THE COPERNICUS SENTINEL-3 MISSION

Jaime Fernández [1], Carlos Fernández [1], Pierre Féménias [2], Heike Peter [3]

[1] *GMV AD., Isaac Newton 11, 28760 Tres Cantos, Spain*
[2] *ESA/ESRIN, Via Galileo Galilei, I-00044 Frascati, Italy*
[3] *PosiTim UG, In den Löser 15, 64342 Seeheim-Jugenheim, Germany*

e-mail:jfernandez@gmv.com, cfernandez@gmv.com, pierre.femenias@esa.int, heike.peter@positim.com

1. Abstract

The **Sentinel-3** mission is part of **Copernicus project**, the European Programme for the establishment of **European capacity for Earth observation**. The mission is jointly operated by ESA and EUMETSAT to deliver **operational ocean and land observation services**.
Sentinel-3A was launched on 16 February 2016 and it carries a **GPS receiver**, a **Laser Retro Reflector (LRR)**, and a **DORIS receiver** for **Precise Orbit Determination (POD)** in support of the **altimetry mission**. Observations from all three techniques are equally important to fulfil the stringent **orbit accuracy requirements of 2-3 cm in radial direction**.
Satellite Laser Ranging (SLR) is a key technique to calibrate the GPS and DORIS instrument and the overall POD processing chain. With the demanding accuracies of the mission, SLR is needed for the entire mission life-time to perform periodic checks of the biases that could exist between different tracking techniques.
The **Copernicus POD Service**, a GMV-led consortium being in charge of generating precise orbital products for Sentinel-1, -2, and -3, is in charge of generating the **CPF orbit** files to the ILRS community and is a **main user** of the SLR measurements to compute the precise orbital products of Sentinel-3.
The **status of the Sentinel-3 mission** and the quality of its orbit products is presented in particular focusing on the helpful contributions from ILRS. A detailed assessment of the quality and the amount of the SLR data is done for the commissioning phase as well as for the first months of the operational phase. Finally the future needs of SLR data are presented.

2. Overview of the Copernicus POD Service

The **European Space Agency** (ESA) is currently deploying an **operational system** for routine Earth Observation named **Copernicus**, a joint initiative of the **European Commission** and the European Space Agency, designed to support a sustainable European information network by monitoring, recording and analyzing environmental data and events around the globe. The Copernicus program consists of six different families of satellites being the first three missions Sentinel -1, -2, and -3. These missions have very demanding requirements in terms of **orbital accuracy** and **timeliness**, with requirements of 8-10 cm in less than **30 minutes** for Near Real Time applications and **2-3 cm** in less than one month for Non-time Critical applications.

GMV developed and is currently operating the **Copernicus POD (CPOD) Service** (Figure 1), in charge of providing accurate orbit and attitude products for the Sentinel -1, -2, and -3 missions as an **operational service**. This service is operated by GMV routinely and continuously on a **7x24 basis** for a global community of users from its premises in Tres Cantos, near Madrid, Spain. Although being operated as an external service, the **Copernicus POD Service** is part of the **Payload Data Ground Segment (PDGS)** of the Sentinel missions and it is subject to a **Service Level Agreement** (SLA) that monitors the quality of the service provided. Finally, a Quality Working Group (**QWG**) has been established to monitor the performance of the CPOD products, and in particular the accuracy of the orbital products.

