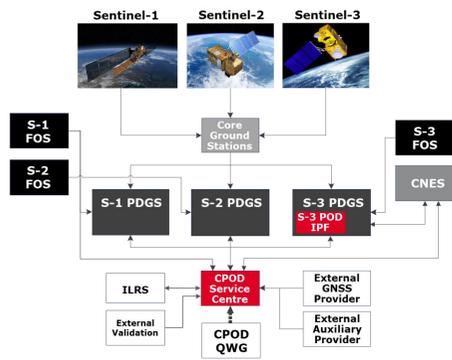


# The Copernicus POD Service and beyond: Scientific exploitation of the orbit-related data and products

EGU2017- 6731  
EGU General Assembly 2017  
April 23-29, 2017, Vienna, Austria

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## Copernicus POD Service



The Copernicus POD (Precise Orbit Determination) Service is an operational service to provide accurate orbit and attitude products for the Sentinel-1, -2, and -3 missions.

All these Sentinel satellites are equipped with two dual-frequency GPS receivers (nominal and redundant) delivering the observables for the precise orbit determination. Sentinel-3 is also equipped with a laser retro reflector for Satellite Laser Ranging and with a DORIS receiver. Both techniques allow for an independent validation of the GPS-derived orbit products.

### Copernicus POD Quality Working Group

The Copernicus POD Service is supported by the Copernicus POD Quality Working Group (QWG) which is built by POD experts from the following institutions:

- Astronomical Institute, University of Bern, Switzerland
- Deutsches Zentrum für Luft- und Raumfahrt, Oberpfaffenhofen, Germany
- European Space Operations Centre, Darmstadt, Germany
- Delft University of Technology, Delft, The Netherlands
- Technische Universität München, Munich, Germany
- CNES (Centre Nationale d'Etudes Spatiales), Toulouse, France (only for S-3)
- Eumetsat (European Organisation for the Exploitation of Meteorological Satellites), Darmstadt, Germany (only for S-3)

The QWG institutions provide independent Sentinel orbit solutions for validation. Different software packages and different orbit parametrization are used from the QWG.

## Orbit-related data

Table1: Orbit products, accuracy and latency requirements, and coverage

Mission	Category	Orbit (RMS)	Accuracy	Latency	Coverage
S-1	NRT	10 cm (2D)		180 min	2 orbits
	NTC	5 cm (3D)		20 days	26 h
S-2	NRT (pred.)	3 m (2D)		90 min before ANX	2 orbits
	NRT	1 m (3D)		30 min	Received PVT span + 2 orbits backwards
S-3	NRT	10 cm radial (target of 8 cm)		30 min	Received PVT span + 5 OSV before and after
	STC	4 cm radial (target of 3 cm)		1.5 days	26 h
	NTC	3 cm radial (target of 2 cm)		25 days	26 h

The Sentinel orbit products (listed in Tab.1) are Level 2 products and are made available for the PDGS of the corresponding mission.

### Orbit-related input data (Level 1):

GPS observation data is available in the well-known RINEX (Receiver INdependent EXchange,[1]) format:

- Sentinel-1 and -2: 0.1 Hz
- Sentinel-3: 1 Hz

### Attitude information is provided

- as input files with quaternions for Sentinel-2 and -3
- as model for Sentinel-1

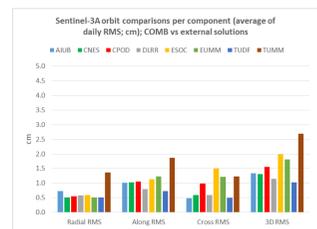
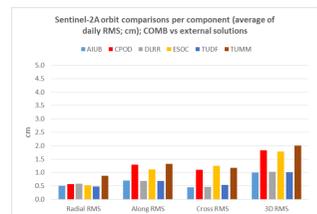
Navigation solutions from the satellites are provided in sp3 [2] format

Auxiliary information such as GPS antenna reference point coordinates, antenna phase center offsets and variations, mass history and CoG position, maneuver information etc. are provided either in separate files or within a specific Technical Note describing the necessary information.

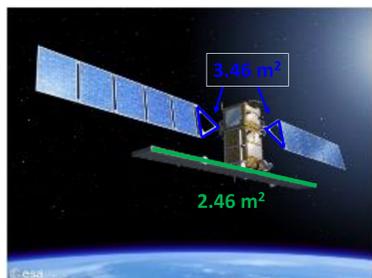
## Scientific Exploitation

The scientific exploitation of the orbit-related data and products is manifold.

