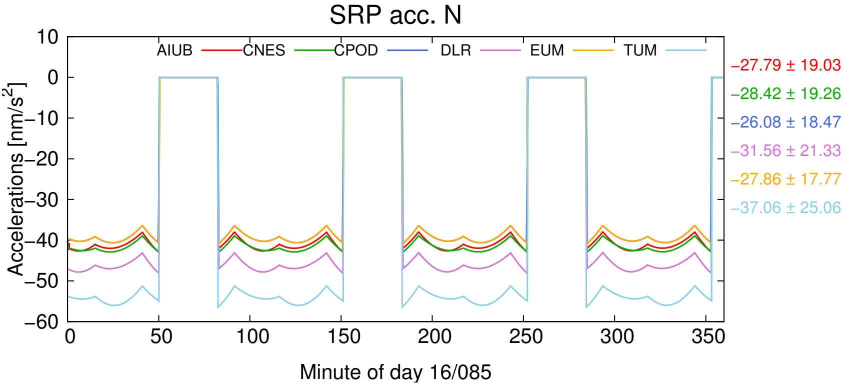

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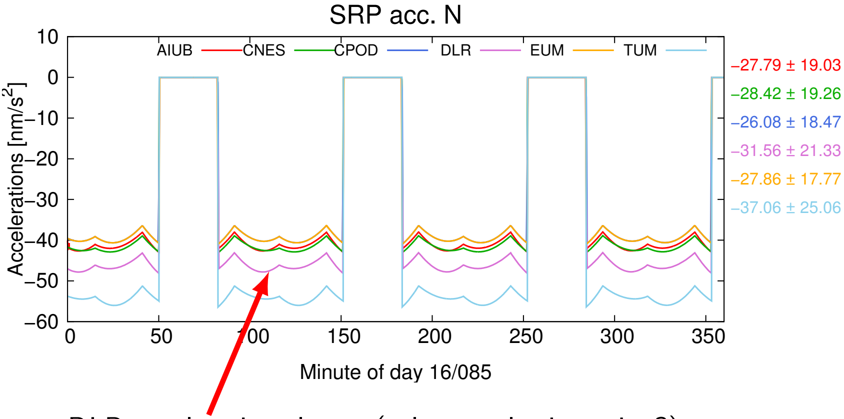
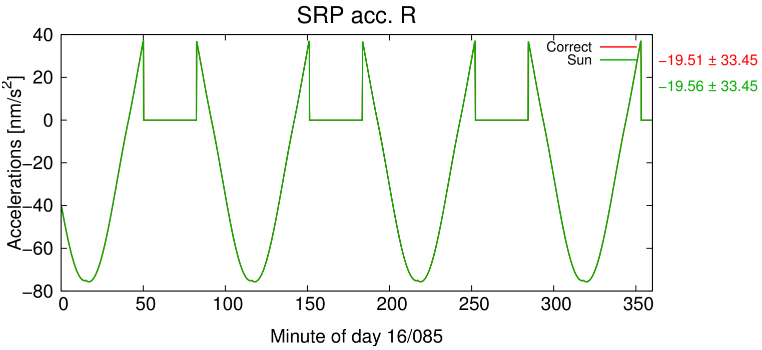


DLR accelerations larger (solar panel orientation?)

Solar panel orientation

Impact of solar panel oriantation. “Correct”: Optimal possible solar panel orientation. “Sun”: Solar panel perfectly perpendicular to the Sun direction.



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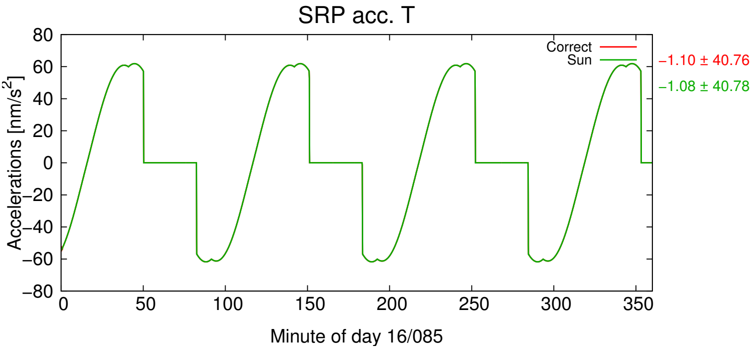

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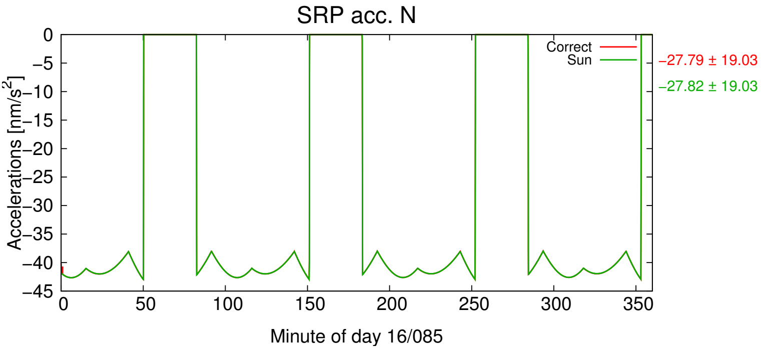

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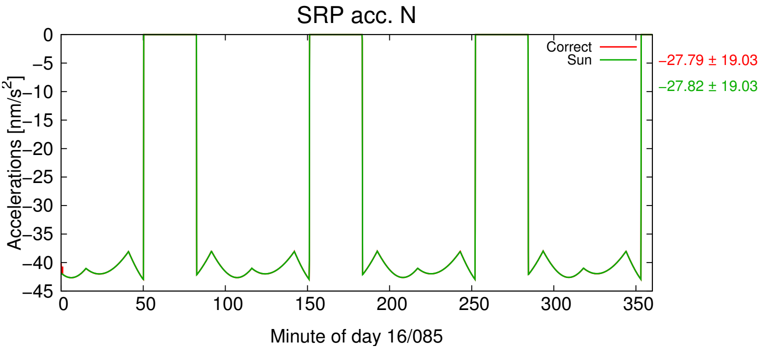

→ cannot explain the differences of the DLR SRP accelerations

Instantaneous re-emission

Acceleration of a flat area element A due to absorbed (α), diffusely reflected (δ) and specularly reflected (ρ) radiation:

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

where

Φ	Solar flux
c	Speed of light
m	Satellite mass
$\vec{e}_{\mathsf{Sun}}$	Unit vector satellite-Sun
$\vec{n}$	Area normal vector
θ	Angle between $\vec{e}_{\mathsf{Sun}}$ and $\vec{n}$,

and $\alpha + \delta + \rho = 1$.

Instantaneous re-emission

If the absorbed radiation is instantaneously re-radiated according to Lambert's law, the following contribution needs to be added:

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

and the total radiation pressure acceleration amounts to

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

$[(\alpha, \delta, \rho) \rightarrow (0, \alpha + \delta, \rho)]$

Instantaneous re-emission

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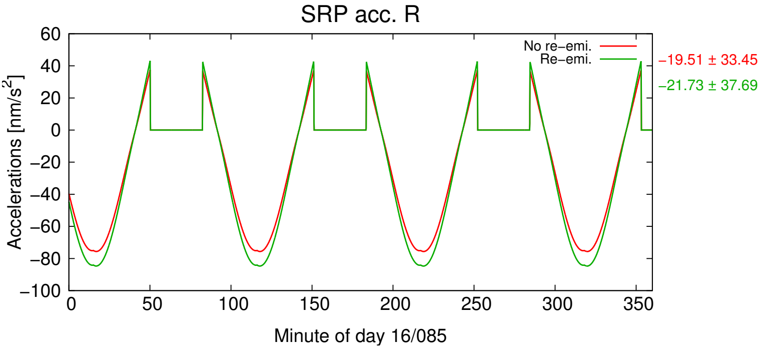

