

# Copernicus POD Service – Evolutions in Sentinel-3 Orbit Determination

6<sup>th</sup> S3VT virtual meeting  
15-17 December 2020

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# Copernicus POD Service – general information



Copernicus Sentinel-1



Copernicus Sentinel-2



Copernicus Sentinel-3



Copernicus Sentinel-6  
Michael Freilich



- Sentinel satellites are equipped with various Earth observation instruments
- Mission requirements demand high levels of orbital accuracy  
(GPS, DORIS+SLR only S-3 + S-6 (+GAL)) → Copernicus POD Service

## Copernicus POD Service

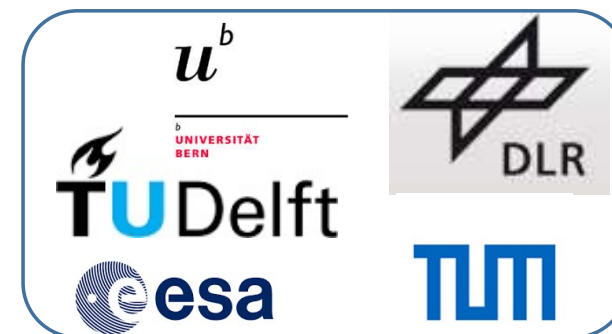
- Consortium led by **GMV**, Tres Cantos, Spain
- **magicGNSS**, external GPS orbit and clock provider (NRT, STC), backup **DLR**
- **PosiTim**, QWG management, quality control, improvements, scientific outreach ...
- **DLR, TUM, AIUB, TUD, GFZ** quality control, QWG members

# Copernicus POD Service – general information

Mission	Category	Orbit Accuracy (RMS)
S-1	NRT (predicted)	1 m (2D)
	NRT	10 cm (2D)
	NTC	<b>5 cm (3D)</b>
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	<b>3 cm radial (target of 2 cm)</b>
S-6	NRT	5 cm radial (target of 3 cm) – compared to POE



Copernicus POD Quality Working Group  
 ⇒ Orbit validation and quality control



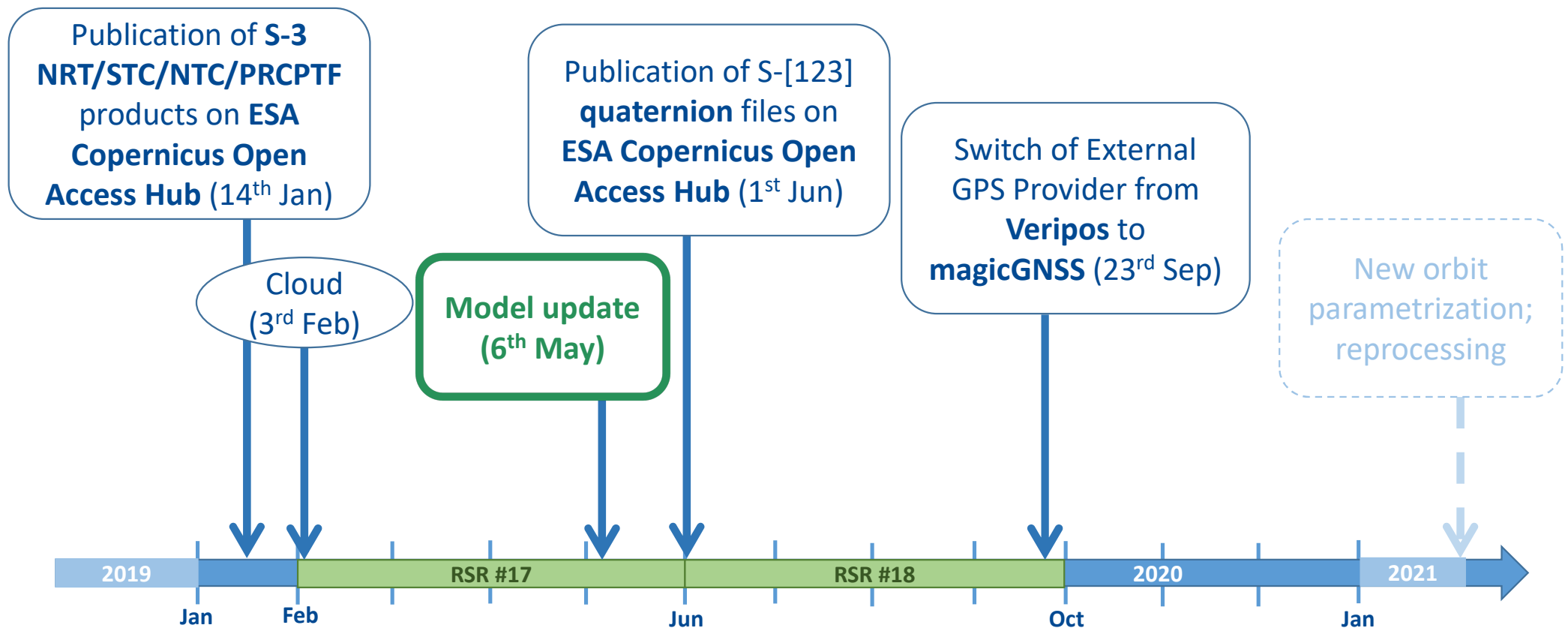
- There are two official orbit providers for the S-3 mission. Copernicus POD Service provides NRT, STC and NTC orbit products. CNES provides STC and NTC orbit products. Operational configuration is NRT (CPOD), STC & NTC (CNES).

