

Copernicus POD Service – Evolutions in Sentinel-3 Orbit Determination

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POD splinter
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Copernicus POD Service – general information



Copernicus POD Service is responsible for POD of Sentinel-1, -2 and -3 satellites

Sentinel-1



Sentinel-2



Sentinel-3



- Sentinel satellites are equipped with various Earth observation instruments
- Mission requirements demand high levels of orbital accuracy (GPS, DORIS+SLR only S-3) → Copernicus POD Service




Copernicus POD Service


- Consortium led by **GMV**, Tres Cantos, Spain
- **magicGNSS**, external GPS orbit and clock provider (NRT, STC)
- **PosiTim**, QWG management, quality control, improvements, scientific outreach ...
- **DLR, TUM, AIUB, TUD, GFZ** quality control, QWG members

Copernicus POD Service – general information


Sentinel-1



Sentinel-2



Sentinel-3




Mission	Category	Orbit Accuracy (RMS)
S-1	NRT (predicted)	1 m (2D)
	NRT	10 cm (2D)
	NTC	5 cm (3D)
S-2	NRT (predicted)	3 m (2D)
	NRT	1 m (3D)
S-3	NRT (S3PODIPF)	10 cm radial (target of 8 cm)
	STC	4 cm radial (target of 3 cm)
	NTC	3 cm radial (target of 2 cm)


Focus of this presentation is on S-3 (NTC)

- Official orbit provider for S-3 is CNES, Copernicus POD Service delivers alternative solutions.

Copernicus POD Quality Working Group ⇒ Orbit validation and quality control

all satellites







only S-3









CPOD Service - Regular Service Reviews

- Regular Service Reviews (RSR) are performed every 4 months, e.g., RSR#17: Feb – May 2020, RSR#18: Jun – Sep 2020
- Quality Working Group (QWG) members are asked to provide orbit solutions based on their software and processing setups.
- Most of the institutions deliver GPS-only orbit solutions, except CNES (combined GPS+DORIS) and CLS (DORIS only).
- Cross-comparisons between the orbit solutions are done.
- A combined orbit is generated based on a weighted average of the individual orbit solutions. It is used as „reference“.
- SLR validation is done using 12 core stations; station range bias estimation is performed beforehand based on combined QWG orbit.
- Last RSR documents may be found at <https://sentinel.esa.int/web/sentinel/technical-guides/sentinel-3-altimetry/pod/documentation>

Sentinel-3 NTC POD settings until 12 April 2020

- NAPEOS (NAVigation Package for Earth Orbiting Satellites)
- IERS2010 conventions
- IGS Final orbits and clocks (30 s), igs14.atx
- 10 s S-3 GPS data, 1° x 1° PCVs, ambiguity-float solution
- 32 h arc; 19:00 (day-1) – 03:00 (day+1)

- EIGEN.GRGS.RL03 gravity field (120 x 120), time-variable coefficients (50 x 50)
- EOT11a ocean tides (50 x 50)
- Atmosphere gravity product from massloading.net, atmosphere tides (Ray-Ponte, 2003)

- Satellite macro model for non-gravitational force modelling
- Atmosphere model MSISE90 + HWM93, 15 drag coefficients per arc
- Earth albedo and IR radiation
- One solar radiation pressure coefficient per arc

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

Old S-3 POD settings are valid until 12 April 2020; items in red are exchanged; visible as solution CPOD in slide 7

Sentinel-3 NTC POD settings since 12 April 2020

- NAPEOS (NAVigation Package for Earth Orbiting Satellites)
- IERS2010 conventions
- CODE Final orbits, clocks (30 s) and biases, igs14.atx
- 10 s S-3 GPS data, 1° x 1° PCVs, ambiguity-fixed solution
- 32 h arc; 19:00 (day-1) – 03:00 (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 RL06, atmosphere tides from GFZ AOD product

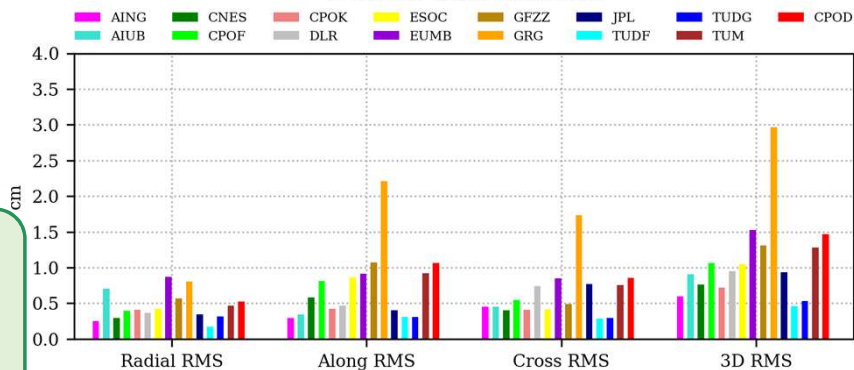
- Satellite macro model for non-gravitational force modelling
- Atmosphere model MSISE00 + HWM93, 15 drag coefficients per arc
- Earth albedo and IR radiation
- One solar radiation pressure coefficient per arc

