Improved box-wing modelling for the low Earth orbiting Sentinel satellites

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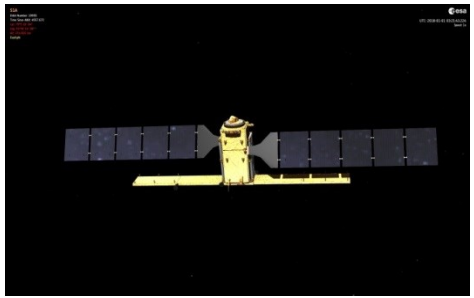

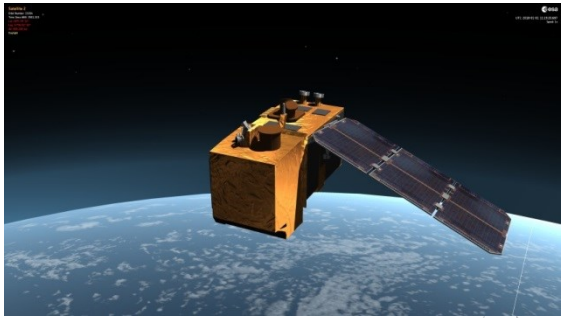

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Introduction

- The **Copernicus POD Service** is responsible to provide **accurate orbit and attitude products** to the PDGSs of the **Sentinel-1**, **-2**, and **-3** satellites.

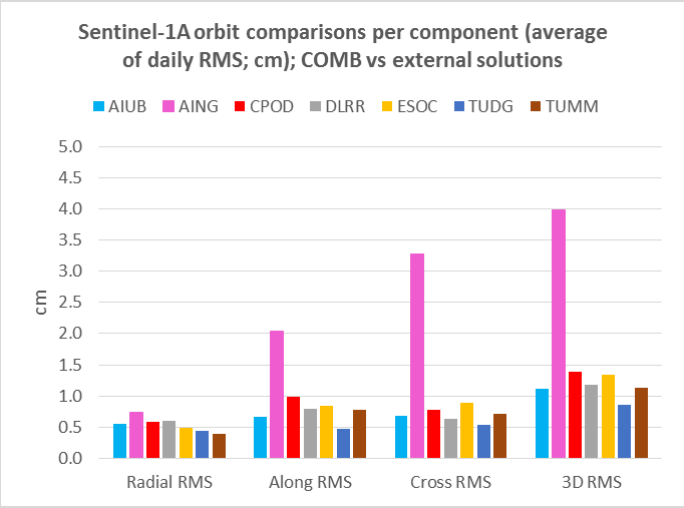
- Software core is NAPEOS (NAvigation Package for Earth Observation Satellites)

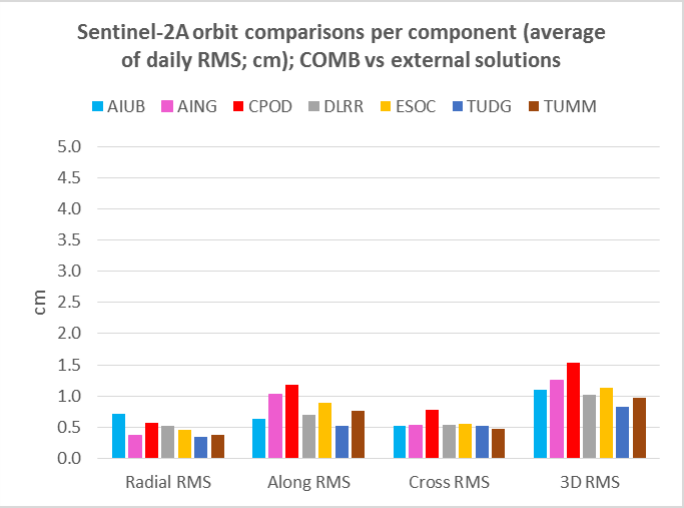
- Reduced-dynamic orbit determination approach is used:
  - Gravitational force modelling (time-variable gravity, ocean tides, solid Earth tides …)
  - Non-gravitational force modelling of **solar radiation pressure**, Earth radiation pressure, and atmospheric drag (possibility to estimate scale factors)
    - ➢ **Box-wing model of the satellites**
  - Compensation for model errors / mismodelling:
    - empirical parameters in three orbital directions (RTN, normally only T+N are used) with one cycle per revolution (CPR) period:
      - constant, sine and cosine

Sentinel missions – satellites description

	SENTINEL MISSIONS		
	Sentinel-1	**Sentinel-2**	**Sentinel-3**
Altitude	639 km	786 km	814.5 km
Inclination	98.18 deg.	98.58 deg.	98.65 deg.
Period	98.6 minutes	100.6 minutes	100.99 minutes
Cycle	12 days	10 days	27 days
Mass	2300 kg	1140 kg	1250 kg
GPS	2 GPS receivers	2 GPS receivers	2 GPS receivers
LRR	None	None	1 LRR
DORIS	None	None	1 DORIS
Attitude	Zero-Doppler + roll steering	Yaw steering	Yaw steering
Instruments	C-Band SAR	Multi-Spectral Instrument	Radar Altimeter, OLCI, Microwave Radiometer
Launch date	3rd April, 2014 (S1A) 22nd April, 2016 (S1B)	23rd June, 2015 (S2A) 7th March, 2017 (S2B)	16th February, 2016 (S3A) 25th April 2018 (S3B)
Picture			

