COPERNICUS POD SERVICE OPERATIONS – ORBITAL ACCURACY OF SENTINEL-1A AND SENTINEL-2A

Jaime Fernández[(1)]**, Diego Escobar**[(2)]**, Heike Peter**[(3)]**, Pierre Féménias**[(4)]

[(1)] *GMV AD., Isaac Newton 11, 28760 Tres Cantos, Spain, jfernandez@gmv.com*

[(2)] *GMV AD., Isaac Newton 11, 28760 Tres Cantos, Spain, descobar@gmv.com*

[(3)] *PosiTim UG, In den Löser 15, 64342 Seeheim-Jugenheim, Germany, heike.peter@positim.com*

[(4)] *ESA/ESRIN, Via Galileo Galilei, I-00044 Frascati, Italy, pierre.femenias@esa.int*

Abstract: *The **Copernicus Precise Orbit Determination (CPOD) Service** is part of the **Copernicus PDGS Ground Segment** of the Sentinel missions. A GMV-led consortium is operating the 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.*
*The first three Sentinels 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 of 20-30 days. The **accuracy** requirements are very challenging, targeting **5 cm** in 3D for Sentinel-1 and **2-3 cm** in radial direction for **Sentinel-3**.*
*This paper describes the **physical models** and **strategies** used by the different POD SW packages used by CPODS and external validation institutions to compute the precise orbital products of Sentinel-1A and Sentinel-2A. It also shows the differences found among the different orbital solutions; in particular systematic **biases** and differences in the different orbit solutions. Finally the preparations and recommendations for the altimetry mission Sentinel-3A will be discussed.*

Keywords: *Copernicus POD Service, GPS, QWG, Sentinel-1A, Sentinel-2A.*

1. Introduction

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 consists of different families of satellites, being the first three families the subject of the Copernicus POD Service.

The first family is **Sentinel-1**, and consists of two satellites with imaging C-band and Synthetic Aperture radars (SAR). The second family is **Sentinel-2**, which consists of two satellites with optical sensors. The main instrument is the Multi-Spectral Instrument (MSI), which will operate from visible to shortwave infrared. The last family is **Sentinel-3**, which consists of 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** (CPOD 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 has been **developed** and it is being **operated by a GMV-led consortium** with a system running at GMV premises to provide orbital 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 Instrument Processing Facility (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 NRT orbital products for the Sentinel-3 mission.

The accuracy of the orbital products is being assessed by a number of **external validation institutions**, all of them being part of the **Copernicus POD Quality Working Group (QWG)**. The main purpose of the Copernicus 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.

This paper describes firstly the architecture of the Copernicus POD Service including the role of the QWG. Then the characteristics of the Sentinels satellites are summarized followed by the POD processing scheme used by each processing centre. Finally the accuracy obtained by different centres is presented together with an analysis of the biases and the progress in this area. Finally it is commented the preparations carried out for the next Sentinel-3A launch.

2. Copernicus POD Service

The CPOD Service is part of the PDGS Ground Segment of the Sentinel missions. Fig. 1 shows the different elements that interact with the CPOD Service. On top we have the Sentinels satellites, all of them with two GPS Receivers on-board (S-3 also has a LRR and DORIS). The raw L0 data is downloaded at least once per orbit to one of the Ground Stations used (particularly Svalbard, but also Maspalomas and Matera are used). The raw L0 data that contains the GPS and attitude data is circulated to the Sentinels PDGS and from there it is made available to the CPOD Service Centre, which will generate orbital products with different timelines.

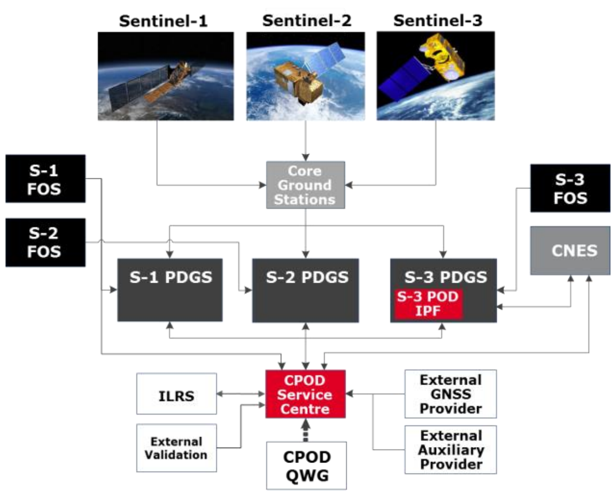

Figure 1. CPOD Service Elements

The different Sentinels Flight Operation Segments (FOS) provides orbital products (restituted and predicted) plus manoeuvre and mass history information. CNES provides also orbital products and DORIS data for Sentinel-3, and it receives GPS Rinex (Receiver Independent Exchange Format) files from the CPOD Service Centre.