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

New S-3 POD settings are valid since 12 Apr 2020 (CPOD); solution CPOF is based on new settings for the entire time interval shown on slide 7

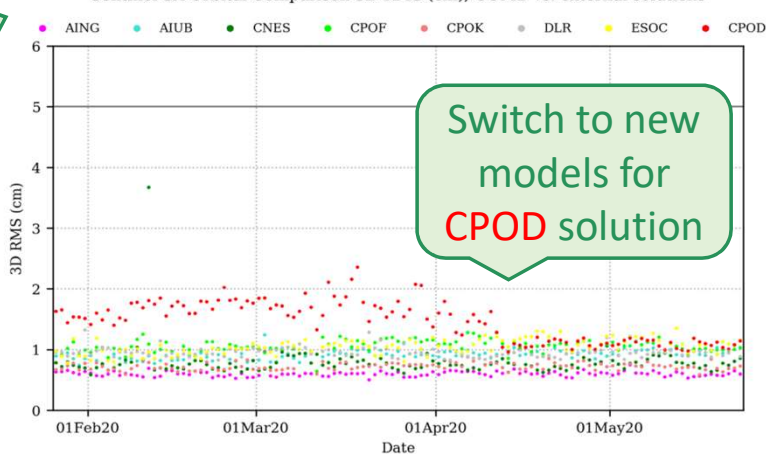
Regular Service Review – RSR#17 Feb – May 2020

Sentinel-3A orbital comparison per component (avg. of daily RMS, cm)
COMB vs. external solutions



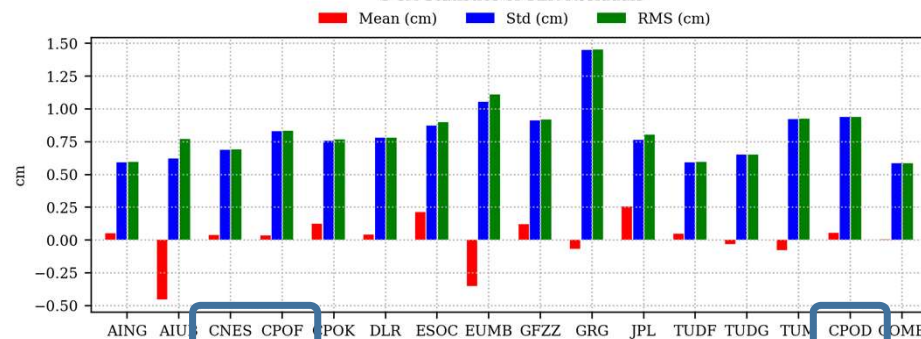
Results for CPOD are a mixture of old and new POD settings

Sentinel-3A Orbital Comparison 3D RMS (cm); COMB vs. external solutions



Switch to new models for CPOD solution

S-3A Statistics of SLR Residuals



Results for CPOF show the performance of the new POD settings for the entire time interval

	Mean	Standard Deviation	RMS
AING	0.05	0.59	0.59
AIUB	-0.45	0.62	0.77
CNES	0.04	0.69	0.69
CPOF	0.03	0.83	0.83
CPOK	0.12	0.76	0.76
DLR	0.04	0.78	0.78
ESOC	0.21	0.87	0.90
EUMB	-0.35	1.05	1.11
GFZ	0.12	0.91	0.92
GRG	-0.07	1.45	1.45
JPL	0.25	0.76	0.80
TUDF	0.05	0.59	0.59
TUDG	-0.03	0.65	0.65
TUM	-0.08	0.92	0.93
CPOD	0.05	0.94	0.94
COMB	0.00	0.58	0.58

SLR statistics

Test of different orbit parametrizations

- RSR#17 results show a significant improvement of the S-3 orbit solutions but the majority of the QWG orbit solutions compare better to the combined QWG orbit than CPOD/CPOF and has better SLR validation results.

⇒ Review of the CPOD orbit parametrization

(all other QWG solutions use significantly more empirical parameters)

CPOD orbit parameters (only scale factors+empirical parameters):

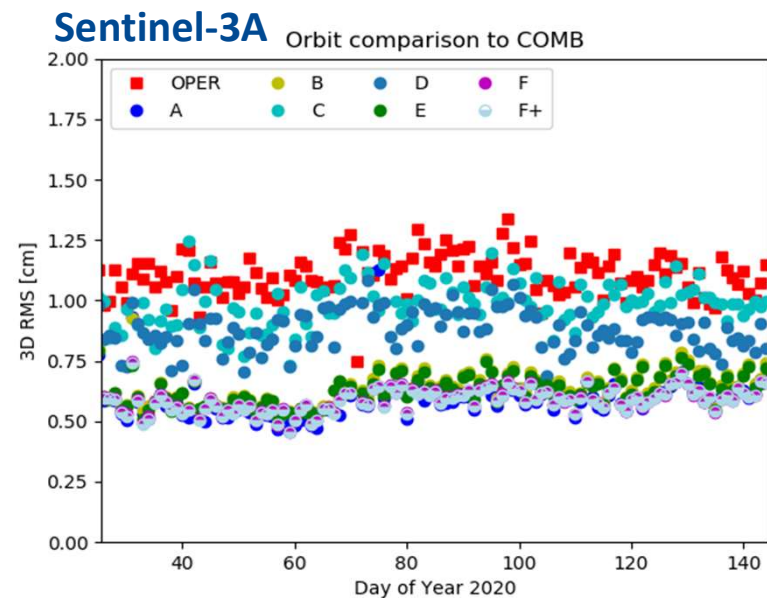
- 15** atmosphere drag coefficients per arc
- 1** solar radiation pressure coefficient per arc
- Empirical CPR (cycle-per-revolution) parameters: **3** sets/arc
 - along-track sine + cosine, cross-track sine + cosine

