Long-term evaluation of estimated solar radiation pressure coefficients from Copernicus Sentinel-1, -2, -3 satellites

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Introduction / Abstract

The Copernicus POD (Precise Orbit Determination) Service [1] is responsible for the generation of precise orbital products of the Copernicus Sentinel-1, -2, and -3 missions. The operational processing setup of the Copernicus POD Service has just (4 May 2020) been updated to state-of-the-art background models (geopotential, ocean tides and atmospheric gravity) and the use of single-receiver ambiguity fixing using CODE (Center for Orbit Determination in Europe) products => CPOD Service Sentinel POD settings (red box)
In the current orbit parametrization of the six satellites, a **solar radiation pressure (SRP) coefficient** is estimated for each daily arc. To provide long-term stability, in particular for the time series of the altimeter Sentinel-3 satellites, it would be preferable to use a **constant SRP** coefficient in the processing.

A reprocessing based on the updated models and set-up will be used to compute daily estimates of the SRP coefficient for all satellites. The analysis may reveal satellite model deficiencies and might help to improve the satellite macro-models.
Mean values of the SRP coefficients from the long-term series can be used on future operational processing. At the same time a refinement of the selection of the estimated orbit parameters might also be done if necessary, in particular the empirical accelerations. Impact on the orbit determination results and on the quality of the orbits is presented for all six satellites.

Test solutions

- **Current CPOD Service Sentinel POD settings** (see red box) are used for an offline reprocessing of all six Sentinel satellites from the beginning of the individual missions until the end of 2019.
- Exception: CODE rapid orbits, clocks and biases are replaced by GRGS final orbits, clocks and biases, because these products are available for the entire time span; before 29 Jan 2017 igs08.atx is used
- Solution id **SRPest:** no CPR parameters are estimated to get the pure SRP estimates
- Solution id **OPER**: solution as indicated in red box
- Solution id **SRPconst**: mean SRP estimates from **SRPest** solution are used as fixed values
- Solution id **SRPconstCRO**: mean SRP estimates from **SRPest** are used as fixed values, CRP cross-track constant parameters are added

