Validating radiation pressure force models for GRACE with SLR

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BACKGROUND

What force model is the best one? Precise **radiation pressure (RP) force models** are crucial for precise orbit determination (POD). However, a validation remained difficult. For GRACE, a comparison to measured non-gravitational accelerations is possible, but separating residual effects of the calibration procedure from errors in the radiation pressure force model is challenging[2]. Here, we perform a **validation** of modeled RP accelerations **against independent satellite laser ranging (SLR) data,** which do not require such calibration.

TWO STEP APPROACH

1. POD with kinematic orbits as input. Gravitational background models (Tab. 1), fixed aerodynamic model, **RP model**
2. Compute **residuals** between the derived **orbit and SLR** observations (Tab. 2)

Tab.1: Gravitational background models[1].

Force Model	Description
Gravity field, static	GOCO06s (Kvas et al. 2019) up to d/o 120
Gravity field, time-variable	ITSG2018 (Kvas et al. 2019) up to d/o 60
Atmosphere/ocean dealiasing	AOD1B RL06 (Dobslaw et al 2017)
Direct tides	JPL DE-421 ephemerides
Solid Earth tides	IERS Conventions 2010
Pole tides	IERS Conventions 2010
Pole ocean tides	Desai (2002)
Ocean tides	FES2014b + admittance waves
Atmospheric tides	AOD1B RL06

Tab. 2: Data and models for SLR processing[1].

Parameters	Description
Normal points	ILRS (Perlman et al. 2002)
Station coordinates	SLRF2014
Solid Earth tides	IERS Conventions 2010 (Petit & Luzum 2010)
Ocean tidal loading	FES2014b
Ocean nontidal loading, atmosphere (non)tidal loading	EOST Strasbourg (Boy et al. 2009)
Tropospheric delay	Mendes and Pavlis (2004)
Relativistic delay	IERS Conventions 2010