Different orbit parametrizations are tested for S-3A. Resulting orbits are compared to combined QWG orbit for the RSR#17 period.

	Drag scale factor	SRP scale factor	1/rev parameter
CPOD OPER	15 / arc (constraint: 1.0)	1 / arc	3 / arc alo: sin+cos (constraint: $1 \cdot 10^{-5}$ km/s ²) cro: sin+cos ($1 \cdot 10^{-5}$ km/s ²)
A	1 / arc (constraint: 1.0)	Fixed to 1.0	64 / arc alo: const ($1 \cdot 10^{-9}$ km/s ²) cro: const ($1 \cdot 10^{-9}$ km/s ²)
B	1 / arc (constraint: 1.0)	Fixed to 1.0	15 / arc alo: const,sin+cos ($1 \cdot 10^{-9}$ km/s ²) cro: const,sin+cos ($1 \cdot 10^{-9}$ km/s ²)
C	1 / arc (constraint: 1.0)	Fixed to 1.0	10 / arc alo: const,sin+cos ($1 \cdot 10^{-9}$ km/s ²) cro: const,sin+cos ($1 \cdot 10^{-9}$ km/s ²)
D	1 / arc (constraint: 1.0)	Fixed to 1.0	12 / arc alo: const,sin+cos ($1 \cdot 10^{-11}$ km/s ²) cro: const,sin+cos ($1 \cdot 10^{-11}$ km/s ²)
E	1 / arc (constraint: 0.3)	Fixed to 1.0	15 / arc alo: const,sin+cos ($1 \cdot 10^{-12}$ km/s ² , $1 \cdot 10^{-11}$ km/s ²) cro: const,sin+cos ($1 \cdot 10^{-12}$ km/s ² , $1 \cdot 10^{-11}$ km/s ²)
F F+: S3A&S3B	1 / arc (constraint: 0.3)	Fixed to 1.0 F+ S3A:0.97 F+ S3B:0.96	16 / arc alo: const,sin+cos ($1 \cdot 10^{-12}$ km/s ² , $1 \cdot 10^{-11}$ km/s ²) cro: const,sin+cos ($1 \cdot 10^{-12}$ km/s ² , $1 \cdot 10^{-11}$ km/s ²)

Analysis of different orbit parametrizations

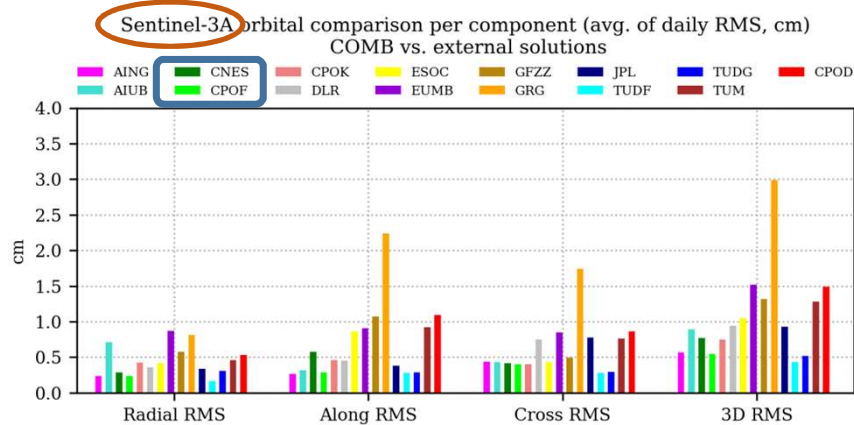
	Drag scale factor	SRP scale factor	1/rev parameter
CPOD OPER	15 / arc (constraint: 1.0)	1 / arc	3 / arc alo: sin+cos (constraint: $1 \cdot 10^{-5}$ km/s ²) cro: sin+cos ($1 \cdot 10^{-5}$ km/s ²)
A	1 / arc (constraint: 1.0)	Fixed to 1.0	64 / arc alo: const ($1 \cdot 10^{-9}$ km/s ²) cro: const ($1 \cdot 10^{-9}$ km/s ²)
B	1 / arc (constraint: 1.0)	Fixed to 1.0	15 / arc alo: const,sin+cos ($1 \cdot 10^{-9}$ km/s ²) cro: const,sin+cos ($1 \cdot 10^{-9}$ km/s ²)
C	1 / arc (constraint: 1.0)	Fixed to 1.0	10 / arc alo: const,sin+cos ($1 \cdot 10^{-9}$ km/s ²) cro: const,sin+cos ($1 \cdot 10^{-9}$ km/s ²)
D	1 / arc (constraint: 1.0)	Fixed to 1.0	12 / arc alo: const,sin+cos ($1 \cdot 10^{-11}$ km/s ²) cro: const,sin+cos ($1 \cdot 10^{-11}$ km/s ²)
E	1 / arc (constraint: 0.3)	Fixed to 1.0	15 / arc alo: const,sin+cos ($1 \cdot 10^{-12}$ km/s ² , $1 \cdot 10^{-11}$ km/s ²) cro: const,sin+cos ($1 \cdot 10^{-12}$ km/s ² , $1 \cdot 10^{-11}$ km/s ²)
F F+: S3A&S3 B	1 / arc (constraint: 0.3)	Fixed to 1.0 F+ S3A:0.97 F+ S3B:0.96	16 / arc alo: const,sin+cos ($1 \cdot 10^{-12}$ km/s ² , $1 \cdot 10^{-11}$ km/s ²) cro: const,sin+cos ($1 \cdot 10^{-12}$ km/s ² , $1 \cdot 10^{-11}$ km/s ²)