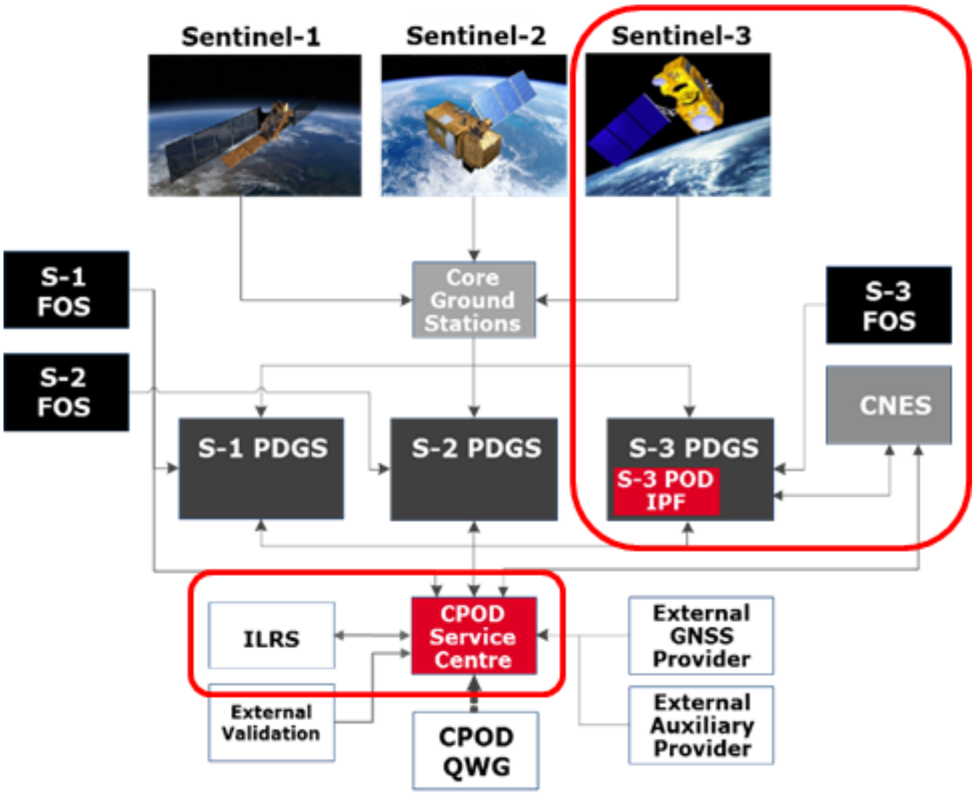

Figure 1: Overview of Copernicus POD Service

Among others, the CPOD service is responsible for the generation of the Consolidated Prediction Format (**CPF**) files for the ILRS, and it is using the SLR observations for calibration and accuracy assessment purposes.

3. Overview of the Sentinel-3 Mission:

The Sentinel-3 mission will ensure the future continuity of medium resolution sensors like MERIS, (A)ATSR and VGT, as well as for the **Altimetry System** (RA-2, MWR, DORIS) on-board ENVISAT and on-board the ERS platforms (RA, MWR, PRARE) for global ocean and land monitoring. The primary objective is **marine observation**, and it will study sea-surface topography, sea and land surface temperature, ocean and land color with high accuracy and reliability to support ocean forecasting systems, environmental monitoring and climate monitoring. The mission is composed of a constellation of two satellites, Sentinel-3A and Sentinel-3B, in a near-polar, sun-synchronous orbit with a 27 days repeat cycle. The Mean Local Solar Time (MLST) at the descending node is 10:00 (am). Both satellites share the same orbital plane with a 140° orbital phasing difference.

Figure 2: Sentinel-3 (credit: ESA)

Sentinel-3 satellites (see Table 1) carry two dual-frequency GPS receivers, a DORIS receiver and a Laser Retro-Reflector (LRR) for the purpose of POD. The GPS receivers provide observations with a rate of 1Hz. Only one receiver provides observations at any time, switching to the other in case of failure. Finally the Attitude and Orbital Control Systems (AOCS) provides the quaternions representing the attitude of the satellite.

Table 1: S-3A characteristics

Launch Date	S-3A: 16/02/2016 S-3B: Q4; 2017
Mission Life	7 year with consumables for 12 years
Orbit	Polar, sun-synchronous at altitude of 815 km
Inclination	98.65º
Cycle	27 days
Mass	1250 kg
Instrument for POD processing	2 GPS receivers
	1 LRR
	1 DORIS receiver

Table 2: S-3 Orbital Products Requirements

S-3 Orbital Products Requirements		
Category	**Latency**	**Radial Accuracy (RMS)**
NRT	30 min.	10 cm (target: 8 cm)
STC	1.5 days	4 cm (target: 3 cm)
NTC	25 days	3 cm (target: 2 cm)