The source of accurate GPS orbits and clocks is Veripos for NRT and STC latencies and IGS for NTC and REP latencies. The CPOD also has an in-house back-up of Veripos based on ***magicGNSS***, which provides NRT GPS orbits and clocks. For Sentinel-3 ILRS and DORIS data will also be used. Finally the CPOD Service interacts with the CPOD QWG and a number of external validation centres.

There are two places where the operational orbits are computed. The so-called CPOD Service Centre, located in GMV´s premises, is in charge of computing all orbital products of Sentinel-1 and -2 and all STC and NTC products of Sentinel-3. The S-3 POD IPF is in charge of computing the Sentinel-3 NRT orbital products and it will be running at two locations, the Marine centre (located in EUMETSAT, Darmstadt) and the Core Ground Station (located in Svalbard).

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 20 years. Refer to [1] for a more detailed description of the Copernicus POD Service.

2.1. Quality Working Group

The main purpose of the Copernicus POD Quality Working Group (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. As a result recommendations on the upgrade of the Sentinel POD system for improving the orbit product performance are given to ESA Mission Management. Once approved by the Agency, the recommendations are implemented. The Copernicus POD QWG will maintain the same standards for all Sentinel missions to ensure homogeneous orbit products among the missions and to allow the user community to better combine the products of the different Sentinel missions into a combined multi-satellite product.

2.2. External Validation of orbital products

The CPOD Service is supported by different external institutions to assess the accuracy of the orbital products computed operationally. The institutions are:

- AIUB (Astronomisches Institut Universität Bern)
- DLR (Deutsches Zentrum für Luft- und Raumfahrt)
- ESA ESOC (European Space Operation Centre)
- TU Delft (Technische Universiteit Delft)
- TUM (Technische Universität München)

Every four months a time period between 15 days and 1 month is selected to generate independent orbital solutions using different SW packages and strategies. Then they are compared against the operational solution to assess the accuracy of the orbital products and to identify ways to improve them.

Additionally the following two institutions will support Sentinel-3:

- CNES (Centre National d'Études Spatiales)
- EUMETSAT (European Organization for the Exploitation of Meteorological Satellites)

All of these institutions are part of the Copernicus POD QWG. The orbital reprocessing performed by them and the results obtained is an input to the QWG meetings.

3. Sentinels missions

Tab. 1 shows the main characteristics of the Sentinels satellites to what concern POD.

Table 1. Characteristics of Sentinel-1, -2 and -3 missions

	Sentinel-1	Sentinel-2	Sentinel-3
Altitude	639 km	786 km	814.5 km
Inclination	98.18 deg.	98.58 deg.	98.65 deg.
Period	98.6 minutes	100.6 minutes	100.99 minutes
Duration Cycle	12 days	10 days	27 days
Mass	2300 kg	1140 kg	1250 kg
GPS	2 GPS receivers	2 GPS receivers	2 GPS receivers
LRR	None	None	1 LRR
DORIS	None	None	1 DORIS
Attitude	Zero-Doppler + roll steering	Yaw steering	Yaw steering
Launch date	3rd April, 2014 (S1A) Expected 2016 (S1B)	23rd June, 2015 (S2A) Expected 2016 (S2B)	Expected 10th Dec, 2015 (S3A) Expected 2017 (S3B)
Picture			

Sentinel-3 is the only mission that owns a LRR and DORIS instruments besides GPS receivers. This additional type of measurements allows performing POD combining different tracking techniques, which has been proven useful before to identify and correct biases (see [2]).

3.1. Requirements of the orbital products

This section presents a summary of the performance requirements in terms of latency 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. 2 shows the latency and orbit accuracy requirements of each category.