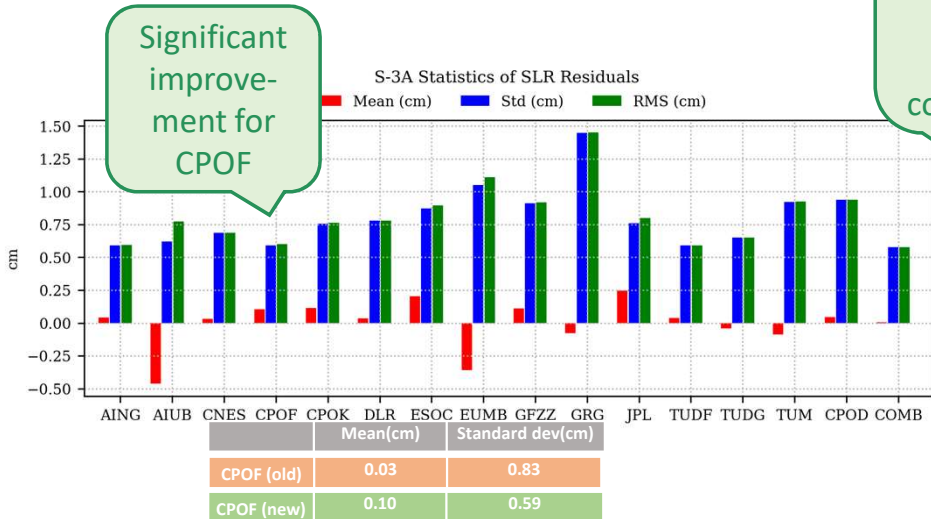
- Several test solutions have been generated for Sentinel-3A
- Favourite solution is solution F+ (21 more parameter than CPOD OPER solution). It compares very well to the QWG combined orbit.
- The empirical 1/rev parameters have a duration of 2h. The SRP (solar radiation pressure) scale factors of 0.97 (S-3A) and 0.96 (S-3B) were derived in a previous study [1].
- SLR validation follows on next slide (solution CPOF).

[1] Peter H., Berzosa J., Fernández J., Féménias P (2020) Long-term evaluation of estimated solar radiation pressure coefficients from Copernicus Sentinel-1, -2, -3 satellites, EGU2020-5288, EGU Sharing Geoscience Online, 4-8 May 2020

Repetition of RSR#17 analysis including F+ solution (CPOF)