# CPOD Service – Regular Service Reviews

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- Regular Service Reviews (RSR) are performed every 4 months, e.g., RSR#17: Feb – May 2020, RSR#18: Jun – Sep 2020; in future every 3 months: RSR#19: Oct-Dec 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 giving information on orbit performance may be found at <https://sentinel.esa.int/web/sentinel/technical-guides/sentinel-3-altimetry/pod/documentation>

# CPOD Service – Evolutions during last year related to S-3



# Sentinel-3 NTC POD settings – model update in May 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)

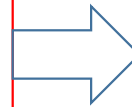
EIGEN.GRGS.RL03 gravity field (120 x 120)  
time-variable coefficients (90 x 90)

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/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



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 (90 x 90)

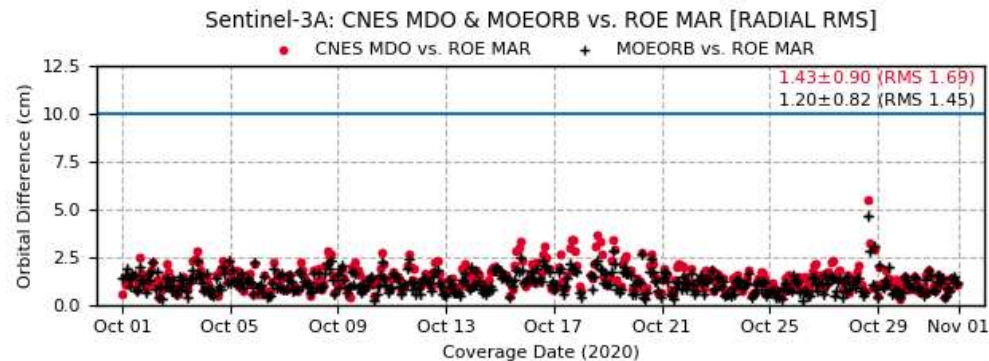
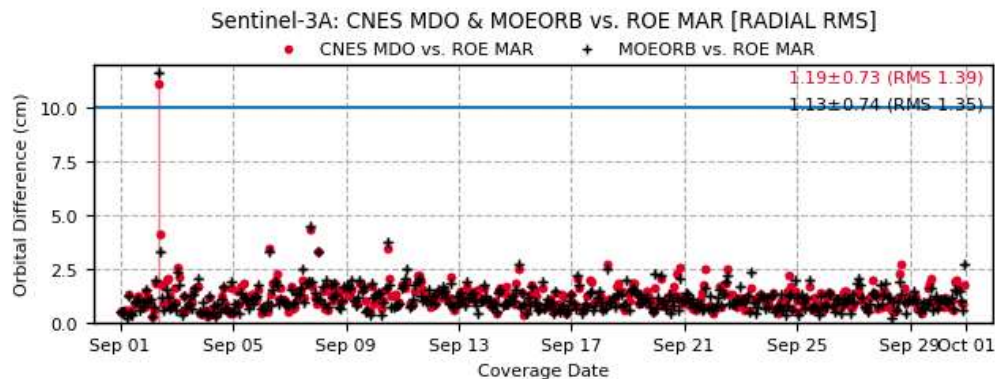
FES2014 ocean tides (100 x 100)