First of all the Sentinel's orbit validation within the Copernicus POD QWG is a scientific exploitation. Different approaches (e.g., purely mathematical or partly based on physical models) to combine the orbit solutions are studied for instance. One idea behind a combined orbit is, e.g., to generate a reference orbit to which all other solutions are compared. Mean RMS values of comparisons of all available orbit solutions to such a combined orbit are shown in the plots below for Sentinel-2A and Sentinel-3A from a 4-month period (Oct 2016-Jan 2017).

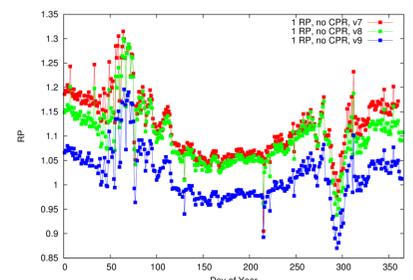


Other opportunities for scientific exploitation are described in the boxes below. These are not the only ones but they exemplarily stand for a number of interesting research topics, which are or will be triggered by the availability of the orbit-related input data from the first three Sentinel missions.



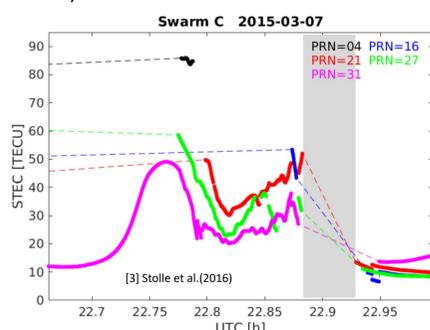
## Orbit modelling

Sophisticated satellite models (in terms of geometry and optical properties) are needed to provide best possible orbit products. The Sentinel-1 satellites have a complex structure where all parts of the satellite have to be considered correctly. In first satellite models the front of the SAR antenna and the mountings of the solar panels were missing. The left plot shows the corresponding areas, which had been added (green => v8, green+blue => v9). The plot on the right shows for the corresponding satellite models the estimated scale factor for the solar radiation pressure acting on the satellite (value of 1 is ideal). This shows the large impact of small changes in a satellite model on the orbit parameters.



## Ionosphere

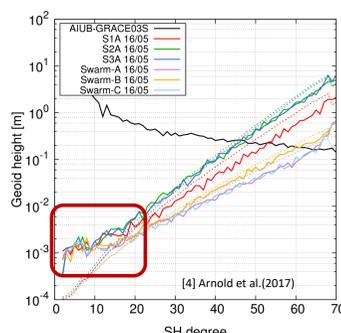
Dual-frequency GPS observations provide information about the TEC (Total Electron Content) in the ionosphere. Data from LEOs are important for TEC studies due to the global coverage and continuous availability.



For instance the slant TEC from different GPS satellite passes tracked on Swarm-C revealed fluctuations in TEC before GPS tracking failures occur (grey shaded). These problems could be minimized by modifications in the GPS receiver settings. The Sentinel GPS data will provide a large amount of additional data to study, e.g., short-time TEC fluctuations.

## Gravity field modelling

Over the last decade the GRACE mission has been used for time-variable gravity field modelling. To bridge the gap between GRACE and the upcoming GRACE-FO mission kinematic orbit data from as many LEO missions as possible are used instead.



The ESA Earth Explorer Swarm mission is already known to be important as gap filler for the time-variable gravity field modelling. The difference degree amplitudes (solid lines) in the plot show that the higher flying Sentinel satellites can contribute on the same level as the Swarm satellites at least to the very low terms of the gravity field. The low terms are the most important ones for time-variable gravity field modelling.

## Summary

The GNSS RINEX L1B files of the first three Sentinel missions are planned to be provided in the Copernicus Open Access Hub (<https://scihub.copernicus.eu/>) in Q3 of this year. Beyond the scope of precise orbit determination the data is suitable for scientific exploitation covering among others geodetic and atmospheric applications.

Anyone you is willing to become a POD S3VT (S-3 Validation Team) member is invited to apply @ <http://earth.esa.int/aos/S3VT>

### References

- IGS RINEX WG, RTCM-SC104 (2015) RINEX – The Receiver INdependent EXchange format, Version 3.03, 14 July 2015. <http://igs.org/pub/data/format/rinex303.pdf>
- Hilla, S. (2015) The Extended Standard Product 3 Orbit Format (sp3-c), <https://igscb.jpl.nasa.gov/igscb/data/format/sp3c.txt>
- Stolle, C. et al. (2016) Strong plasma density fluctuations and GPS and TEC performance, presentation at the 6th Swarm DQW, 24-27 Sep 2016, Edinburgh, U.K.
- Arnold, D. et al. (2017) Combined Swarm/Sentinel Gravity Fields, poster at the 4th Swarm Science meeting, 20-24 Mar 2017, Banff, Canada