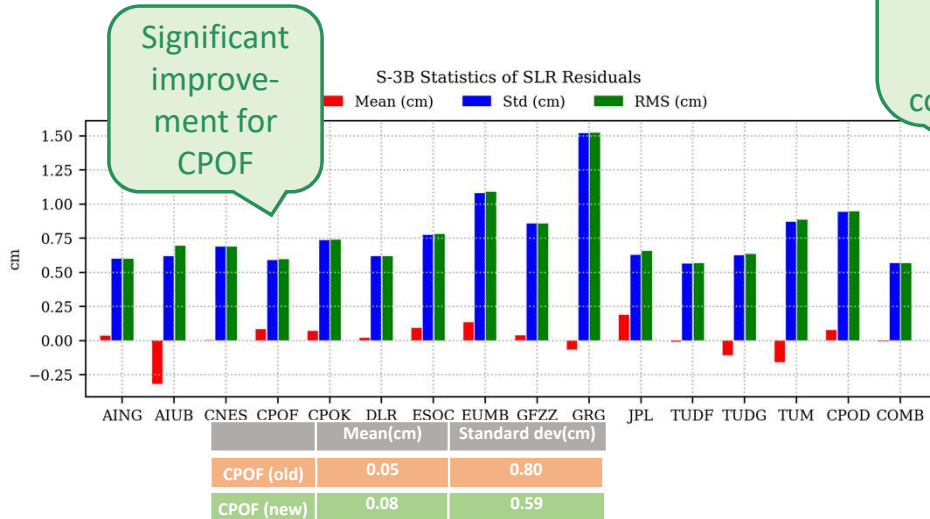
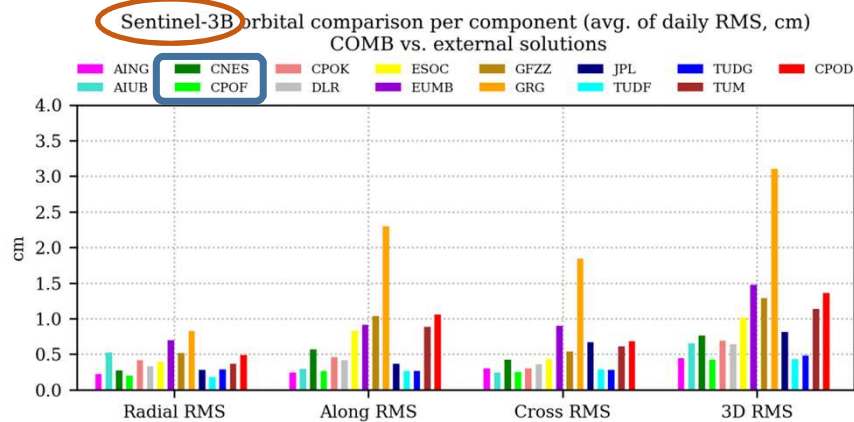
Statistics of other QWG solutions are slightly different because of newly generated combined orbit



	Average of S-3A daily 3D RMS (cm)		Average of S-3A daily Radial RMS (cm)	
	RSR#17 - Old	RSR#17 - New	RSR#17 - Old	RSR#17 - New
AING	0.60	0.57	0.25	0.24
AIUB	0.91	0.89	0.71	0.71
CNES	0.76	0.77	0.29	0.28
CPOF	1.06	0.55	0.39	0.23
CPOK	0.72	0.75	0.41	0.42
DLR	0.95	0.94	0.37	0.36
ESOC	1.05	1.05	0.42	0.42
EUMB	1.53	1.52	0.87	0.87
GFZ	1.31	1.32	0.57	0.57
GRG	2.96	2.99	0.80	0.81
JPL	0.94	0.93	0.35	0.34
TUDF	0.46	0.43	0.17	0.16
TUDG	0.53	0.52	0.31	0.31
TUM	1.28	1.28	0.47	0.46
CPOD	1.47	1.49	0.52	0.53

Significant improvement for CPOF

Repetition of RSR#17 analysis including F+ solution (CPOF)



Statistics of other QWG solutions are slightly different because of newly generated combined orbit

	Average of S-3B daily 3D RMS (cm)	
	RSR#17 - Old	RSR#17 - New
AING	0.48	0.44
AIUB	0.68	0.66
CNES	0.76	0.76
CPOF	1.01	0.42
CPOK	0.66	0.69
DLR	0.66	0.64
ESOC	1.01	1.02
EUMB	1.48	1.47
GFZ	1.28	1.29
GRG	3.08	3.11
JPL	0.83	0.81
TUDF	0.46	0.43
TUDG	0.50	0.48
TUM	1.14	1.13
CPOD	1.33	1.36

	Average of S-3B daily Radial RMS (cm)	
	RSR#17 - Old	RSR#17 - New
AING	0.23	0.22
AIUB	0.52	0.53
CNES	0.27	0.27
CPOF	0.38	0.20
CPOK	0.40	0.42
DLR	0.34	0.33
ESOC	0.40	0.40
EUMB	0.70	0.70
GFZ	0.51	0.52
GRG	0.81	0.83
JPL	0.29	0.28
TUDF	0.19	0.18
TUDG	0.29	0.29
TUM	0.37	0.36
CPOD	0.48	0.49

Significant improvement for CPOF

Geographical Analysis

Sentinel-3A: [Radial RMS]