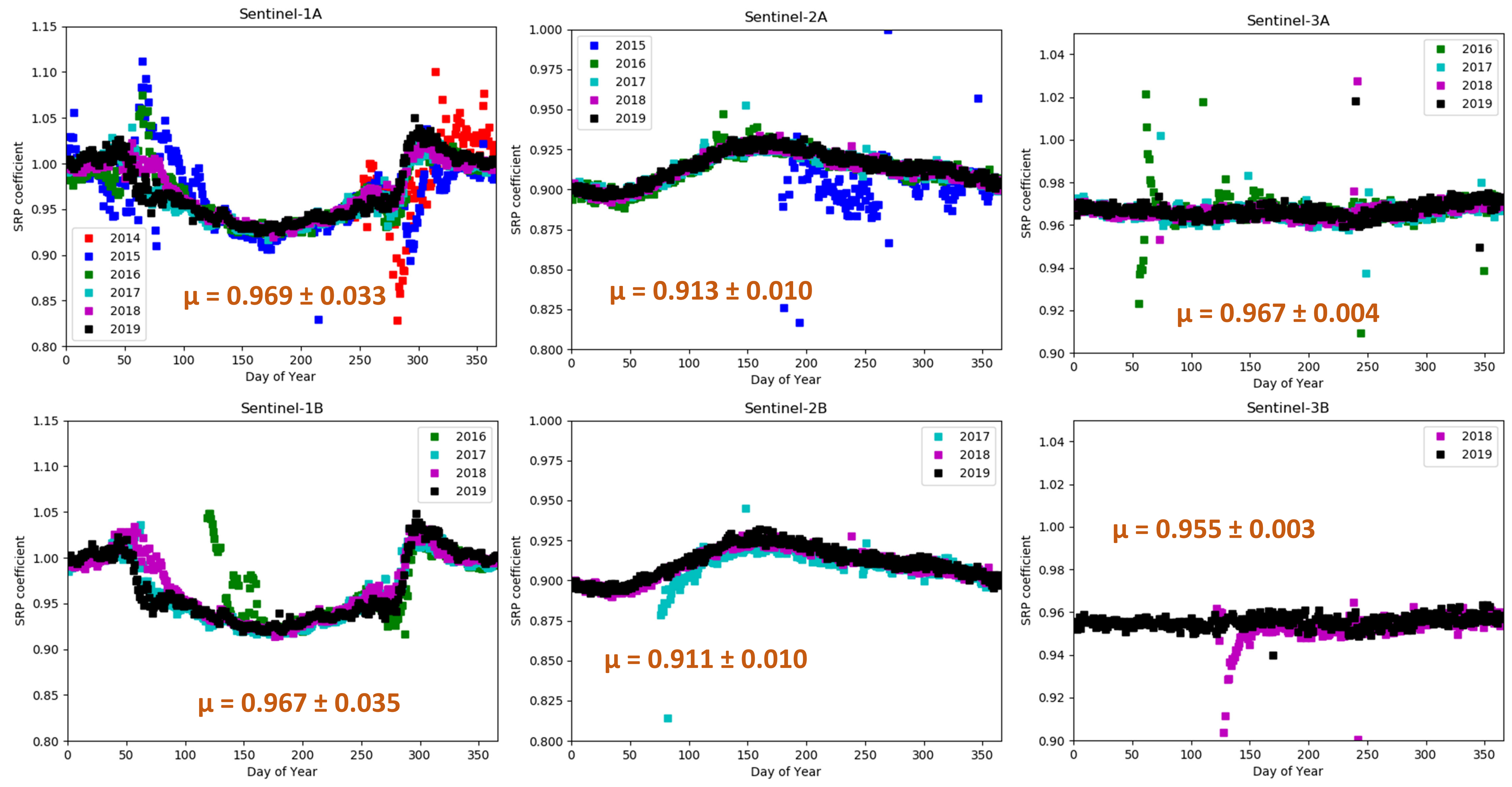
CPOD Service Sentinel POD settings

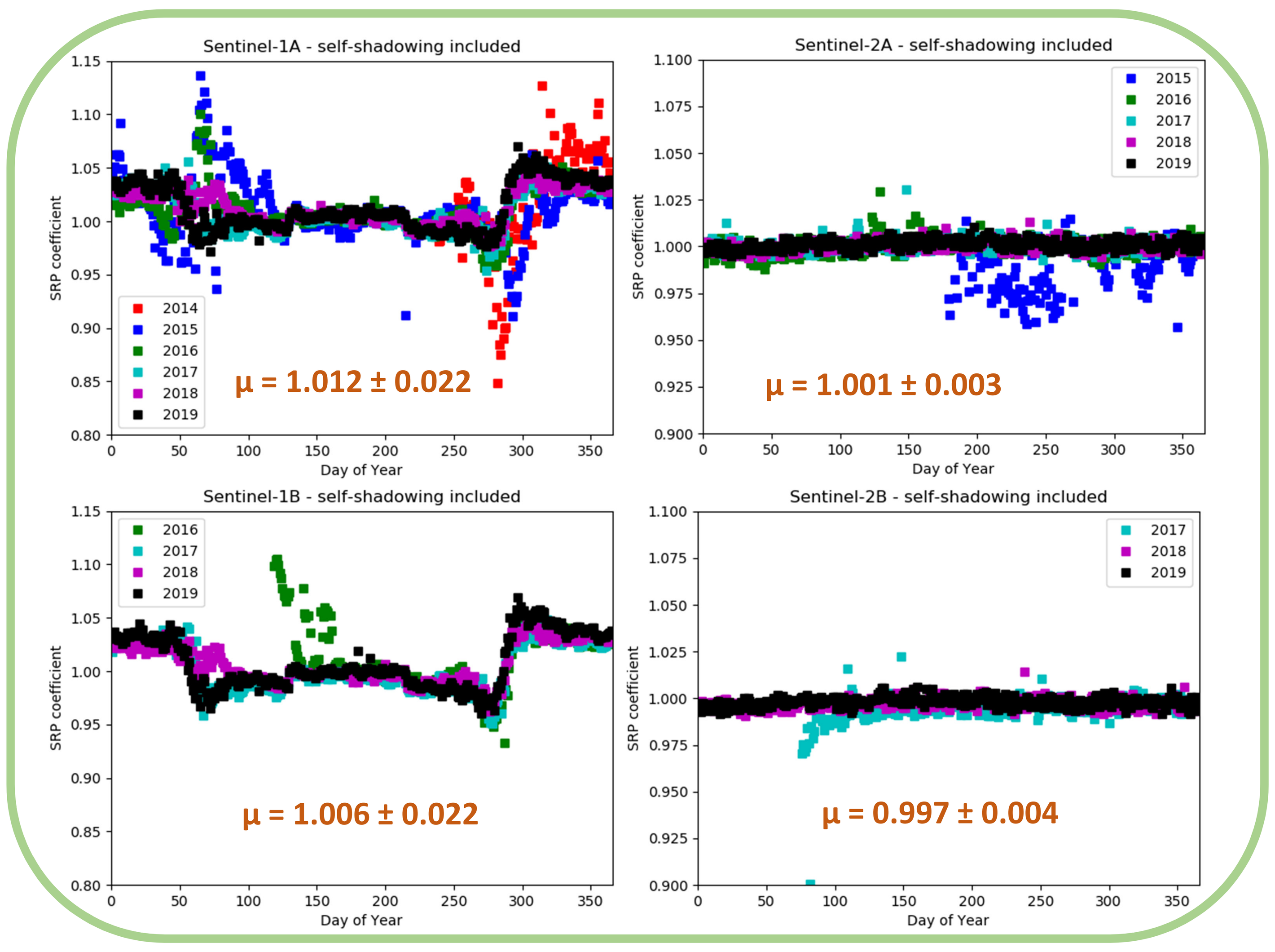
- NAPEOS (NAvigation Package for Earth Orbiting Satellites)
- IERS2010 conventions
- GPS: CODE rapid orbits, clocks (30 s), and biases; igs14.atx
- Sentinel: 10 s GPS data, 1° x 1° PCVs, ambiguity-fixed solution
- 32 h arc;
  - S3: 19:00 (day-1) – 03:00 (day+1)
  - S1&S2: 20:00 (day-1) – 04:00 (day+1)
- EIGEN.GRGS.RL04 gravity field (120 x 120), time-variable coefficients (50 x 50)
- FES2014 ocean tides (100 x 100)
- GFZ AOD L1B, atmosphere tides from GFZ AOD product