Introduction

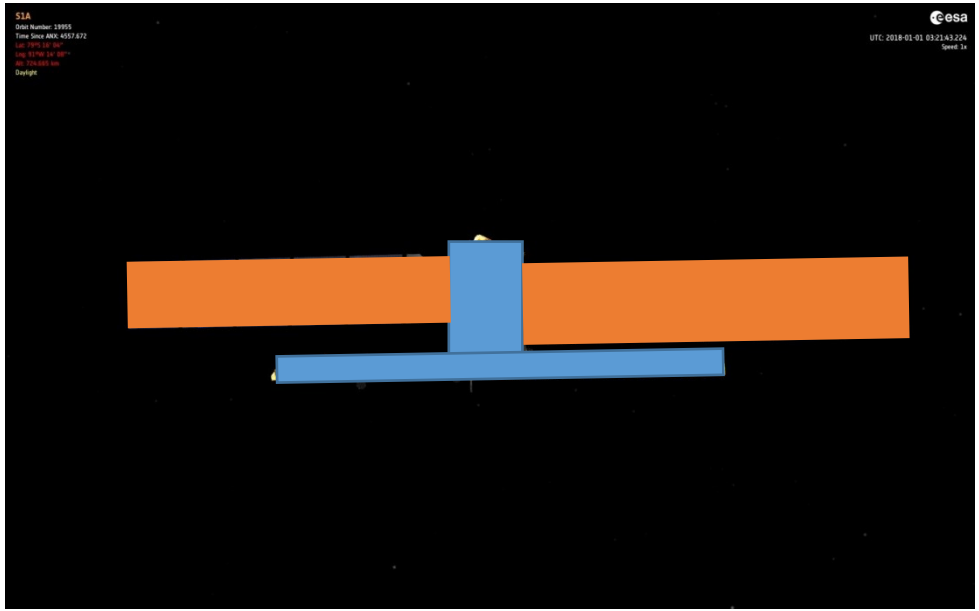




- Results from the last Regular Service Review – Feb-May 2018 orbit comparison between different orbit solutions
- Excellent quality of the CPOD orbits, nevertheless the ambition is to improve the orbit modelling to the extent possible

Updated box-wing modelling

Sentinel-1



- Aim of this work is to **improve** the **box-wing modelling** (and thus the dynamic orbit modelling)
- The **box-wing model** in NAPEOS does **not include** possible **self-shadowing effects**
  - Normal input are the surfaces of the satellite „box“ and the two sides of the solar „wing“
- For instance Sentinel-1 is a complex satellite with large surfaces close together (solar panel, SAR antenna)

Updated box-wing modelling

Sentinel-2

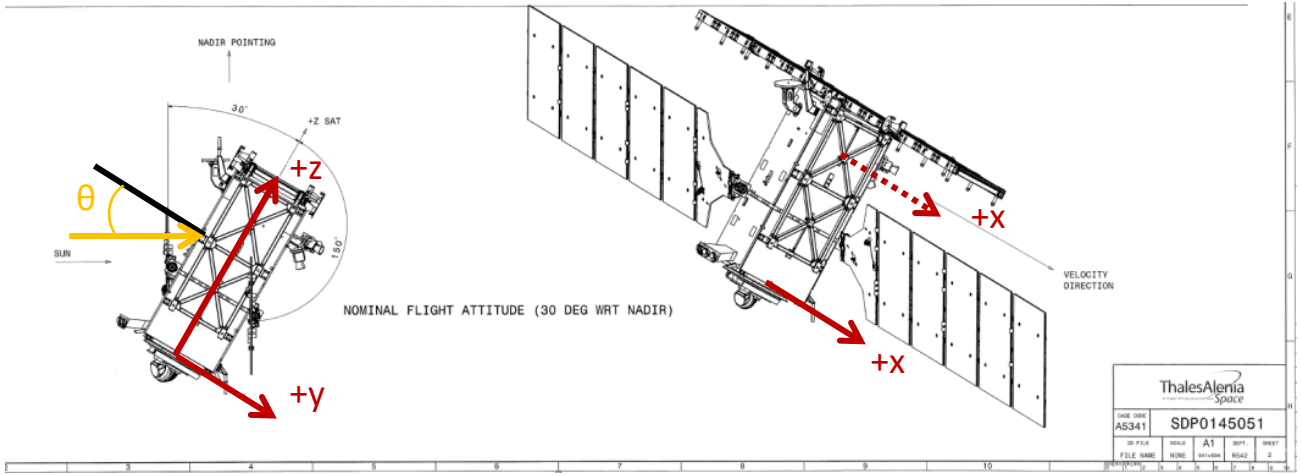
- Aim of this work is to improve the **box-wing modelling** (and thus the dynamic orbit modelling)
- The **box-wing model** in NAPEOS does **not include** possible **self-shadowing effects**
  - Normal input are the surfaces of the satellite „box“ and the two sides of the solar „wing“
- Sentinel-2 has a solar panel shadowing part of the surface below, percentage is changing due to rotation of the solar panel

- How can self-shadowing effects can be considered?
- What is the impact on the orbit modelling and on the results?

Updated box-wing modelling - preparations

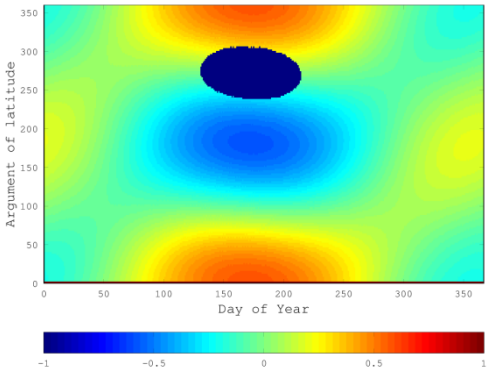
- **Sentinel-1**:
  - +x => velocity direction
  - +y => anti-sun direction
  - +z => observation direction of the SAR
  - Solar panel => fixed to 30° w.r.t. z-axis

- Visualize the sun income angle on the individual surfaces of the satellite to learn about possible shadowing effects for the **solar radiation pressure**
  - $-1 \leq \cos(\theta) \geq 1$:
    - values > 0 indicate sun light on the surface
    - value of 1 means sun light is perpendicular to surface plane (full solar radiation pressure)