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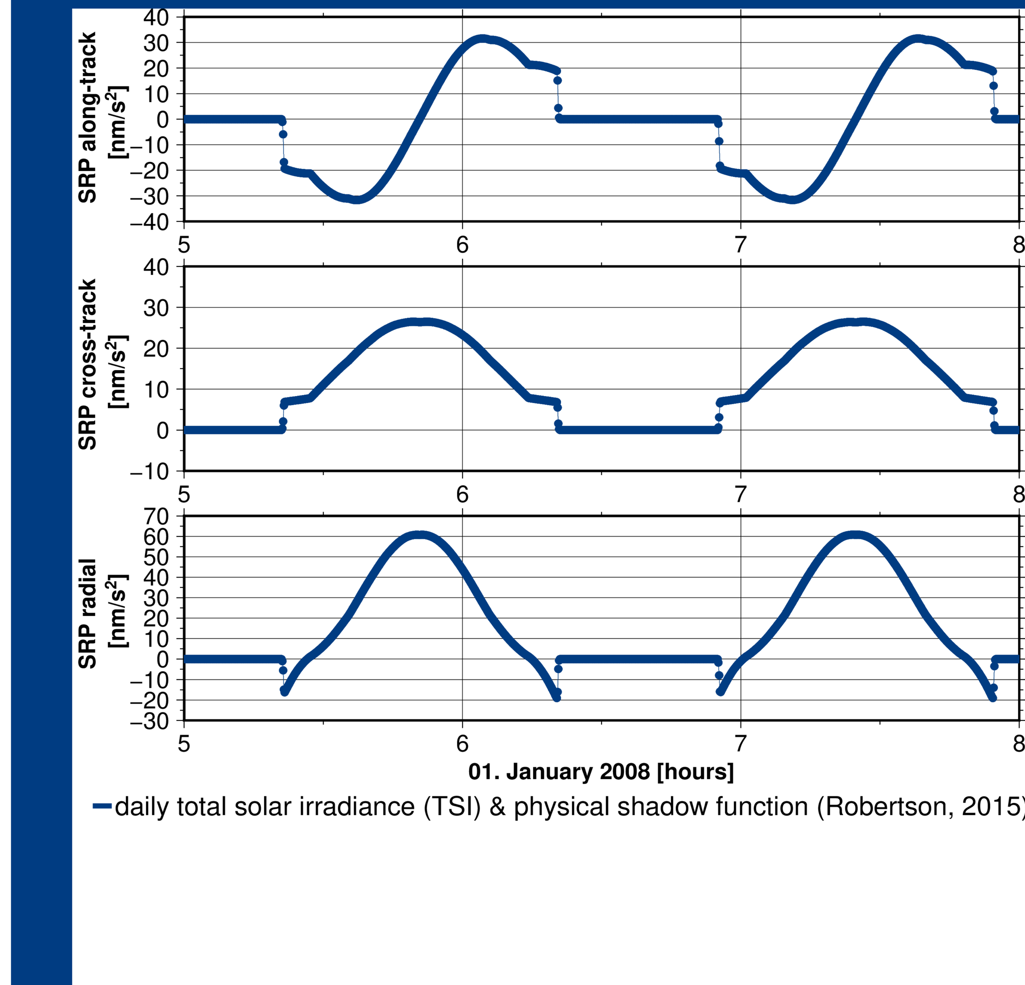
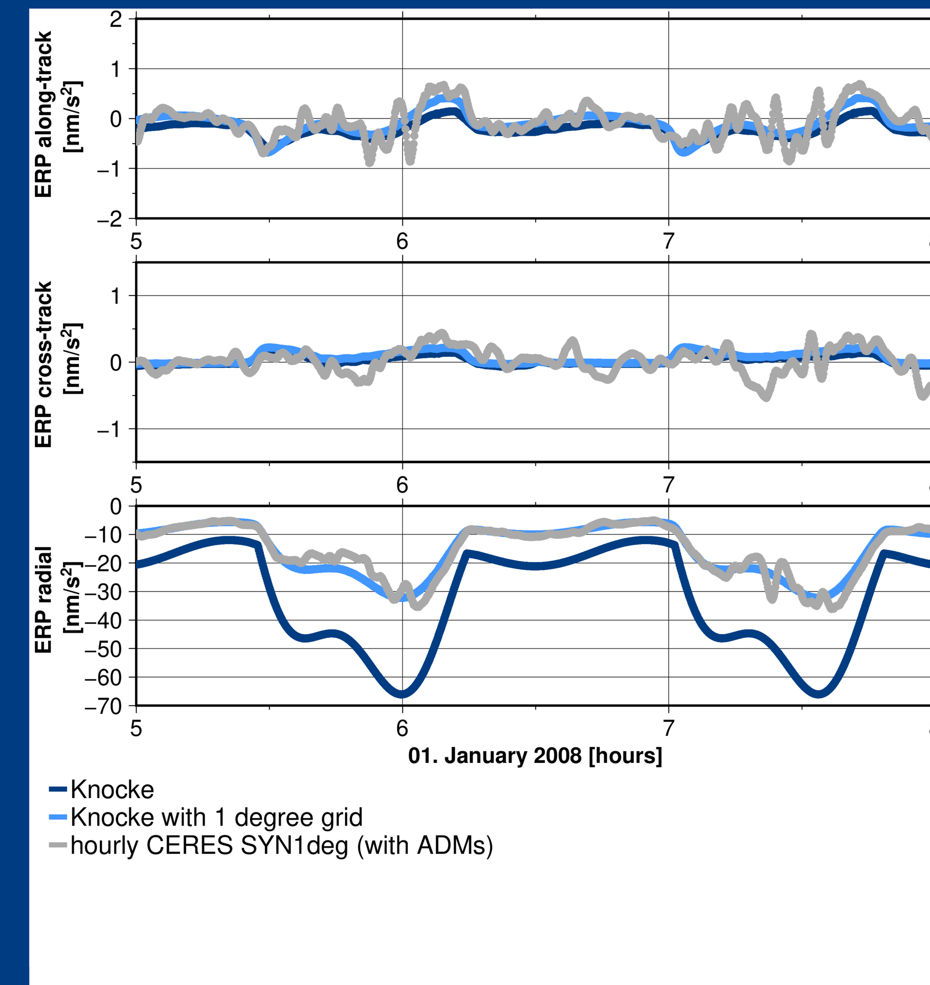
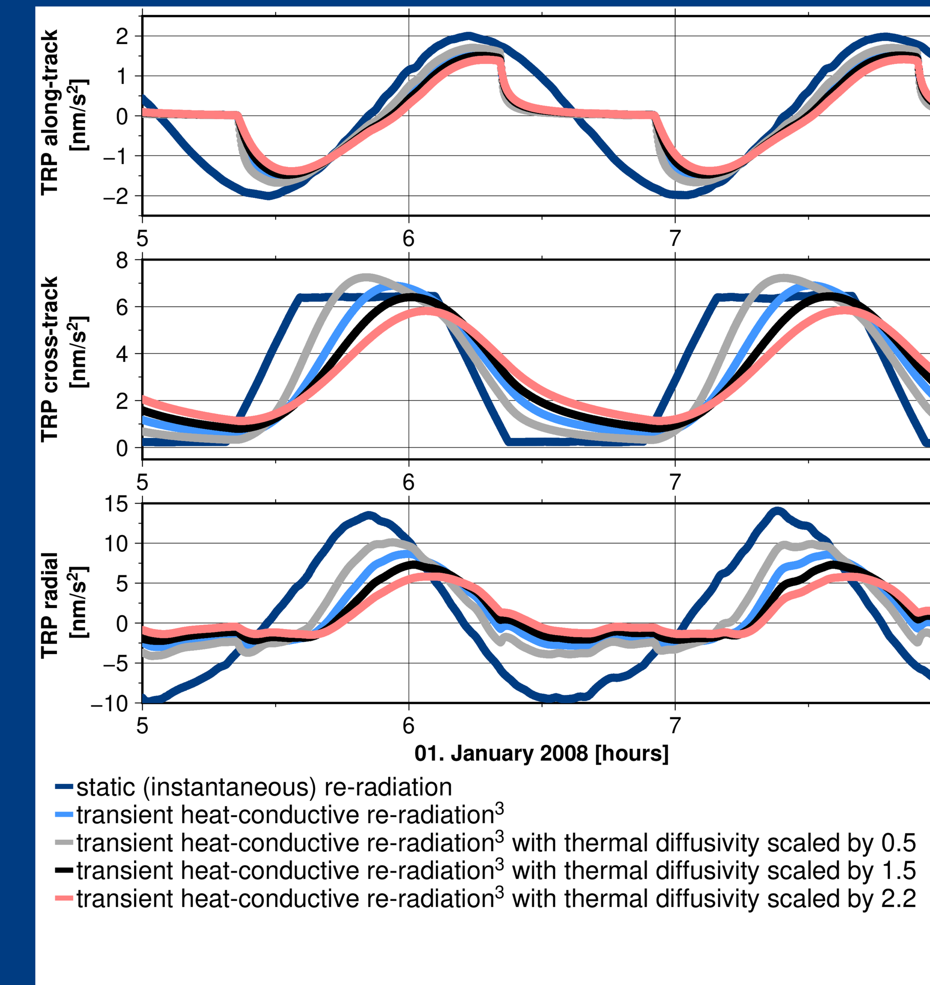
Solar radiation pressure (SRP)