Sentinel-3 has demanding orbital products requirements (Table 2), in particular the accuracy requirements, requiring 8/10 cm (radial RMS) in less than 30 minutes since the availability of the GPS data, to 2/3 cm (radial RMS) in less than 25 days. The generation of the orbital products is mainly based on GPS data (in the future the CPOD will also use DORIS data in combination with GPS). SLR data can be used in two ways: either to incorporate the measurements into the overall orbit determination process, or to fix the estimated orbit and use the SLR data to compute the residuals as an independent way to assess the quality of the orbital products. The second method is currently used, and will allow to estimate the potential biases existing in GPS and DORIS.

4. ILRS Stations Statistics – Sentinel-3A

Sentinel-3 carries an instrument, the Ocean and Land Colour Instrument (OLCI), which contains a coating that can be degraded by direct radiation, in particular by lasers used within the ILRS network. There is risk only in case too much energy illuminates certain parts of the instrument. As a result, ESA and Thales indicated the maximum amount of energy that could impact it without damaging the instrument. With this information ILRS performed a study to identify which ILRS stations can be used to track Sentinel-3A safely. Figure 3 shows the network of ILRS stations identified, being in green those that track S-3A routinely, while in red those not tracking S-3A since mid-September, 2016, probably due to maintenance works at the stations. The ILRS support started few weeks after the launch (see Figure 4 left for number of S-3A passes tracked by ILRS per week) and increased steadily. Figure 4 right shows the cumulative number of passes per station, where can be seen that Yarragadee and Changchun are the most productive stations, followed by Potsdam, Greenbelt, Herstmonceux, Graz, Mount-Stromlo and Wettzell.

Figure 3: ILRS station network supporting Sentinel-3A. Only those that signed the Sentinel-3 tracking agreement based on power restrictions are included

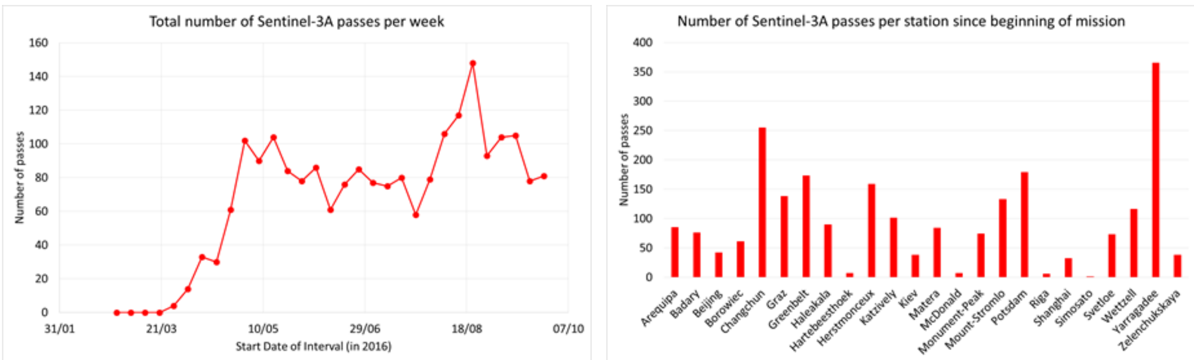

Figure 4: Total number of Sentinel-3A passes (per week on left plot; per station on right plot)

Figure 5 left shows the cumulative number of passes per satellite. Sentinel-3A has been assigned medium priority, and indeed it has an intermediate number of passes, compared to missions like SWARM, but well below Jason-2/3, probably due to the shorter duration of the station passes due to shorter orbital period. Altimetry missions (e.g. CryoSat, Sentinel-3A, Jason-2/-3) have a critical need for SLR measurements because of the demanding radial orbital accuracy. For the time being, the order of priority does not reflect the number of tracked passes per mission, as probably the duration of the station passes has a big impact on the final number of passes obtained. The temporal evolution of number of Sentinel-3A passes per week has stabilised with values similar to Swarm, TerraSAR-X /TanDEM-X and CryoSat-2 (see Figure 5 right).