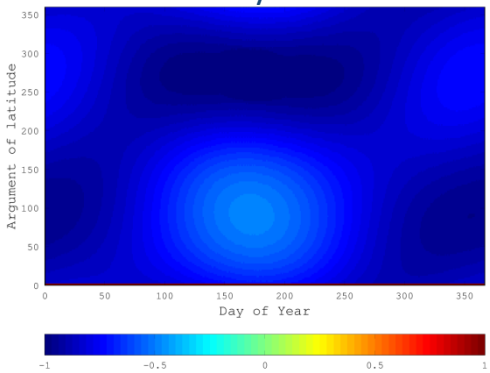


Sentinel-1

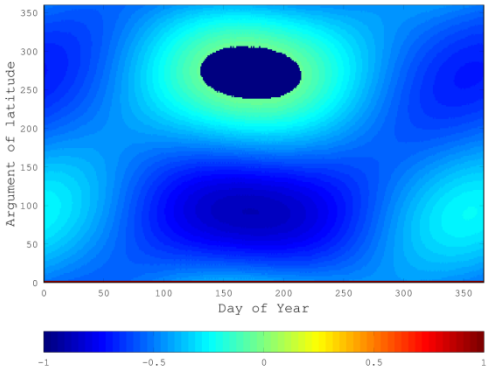
+x



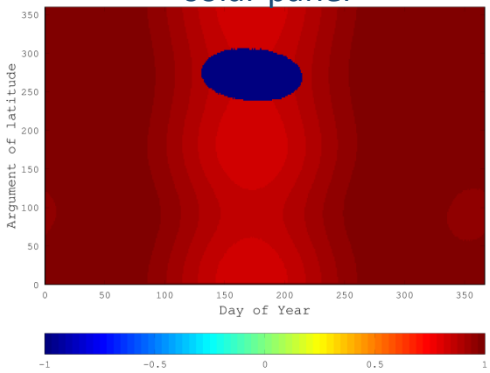
+y



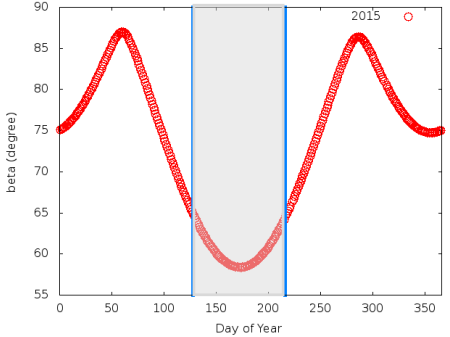
+z



+ solar panel

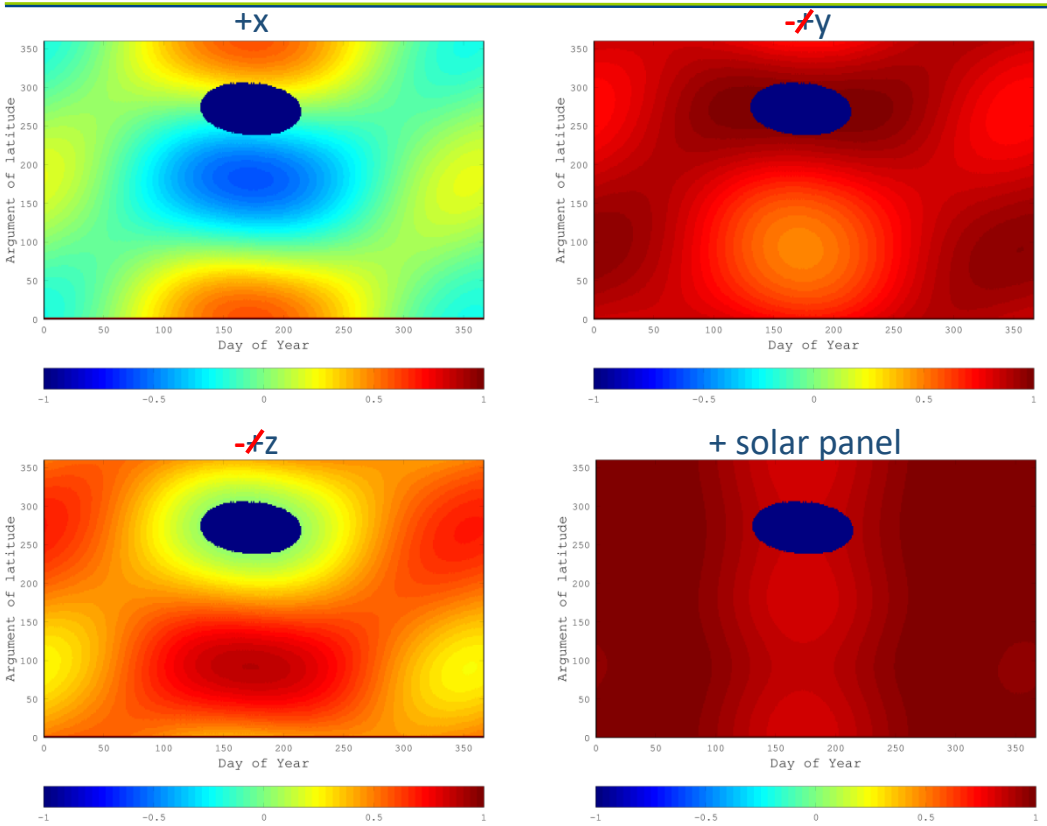


Beta angle of Sun over orbital plane

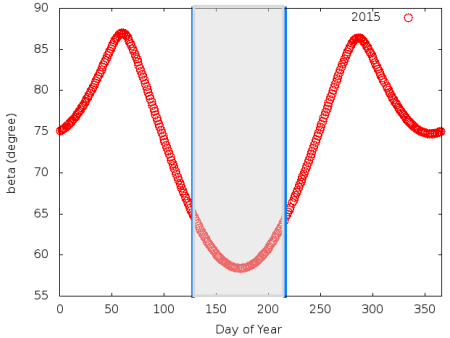


- +/-x surfaces experience largest changes during one orbital revolution, in particular during eclipse period
- +y/+z surfaces (and back of solar panel) are never in sunlight