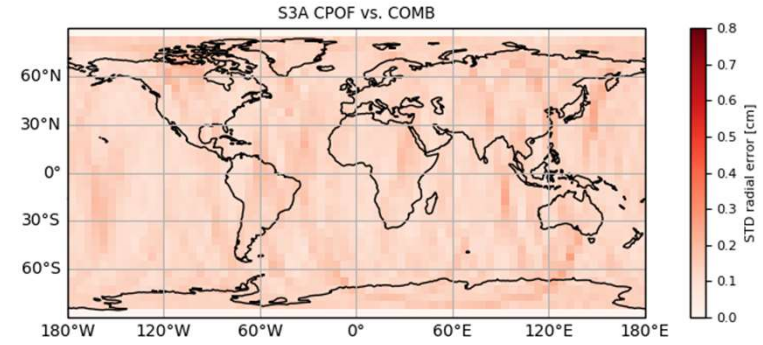
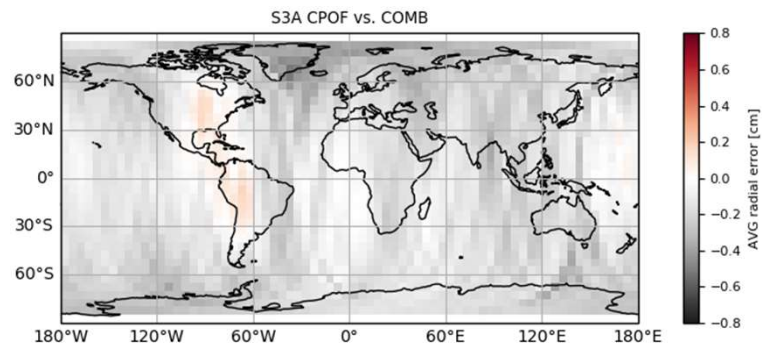
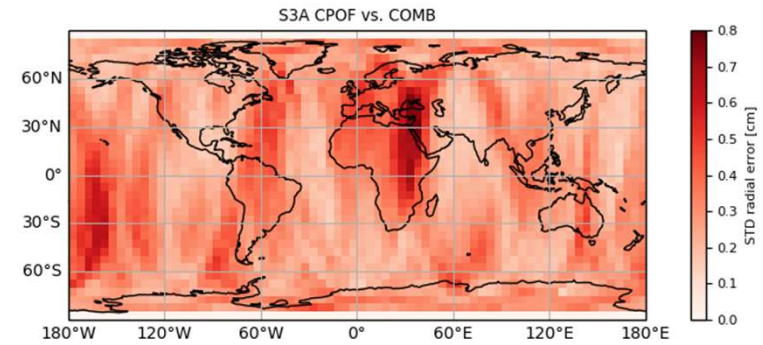
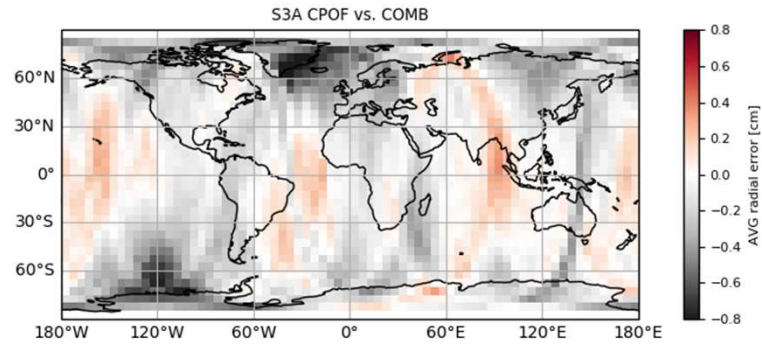
Geographically dependent radial differences w.r.t. combined QWG orbit are significantly reduced.

Average

Standard Deviation

RSR#17 - Old

RSR#17 - New



Geographical Analysis

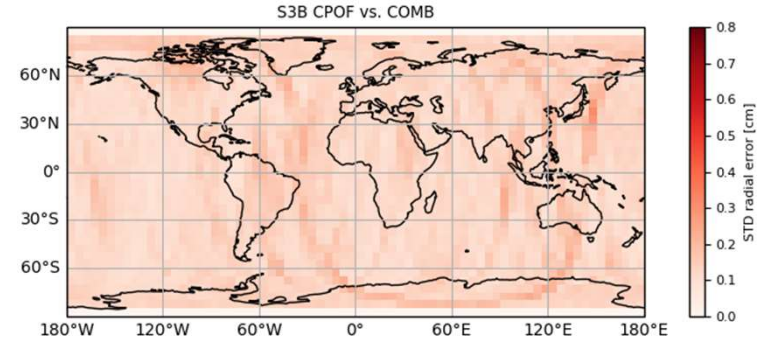
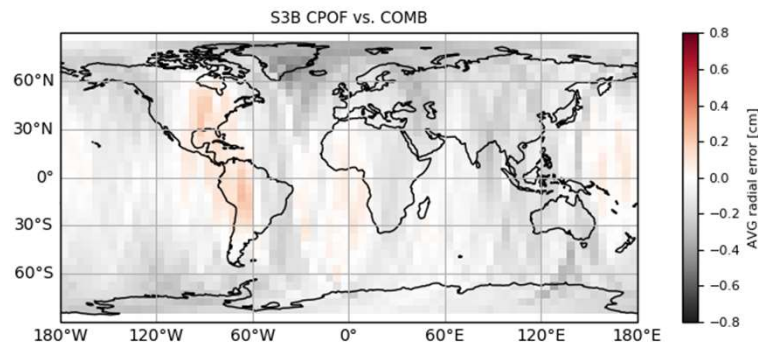
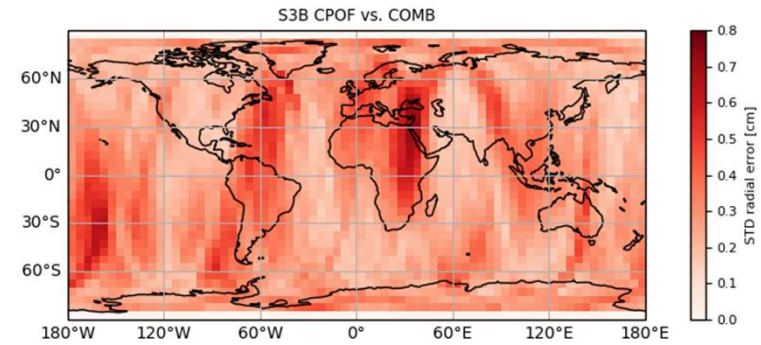
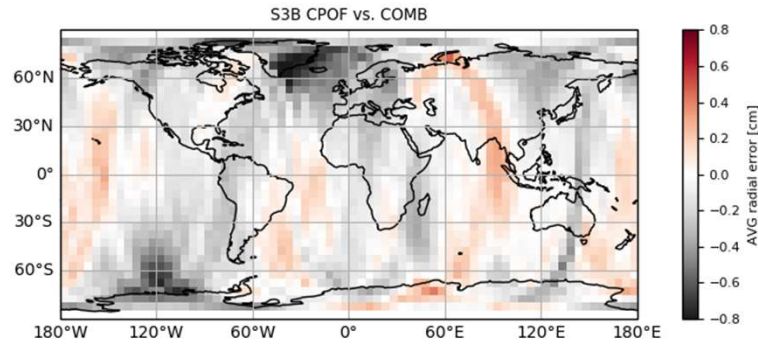
Sentinel-3B: [Radial RMS]

