COPERNICUS POD SERVICE OPERATIONS

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ABSTRACT

The **Copernicus POD (Precise Orbit Determination) Service** is part of the **Copernicus PDGS Ground Segment** of the Sentinel missions. A GMV-led consortium is operating the Copernicus POD Service (CPOD) being in charge of generating **precise orbital products** and auxiliary data files for their use as part of the processing chains of the respective Sentinel PDGS (Payload Data Ground Segment).

This paper describes the **CPOD Service** and presents the current status operating **Sentinel-1A** and its readiness to support the **Sentinel-2A** and in particular **Sentinel-3A** incoming **Commissioning Phases**, with an especial emphasis on describing the Calibration and Validation (**Cal/Val**) activities to be performed during the Comm. Phase. Then, it is shown how the quality of the orbital products is guaranteed through **external validation** activities and the role of the Copernicus POD QWG (**Quality Working Group**).

1. COPERNICUS POD SERVICE DESCRIPTION

The **Copernicus program** is a joint initiative of the European Commission and the European Space Agency (ESA), designed to support a sustainable European information network by monitoring, recording and analysing environmental data and events around the globe. The Copernicus program will consist of different families of satellites, being the first three families the subject of the Copernicus POD Service.

The first family is **Sentinel-1**, and will consist on two satellites with imaging C-band and Synthetic Aperture radars (SAR). The second family is **Sentinel-2**, which will consist on two satellites with optical sensors. The main instrument is the Multi-Spectral Instrument (MSI) which will operate from the visible to the shortwave infrared. The last family is **Sentinel-3**, which will consist on two satellites with several sensors to continue the products of Envisat and ERS, derived from the combination of data produced by the Radar Altimeter, MWR (Micro Wave Radiometer) and GNSS and DORIS (Doppler Orbitography and Radio-positioning Integrated by Satellite) receivers.

The **Copernicus POD Service** is part of the **PDGS Ground Segment** of the Sentinel missions and is in charge of the generation of precise orbital products and auxiliary data files for their use as part of the processing chains of the respective Sentinel PDGS.

The CPOD Service is a service **developed and operated by a GMV-led consortium** with a system running at GMV premises and providing products for the Sentinel missions with different timeliness: near real-time (NRT), short-time critical (STC), non-time critical (NTC) and reprocessing (REP). Additionally the **S-3 POD IPF,** a software package developed as part of the CPOD Service, will run at the S-3 PDGS (on both, the Marine Centre and Core Ground Station) generating near-real time orbits for the Sentinel-3 mission.

The POD SW core of the CPOD Service is based on **NAPEOS** (Navigation Package for Earth Orbiting Satellites), the leading ESA/ESOC (European Space Operations Centre) software for precise orbit determination, in whose development GMV has participated along the last 15 years. The careful selection of models and inputs is important to achieve the different but very demanding requirements in terms of **orbital accuracy** and **timeliness** for the Sentinel -1, -2 & -3 missions. The three missions require orbital products in Near Real Time (**NRT**), with latencies as low as 30 minutes, in Short Time Critical (**STC**) , with latencies of 1.5 days and in Non-time Critical (**NTC**) with latencies between 20-30 days after sensing.

Concerning the missions, the first Sentinel satellite, **Sentinel-1A**, was launched in April 2014. The CPOD Service is running since the first data got available from the satellite. After the end of the Commissioning Phase in September 2014, the CPOD Service turned into operational mode on October 2014, providing routinely the required orbital products. In June 2015 **Sentinel-2A** will be launched and by the last quarter of 2015 **Sentinel-3A** is expected to be launched, so by end of 2015, the CPOD Service will be operating three satellites simultaneously.

2. SUMMARY OF MISSION REQUIREMENTS

This section presents a summary of the performance requirements in terms of latency, coverage and accuracy of each of the CPOD products delivered to the respective PDGS.

The products provided by the CPOD Service can be classified in terms of mission and timeliness. According to this classification, seven categories of requirements are obtained. Tab. 1 shows the **latency and coverage** requirements of each category. Tab. 2 shows the **accuracy** requirements of both orbital and platform (attitude) products.