Table 2. Latency and orbit accuracy requirements per mission and timeliness

Mission	Category	Latency	Orbit Accuracy
S-1	NRT	180 min.	10 cm (2D RMS 1-sigma)
	NTC	20 days	5 cm (3D RMS 1-sigma)
S-2	NRT (predicted)	90 min. before ANX	10 m (2D RMS 3-sigma)
	NRT	30 min.	3 m (3D RMS 3-sigma)

Mission	Category	Latency	Orbit Accuracy
S-3	NRT (S3 POD IPF)	30 min.	10 cm radial RMS 1-sigma (target of 8 cm)
	STC	1.5 days	4 cm radial RMS 1-sigma (target of 3 cm)
	NTC	28 days	3 cm radial RMS 1-sigma (target of 2 cm)

4. Description of processing strategies

This chapter describes the POD processing strategies used by the different validation centres.

Table 3. POD Software name and version

Software	CPOD	ESOC	DLR	TUD	AIUB	TUM
Name and version	NAPEOS 3.3.1	NAPEOS 3.8	GHOST	GHOST	Bernese GNSS Software v5.3	Bernese GNSS Software v5.1(mod)

The six solutions described here can be split in three groups depending on the POD SW used. They either use NAPEOS, GHOST or BERNESE. All of them are state-of-the art POD SW packages.

Table 4. Determination arc length

Arc cut	CPOD	ESOC	DLR	TUD	AIUB	TUM
Arc lengths (hours)	48	24	30	30	24	30
Handle of Manoeuvers	Manoeuvres are calibrated in the POD process				Only days without manoeuvres	

The coverage of the orbits is 24 hours (daily solutions) so the minimum arc length used is 24 hours. Additional hours are included in the boundaries to minimize the higher errors that the least-square algorithms generate in the extremes.

Table 5. Reference Systems

Reference System	CPOD	ESOC	DLR	TUD	AIUB	TUM
Polar motion and UT1	IERS C04 08	IERS C04 08	igs96p02.erp	IGS final erp	CODE final products	IERS C04 08
Pole model	IERS 2010 Conventions	IERS 2010 Conventions			IERS 2010 Conventions	IERS 2010 Conventions
Precession / Nutation	IERS 2010 Conventions	IERS 2010 Conventions	IAU1976 /IAU1980	IAU1976 /IAU1980	IERS 2010 Conventions	IERS 2010 Conventions

Table 6. Gravity model

Gravity	CPOD	ESOC	DLR	TUD	AIUB	TUM
Gravity field (static)	EIGEN-6S2.5ext	EIGEN-6S2.5ext	EIGEN GL04C	GOCO03s (150x150)	EGM2008 (120x120)	EIGEN GL04C

Gravity	CPOD	ESOC	DLR	TUD	AIUB	TUM
	(120x120)	(120x120)	(120x120)			(120x120)
Gravity field (time varying)	drift / annual / semi-annual piece wise linear terms up to degree/order 50	drift / annual / semi-annual piece wise linear terms up to degree/order 50	n/a	n/a	IERS 2010 Conventions	IERS 2010 Conventions
Solid Earth tides	applied (IERS 2010)	applied (IERS 2010)	applied	applied	applied (IERS 2010)	applied (IERS 2010)
Ocean tides	EOT11a (50x50, 106 tidal constituents)	EOT11a (50x50)	applied (CSR 3.0)	applied (FES2004)	FES2004 (50x50)	FES2004 (50x50)
Atmospheric gravity	AGRA (20x20)	AGRA (20x20)	n/a	n/a	none	none
Atmospheric tides		Ray-Ponte 2003	n/a	n/a	none	none
Earth pole tide	IERS 2010	IERS 2010			IERS 2010	IERS 2010
Ocean pole tide	IERS 2010	IERS 2010			IERS 2010	IERS 2010
Third bodies	Sun, Moon, Planets DE405	Sun, Moon, Planets DE405	Sun, Moon (analytical series)	Sun, Moon (analytical series)	Sun, Moon, Planets: DE405	Sun, Moon, Planets: DE405