Average

Standard Deviation

RSR#17 - Old

RSR#17 - New



Planned Sentinel-3 POD settings

- NAPEOS (NAVigation Package for Earth Orbiting Satellites)
- IERS2010 conventions
- CODE Final orbits, clocks (5 s) and biases, igs14.atx
- 10 s S-3 GPS data, 1° x 1° PCVs, ambiguity-fixed solution
- 32 h arc; 19:00 (day-1) – 03:00 (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 RL06, atmosphere tides from GFZ AOD product

- Satellite macro model for non-gravitational force modelling
- Atmosphere model MSISE00 + HWM14, 1 drag coefficient per arc
- Earth albedo and IR radiation
- Fixed solar radiation pressure coefficient per arc; S3-A:0.97, S3-B:0.96

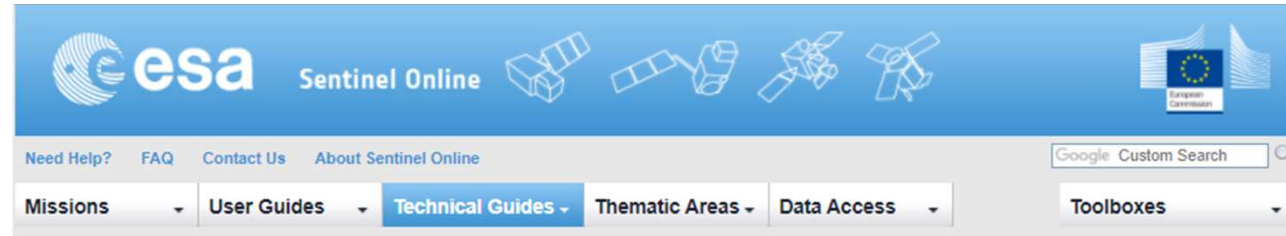
- Empirical CPR (cycle-per-revolution) parameters: 16 sets/arc
 - along-track const, sine + cosine, cross-track const, sine + cosine

If further validation (RSR#18) is positive and CPOD QWG endorses the modification the S-3 POD settings will be adopted as soon as possible for S-3 STC and NTC orbit solutions.

CPOD User Interaction and Web Information available about the Service

Sentinels Online

<https://sentinels.copernicus.eu/web/sentinel/>



1. Satellite Parameters for POD

The following data is updated on a daily bases:

- mass history files *s[123][AB].mhf*
- manoeuvre history files *s[123][AB].man*
- GNSS outages files *s[123][AB].out*
- ANTEX files *e.g. sen08.atx*

2. POD System Baselines and Reprocessing Campaigns

Summary of operational CPOD System versions, relevant changes, as well as description of models and POD settings.

3. SLR tracking

Sentinel-3 SLR tracking statistics, stations map and additional information

CPOD Service

Overview of the CPOD Service , the CPOD QWG, and relevant interfaces.
Under Missions tab.

<https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-3/ground-segment/cpod>

4. SX POD Document Library

User relevant documentation:

- POD File Format Specification
- POD Product Handbook
- Regular Service Review
- SLR Yearly Report
- CPOD QWG conclusions
- Sentinel-[123] Properties for GPS POD

5. Communication

List of publications and posters to which the CPOD Service has contributed.

Technical Guides

Technical Guides Home

Sentinel-1 SAR

Sentinel-2 MSI

Sentinel-3 OLCI

Sentinel-3 SLSTR

Sentinel-3 Synergy

Sentinel-3 Altimetry

Surface Topography Instruments

Products and Algorithms

Processing Baseline

Anomalies and Events

Calibration and Validation

Mission Performance

Data Product Quality Reports

POD Instruments and Products

POD Products and Requirements

1 Satellite Parameters for POD

2 POD System Baselines and Reprocessing Campaigns

EGP Information

3 SLR Tracking

4 S3 POD Document Library

Communication

Quality Control

FAQ

Appendices

Sentinel-5P TROPOMI

Copernicus Sentinels POD Data Hub

<https://scihub.copernicus.eu/gnss/>

Online POD products uploaded on a **daily bases**.