- Satellite macro model for non-gravitational force modelling
- Atmosphere model MSISE00 + HWM14, 15 drag coefficients per arc
- Earth albedo and IR radiation
- **One solar radiation pressure (SRP) coefficient per arc**

- Empirical CPR (cycle-per-revolution) parameters: three sets/arc
  - along-track sine + cosine, cross-track sine + cosine

Solar radiation pressure coefficient estimates from SRPest solutions – different scales !!!





- SRP estimates are constant over the different years.
- S1A/B (top): high seasonal variations; insufficient satellite model ?
- S2A/B: small seasonal variations
- S3A/B: very constant during the year
- Mean values μ w/o first calendar year of operations, except S-2B and S-3B (all data)
- S1A/B + S2A/B (left): additional solutions with macro model including self-shadowing [2],[3]; seasonal variations reduced for both missions; variations for S1A/B are still significant; S2A/B => „perfect“

RMS of 2h orbit overlaps (cm)

	radial	along-track	cross-track	3D
S1A / S1B				
OPER	0.18 / 0.17	0.45 / 0.42	0.22 / 0.24	0.55 / 0.53
SRPconst *	0.18 / 0.17	0.45 / 0.42	0.23 / 0.25	0.56 / 0.53
SRPconstCRO*	0.18 / 0.17	0.45 / 0.42	0.28 / 0.29	0.58 / 0.56
S2A / S2B				
OPER	0.15 / 0.15	0.37 / 0.38	0.22 / 0.24	0.46 / 0.49
SRPconst*	0.15 / 0.15	0.36 / 0.38	0.22 / 0.24	0.46 / 0.48
SRPconstCRO*	0.15 / 0.15	0.37 / 0.38	0.27 / 0.28	0.49 / 0.51
S3A / S3B				
OPER	0.21 / 0.23	0.46 / 0.50	0.26 / 0.30	0.59 / 0.65
SRPconst	0.21 / 0.23	0.46 / 0.50	0.26 / 0.30	0.58 / 0.64
SRPconstCRO	0.20 / 0.22	0.46 / 0.50	0.30 / 0.33	0.60 / 0.65