Table 7. Surface and empirical forces

Surface and empirical Forces	CPOD	ESOC	DLR	TUD	AIUB	TUM
Radiation Pressure model	Box-wing model (S1) Constant area model (S2)	constant area model	cannon-ball	canon-ball	no explicit modeling	constant area
Earth radiation	NAPEOS model for Albedo and IR	NAPEOS model for Albedo and IR	n/a	n/a	no explicit modeling	not explicitly modelled
Atmospheric density model	msise90	msise2000	Jacchia 71 Gill	Jacchia 71 Gill	no explicit modeling	MSISe-90
Radiation pressure coefficient	1 per arc; estimated	fixed	1 per arc; estimated	1 per arc; estimated	no explicit modeling	fixed=1
Drag coefficients	10 per day	10 per day	1 per arc; estimated	1 per arc, estimated	no explicit modeling	fixed=1

Surface and empirical Forces	CPOD	ESOC	DLR	TUD	AIUB	TUM
1/rev empiricals	2 daily sets in along and cross track direction (sine/cosine)	2 daily sets in along and cross track direction (constant/sine/ cosine)	n/a	n/a	n/a	constant and 1/rev per day in TRL-directions, no constraints applied
Other empiricals			Constant empirical accelerations in RTN at 10 min intervals; constrained to zero	10-min constant along-track, radial and cross-track (constrained 5e-9 m/s2)	piecewise constant empiricals in R,S,W, every 6' (constrained)	stoch. velocity changes every 15 min (constr. 5e-7m/s2)

Table 8. Characteristics of the GPS measurements

GPS meas.	CPOD	ESOC	DLR	TUD	AIUB	TUM
Relativity	applied	applied	applied	applied	applied	applied
Sampling	10 sec	10 sec	10 sec	10 sec	10 sec	10 sec
Observations	iono-free linear combinations of phase and pseudo-range	iono-free linear combinations of phase and pseudo-range	iono-free linear combinations of phase and pseudo-range	iono-free linear combinations of phase and pseudo-range	iono-free linear combination of phase (pseudo-range used only for clock synch.)	iono-free linear combinations of phase and pseudo-range
Weight	0.8 m (pseudo-range) / 10 mm (carrier-phase)	1.0 m (pseudo-range) / 10 mm (carrier-phase)	0.5 m (pseudo range) / 30 mm (carrier-phase)	0.85 m (pseudo range) / 10 mm (carrier-phase)		carrier-phase/pseudo-range ratio: 10'000
Elevation angle cutoff	7 degrees	7 degrees	0 degrees	7 degrees	0 degrees	0 degrees
Downweigh-ting law	none	none	none	none	none	none
Antenna phase-center wind-up correction	applied	applied	applied	applied	applied	applied
Antenna phase-center variation	applied (after inflight calibration from CP residuals)	applied (after inflight calibration from CP residuals)	applied (after inflight calibration from CP residuals)	applied (after inflight calibration from CP residuals)	applied (after inflight calibration from CP residuals)	applied (after inflight calibration from CP residuals)

Table 9. GPS parameters

GPS parameters	CPOD	ESOC	DLR	TUD	AIUB	TUM
Receiver clocks	per epoch, every 10 sec	per epoch, every 10 sec	per epoch, every 10 sec	per epoch, every 10 sec	per epoch, every 10 sec	per epoch, every 10 sec
Receiver ambiguities	estimated (float)	estimated (float)	estimated (float)	estimated (float)	estimated (float)	estimated (float)
GPS orbits	fixed (IGS finals)	fixed	fixed	fixed (IGS finals)	fixed (CODE final products)	fixed (CODE final)
GPS clocks	fixed (IGS finals)	fixed	fixed	fixed (IGS finals, 30-sec clocks)	fixed (CODE final products, 5-sec clocks)	fixed (CODE final products, 5-sec clocks)

5. Orbital accuracy results

5.1. Sentinel-1A

Sentinel-1A was launched the 3rd of April 2014. After 6 months of commissioning, the CPOD Service started the Routine Operation Phase (ROP) on October 2014. Since then, every four months the quality of the service is assessed, including the accuracy of the orbital products. For this, a specific period of time is selected for re-processing by the external validation institutions (i.e. AIUB, DLR, ESOC, TU Delft and TUM). This exercise has been performed twice since the beginning of the ROP phase. This section summarizes the accuracy obtained during these periods of time.

The **first Regular Service Review** covered the period from October 2014 to January 2015. The time interval from 10th to 26th of January 2015 was selected to perform a re-processing by all the institutions. Tab. 10 shows the cross-comparisons, in terms of 3D RMS, where each value is the average of the different days processed. The final row is the average per institutions. It can be seen that the differences are typically below the required 5 cm.