Sentinel-3 mission requires the support of SLR measurements for independent orbit validation throughout its entire life to ensure the demanding accuracy requirements for altimetry processing are regularly met. Thus, the contribution from the ILRS Community is crucial for the full success of the altimetry mission within the Copernicus Programme.

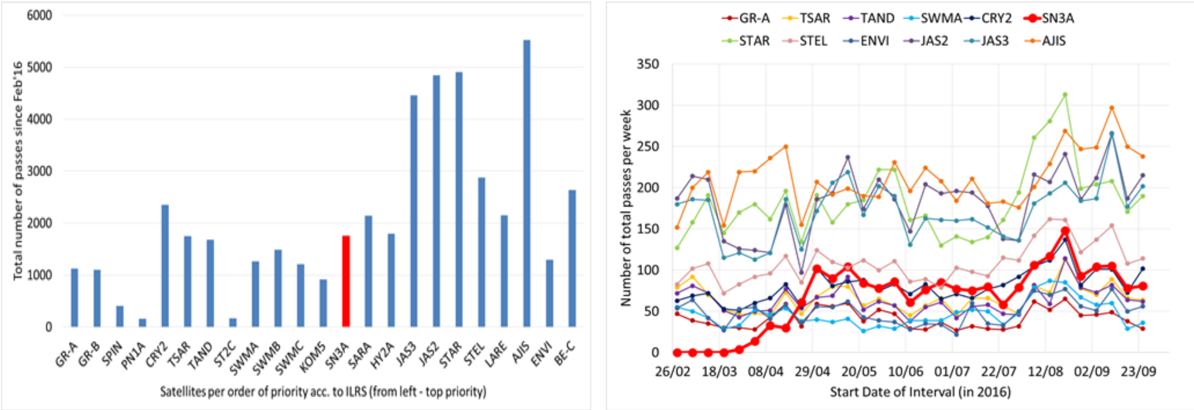

Figure 5: Total number of passes per station (left); Number of passes per week (right)

5. Analysis of Sentinel-3A Orbital Accuracy

There are several ways to assess the accuracy of the Sentinel-3A orbits. Those presented here are i) based on cross-comparisons between the CPOD orbits and other orbital products computed by external centres and ii) based on the SLR residuals.

The comparison of Sentinel-3A NTC orbits computed by CPOD against external GPS-derived solutions (provided by AIUB, CNES, DLR, ESOC, TU Delft, TU Munich and a combination of all of them) shows typically a 3D RMS in the order of **3 cm** and a radial RMS around **1 cm** (see Figure 6). This indicates that the radial orbital requirement of Sentinel-3A is already fulfilled.

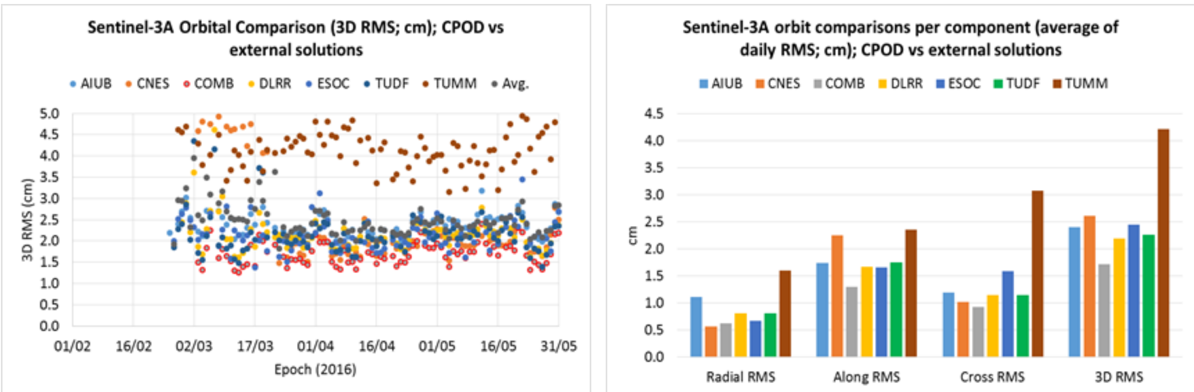

Figure 6: Sentinel-3A orbital accuracy (CPOD solution vs. others)

NTC orbits are compared against **SLR measurements for independent orbit validation**. For this purpose, they are not taken into account in the orbit determination process; instead, once the orbit has been obtained, the residuals between the SLR measurements and the orbits are computed. The SLR residuals vs NTC orbits for August 2016 shown in Figure 7 left have a **standard deviation of 1.78 cm and a mean offset of 0.3 cm**. This confirms the excellent performance and **accuracy** of the NTC orbits and allows identifying biases between different techniques and centres.