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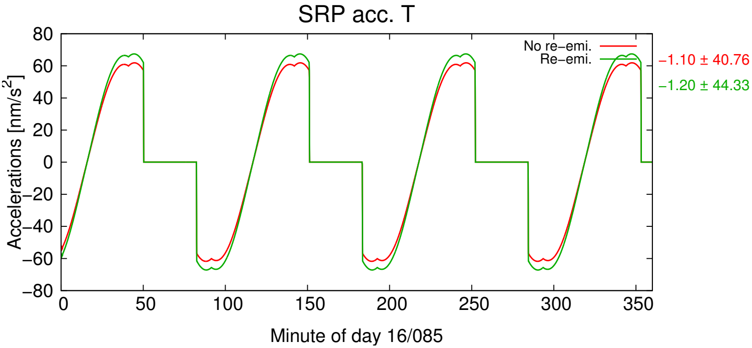

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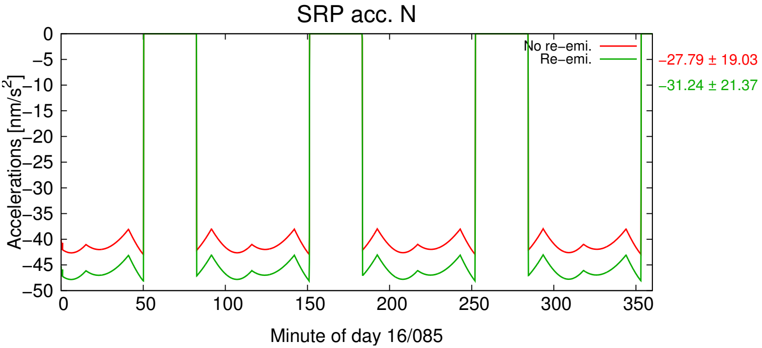

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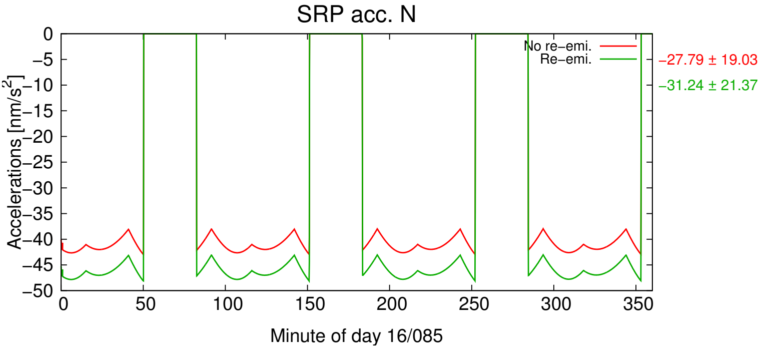

→ Modeling of instantaneous re-emission is very likely one of the main reasons for the larger DLR accelerations in normal direction. Surprisingly, CNES (which also models inst. re-emission) does not show larger cross-track accelerations.

Instantaneous re-emission: Updates

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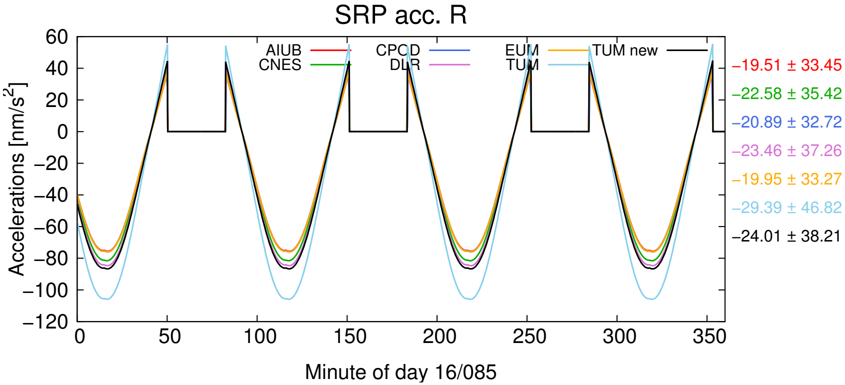

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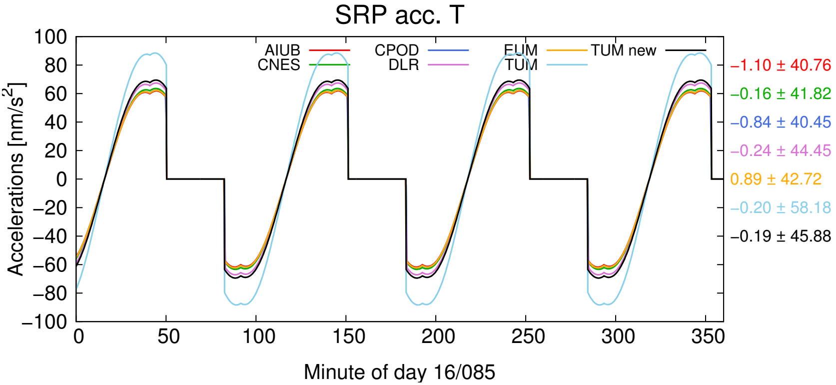

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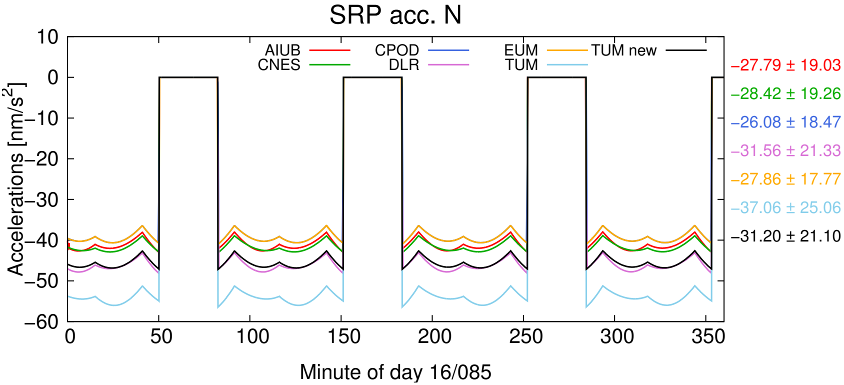

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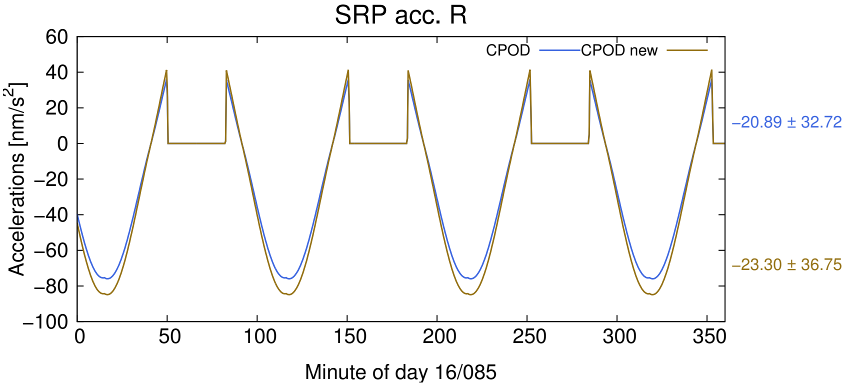

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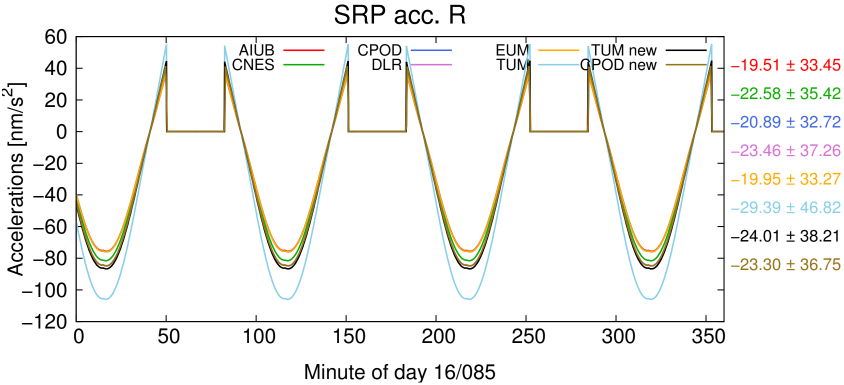