Table 10. Sentinel-1A 3D-RMS averaged (cm) – RSR#1

	CPOD	ESOC	DLR	TUD	AIUB	TUM
ESOC	2.71					
DLR	6.45	5.63				
TUD	4.75	3.86	3.88			
AIUB	4.33	3.95	6.59	5.35		
TUM	3.42	3.36	6.60	4.87	2.90	
Average	4.33	3.90	5.83	4.54	4.62	4.23

Tab. 11 shows the information per component (radial, along-track and cross-track). Two values are provided per component, the RMS and the standard deviation, which has been computed removing the bias. The final rows are the averages per institutions.

Table 11. Sentinel-1A Radial (R), Along-track (A) and Cross-track (C) RMS / Standard Deviation averaged – RSR#1

		CPOD		ESOC		DLR		TUD		AIUB		TUM	
ESOC	R	0.78	0.76										
	A	1.87	1.20										
	C	1.77	0.20										
DLR	R	2.21	1.84	2.05	1.67								
	A	4.40	4.34	4.19	3.49								
	C	4.16	1.20	3.14	1.73								
TUD	R	1.64	1.25	1.47	1.05	1.43	1.40						
	A	3.53	3.33	3.31	2.43	2.68	2.58						
	C	2.70	0.27	1.27	0.45	2.41	2.17						
AIUB	R	3.42	0.26	3.36	0.22	4.07	0.53	3.89	0.34				
	A	2.19	1.98	1.63	1.19	4.04	3.78	3.20	2.79				
	C	1.46	0.58	1.26	0.56	3.22	1.23	1.75	0.18				
TUM	R	1.92	0.58	1.97	0.65	2.87	1.17	2.47	0.72	2.06	0.27		
	A	2.47	1.84	1.96	1.92	4.40	3.70	3.39	2.56	1.53	1.11		
	C	1.34	1.21	1.85	0.41	3.96	1.17	2.42	0.18	1.31	0.59		
Average	R	1.99	0.94	1.93	0.87	2.53	1.32	2.18	0.95	3.36	0.32	2.26	0.68
	A	2.89	2.54	2.59	2.05	3.94	3.58	3.22	2.74	2.52	2.17	2.75	2.23
	C	2.29	0.69	1.86	0.67	3.38	1.50	2.11	0.65	1.80	0.63	2.18	0.71

Fig. 2 represents the average RMS per institution in the left. It can be seen that the radial component (which is key for Sentinel-3) is below 2.5 cm for all institutions except AIUB and DLR. However Fig. 2 in the right, which represent the average standard deviation (i.e. RMS minus biases) shows that the AIUB decreases to less than 0.5 cm and DLR to less than 1.5 cm, showing that there is a consistent bias, mostly in the AIUB solution, in the radial component. This bias has been linked to the phase centre offsets (PCO) used. The PCO seem to be erroneous impacting the orbit solutions differently due to different orbit determination strategies implemented in the three SW packages. By the time of writing this paper, the PCO has been re-estimated to remove these biased in the radial direction. [3] contains the initial efforts to estimate the corresponding PCV values which also has an impact on the radial and cross-track directions and a future paper will describe the process of re-estimating the PCO to remove the systematic biases in the radial direction. This work is very essential for the preparations of Sentinel-3 mission, where the radial component is the most important.

At the same time, the cross-track component shows also a clear reduction from RMS to standard deviation, again showing systematic biases among different solutions. This has been linked to the effect of the solar radiation pressure in the huge solar panel of the satellite. Future work will focus on this area to improve the modelling and reducing the systematic biases.