Sentinel-1



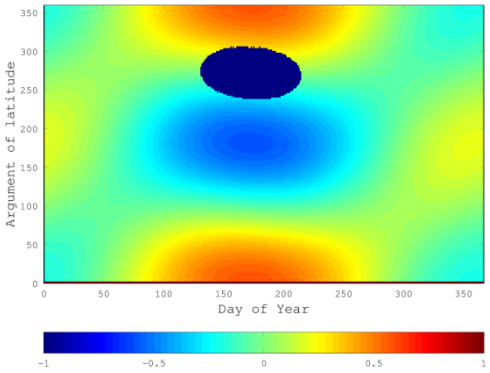
Beta angle of Sun over orbital plane



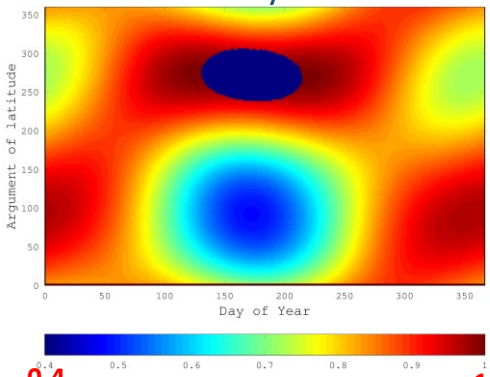
- +/-x surfaces experience largest changes during one orbital revolution, in particular during eclipse period
- +y/+z surfaces (and back of solar panel) are never in sunlight

Sentinel-1

+x

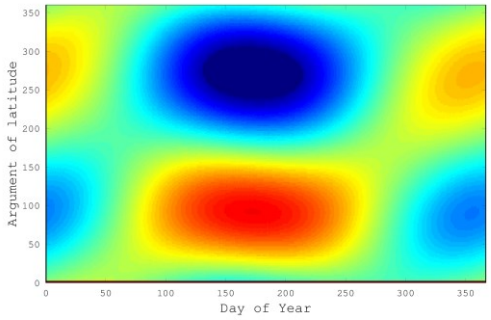


-~~+~~y



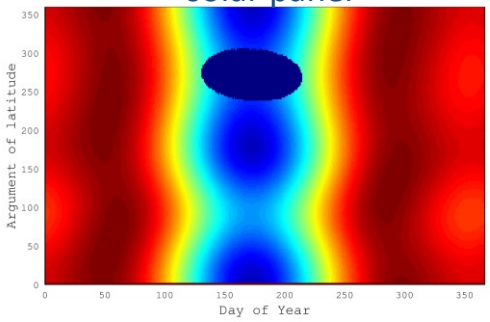
0.4 1

-~~+~~z



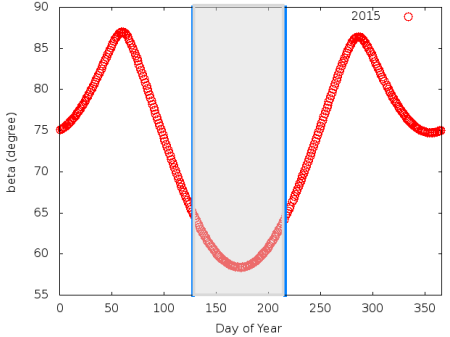
0 1

+ solar panel



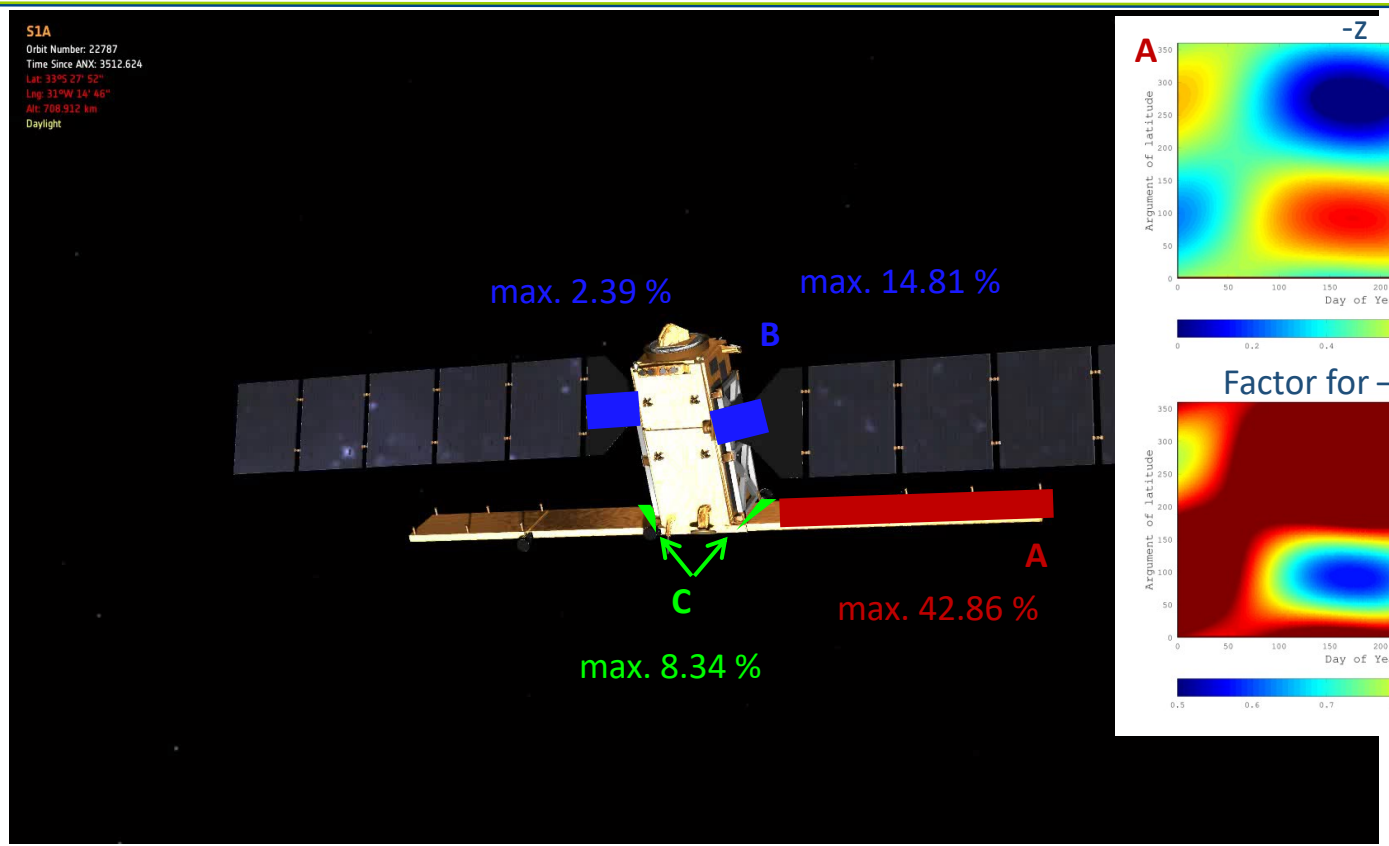
0.8 1

Beta angle of Sun over orbital plane



- +/-x surfaces experience largest changes during one orbital revolution, in particular during eclipse period
- +y/+z surfaces (and back of solar panel) are never in sunlight