Table 1: Latency and Coverage Requirements

Mission	Category	Latency	Coverage
S-1	NRT	180 min.	Two orbits
	NTC	20 days	26 hours
S-2	NRT (predicted)	90 min. before ANX	Two orbits
	NRT	30 min.	received PVT span + 2 orbits backwards
S-3	NRT (S3 POD IPF)	30 min.	received PVT span + 5 OSV before and after
	STC	1.5 days	26 hours
	NTC	28 days	26 hours

Table 2: Accuracy Requirements

Mission	Category	Orbit Accuracy (RMS)	Platform Accuracy
S-1	NRT	10 cm (2D)	N/A
	NTC	5 cm (3D)	0.005 deg raw, pitch, yaw
S-2	NRT (predicted)	3 m (2D)	N/A
	NRT	1 m (3D)	N/A
S-3	NRT (S3-IPF)	10 cm radial (target of 8 cm)	0.05 deg pitch 0.05 deg roll 0.5 deg yaw
	STC	4 cm radial (target of 3 cm)	
	NTC	3 cm radial (target of 2 cm)	

It can be seen that the **accuracy** requirements are very challenging, targeting 5 cm in 3D for Sentinel-1 and **2-3 cm** in radial direction for **Sentinel-3**.

3. DESCRIPTION OF THE SYSTEM

The **CPOD Service** is part of the **PDGS Ground Segment** of the Sentinel missions. It is a complex system where several partners are involved and many elements interact to obtain the required accuracies in a timely manner. The system located at GMV is also a complicated set of hardware elements set up to reduce risk of unavailability to its lowest levels. Finally, a studied logical disposition of the software elements makes feasible the three missions running simultaneously and providing products for the six Sentinel satellites.

This section gives an overview of the main elements of the system.

Partners

Main members:

- ESA ESRIN (European Space Research Institute)
- ESA ESOC
- EUMETSAT (European Organization for the Exploitation of Meteorological Satellites)
- CNES (Centre National d'Études Spatiales)
- GMV Innovating Solutions
- POSITIM UG
- DLR (Deutsches Zentrum für Luft- und Raumfahrt)
- TUM (Technische Universität München)
- AIUB (Astronomisches Institut Universität Bern)
- TU Delft (Technische Universiteit Delft)
- VERIPOS

Fig. 1 shows in the map of Europe the location of the above mentioned centres and companies.

Figure 1: Location of the Partners of the CPOD System

GMV leads the consortium formed by POSITIM, DLR, TUM, AIUB, TU Delft and VERIPOS. GMV interfaces with ESA centres, EUMETSAT and CNES; and it is in charge of the management of the whole system (see Fig.2).

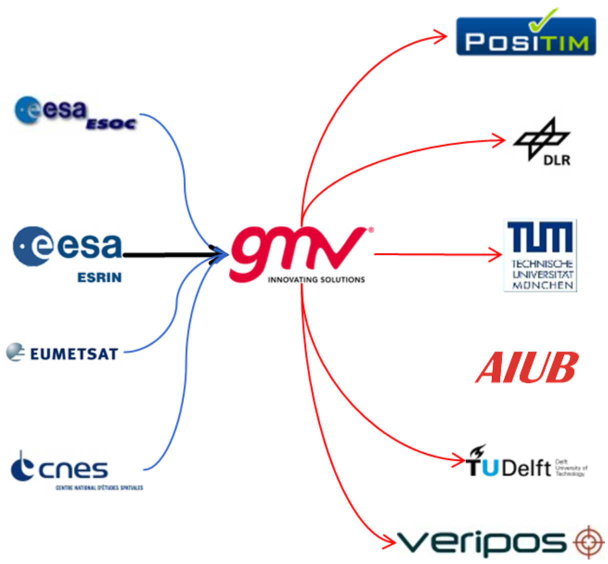

Figure 2: Partners and GMV-led consortium

The different roles of the partners of the consortium are represented schematically in Fig. 3.