Regarding the **Consolidated Prediction Format (CPF)** files, they are delivered to the ILRS Community by CPOD, and are based on an orbit propagation from the STC product computed by CPOD. It contains 5 days into the future. The accuracy of the CPF files is assessed by comparison to the STC product with the coverage of the first predicted day of the CPF. The results (Figure 7 right) show that the CPFs accuracy is typically below **10 m 3D RMS**.

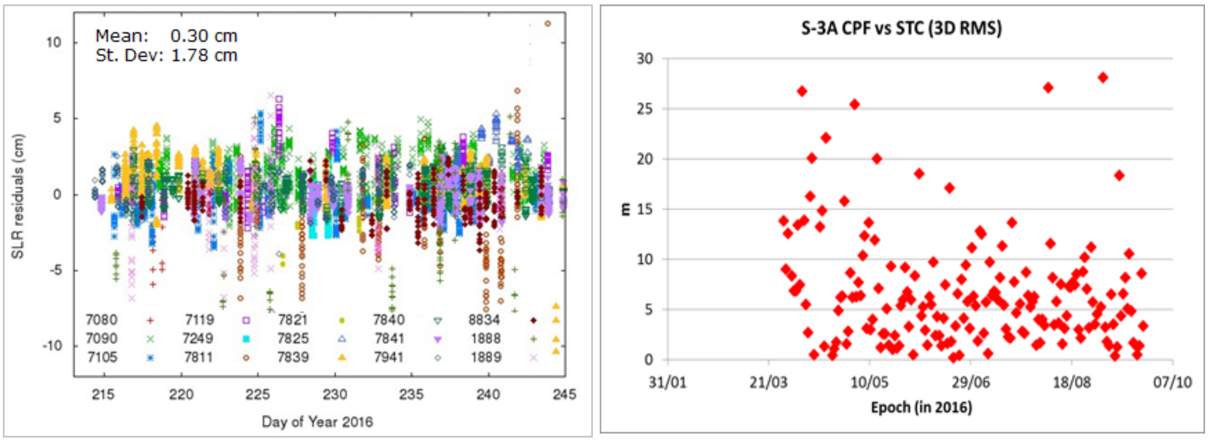

Figure 7: Sentinel-3A SLR residuals to CPOD solution (left) and S-3A CPF accuracy (right)

6. CONCLUSIONS

The main conclusions are:

- **The Copernicus POD Service** is responsible for the generation of Precise Orbit products for the Sentinel-3 mission, which has **very demanding accuracy requirements** in support of the altimetry processing.
- There is an important need for **independent validation** of the precise orbits throughout the entire mission span to ensure that there are no unexpected biases in the orbital products which might have a negative impact on the altimeter results. **SLR measurements** perfectly fit this purpose.
- The **Copernicus POD Service** serves as the **interface** with the ILRS Community, and is in charge of the generation of the **CPF** orbit files with the adequate latency and accuracy requirements. Moreover, it is responsible for the routinely use of the SLR measurements from all stations to validate the generated orbital products.
- It is in the best interest of the mission to understand the needs of the **ILRS Community** and how their **support**, gratefully acknowledged, could be **encouraged** for Sentinel-3. The situation in perspective with other scientific missions has been presented to gain an idea about the global situation of SLR tracking, focusing on those with altimetry applications.
- Finally, an **example of the orbit validations** using the Copernicus POD Service orbits has been presented, showing that indeed there is a very close agreement between the precise orbits obtained by GPS and the SLR measurements.

7. ACKNOWLEDGE

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