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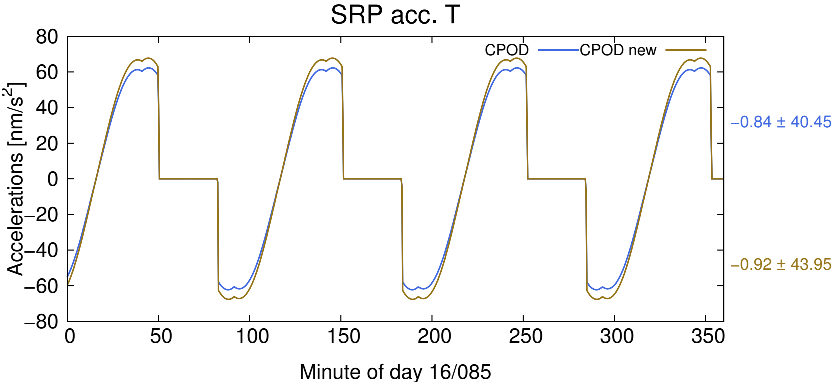

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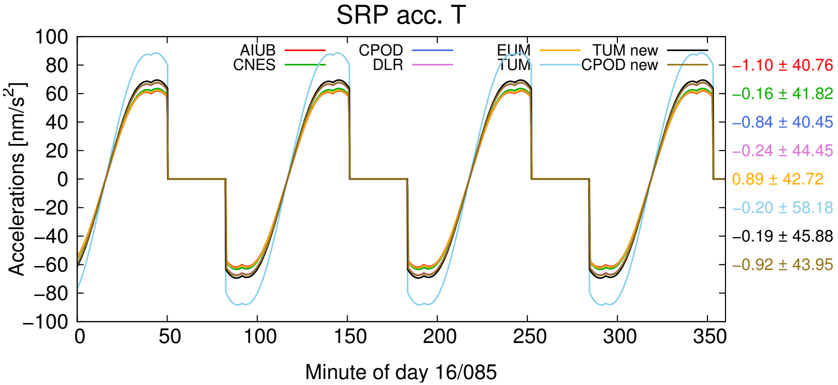

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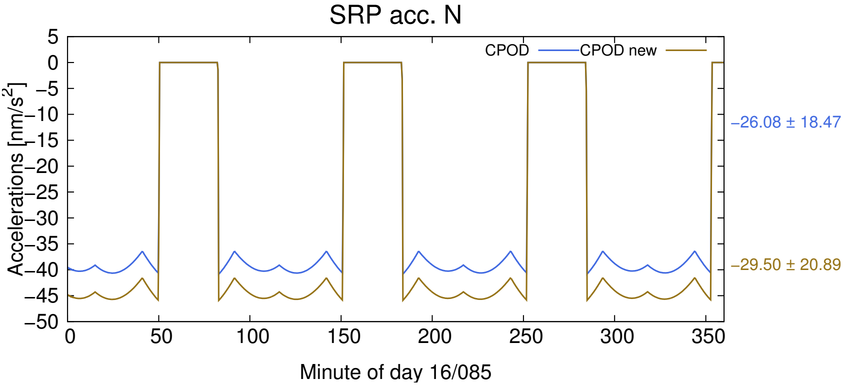

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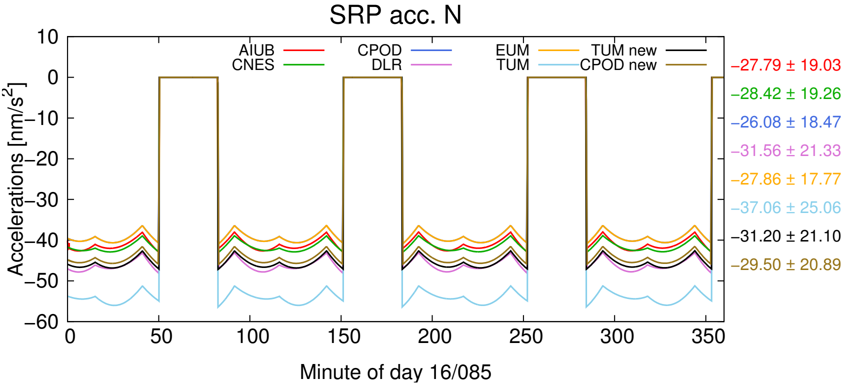


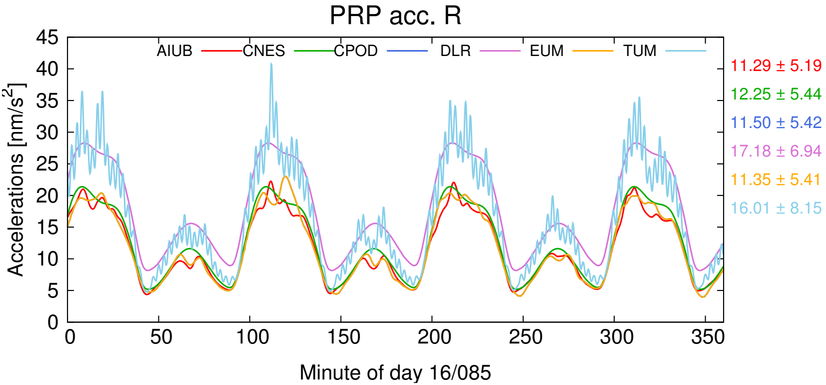
Planetary radiation pressure modeling

	Earth model	Radiation model
AIUB	Grid $2.5° \times 2.5°$	CERES
CNES	Ring segments	Knocke et al., 1988
CPOD	Grid $5° \times 5°$	CERES
DLR	Ring segments	CERES, approx.
EUM	Grid $5° \times 5°$	CERES
TUM	Grid $10° \times 10°$	CERES

- "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):



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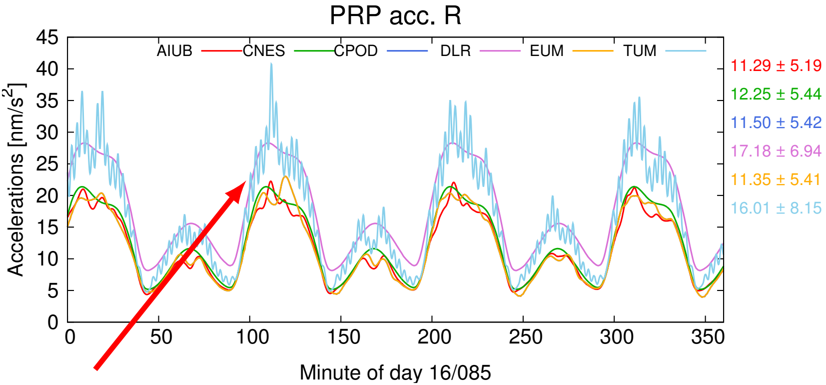

TUM accelerations are noisy and show larger amplitude

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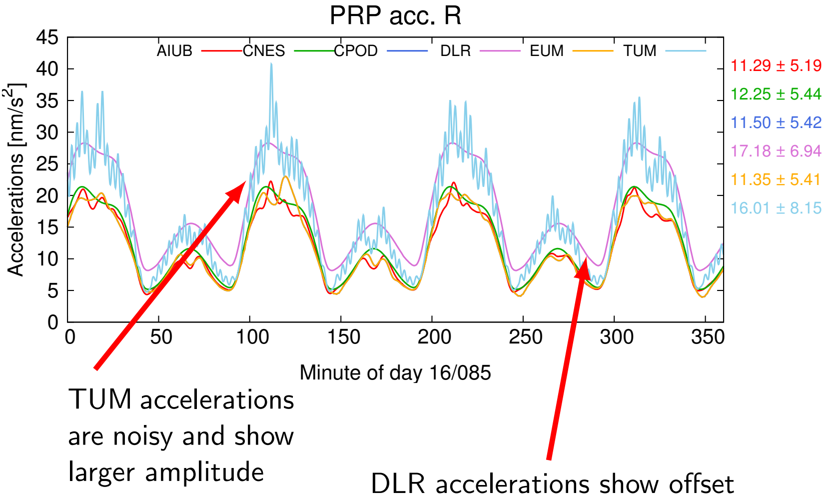