GFZ AOD L1B RL06  
atmosphere tides from GFZ AOD product

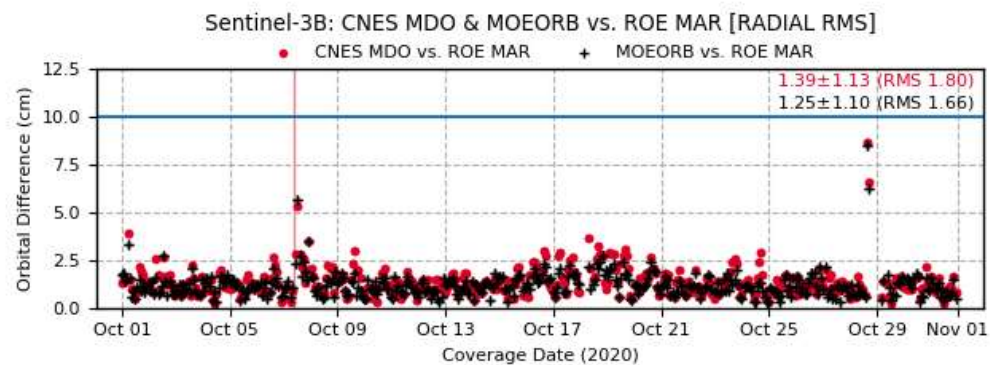
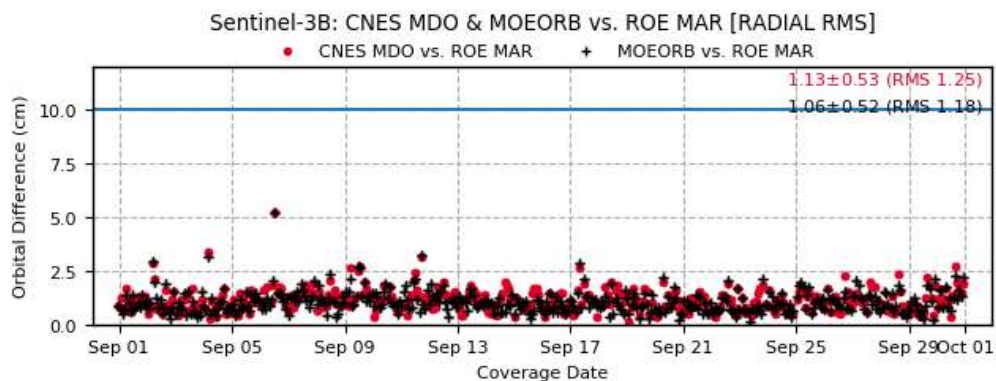
Satellite macro model for non-gravitational force modelling  
Atmosphere model MSISE00 + HWM93, 15 drag coefficients/arc  
Earth albedo and IR radiation  
One solar radiation pressure coefficient per arc