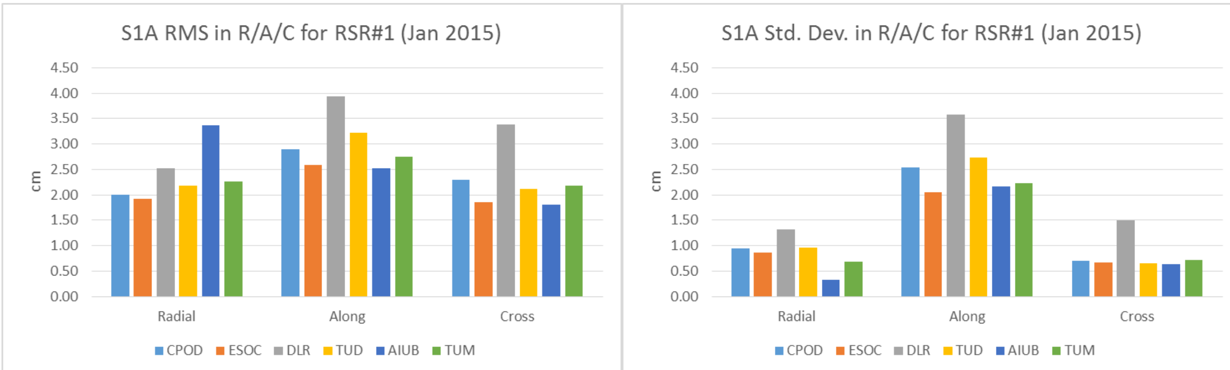

Figure 2. Average RMS (left) and Standard Deviation (right) per component for S-1A during RSR#1

The **second Regular Service Review** covered the period from February to May 2015. The time interval from 29th of March to 11th of April was selected to perform a re-processing by all the institutions. Tab. 12 shows the cross-comparisons, in terms of 3D RMS, where each value is the average of the different days processed. The final row is the average per institution and shows that while most of the values are lower or close to the required 5 cm, they are slightly higher than the values obtained in the previous RSR. Tab. 13 shows the differences per component, similar to Tab. 11.

Table 12. Sentinel-1A 3D-RMS averaged (cm) – RSR#2

	CPOD	ESOC	DLR	TUD	AIUB	TUM
ESOC	2.58					
DLR	6.33	5.49				
TUD	6.54	5.65	1.37			
AIUB	4.45	3.93	7.42	7.64		
TUM	3.88	3.09	5.82	6.00	1.95	
Average	4.76	4.15	5.29	5.44	5.08	4.15

Table 13. Sentinel-1A Radial (R), Along-track (A) and Cross-track (C) RMS / Standard Deviation averaged – RSR#2

		CPOD	ESOC	DLR	TUD	AIUB	TUM
ESOC	**R**	0.77 0.74					
	A	2.23 1.76					
	C	0.94 0.42					
DLR	**R**	1.63 1.22	1.51 1.08				
	A	4.17 3.92	3.49 2.77				
	C	4.45 0.27	3.93 0.27				

		CPOD		ESOC		DLR		TUD		AIUB		TUM	
TUD	R	1.64	1.18	1.48	1.00	0.39	0.34						
	A	4.22	3.82	3.52	2.66	0.91	0.78						
	C	4.69	0.14	4.14	0.12	0.93	0.62						
AIUB	R	3.41	0.19	3.35	0.16	4.22	0.57	4.27	0.57				
	A	2.56	2.31	1.77	1.05	4.21	4.16	4.25	4.05				
	C	1.12	0.92	1.00	0.75	4.13	0.16	4.41	0.09				
TUM	R	2.49	0.21	2.39	0.13	2.96	0.27	2.98	0.25	1.23	0.30		
	A	2.65	2.31	1.61	1.44	3.15	2.59	3.16	2.44	1.19	0.62		
	C	1.23	0.77	1.08	1.06	3.87	0.20	4.12	0.07	0.92	0.61		
Average	R	1.99	0.71	1.90	0.62	2.14	0.70	2.15	0.67	3.30	0.36	2.41	0.23
	A	3.17	2.82	2.52	1.94	3.19	2.84	3.21	2.75	2.80	2.44	2.35	1.88
	C	2.49	0.50	2.22	0.52	3.46	0.30	3.66	0.21	2.32	0.51	2.24	0.54

Fig. 3 shows clearly the biases in the radial and cross-track component. As explained above, the radial bias is due mainly to the PCO values used during these re-processing and the cross-track bias is thought to be due to the modelling of the solar radiation force due to the large solar panel of the satellite. By the time of writing this paper, the problem with the biases in the radial direction is already solved by re-estimating the PCO, and should be shown in the next RSR report, while the bias in the cross-track is an open area where all institutions are working on.