Planetary radiation pressure

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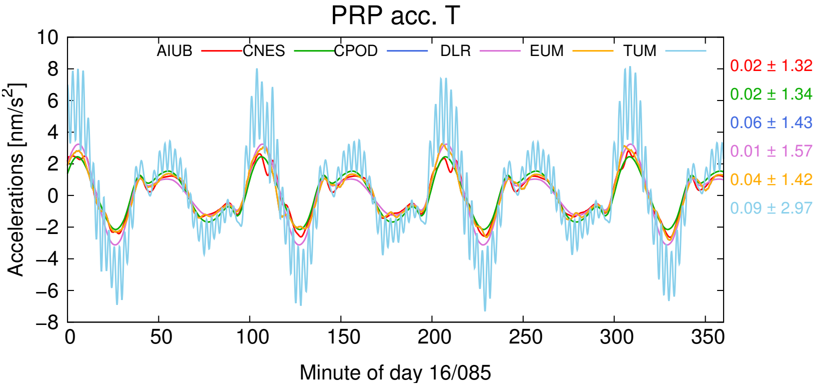

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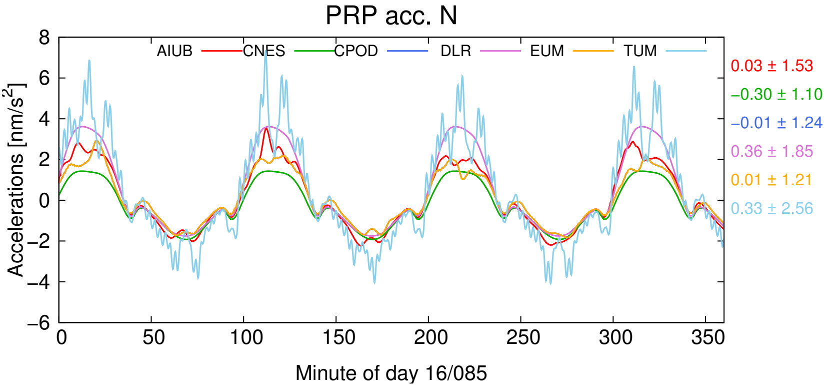

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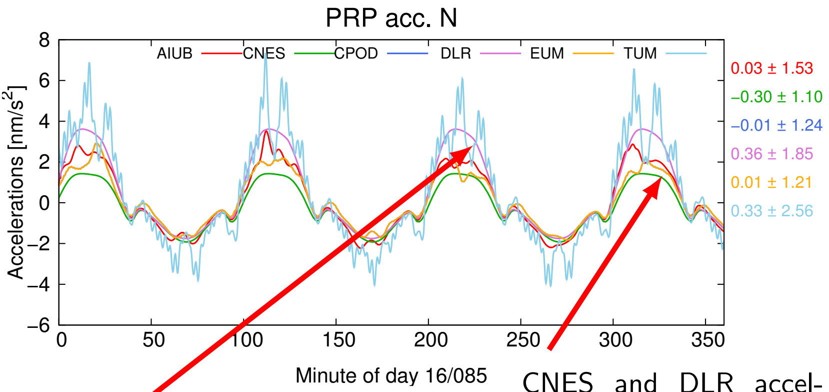
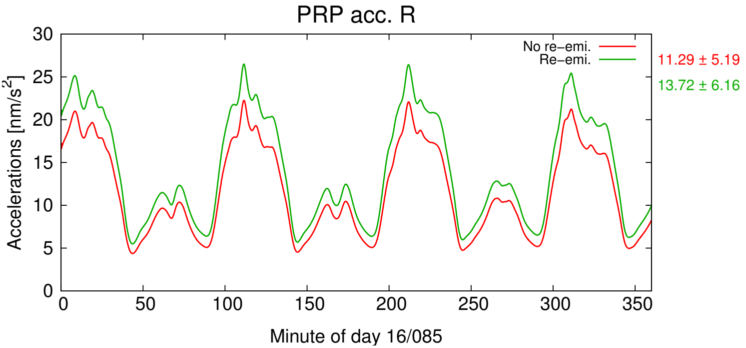


DLR accelerations show larger amplitudes

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

PRP: Instantaneous re-emission

Impact of instantaneous re-emission:



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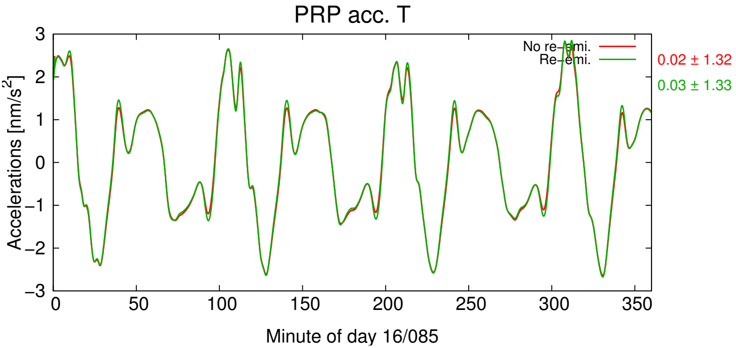

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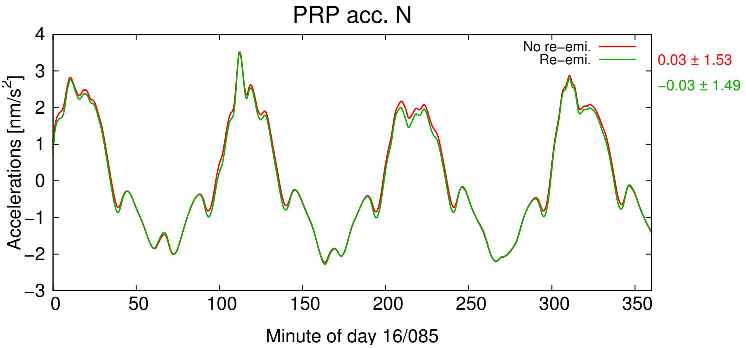

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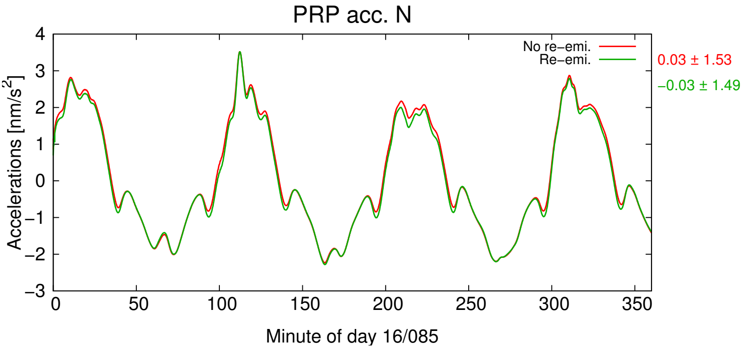

→ Modeling of instantaneous re-emission is very likely one of the main reasons for the offset in DLR accelerations in radial direction. Surprisingly, CNES (which also models inst. re-emission) does not show the same acceleration offset in radial direction.

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- 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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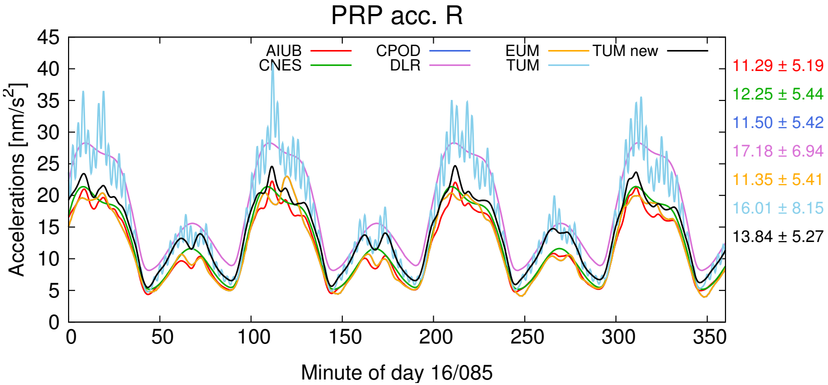