Sentinel-1


S1A
Orbit Number: 22787
Time Since ANX: 3512.624
Lat: 33°S 27' 52"
Lng: 31°W 14' 46"
Alt: 708.912 km
Daylight
max. 2.39 %
max. 14.81 %
B
A
C
max. 42.86 %
max. 8.34 %

-Z
A
Argument of latitude
Day of Year
Factor for –z-area
Argument of latitude
Day of Year

Results – Sentinel-1A

- Sentinel-1A (results for Sentinel-1B are equivalent)
- Data: 1 Feb 2017 – 31 Jan 2018
- 24h arc
- Radiation pressure coefficient estimated

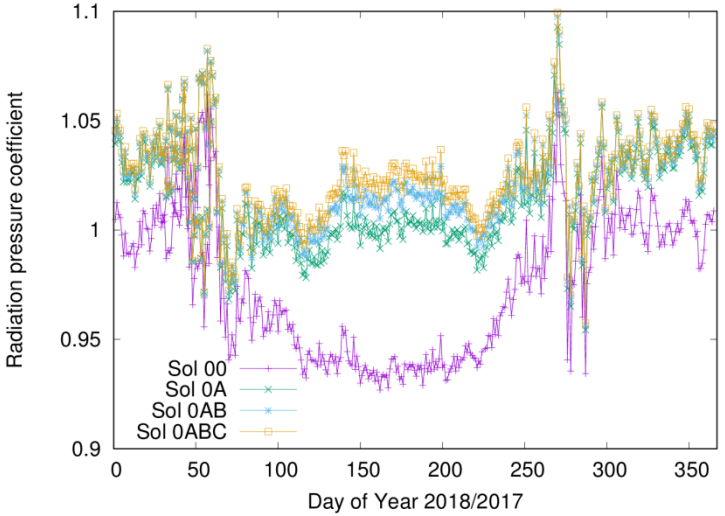
- Solution **00**: no shadowing considered
- Solution **0A**: Shadowing of zone A considered
- Solution **0AB**: Shadowing of zone A+B considered
- Solution **0ABC**: Shadowing of zone A+B+C considered

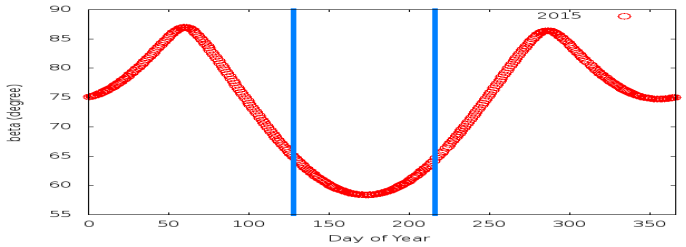
⇒ **Estimates of radiation pressure coefficient get more consistent over the year**

=> Solutions on next slides will include two (1/12h) sets of empirical CPR (cycle-per-revolution) parameters
- along-track sine+cosine
- cross-track sine+cosine

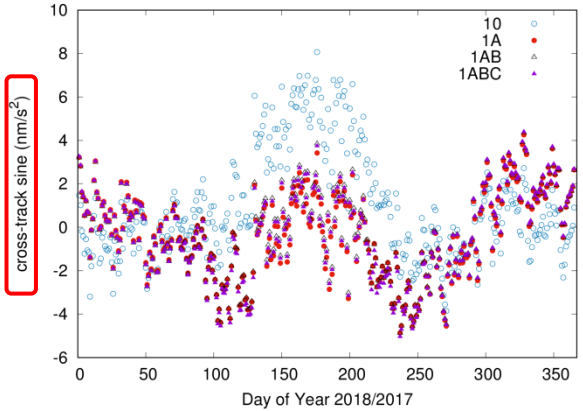
=> Solutions **10**, **1A**, **1AB**, **1ABC**

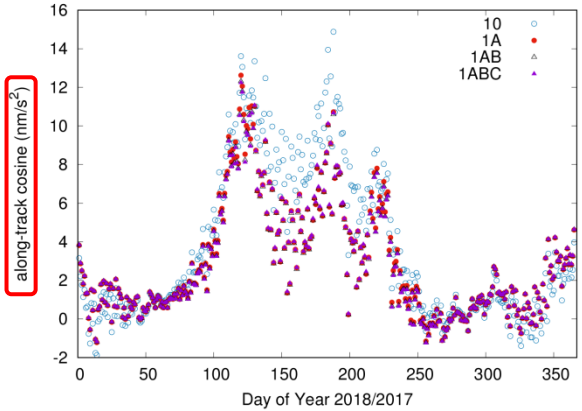
Radiation pressure coefficient





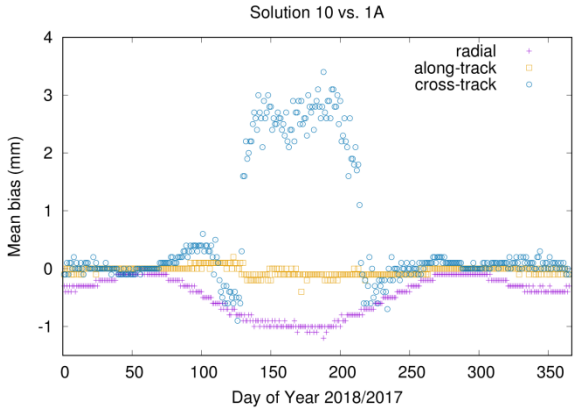
Orbit determination results – Sentinel-1A