Earth radiation pressure (ERP)



Thermal re-radiation pressure (TRP)



EXPERIMENT A

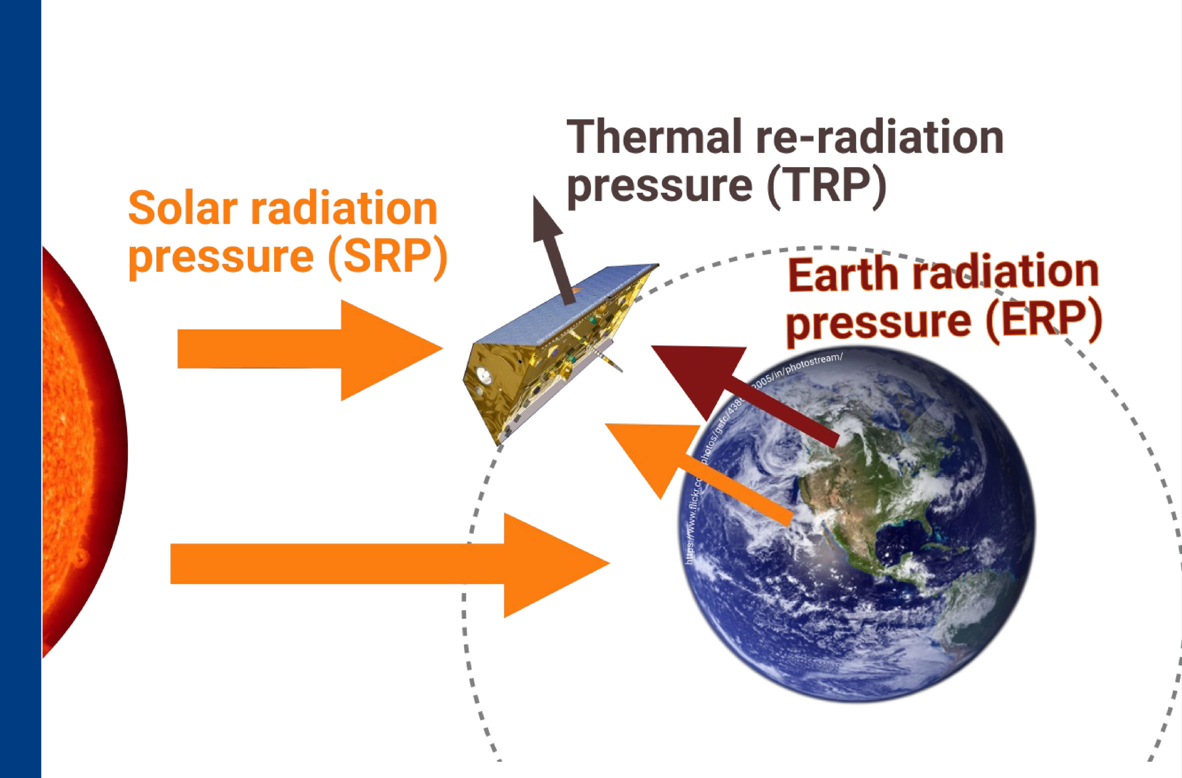
Repeat two step approach with different RP model versions, i.e., combinations of SRP+ERP+TRP, for GRACE-A with data for the whole year 2008.
An aerodynamic scale factor is coestimated.