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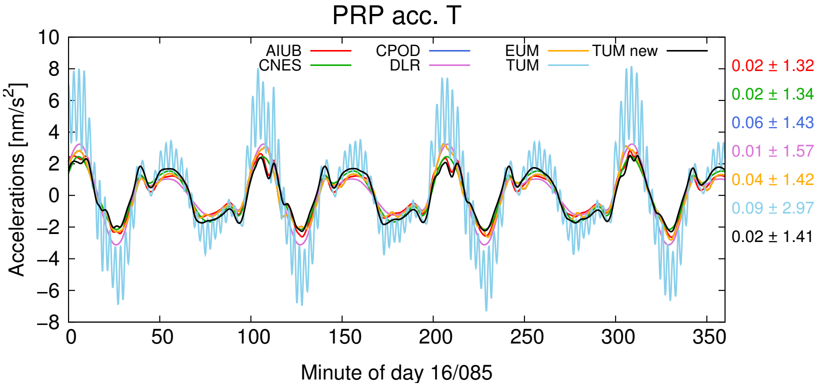

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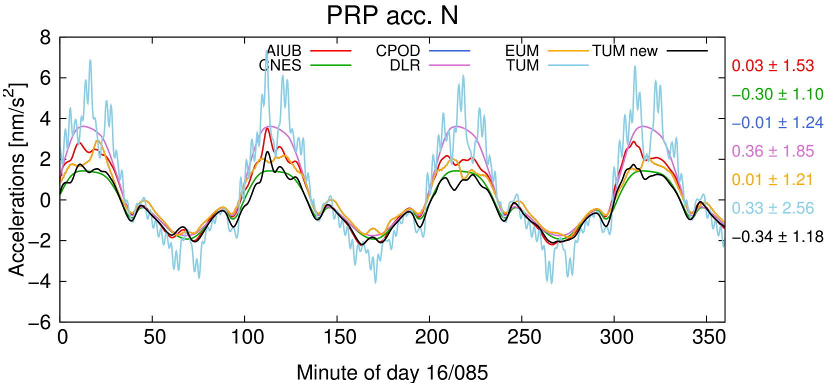

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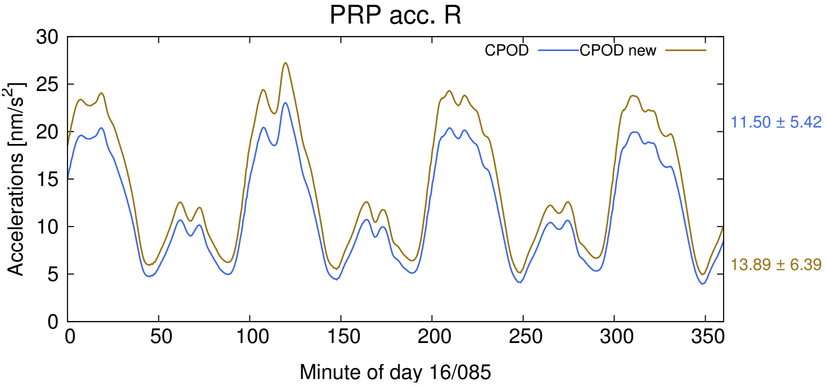

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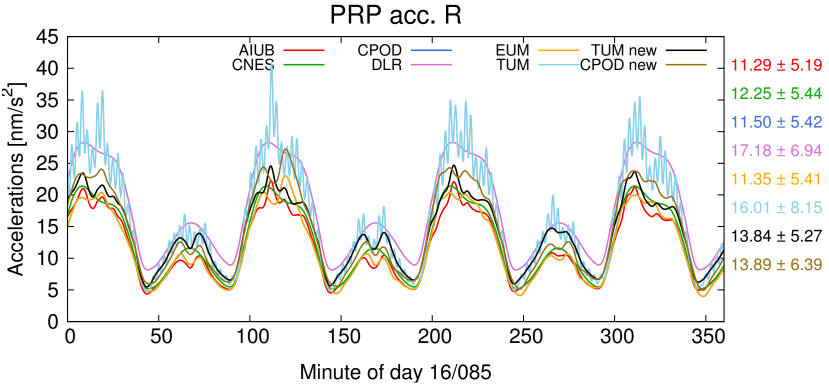

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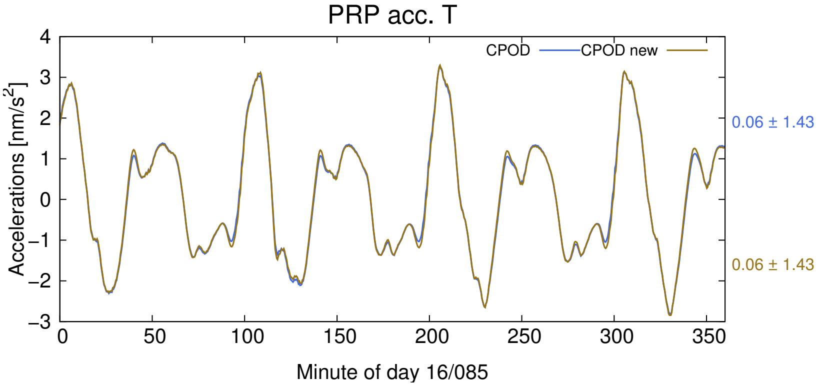

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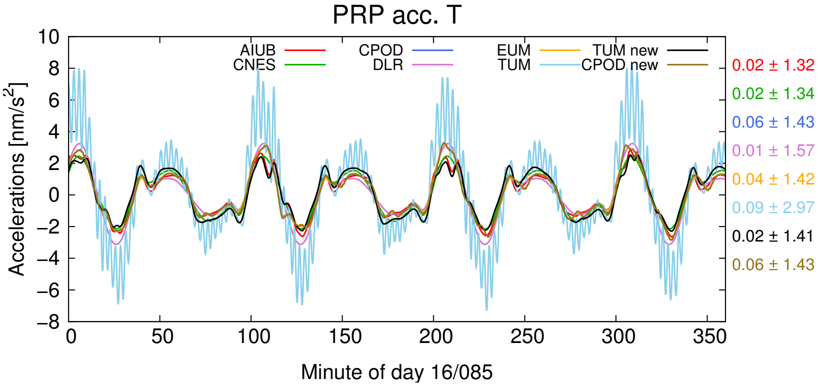

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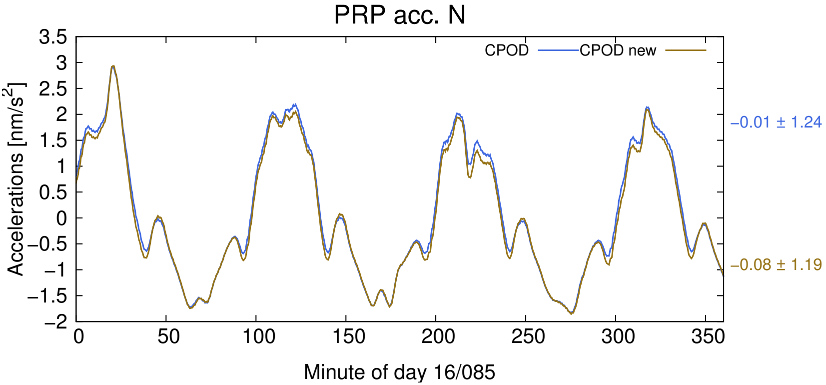

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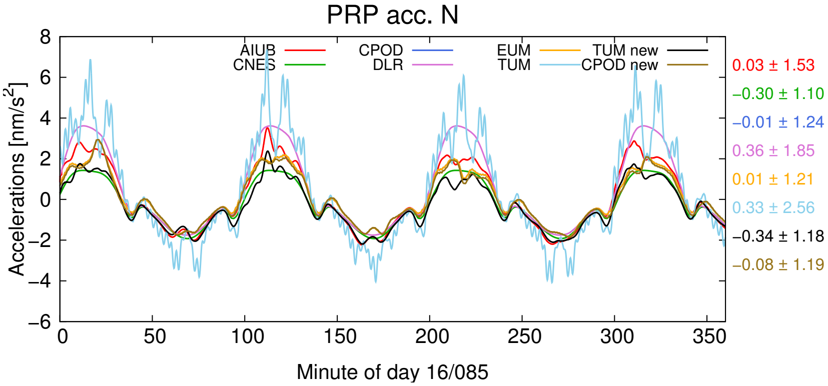