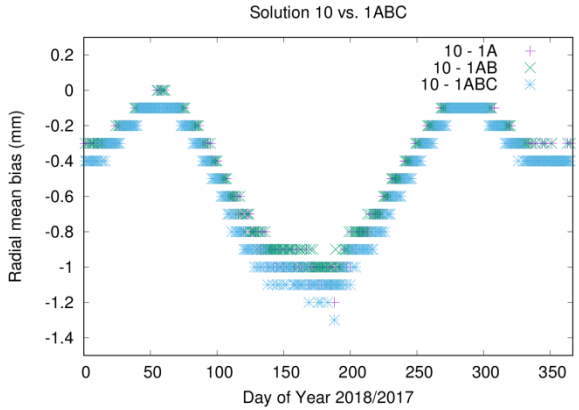


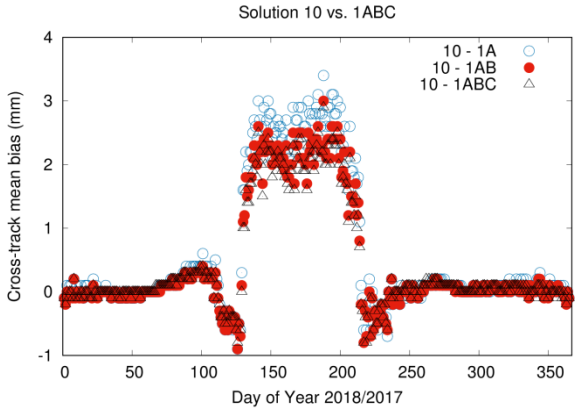


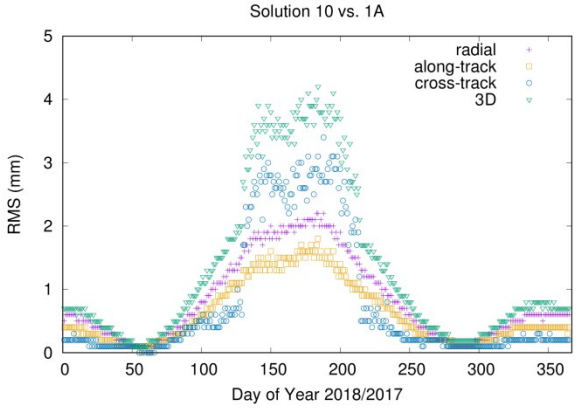
- Two of the empirical CPR parameters show improvements if self-shadowing is considered.
- Seasonal variations are still pronounced, in particular for the along-track cosine parameter.
- The other two CPR parameters (cross-track cosine, along-track sine) do not change significantly.

Orbit comparison results – Sentinel-1A









- Orbit differences due to shadowing included are below a few mm
- Cross-track mean offsets between the solutions are most pronounced during eclipse period

Orbit overlap results – Sentinel-1A

Mean RMS of overlaps at midnight (mm), 1 Feb 2017 - 31 Jan 2018

Solution	radial	along-track	cross-track	3D
10	9.54	20.51	**10.52**	27.98
1A	9.47	20.52	10.54	27.93
1AB	**9.45**	20.43	10.54	**27.83**
1ABC	**9.45**	**20.42**	10.53	**27.83**

- Improvements of overlap results are very small but measurable.

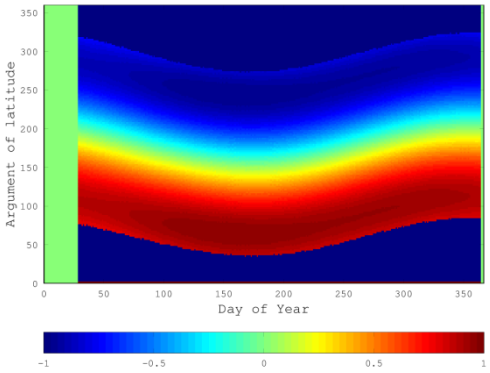
⇒ **Sentinel-1:** Considering self-shadowing improves the dynamic orbit modelling.

⇒ Updated dimensions of the satellite body and solar panels recently became available.

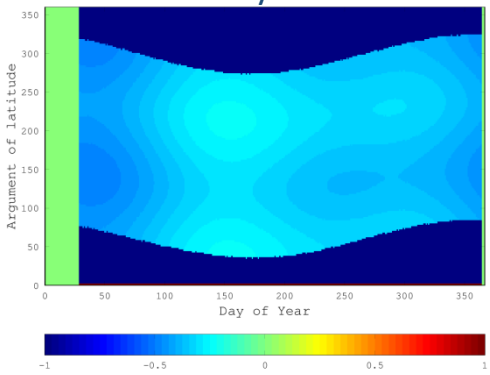
⇒ Review of the box-wing model itself is expected to further improve the results.