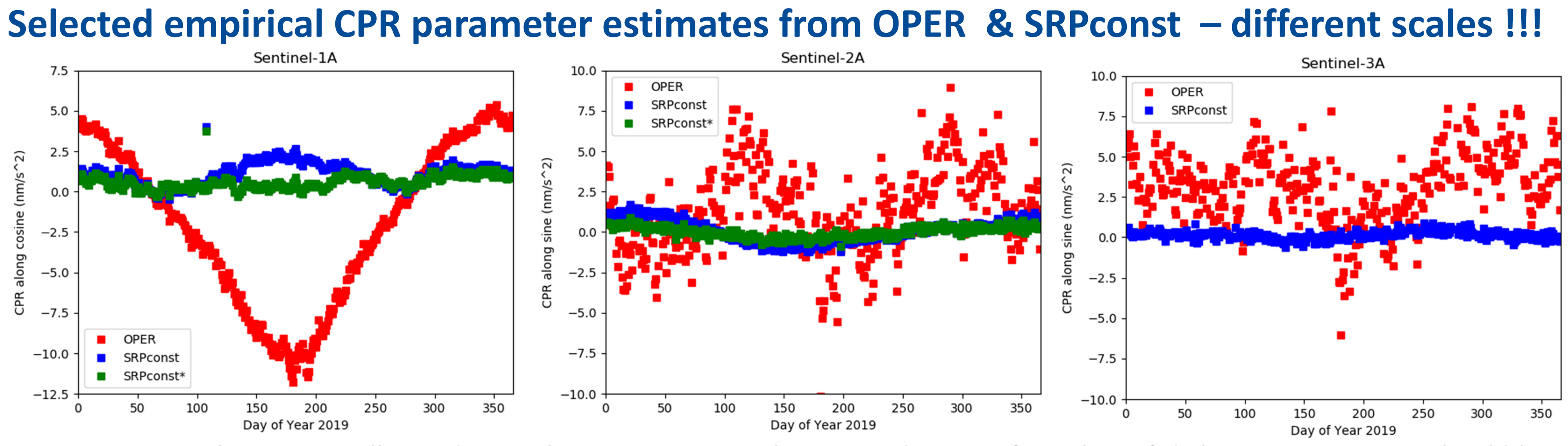
- * self-shadowing included
- Orbit overlaps are very similar for the different solutions
- **SRPconstCRO** slightly worse than others

Orbit comparisons (cm)

	radial	along-track	cross-track	3D
S2A / S2B vs. Combined orbit solution – Years 2018/2019				
OPER	0.40 / 0.44	0.77 / 0.79	0.55 / 0.58	1.04 / 1.08
SRPconst*	0.38 / 0.41	0.77 / 0.77	0.56 / 0.60	1.03 / 1.06
SRPconstCRO*	0.40 / 0.42	0.77 / 0.77	0.55 / 0.60	1.03 / 1.07
S3A / S3B vs. Combined orbit sol. – 2018/2019, S3B from 23 May 2018				
OPER	0.45 / 0.38	0.74 / 0.72	0.67 / 0.54	1.10 / 0.98
SRPconst	0.46 / 0.36	0.74 / 0.71	0.60 / 0.54	1.07 / 0.97
SRPconstCRO	0.46 / 0.36	0.74 / 0.71	0.66 / 0.55	1.10 / 0.98
S3A / S3B vs. CNES POE – from 10 Nov 2018 until end of 2019				
OPER	0.43 / 0.46	0.93 / 0.96	0.55 / 0.53	1.16 / 1.20
SRPconst	0.43 / 0.45	0.92 / 0.96	0.52 / 0.51	1.15 / 1.18
SRPconstCRO	0.43 / 0.45	0.92 / 0.96	0.58 / 0.58	1.18 / 1.22

- * self-shadowing included
- Orbit comparisons are also very similar for the different solutions
- **SRPconst** slightly better than others

Selected empirical CPR parameter estimates from OPER & SRPconst – different scales !!!



- CPR parameters become smaller and smoother in **SRPconst** solutions, reduction of number of daily CPR parameters should be investigated.

Summary

The estimates of the solar radiation pressure (SRP) coefficients for all six Copernicus Sentinel-1,-2, and -3 satellites are very consistent over the years. The values for Sentinel-2 and -3 are also constant over the year showing a very good agreement with the satellite model used. The estimates for Sentinel-1 show seasonal variations, which cannot fully be removed by including self-shadowing into the satellite model.
Using constant and fixed SRP coefficients in precise orbit determination is feasible for Sentinel-2 and -3. It is also possible for Sentinel-1 but further analyses should be done to reduce the seasonal variations of the SRP estimates and to improve the satellite model used.
Reduction of the number of empirical CPR estimates will be a topic for further investigations as well.

References:
[1] Fernández J., Escobar D., Águeda A. et al., 2014. Sentinels POD service operations. In: SpaceOps 2014 Conference, SpaceOps Conferences, AIAA 2014-1929. https://dx.doi.org/10.2514/6.2014-1929.
[2] Peter H., Fernández J., Féménias P., 2020. Copernicus Sentinel-1 satellites: sensitivity of antenna offset estimation to orbit and observation modelling, Adv.Geosci., 50,87-100, https://dx.doi.org/10.5194/adgeo-50-87-2020.
[3] Peter H., Fernández J., Otten M., Féménias P., 2018. Improved box-wing modelling for the low Earth orbiting Sentinel satellites, Presentation at 42nd COSPAR Scientific Assembly, 14-22 July 2018, Pasadena, CA

Poster compiled by H. Peter, April 2020
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