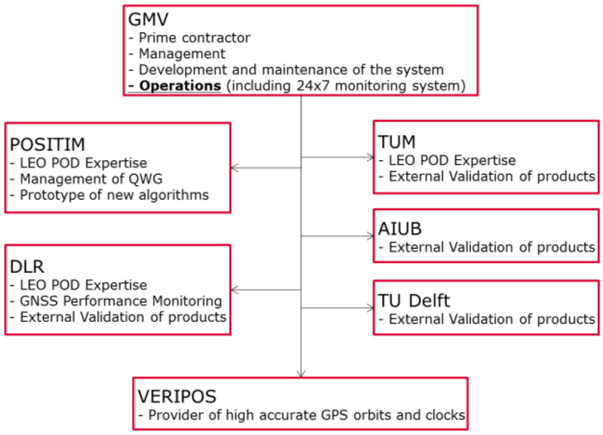

Figure 3: Roles of the partners of the consortium

Elements

The following main external interfaces are defined [1]:

Payload Data Ground Segment (PDGS): It is part of the Ground Segment of the Copernicus program. It is in charge of processing the scientific data retrieved by the Sentinel satellites. The CPOD Service is part of the PDGS Segment, in charge of providing orbital products and platform data files, which are used in the different scientific processing done by the PDGS. The PDGS is the main provider of inputs to the CPOD Service (L0 data containing the GNSS measurements, PVt solutions and attitude information) and the unique receiver of the products generated.

Sentinels Flight Operations Segment (FOS): They provide operational orbit, manoeuvre information and the satellite mass and centre of gravity evolution.

External GNSS data Provider (EGP): A dedicated high accuracy and availability external GPS data provider (**VERIPOS**). High rate orbits and clocks are provided with different levels of timeliness and accuracy. In case of unavailability a back-up solution has been put in place based on ***magicGNSS***[9], a GMV solution for GNSS accurate products.

International Laser Ranging Service (ILRS): They provide SLR data while the CPOD provide orbit predictions (CPF files) of Sentinel-3 to ILRS.

External Auxiliary providers: Other ancillary data (from several sources): Mainly Earth Orientation Parameters and leap seconds from IERS (International Earth Rotation Service), solar and magnetic activity information for geodesy computations from NOAA and atmospheric gravity models from NASA.

Centre National d'Études Spatiales (CNES): They provide Sentinel-3 orbital and attitude products (for comparison purposes), together with DORIS data. CPOD provides GNSS Observation Rinex files to CNES.

External Validation: A number of independent institutions (ESOC, DLR, TUM, AIUB, TU Delft) provide independent orbit solutions for validation purposes to assess the quality of the CPOD products.

CPOD Quality Working Group (CPOD QWG): The main purpose is to monitor the performance of the operational POD products (both the orbit products as well as the input tracking data) and to define potential and future enhancements to the orbit solutions.

A summary of these elements and the dataflow is represented in Fig 4.

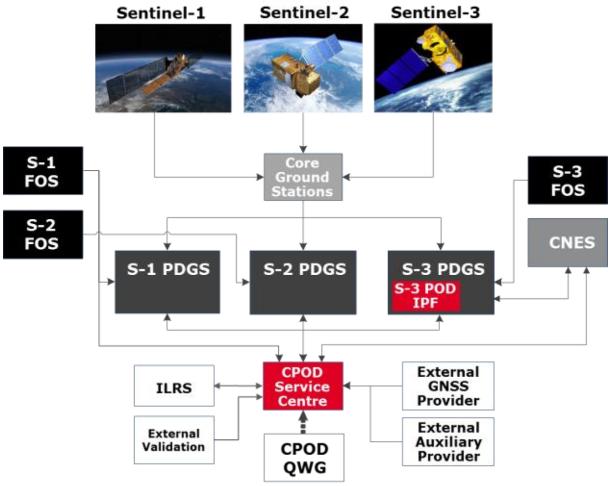

Figure 4 CPOD elements

Physical Architecture of the CPOD

From the point of view of the physical architecture, the CPOD system consists of three independent environments: Operational, Validation and Development. These systems are distributed into two independent networks, the CPOD (operational) network and the GMV network. The GMV network contains a system architecture emulating that of the operational network where the Validation system is installed. In this network there is an additional machine devoted to the Development system. Here CPOD engineer makes the improvements to the system. See Fig. 5.