Sentinel-2

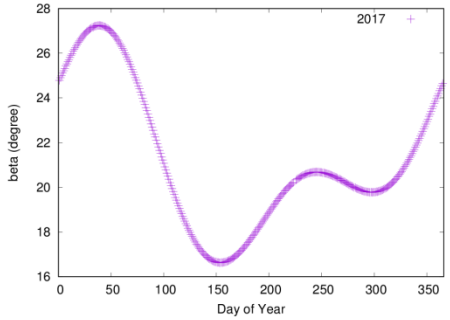
+x



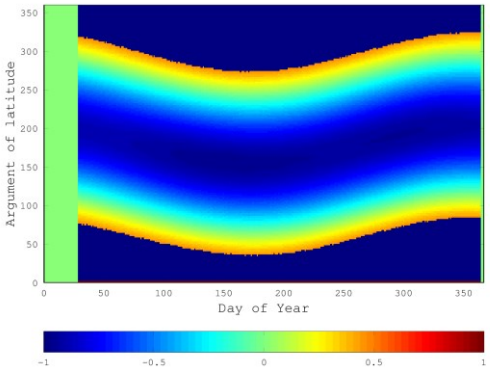
+y

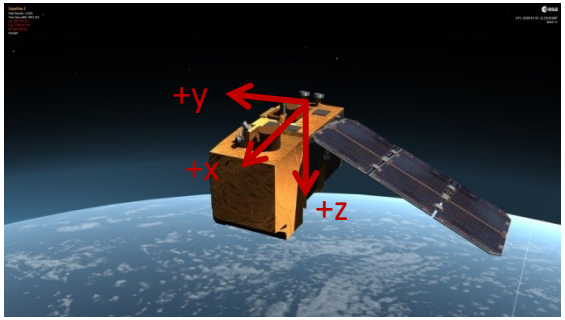


Beta angle of Sun over orbital plane



+z

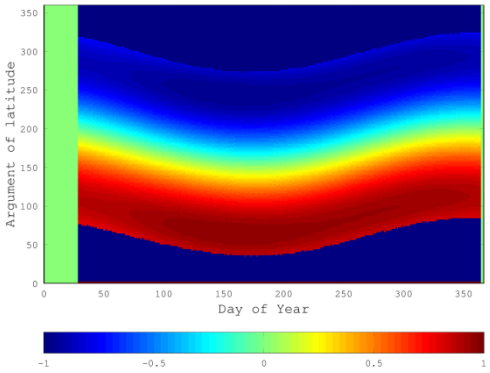




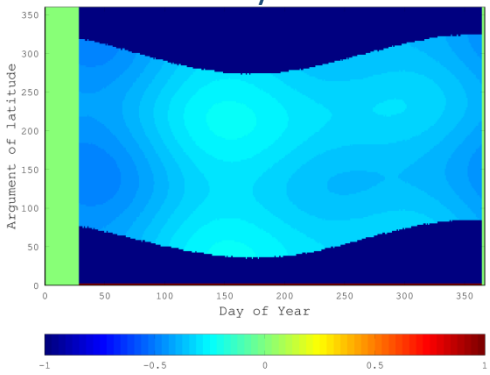
- eclipse during each orbital revolution
- +/-x surfaces experience largest changes during one orbital revolution
- +y/+z surfaces (and back of solar panel) are never in sunlight
- Solar panel is rotating to be optimally oriented to the Sun

Sentinel-2

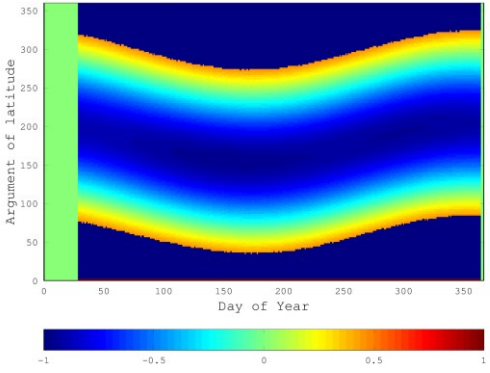
+x



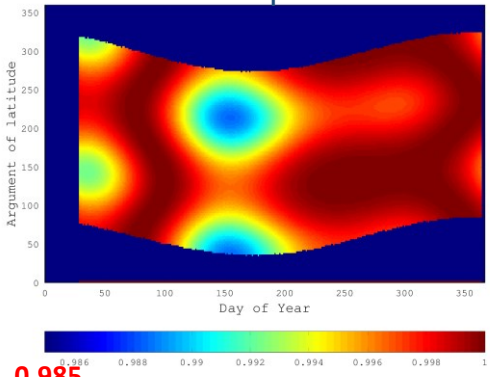
+y



+z

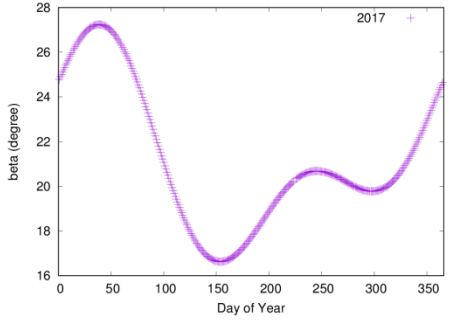


+ solar panel



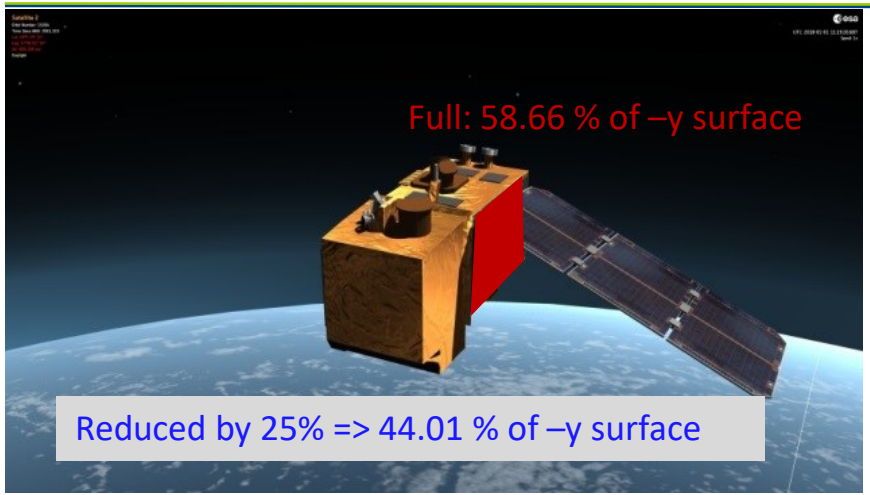
0.985

Beta angle of Sun over orbital plane



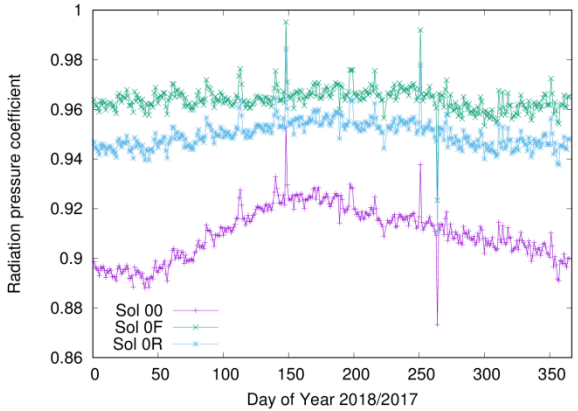
- eclipse during each orbital revolution
- +/-x surfaces experience largest changes during one orbital revolution
- +y/+z surfaces (and back of solar panel) are never in sunlight
- Solar panel is rotating to be optimally oriented to the Sun