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

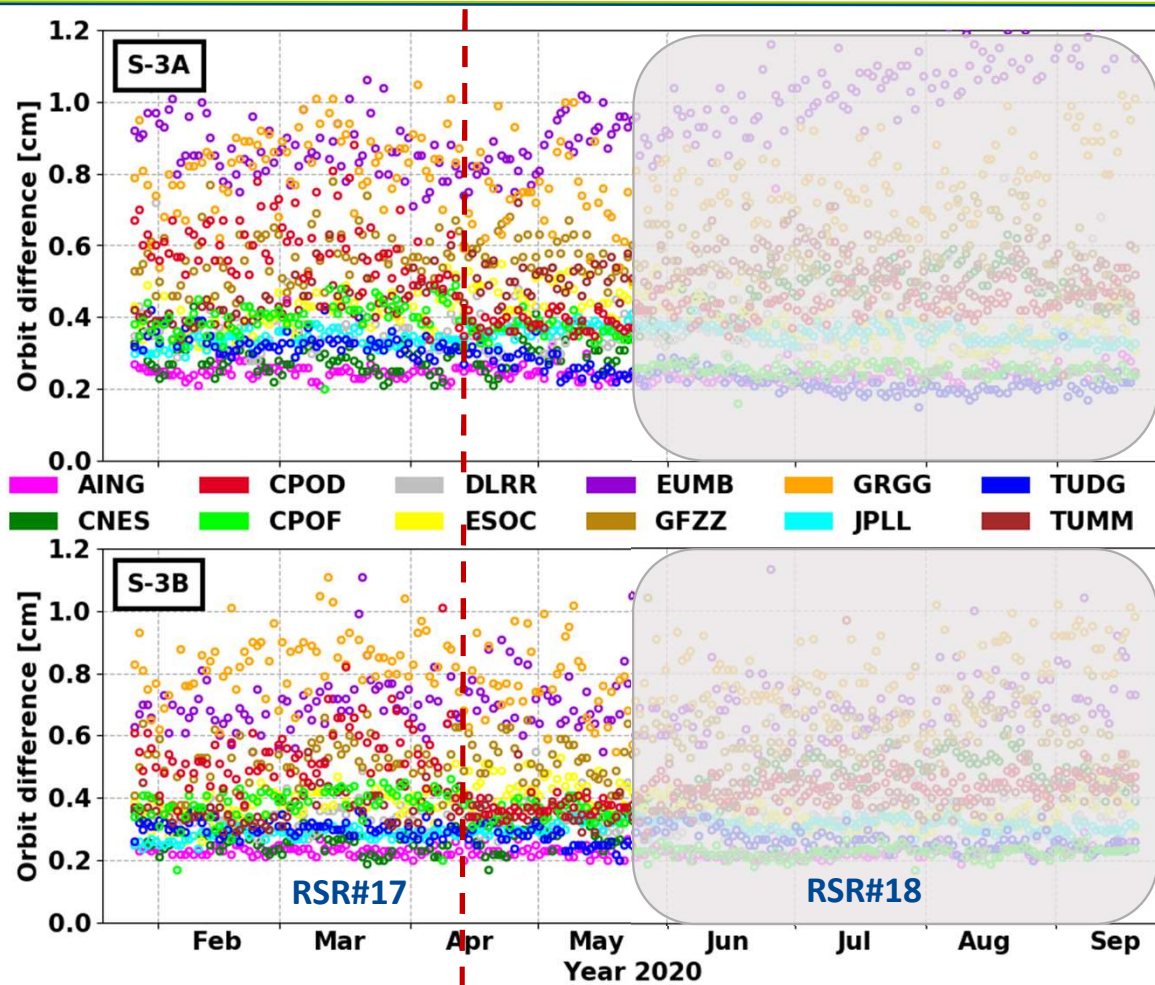
# Sentinel-3 NRT orbits – EGP switch



- Radial RMS (cm) of S-3 NRT from Marine Center vs. CNES and CPOD STC orbits
- Switch of External GPS Provider (EGP) happened on 23<sup>rd</sup> September (not visible in orbit performance!), very smooth transition.