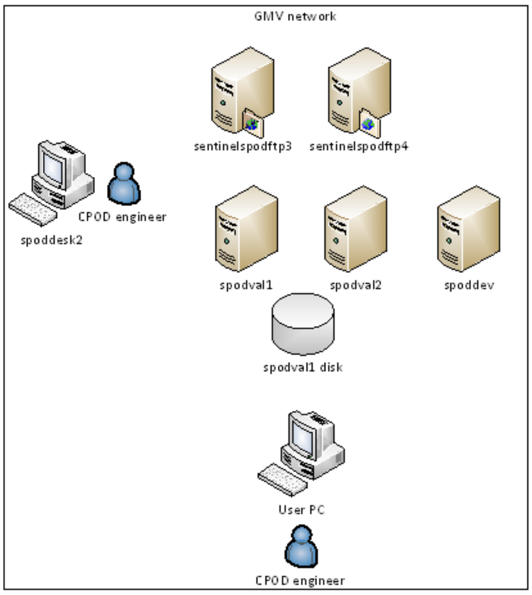

Figure 5 GMV network

The Operational system is installed inside the CPOD network. It consists of a redundant ftp service with two machines mounted as a cluster, showing a single virtual IP direction to the external users through a redundant firewall. Two operational machines process the received data independently, one working as the nominal and other as the backup. These two machines store the redounded data into a Storage Area Network (SAN) system mounted in RAID 5 to ensure the required low risk levels. The system can be accessed through a desktop machine for upgrades of the system and through a VPN service for operations. Fig. 6 represents a schematic of this network.

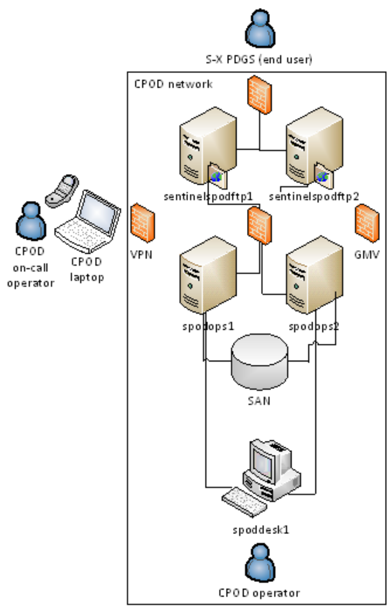

Figure 6: CPOD network

Logical Configuration of the CPOD System

Logically the system is configured with several accounts (Fig. 7). There is one account (SPOD) that includes the software and configuration packages. These packages are shared for all Sentinel missions to ensure consistency, although internally are separated to allow independent operation. A common account (SPODOPS) is devoted to the processing of shared elements, like the update of common NAPEOS databases, the management of auxiliary data files, and the management of the external GPS products. Then there are three dedicated accounts, one for each of the missions:

- S1PODOPS
- S2PODOPS
- S3PODOPS

In each account, several processing chains run automatically performing the following tasks:

- Download data from ftp and store into archive
- Process NAPEOS database files
- Process inputs to obtain products
- Archive products
- Perform quality control and comparisons
- Generate quality control reports
- Upload data from archive to ftp

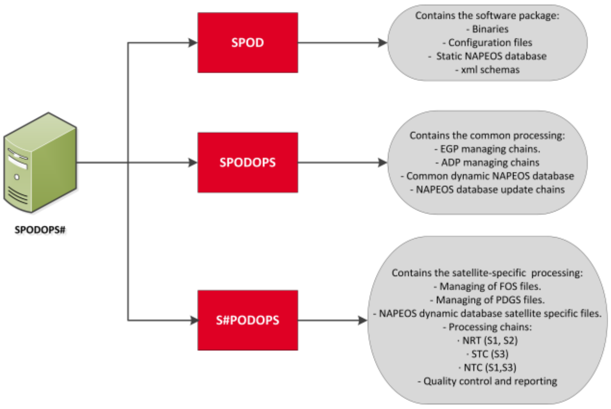

Figure 7 Logical configuration

Functional components

The main building blocks or functional components of the CPOD Service are the following [1]:

Storage and Dissemination: An archiving system where the incoming data and the generated products are stored according to the specific requirements for each mission. The stored products are exposed to the users by means of shared storage system of an FTP server.

POD Computational Core: All low level functions associated to the processing of the POD data. The interfaces of the POD computational core to the Data Management System are standard navigation formats (i.e. RINEX, SP3, ANTEX, etc.). Following section provides details on the computational processing chains that are used to process the data.