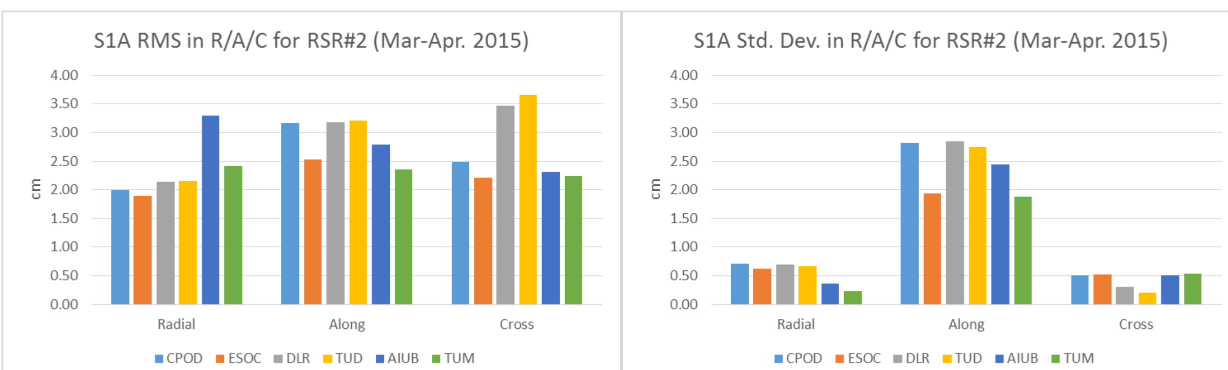

Figure 3. Average RMS (left) and Standard Deviation (right) per component for S-1A during RSR#2

5.2. Sentinel-2A

Sentinel-2A was launched on the 23rd of June, 2015. By the time of writing this paper, the commissioning phase is expected to finish by mid/end October 2015, so the Routine Operation Phase (ROP) is expected to begin on November 2015. During the commissioning phase the orbit accuracy has been assessed by the same means used with Sentinel-1A, selecting a period of time to be re-processed by the external validation institutions.

The period of time from 21st of July to 1st of August 2015 was selected to perform a re-processing by all the institutions. Tab. 14 shows the cross-comparisons, in terms of 3D RMS, where each value is the average of the different days processed. The final row, which shows the average per institution, shows differences around 3 cm, which indeed is better than what has been obtained for Sentinel-1A. Tab. 15 shows the differences per component.

Table 14. 3D-RMS averaged (cm)

	CPOD	ESOC	DLR	TUD	AIUB	TUM
ESOC	2.34					
DLR	2.73	3.21				
TUD	3.12	2.62	1.10			
AIUB	3.89	3.75	3.63	3.57		
TUM	3.48	3.15	3.64	2.95	2.31	
Average	3.11	3.01	2.86	2.67	3.43	3.11

Table 15. Radial (R), Along-track (A) and Cross-track (C) RMS / Standard Deviation averaged

		CPOD		ESOC		DLR		TUD		AIUB		TUM	
ESOC	**R**	0.77	0.73										
	A	1.80	1.11										
	C	1.26	0.65										
DLR	**R**	1.21	0.57	0.93	0.35								
	A	2.71	1.58	2.29	0.42								
	C	1.18	0.90	1.32	0.52								
TUD	**R**	1.17	0.57	0.99	0.44	0.44	0.42						
	A	2.14	1.25	2.47	1.06	1.48	1.24						
	C	1.05	0.81	1.33	0.48	0.49	0.47						
AIUB	**R**	2.68	0.94	2.64	0.20	3.12	0.11	3.09	0.11				
	A	2.29	1.96	2.10	1.28	1.55	0.67	1.45	0.87				
	C	1.58	1.45	1.61	0.80	0.99	0.97	1.01	0.97				
TUM	**R**	2.16	0.94	2.10	0.38	2.43	0.14	2.41	0.15	1.28	0.56		
	A	2.37	2.19	2.05	1.45	1.69	0.57	1.55	0.73	1.61	1.38		
	C	1.28	1.09	1.11	0.64	0.70	0.42	0.68	0.31	1.04	0.70		
Average	**R**	1.60	0.75	1.49	0.42	1.63	0.32	1.62	0.34	2.56	0.38	2.08	0.43
	A	2.26	1.62	2.14	1.06	1.94	0.90	1.82	1.03	1.80	1.23	1.85	1.26
	C	1.27	0.98	1.33	0.62	0.94	0.66	0.91	0.61	1.25	0.98	0.96	0.63

Fig. 4 shows again a bias in the radial component, which it is believed to be due to the PCO used, like in the case of Sentinel-1A. A new set of PCO values have been estimated like with Sentinel-1A to try to reduce the systematic biases. In the other components the presence of systematic biases is not as obvious as with the radial, but there is still room for improvement, mainly in the modelling of the solar radiation and drag modelling.