# Model update: RSR #17 + #18: Feb – Sep 2020



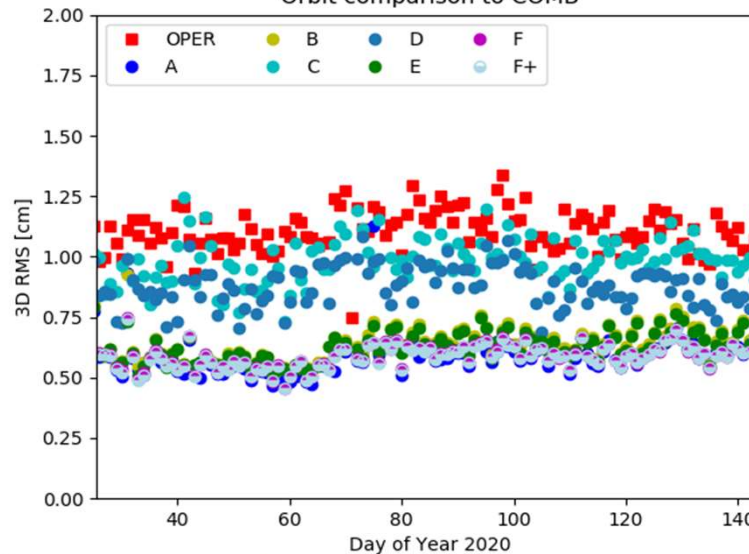
- Radial RMS of orbit differences to combined QWG orbit; < 1.0 cm for all solutions
  - **CPOD** is the operational solution; **CPOF** is test solution
  - Improvement of model update (red dashed line) can clearly be noticed
  - There are still other S-3 orbit solutions, which compare better to the combined QWG orbit.
- ⇒ **Review of orbit parametrization**  
 (almost all other groups use more empirical parameters in their orbit parametrization )



# Review and refinement of orbit parametrization

	Drag scale factor	SRP scale factor	1/rev parameter
CPOD OPER	15 / arc (constraint: 1.0)	1 / arc	3 / arc alo: sin+cos (constraint: 1·10 <sup>-5</sup> km/s <sup>2</sup> ) cro: sin+cos (1·10 <sup>-5</sup> km/s <sup>2</sup> )
A	1 / arc (constraint: 1.0)	Fixed to 1.0	64 / arc alo: const (1·10 <sup>-9</sup> km/s <sup>2</sup> ) cro: const (1·10 <sup>-9</sup> km/s <sup>2</sup> )
B	1 / arc (constraint: 1.0)	Fixed to 1.0	15 / arc alo: const,sin+cos (1·10 <sup>-9</sup> km/s <sup>2</sup> ) cro: const,sin+cos (1·10 <sup>-9</sup> km/s <sup>2</sup> )
C	1 / arc (constraint: 1.0)	Fixed to 1.0	10 / arc alo: const,sin+cos (1·10 <sup>-9</sup> km/s <sup>2</sup> ) cro: const,sin+cos (1·10 <sup>-9</sup> km/s <sup>2</sup> )
D	1 / arc (constraint: 1.0)	Fixed to 1.0	12 / arc alo: const,sin+cos (1·10 <sup>-11</sup> km/s <sup>2</sup> ) cro: const,sin+cos (1·10 <sup>-11</sup> km/s <sup>2</sup> )
E	1 / arc (constraint: 0.3)	Fixed to 1.0	15 / arc alo: const,sin+cos (1·10 <sup>-12</sup> km/s <sup>2</sup> , 1·10 <sup>-11</sup> km/s <sup>2</sup> ) cro: const,sin+cos (1·10 <sup>-12</sup> km/s <sup>2</sup> , 1·10 <sup>-11</sup> km/s <sup>2</sup> )
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 (1·10 <sup>-12</sup> km/s <sup>2</sup> , 1·10 <sup>-11</sup> km/s <sup>2</sup> ) cro: const,sin+cos (1·10 <sup>-12</sup> km/s <sup>2</sup> , 1·10 <sup>-11</sup> km/s <sup>2</sup> )

Sentinel-3A Orbit comparison to COMB



- 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].