RESULTS OF EXPERIMENT A

Version			RMS	Aero. scale
SRP	ERP	TRP	[cm]	[-]
TSI, physical shadow	Knocke	none	4.519	0.741
TSI, physical shadow	Knocke with 1 degree grid	none	2.801	0.703
TSI, physical shadow	CERES	none	2.737	0.701
TSI, physical shadow	CERES	static (instantaneous)	3.167	0.703
TSI, physical shadow	CERES	transient heat-conductive	2.409	0.700
TSI, physical shadow	CERES	transient heat-conductive*0.5	2.584	0.698
TSI, physical shadow	CERES	transient heat-conductive*1.5	2.335	0.701
TSI, physical shadow	CERES	transient heat-conductive*2.2	2.314	0.701

Tab. 3: Annual average of the RMS per pass of the residuals between SLR ranges and dynamic orbits for GRACE-A estimated using different RP model versions for the whole year 2008 and coestimated aerodynamic scale factor for the NRLMSIS 2.0 model .

- Non-gravitational force modeling for GRACE including heat-conductive thermal re-radiation with fitted thermal diffusivity **decreases the SLR residuals by 36%** compared to using instantaneous re-radiation and by 4% without fitting the thermal diffusivity.
- Considering the Earth's outgoing radiation on a **1° grid instead of the Knocke model decreases the SLR residuals by 38%.**
- The aerodynamic scale factor is highly correlated with the SLR residuals (0.93).



EXPERIMENT B

For comparison, the modeled non-grav. accelerations (aero+RP) are replaced with (calibrated) accelerometer data.

RESULTS OF EXPERIMENT B

Tab. 4: Annual average of the RMS per pass of the residuals between SLR ranges and kinematic or estimated dynamic GRACE-A orbits for the whole year 2008.

Orbit version	RMS [cm]
Kinematic orbit	1.29
Dynamic orbit (1d bias, mission scale²)	4.75
Dynamic orbit (3h bias)	2.54
Dynamic orbit (3h bias, 1d scale)	2.24
Dynamic orbit (1h bias)	1.85
Dynamic orbit (without any non-gravitational accelerations)	754.17

- Non-gravitational forces are essential for a successful POD, since without them the SLR residuals are above 7m.
- The **choice of the accelerometer calibration** strongly impacts the orbit solution.
- Increasing the temporal resolution of the **accelerometer bias** estimate reduces the SLR residuals. When applying a 1h bias, the solution is closest to the kinematic orbit.

References

[1] Löcher, A. and J. Kusche. "A hybrid approach for recovering high-resolution temporal gravity fields from satellite laser ranging." In: Journal of Geodesy 95.6 (2021). doi:10.1007/s00190-020-01460-x.

[2] Vielberg, K. and J. Kusche. "Extended forward and inverse modeling of radiation pressure accelerations for LEO satellites." In: Journal of Geodesy 94.4 (2020). doi:10.1007/s00190-020-01368-6.

[3] Wöske, F., T. Kato, B. Rievers, and M. List. "GRACE accelerometer calibration by high precision non-gravitational force modeling." In: Advances in Space Research 63.3 (2019), pp. 1318–1335. doi:10.1016/j.asr.2018.10.025.