Quality Check: Verification on the resulting POD products. The type of quality checks implemented depends on type of implemented POD process, NRT, STC or NTC. In the NRT systems this function is limited by the availability of reference data but it is intended to implement sufficient checks to guarantee the outgoing product quality and integrity. As part of the Copernicus POD Service, the NRT product will be quality controlled with respect to the non-time critical (NTC) solutions and the NTC solutions themselves will undergo internal and external (external validation) checks.

Reporting: Recollection of POD and monitoring information to generate the data required to analyse and assess the POD system performance. **Interface**: Pre-processing of the incoming data and the formatting of the outgoing products.

Management System: Manages the incoming and outgoing data and the processes that manipulate the data as part of the POD process.

Computational Processing Chains

The whole POD Computational Core of the CPOD Service (and also the Sentinel-3 NRT POD IPF) is based on the existing ESA's **NAPEOS** technology [2].

The NAPEOS-based POD processing shares the same functional modules across the different Sentinel missions and orbit solution levels (NRT, STC, NTC). In this way, the consistency among the different levels of solutions is ensured in what regards processing algorithms, reference frames, dynamic and measurement models, etc. Fig. 8 shows the proposed overall generic processing scheme for the Sentinel missions.

Basically, each sequence involves the following generic steps:

1. Data retrieval from the archive which contains all inputs and products for the complete mission
2. Processing
3. Quality control of products
4. Storage of products in the archive
5. Publication of products in the FTP server

The processing steps needed for each of the chains depends on the mission and on the products level (NRT, STC, NTC)

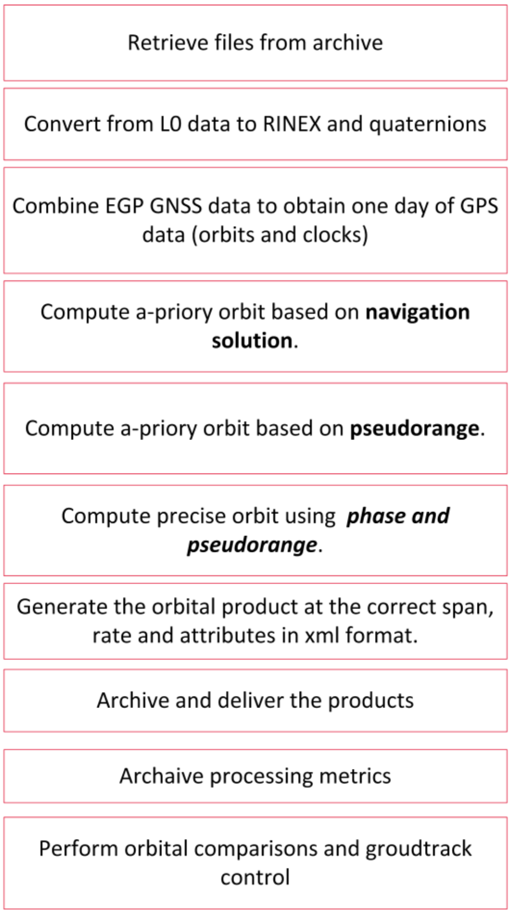

Figure 8: POD processing sequence

Quality Control and Reporting System

The Quality Control element is in charge of the Operational NRT/STC POD quality control as well as the Long Term Monitoring and Validation of all products. The results of these two analyses must be included in the reports generated by the CPOD Service. The following aspects will be considered as part of the orbit processing chain and the POD quality control activities itself: orbit comparisons (e.g. against CNES for S-3), analysis of orbits overlaps between consecutive solutions, analysis of OD performance metrics, analysis of the external GPS orbits and clocks quality and analysis of mission constraints (e.g. ground-track, see Fig. 9).
An on-line system to routinely monitor the status of the CPOD Service has been also developed. This system is accessible by a standard web browser via https and it is based on NAGIOS tool.

NAGIOS is an open source monitoring and alerting application for servers, switches, applications, and services.