[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

# Sentinel-3 NTC POD – planned parametrization update

NAPEOS (NAVigation Package for Earth Orbiting Satellites)

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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 (90 x 90)

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/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



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 (90 x 90)

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/arc

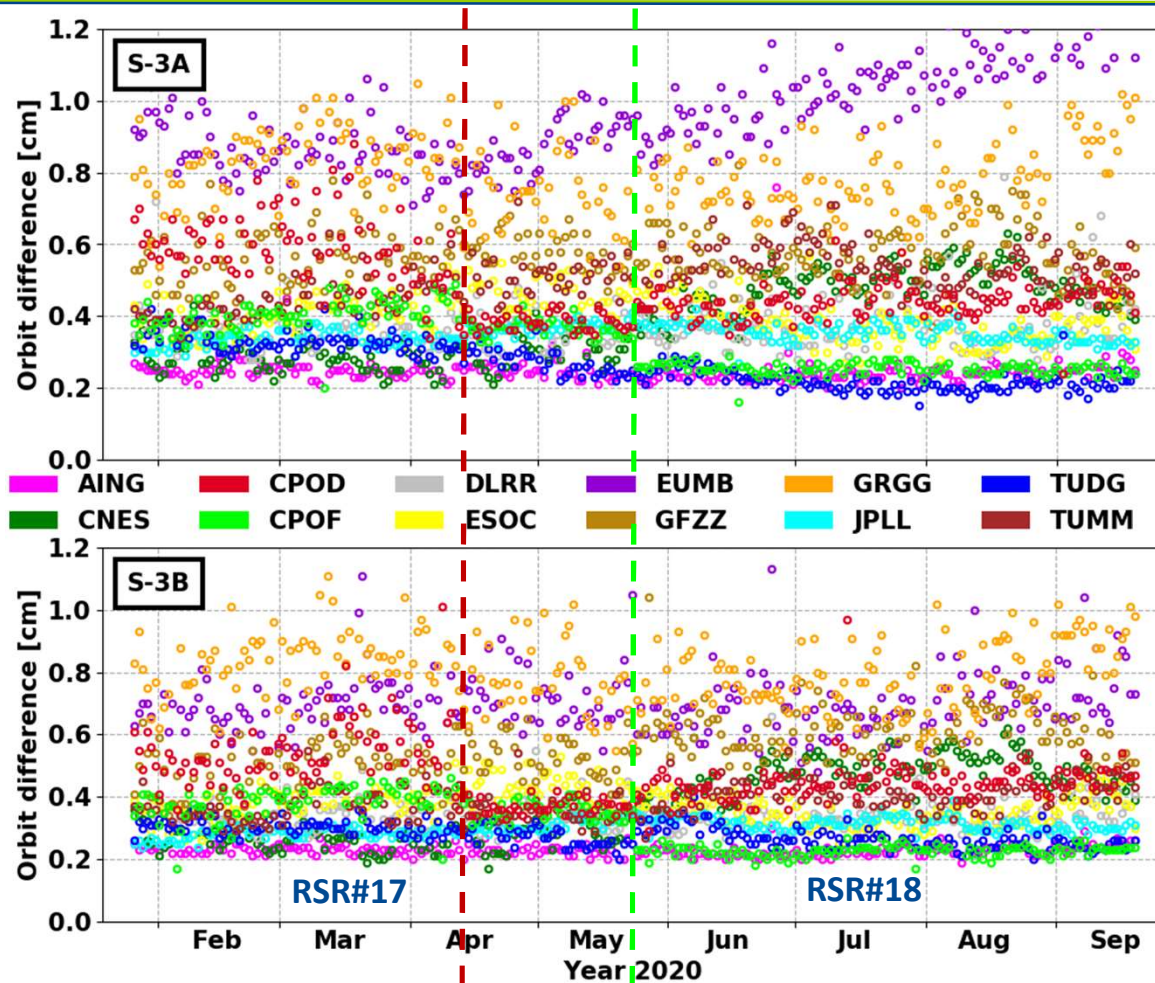
Earth albedo and IR radiation

**SRP coefficient fixed to 0.97 (S-3A) + 0.96 (S-3B)**

Empirical CPR (cycle-per-revolution) parameters: **16** sets/arc

along-track **const**, sine + cosine, cross-track **const**, sine + cosine