Aerodynamic acceleration modeling

	Density model	Horizontal wind model
AIUB	DTM2013	HWM14
CNES	MSIS-86	None
CPOD	MSISE-90	HWM93
DLR	NRLMSISE-00	None
EUM	MSISE-90	HWM93
TUM	MSISE-90	None

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- All groups except EUM and TUM model aerodynamic lift accelerations

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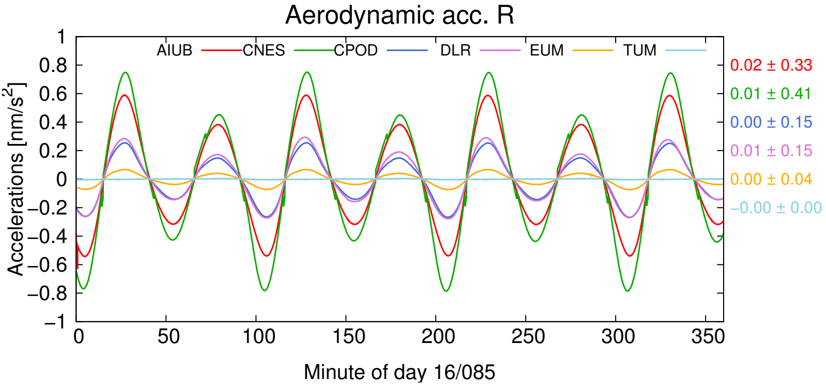
- All groups except EUM and TUM model aerodynamic lift accelerations
- Aerodynamic accelerations offer largest potential for differences: many different atmospheric models, different proxies, many differences in modeling of gas-surface interaction, ...

Aerodynamic accelerations

Day 16/085, radial direction:



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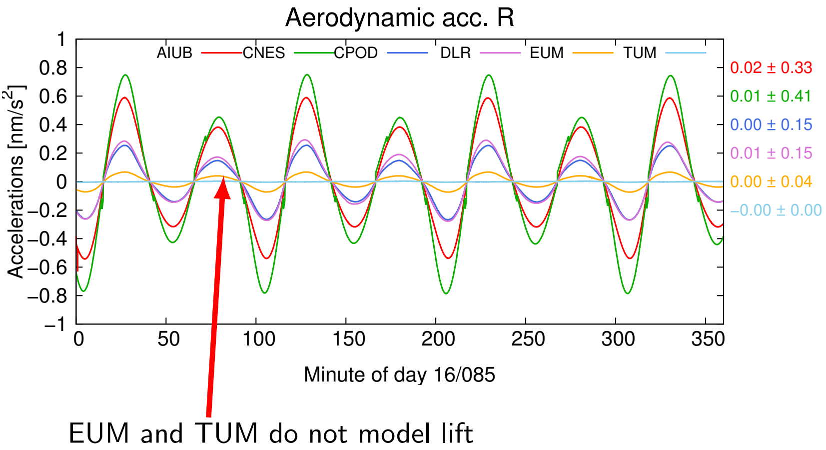

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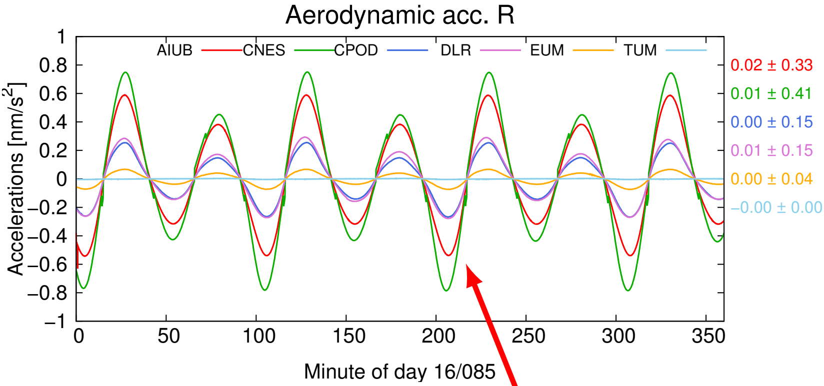
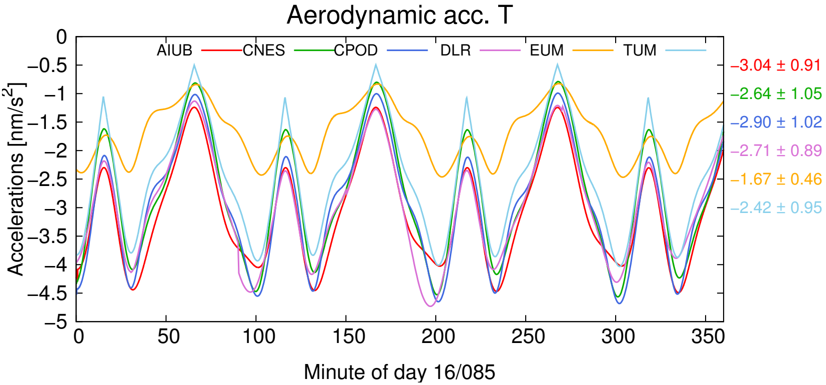


AIUB and CNES show larger amplitudes (density models?)

Aerodynamic accelerations

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



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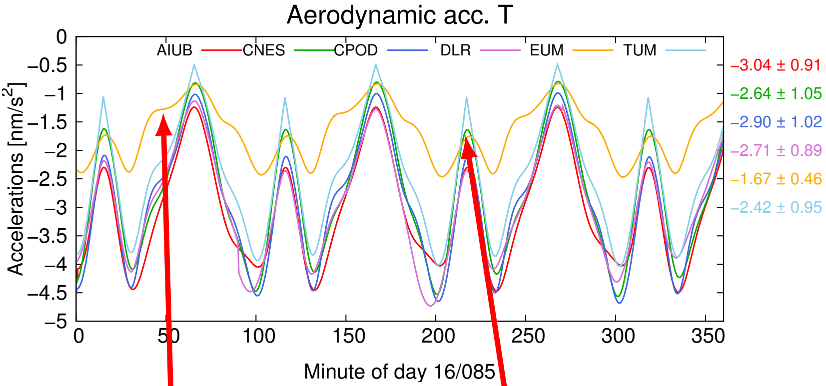
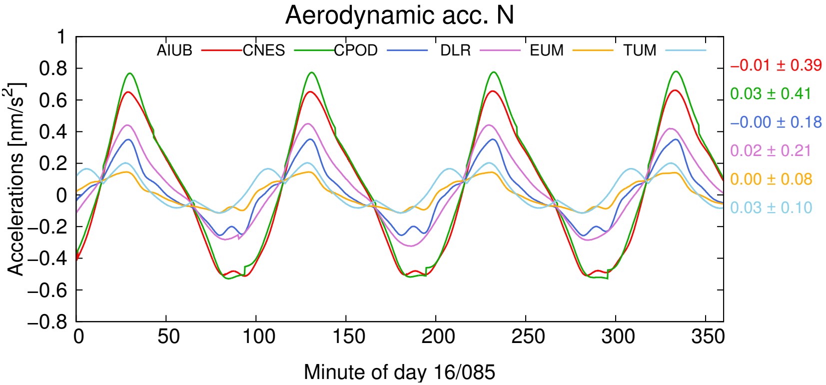


EUM acceleration smaller

CNES and TUM accelerations show larger amplitudes

Aerodynamic accelerations

Day 16/085, cross-track direction:



Aerodynamic accelerations

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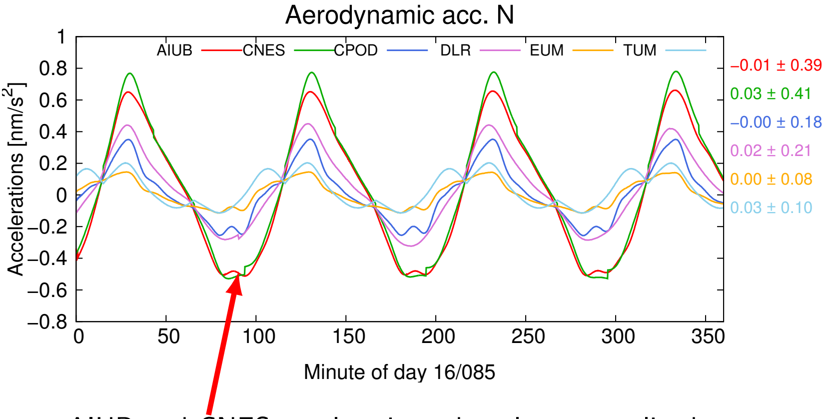