RINEX (AUX_GNSSRD)

Description: GNSS pseudorange and carrier-phase observations
Missions: Sentinel-1, -2, -3
Coverage: 24 hours
Data availability: Full mission
Timeliness: 7 days.

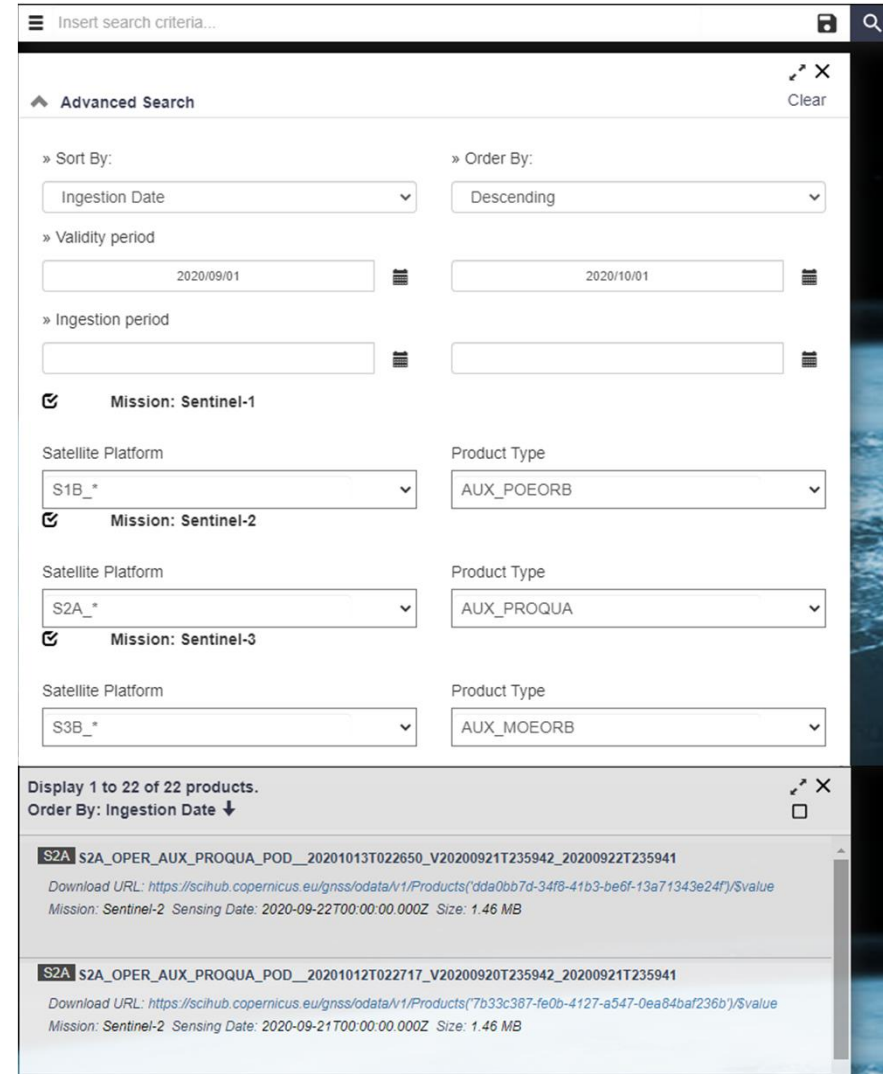
Attitude Quaternions (AUX_PROQUA)

Description: Decoded satellite attitude provided as quaternions
Missions: Sentinel-1, -2, -3
Coverage: 24 hours
Data availability: Full mission
Timeliness: 21 (S-1&2) 26 (S-3) days

Orbit and Platform products

Description: Orbital and platform products.

- **Sentinel-3 SR___ROE_AX**
Coverage: ~100 min
Timeliness: <1 day
- **Sentinel-3 AUX_POEORB, AUX_PRCPTF**
Coverage: ~26 hours
Data availability: Full mission
Timeliness: 26 days
- **Sentinel-3 AUX_MOEORB**
Coverage: ~26 hours
Timeliness: 1-2 days
- **Sentinel-1 AUX_RESORB and AUX_POEORB**
Soon to be released



Summary

- The Copernicus POD Service is responsible for Sentinel-1, -2, and -3 POD processing.
- Significant background model update (gravity field, ocean tides, etc.) has successfully been performed in spring 2020.
- Review of orbit parametrization led to significant improvement of the CPOD orbit solution compared to the CPOD QWG combined solution and in terms of SLR validation.
- Copernicus POD QWG has to approve new orbit parametrization for all three Sentinel missions before the switch can be done.
- Information on CPOD user interaction are given.



Thank you for your attention!

Acknowledgements:

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