Self-shadowing – Sentinel-2A



- Sentinel-2A (results for Sentinel-2B are equivalent)
- Data: 1 Feb 2017 – 31 Jan 2018
- 24h arc
- Radiation pressure coefficient estimated

- Solution **00**: no shadowing considered
- Solution **0F**: Full shadowing of –y surface considered
- Solution **0R**: Reduced shadowing of –y-surface considered

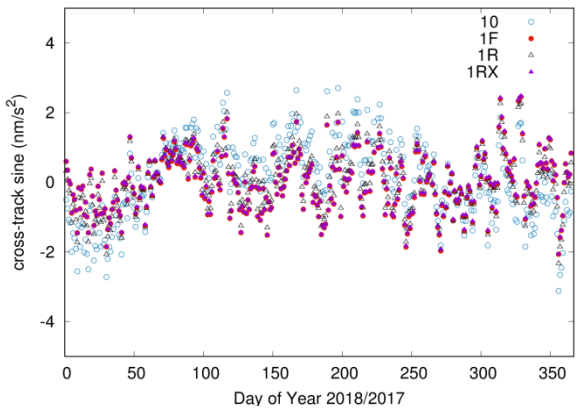


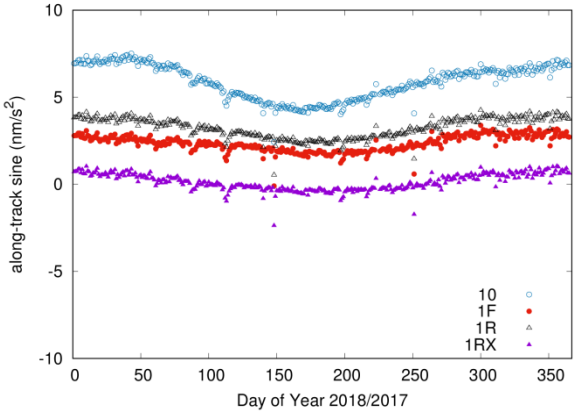
=> Solutions on next slides will include one (1/24h) set of empirical CPR parameters

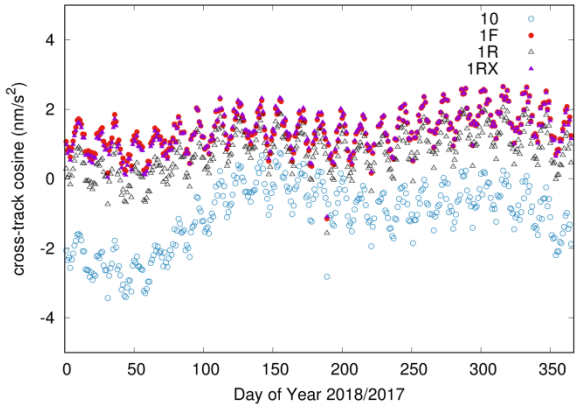
- along-track sine+cosine
- cross-track sine+cosine, constant

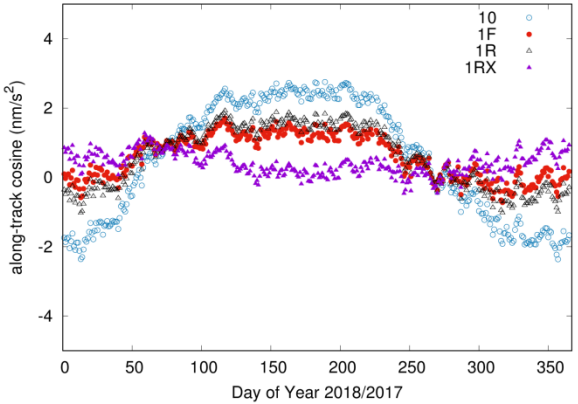
- Radiation pressure coefficient is fixed to 1.0 (solutions **20,2F,2R**) or to 0.95 (solution **2RX**)

Orbit determination results – Sentinel-2A









- Three of the empirical CPR parameters show improvements if self-shadowing is considered.
- Solution **1RX** gives the best results.
- Orbit differences are below 1-2 mm.

Extrapolations – Sentinel-2A

Mean RMS of first / second extrapolated day (mm), 1 Feb 2017 - 31 Jan 2018

Solution	radial	along-track	cross-track	3D
E0	361.78	1341.46	111.82	1438.42
EF	152.14	1059.73	114.97	1114.08
ER	203.62	1119.22	**101.62**	1182.38
ERX	**42.78**	**965.67**	114.94	**1005.19**
E0	719.40	4188.40	161.83	4317.30
EF	298.57	3714.68	170.23	3777.64
ER	401.91	3814.08	**142.94**	3889.80
ERX	**81.21**	**3561.12**	170.28	**3604.02**

- Parametrization: 1 CD coefficient (instead of 10) and no CPR parameters

=> Solution **ERX** gives the best results except for the cross-track direction

Summary and conclusion

- As provider of precise orbit products for the **Sentinel-1, -2, and -3** satellites the **Copernicus POD Service** is trying to improve the orbit modelling to the extent possible.

- Due to the complexity of the satellites, **self-shadowing is investigated** to improve the box-wing modelling (for Sentinel-1 and Sentinel-2).

- **Sentinel-1**: Three different zones with self-shadowing are detected and applied.

- **Sentinel-2**: Solar panel is shadowing part of the satellite body, difficult to model due to rotation of solar panel.

⇒ **Validation is difficult** due to missing external validation such as SLR.
⇒ Validation of results show **slight improvements** of the dynamical orbit modelling.
⇒ **Ongoing work**, updated dimensions for Sentinel-1 might further improve the results.

In case of questions concerning the **Copernicus products** please contact
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Thank you for your attention!

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