AIUB and CNES accelerations show larger amplitudes

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

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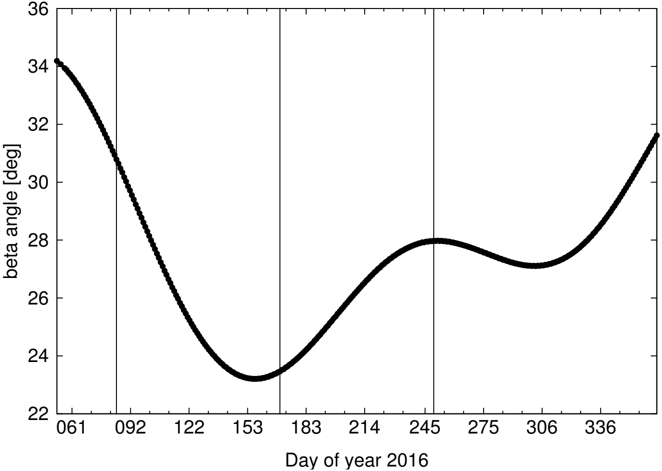
- Beta angle:



Environment

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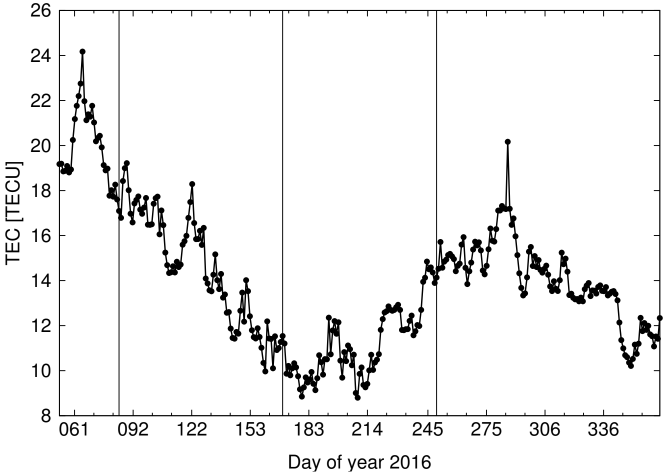
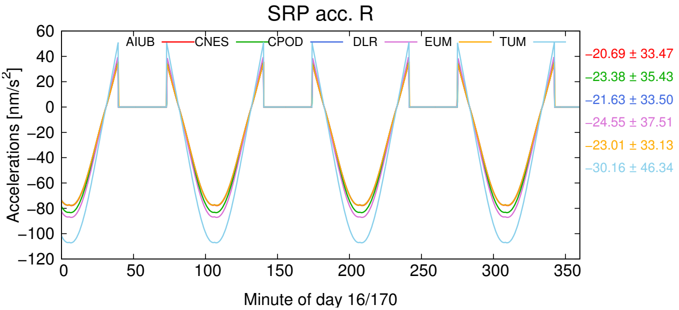
- TEC:



Solar radiation pressure

Days 16/170 and 16/250:



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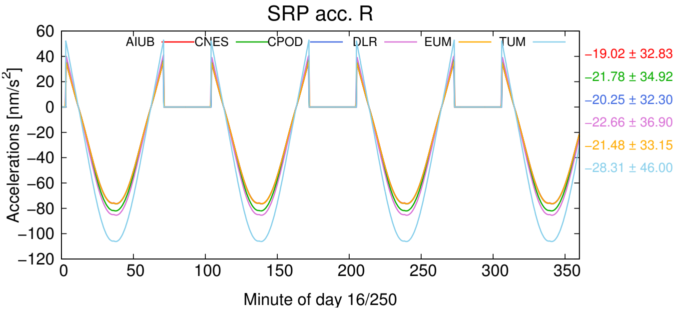

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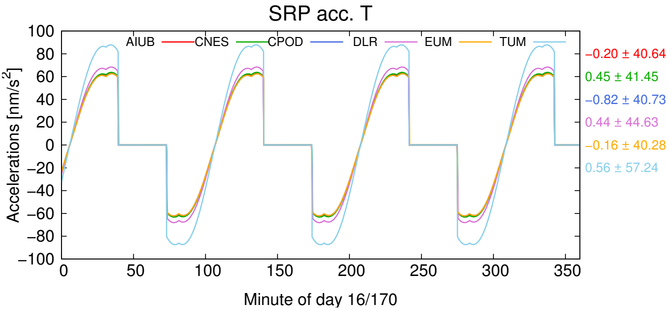

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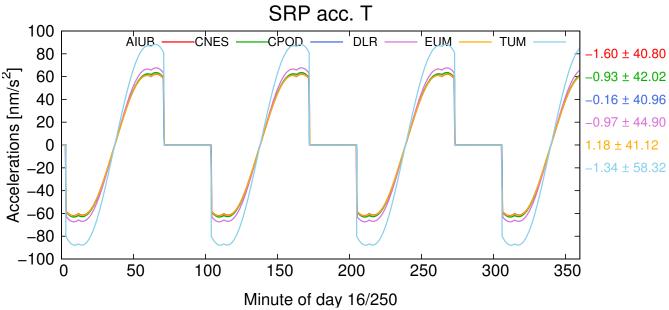

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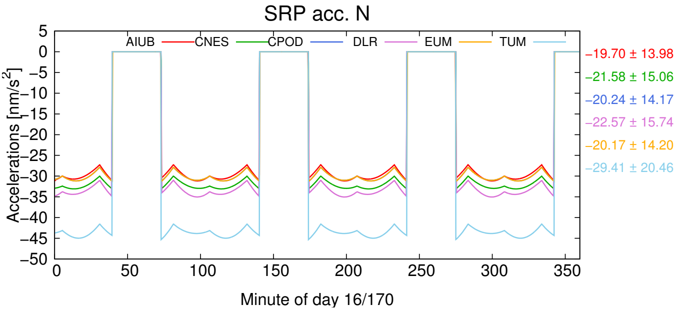

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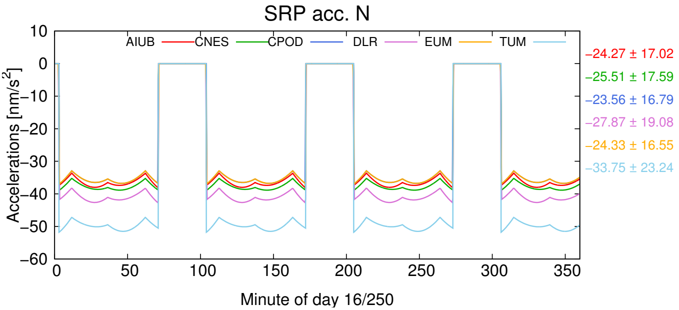

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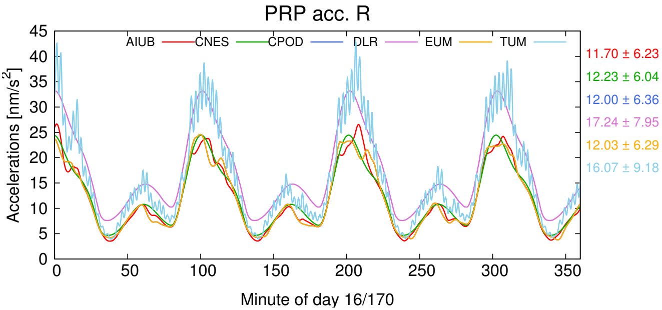

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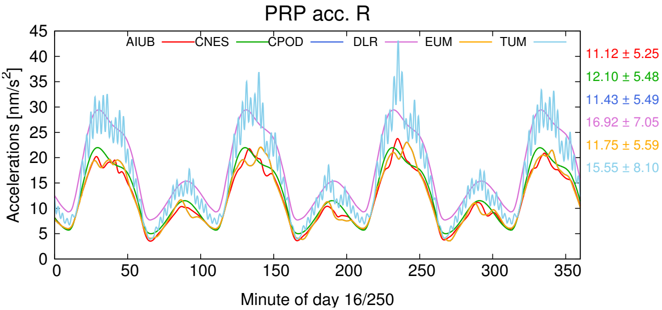