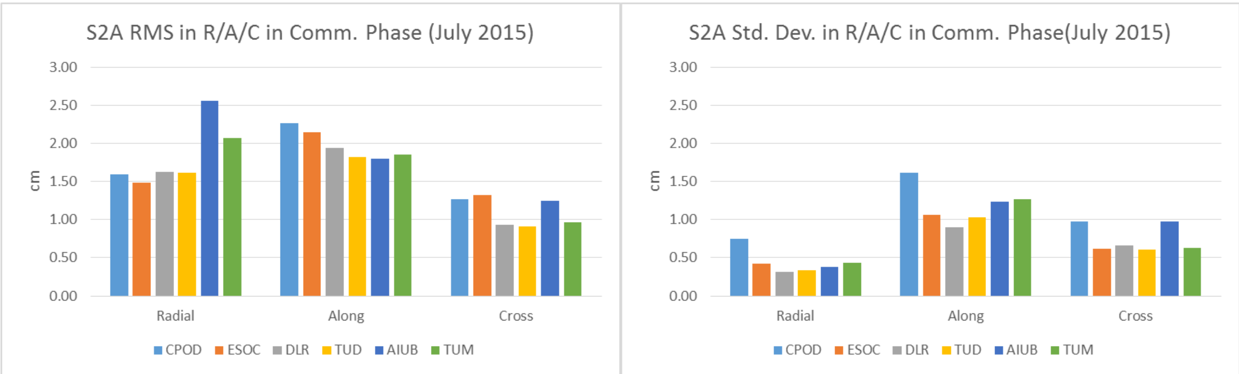

Figure 4. Average RMS (left) and Standard Deviation (right) per component for S-2A during commissioning phase

6. Sentinel-3

Sentinel-3A will be launched in December 2015. The main differences with respect to Sentinel-1A and Sentinel-2A are that it has a Laser Retro-Reflector and a DORIS instrument. Besides the rate of the GPS measurements will be 1 Hz, instead of 0.1 Hz that is used in S-1 and S-2.
Finally the altitude of Sentinel-3A is the highest of the three missions, so it should reduce the impact of the atmospheric disturbances.

At the same time, the accuracy requirements of Sentinel-3 are the most demanding, requiring 3 cm in radial direction with the goal of 2 cm. The main usage of these orbital products will be altimetry, where an accurate and stable satellite platform is paramount.

All the work already performed with Sentinel-1A and Sentinel-2A has paved the way to perform a successful commissioning phase of Sentinel-3A. It has been clearly proven that the required accuracy of 2-3 cm in radial direction can be achieved with the current NAPEOS SW used by the CPOD Service, but at the same time, a careful estimation of the PCO values is needed to achieve the required radial accuracy. Besides that the support of the external validation institutions has proved very helpful to identify issues in the modelling and removing biases.

Sentinel-3A will pose its own challenges, like being able to process simultaneously GPS+SLR+DORIS. While not directly required, it has been showed previously that the combined solutions have the capabilities to improve the final orbital products ([2]).

7. Conclusions

The Copernicus program has the ambition to provide operationally a global monitoring of the Earth. Previous ESA missions, like ERS or ENVISAT have paved the way along the years to reach this point, where it is possible to obtain state-of-the-art products from these satellites in an

operational way. The Copernicus POD Service has been established as an operational POD centre to support the first three Sentinels missions.
Once again, thanks to the work performed during the last two decades in the field of POD of LEOs, it has been possible to obtain outstanding orbital accuracies in a short period of time.

This paper has presented the overall architecture of the CPOD Service, the role of the QWG and the external validation institutions. Then the POD processing scheme used by each institution has been presented followed by the orbital accuracies obtained for Sentinel-1A and Sentinel-2A and the identification of the systematic biases between the different solutions together with an insight of each origin.

Finally, the impact of all this work on Sentinel-3A has been shortly presented.

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