# Regular Service Review #17 + #18: Feb – Sep 2020

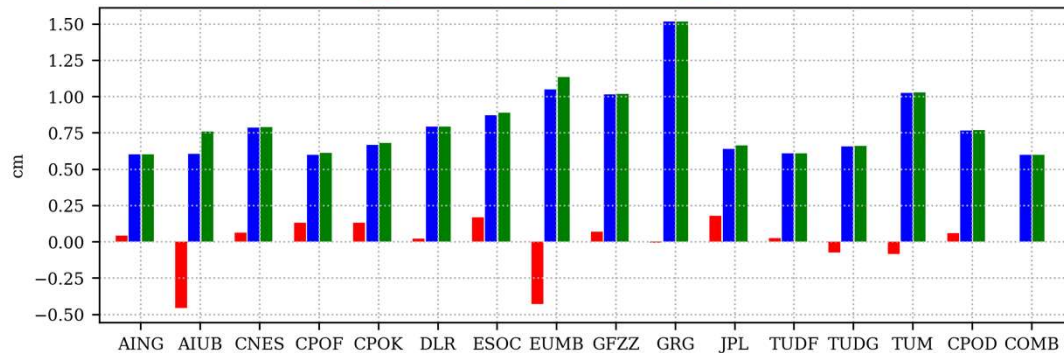


- Radial RMS of orbit differences to combined QWG orbit; < 1.0 cm for all solutions
- **CPOD** is the operational solution; **CPOF** is test solution
- RSR#18: **CPOF** uses the new proposed orbit parametrization (starting at green dashed line)
- An additional clear improvement w.r.t. the combined QWG orbit

# Satellite Laser Ranging (SLR) validation - RSR #18

S-3A Statistics of SLR Residuals

Mean (cm) Std (cm) RMS (cm)



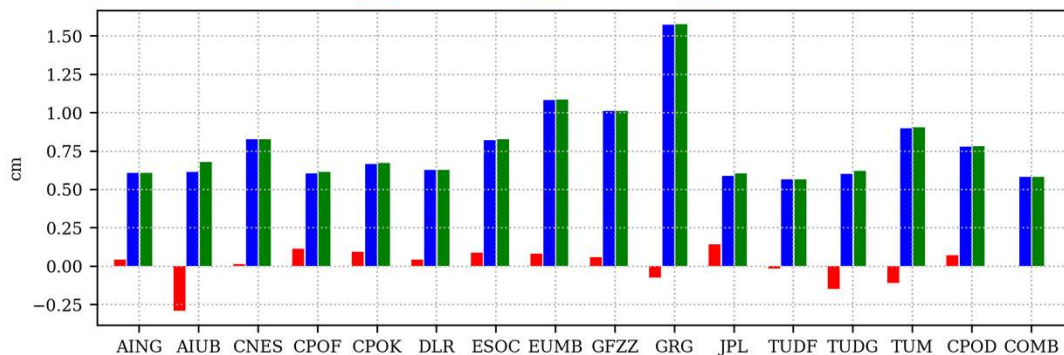
Selected statistics (cm)

	Mean	RMS
CNES	0.06	0.79
CPOF	0.13	0.61
CPOD	0.06	0.77
COMB	0.00	0.60

- SLR validation based on 12 core stations
- > 10 deg elevation
- SLR station bias estimation based on combined orbit
- Clear improvement of CPOF w.r.t. CPOD