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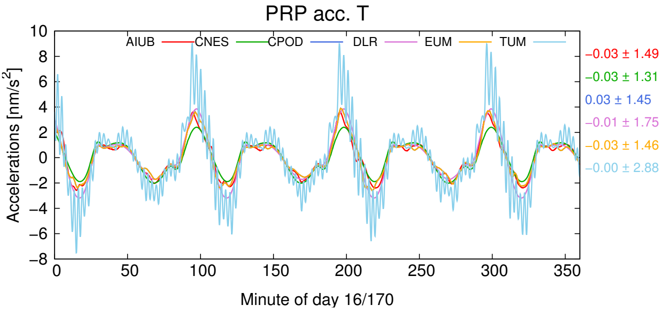

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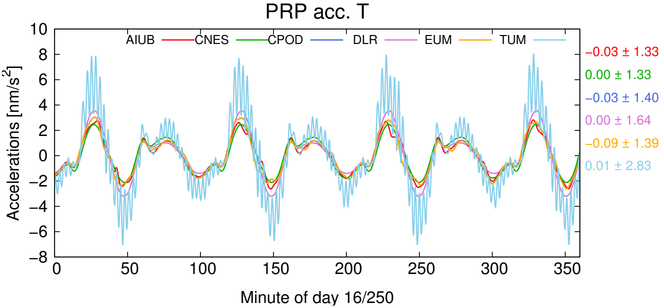

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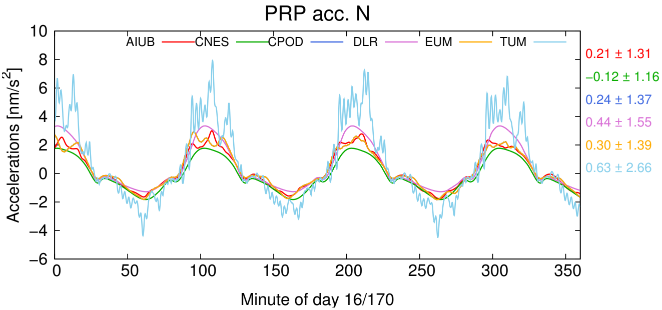

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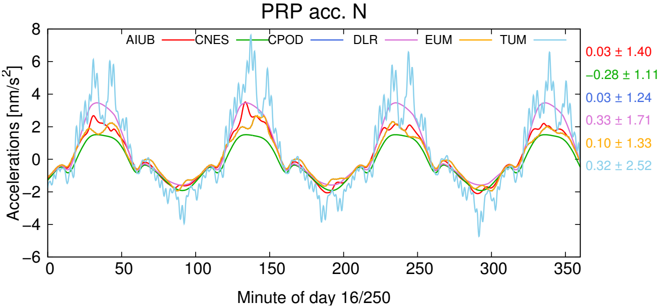
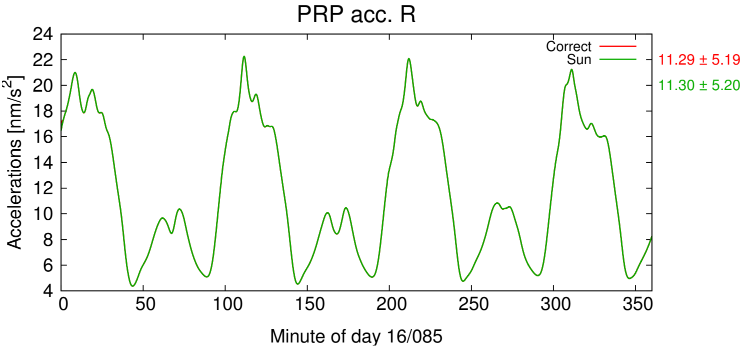


PRP: Solar panel orientation

Impact of solar panel orientation. "Correct": Optimal possible solar panel orientation. "Sun": Solar panel perfectly perpendicular to the Sun direction.



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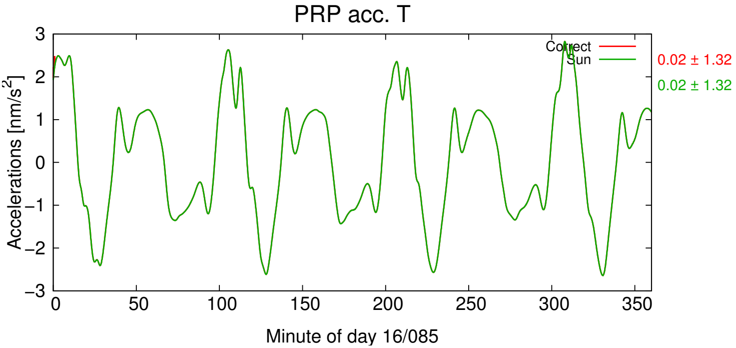

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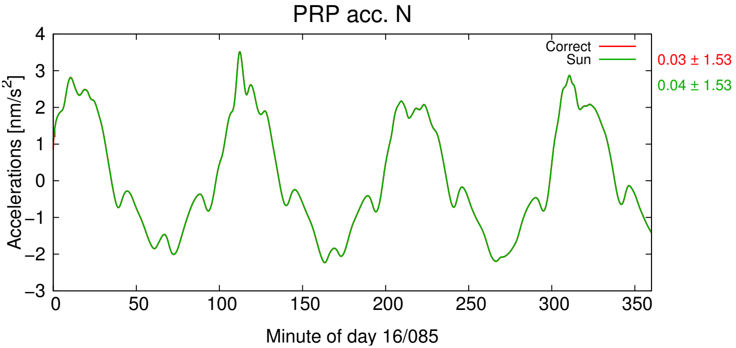

Daniel Arnold: An inter-agency comparison of non-gravitational force modeling for Sentinel-3A
COSPAR Scientific Assembly, July 16, 2018

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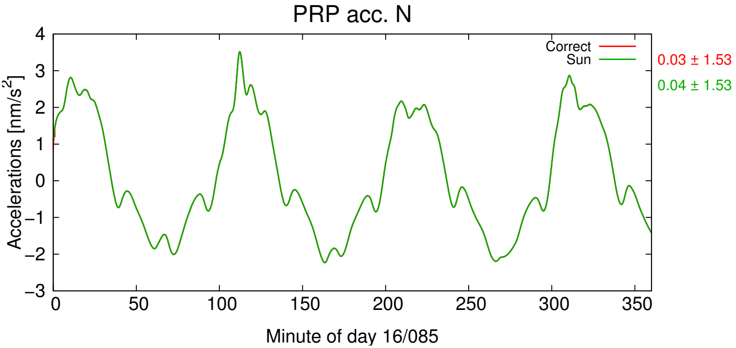
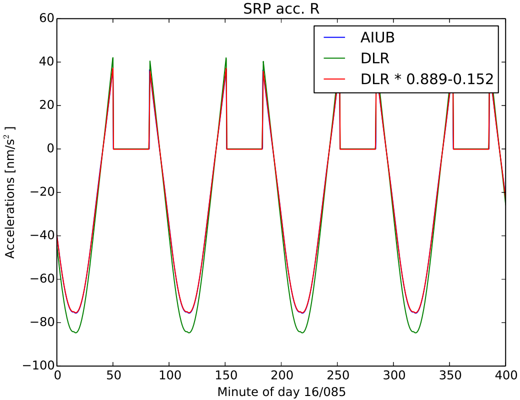


→ Impact negligible (as for SRP)

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:



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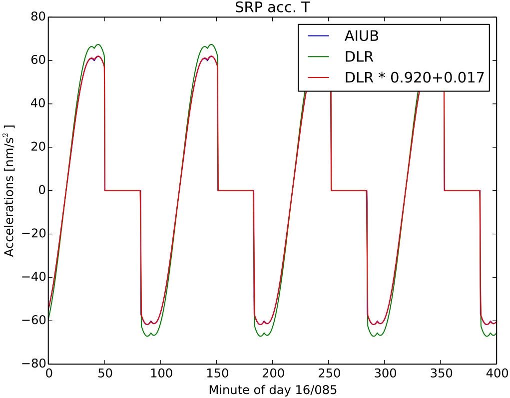

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