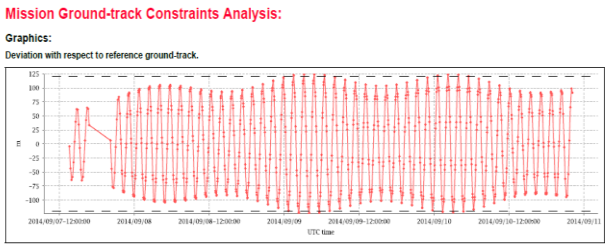

Figure 9: Example of plot with ground-track control

Operations

The operations of the CPOD Service [1] are managed by an expert Service Manager who is expert in all the POD processes and products involved. He is supported by a deputy Service Manager, also expert in POD. Both personnel have also managed the implementation of the Copernicus POD Service.

They are in charge of the operation and daily monitoring of the POD service following the procedures of the operational baseline and of the maintenance and evolution of the system as a whole and of the POD software in particular, following the recommendations from the QWG experts.

They are also supported by a Service Operations Manager, who is responsible for the routine 7x24 operations, monitoring and first-line support to external users. The Service Operations Manager manages a group of Service. This team will use the NAGIOS deployment for monitoring purposes and will also answer tickets raised in the dedicated ticketing system. In case an issue cannot be resolved by this team, the problem will be escalated to the Service Operations Manager.

4. STATUS OF THE MISSIONS

Sentinel-1A

The Sentinel-1A is in Routine Operations Phase since October 2014. During the commissioning phase, calibration and validation (Cal/Val) activities were performed to fine tuning the parameters and models used. During the first Regular Service Review (RSR) meeting, conducted in March 2015, the service was reviewed thoroughly and in particular the accuracy of the NTC products was assessed. Table 3 shows the differences between the operational NTC products and different external solutions computed by external entities. It can be seen that the accuracy requirement of 5 cm (3D) are fulfilled. More details on updates and improvements done in the CPOD System may be found in [3].

Table 3: Sentinel-1A accuracies

Accuracy of Sentinel-1A (RMS; cm)	AIUB	DLR	ESOC	TU Delft	TUM
S-1 NTC 3D RMS	4.3	6.4	2.7	4.7	3.4
S-1 NTC Radial RMS	3.4	2.2	0.8	1.6	1.9
S-1 NTC Along RMS	2.2	4.4	1.9	3.5	2.5
S-1 NTC Cross RMS	1.5	4.2	1.8	2.7	1.3

Sentinel-2A

The Sentinel-2A is ready for commissioning phase. Launch is scheduled for June 2015. The activities to be done during commissioning are similar to those for Sentinel-3, explained in next section. However, the accuracy required for Sentinel-2 is in the order of 1 meter, instead of few cm for Sentinel-1 and -3. In any case the objective of CPOD Service is to obtain similar accuracies in all Sentinel missions.

Sentinel-3A

The Sentinel-3A is ready for commissioning phase. Launch is scheduled for last quarter of 2015. Currently the S-3 PDGS is being performing integration tests with the different facilities (including CPOD Service and EGP). The objectives for CPOD during the commissioning phase, which will span 5 months, are:

1. Verify the POD processing chains
2. Check PVt solution computed on-board and the attitude quaternions
3. Verification and validation of the POD Service products
4. Validate satellite characteristics like location of center of gravity, location of GPS antennas …
5. Obtain the stability and drift of the GNSS on-board clock
6. Fine-tuning of the physical models
7. Accurate antenna phase centre corrections

The specific Cal/Val tasks for Sentinel-3 are:

1. Validation of the orbital accuracy of NAPEOS POD core: This has already been done with MetOp-A and Sentinel-1A data. The result has shown that NAPEOS is fully capable of achieving the required accuracies after a careful configuration of the characteristics of the satellite.
2. Validation of the S-3 POD processing chains: This was done during the development of the system and it is being done routinely with operations of Sentinel-1A. For Sentinel-3 it will also include the S-3 POD IPF SW, running inside the S-3 PDGS.
3. Validation of the ingestion EGP inputs: This task was already performed during the commissioning phase of Sentinel-1A and nowadays these inputs are being ingested for the operations of Sentinel-1A.
4. Fine tuning of Sentinel-3 POD processing chains: This is a critical task, in particular the careful and accurate configuration of the satellite characteristics, like location and orientation of the GNSS antennas, or the location of the Centre of Gravity of the satellite.
5. Comparison of S-3 POD products with external solutions during commissioning, in particular against solutions provided by CNES, ESOC, DLR, TUM, AIUB and TU Delft.
6. Observation residuals analysis of S-3 processing chain. One of the outputs of this task is the generation of an azimuth-elevation dependant corrections map to the phase measurements.
7. Fine tuning of Sentinel-3 quality flagging mechanism. Each product contains quality flags that depend on the statistics of the processing.
8. Fine tuning of Sentinel-3 Platform data generation
9. Sentinel-3 Orbital products SLR validation
10. Sentinel-3 Nominal – Redundant GNSS validation: There are two GNSS receivers/antennas. If data is available from both, the same activities done with the nominal chain shall be done also with the redundant.
11. Quality control of S-3 POD orbital products: This is a routine task, performed three times per year, to compare the orbital products against externally provided orbital solutions.

5. SENTINEL-3 PECULIARITIES

The POD processing of Sentinel-1A is a good preparation for **Sentinel-3A**, which has similar demanding orbit accuracy requirements. In addition to a GPS receiver Sentinel-3A carries a laser retro reflector and a DORIS receiver. On the one hand, the three different techniques **GPS**, **SLR** and **DORIS** make POD more complex but, on the other hand, it is very helpful to have independent techniques available for validation of the orbit results. The Copernicus POD Service will process GPS and SLR data routinely and have the capacity to process DORIS in NTC and reprocessing campaigns; combining the three techniques has been proven very useful to remove biases present using a single solution, for instance biases in clocks, which are not present if SLR is used.

6. QUALITY WORKING GROUP

The Copernicus POD Service is supported by the **Copernicus POD Quality Working Group** (QWG), which consists of several LEO POD experts along with ESA, EUMETSAT, CNES, users and industry representatives. They gather a high level of expertise in GNSS LEO orbit processing. The main purpose of the Sentinels POD QWG is to monitor the performance of the operational POD products (both the orbit products as well as the input tracking data) and to define potential and future enhancements to the orbit solutions.

Main tasks

Gather information: Through attending conferences and interactions with the IDS Analysis Working Group, the Copernicus POD QWG gathers information on any potential algorithm evolution that could benefit the Copernicus POD system. Besides, the interaction with the international services of all observation techniques available for the Sentinels (IGS, IDS and ILRS) is maintained. The IERS conventions and realizations of the ITRF are updated. The evolution of the (CNES) GDR standards is also considered.

Evaluate: Evolutions are evaluated on a separate validation with at least other POD centre (CNES; ESOC). Quality indicators evaluated are orbit overlap, tracking data residuals, the magnitude of the empirical acceleration, external orbit comparison, and in the case of Sentinel-3 altimeter crossover performance.

Make recommendations: The most promising enhancements are presented and discussed during the QWG meetings.

Implement changes: After the internal and external evaluation and approval of ESA the algorithm evolution is included in the next upgrade of the POD.

Membership

The composition of the Copernicus POD QWG is composed by representatives of ESA, EUMETSAT, CNES, NASA, GMV, POSITIM, DLR, TUM, AIUB, TU Delft, DGFI, Sentinel-3 Validation Team Meeting, the Mission Performance Centre of each Sentinel, Payload Data Ground Segment of each mission, the GMES Service and the Post-Launch Support Office.

7. CONCLUSIONS

The first conclusion is that CPOD service is a complex system which involves multiple parties and many elements. GMV has achieved a quick development of this complex structure; less than one year to make the system operational for Sentinel-1A and less than two to make it ready for all the missions.

The operational phase of Sentinel-1 allows demonstrating that the state-of-the-art of the technologies involved enables to meet the challenging requirements in terms of accuracy, timeliness and coverage of the products. The monitoring system, together with the CPOD reporting tools, can be used to obtain good proof of this fact.

Readiness for Sentinel-2 and Sentinel-3 is proved mostly by the readiness of Sentinel-1, as the requirements are less restrictive (case of Sentinel-2) or similar (case of Sentinel-3) to those of Sentinel-1. However, during commissioning phase of each mission, Cal/Val activities are developed to fine-tune the particularities of each mission.

8. ACKNOWLEDGEMENTS

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6) VERIPOS

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