S-3B Statistics of SLR Residuals

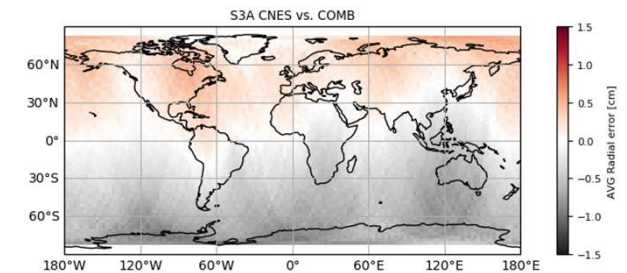
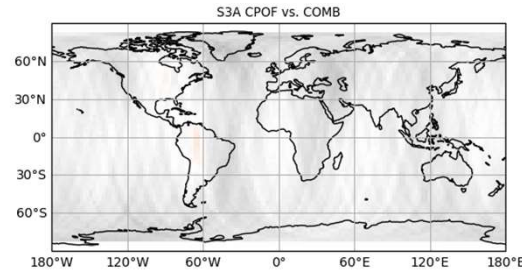
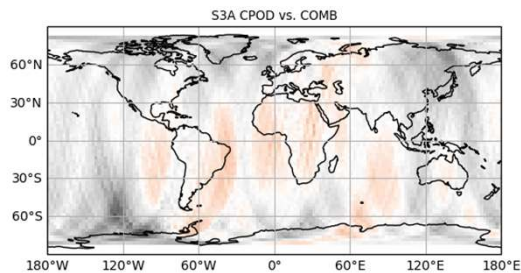
Mean (cm) Std (cm) RMS (cm)



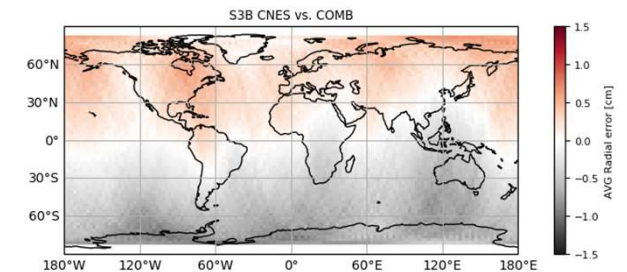
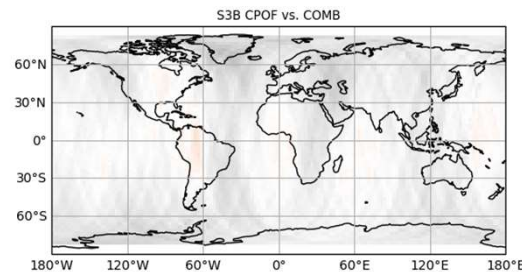
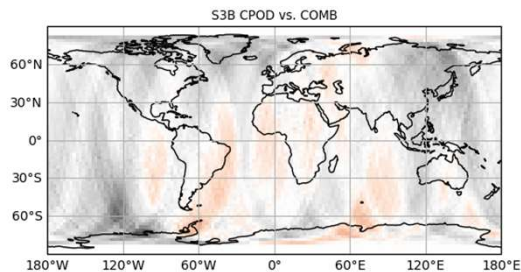
Selected statistics (cm)

	Mean	RMS
CNES	0.01	0.83
CPOF	0.11	0.61
CPOD	0.07	0.78
COMB	0.00	0.58

# Geographical analysis - RSR #18



- Geographical analysis of radial orbit differences w.r.t. combined QWG orbit
- Variations seen for CPOD solution vanish for CPOF solution
- Systematic north-south differences of CNES orbit w.r.t. combined QWG orbit solution have to be investigated, possibly because of different realisation of geocenter variations.



# Summary

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- The Copernicus POD Service is responsible for Sentinel-1, -2, -3 POD processing and associated performance assessment. Sentinel-6 NRT POD is now also part of the service.
- 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 (foreseen for Q1 2021).
- Reprocessing of the CPOD orbit products for the entire mission periods of S-3A & S-3B is in planning (Q2 2021?)



Thank you for your attention!

**Acknowledgements:**

The Copernicus POD Service is financed under ESA contract no. 4000132155/20/I-BG, which is gratefully acknowledged.

The work performed in the frame of this contract is carried out with funding by the European Union. The views expressed herein can in no way be taken to reflect the official opinion of either the European Union or the European Space Agency.

# 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 SL STR

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

SLR Tracking

**3** S3 POD Document Library

**4** 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\_MOEORB**  
Coverage: ~26 hours  
Timeliness: 1-2 days
- **Sentinel-3 AUX\_POEORB, AUX\_PRCPTF**  
Coverage: ~26 hours  
Data availability: Full mission  
Timeliness: 26 days
- **Sentinel-1 AUX\_RESORB and AUX\_POEORB**  
Soon to be released

