SENTINEL-3 SLR YEARLY REPORT - 2016

SENTINELSPOD

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Prepared by: X

E. J. Calero
Project Engineer
Signed by: Emilio José Calero Rodriguez

04/05/2017

Approved by: X

J. Aguilar
Quality Manager
Firmado por: Juan Antonio Aguilar Miguel

04/05/2017

Authorised by: X

J. Fernández
Project Manager
Signed by: Jaime Fernández Sánchez

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1. INTRODUCTION

1.1. PURPOSE

This document describes the Sentinel-3 SLR Yearly Report - 2016, prepared in the frame of the project for the Provision of the Precise Orbit Determination Service for the Copernicus POD Service under ESA contract no. 4000108273/131-NB. It reports about the **Satellite Laser Ranging (SLR)** data of Sentinel-3A used by Sentinel-3 project to perform periodic checks of the biases that could exist between the other tracking techniques (GPS and DORIS) and to assess the accuracy of the operational Sentinel-3 orbits. The covered period is an entire year: since February 2016, starting with the launch of Sentinel-3A, to January 2017.

1.2. SCOPE

This document is a deliverable by GMV to acknowledge the work of the **International Laser Ranging Service (ILRS)** community in support to the Copernicus Sentinel-3 mission. The main aspects that are highlighted herein are the data received from ILRS, the results obtained from the SLR external validation and the Consolidated Prediction Files (CPFs) that GMV provides to the ILRS laser stations to allow the tracking of S-3A. We will appreciate any comment or additional content that could be added in future deliveries. Thus, from GMV, the ILRS community is encouraged to review this document and contact the Copernicus POD (CPOD) Service via the following e-mail: sentinelspodops@gmv.com.

1.3. DISCLAIMER

Sentinel-3 Mission, and in particular the POD Service, would like to thank the **ILRS Community** for their efforts and acknowledge the great contribution to the verification of the stringent accuracy requirements of the S-3 altimetry mission. The SLR tracking data provided has proven to be an invaluable asset for independent orbit validation, allowing to assess the quality of the different available orbital products and ensure the best are used for the altimetry processing.

GMV, as prime contractor of the Copernicus POD Service, and the Copernicus POD Quality Working Group (QWG) members consider satisfactory the performance of SLR tracking. The content presented herein has been gathered with the purpose of informing the ILRS Community about the S-3 SLR tracking statistics, the obtained residuals and how they contribute to the Sentinel-3 orbital products validation. Those cases in which the reported results are worse than expected might either be related to a temporal problem with any given station or wrongly configured parameters at the POD processing (in particular, the station coordinates), not necessarily implying an issue with the observations themselves.

1.4. DEFINITIONS AND ACRONYMS

Definition of terms and acronyms used throughout this document are present in [AD.1]

1.5. APPLICABLE AND REFERENCE DOCUMENTS

1.5.1. APPLICABLE DOCUMENTS

The following documents, of the exact issue shown, form part of this document to the extent specified herein. Applicable documents are those referenced in the Contract or approved by the Approval Authority. They are referenced in this document in the form [AD.X]:

Table 1-1: Applicable Documents

Ref.	Title	Code	Version	Date
[AD.1]	Sentinels POD Glossary of Terms	GMV-GMESPOD-GLO-0001	1.7	01/10/2014

1.5.2. REFERENCE DOCUMENTS

The following documents, although not part of this document, extend or clarify its contents. Reference documents are those not applicable and referenced within this document. They are referenced in this document in the form [RD.X]:

Table 1-2: Reference Documents

Ref.	Title	Code	Version	Date
[RD.1]	GMV-GMESPOD-TN-0028_v1.0_Analysis of elements for Sentinel-3 SLR tracking	GMV-GMESPOD-TN-0028	1.0	10/06/2015
[RD.2]	ILRS List of active stations https://ilrs.cddis.eosdis.nasa.gov/network/stations/active/	N/A	N/A	N/A
[RD.3]	J. Fernández et al. "The Copernicus Sentinel-3 Mission". Presentation on the 2015 ILRS Technical Workshop	N/A	N/A	26/10/2015
[RD.4]	J. Fernández et al. "The Copernicus Sentinel-3 Mission POD Service". Poster and paper on the 20th International Workshop on Laser Ranging	N/A	N/A	9-14/10/2016

2. ILRS STATIONS STATISTICS

Sentinel-3A is equipped with a Laser Retro Reflector (LRR), which allows tracking the satellite using laser ranging from a network of stations belonging to the International Laser Ranging Service (ILRS). Recently, the ILRS Community has considered the ESA proposal to review the ranking of priority for the missions with a favourable outcome for S-3A, which has risen above SWARM.

Figure 2-1 shows the geographical location of ILRS stations that have been agreed to track Sentinel-3A based on an agreement signed upon power restrictions (see [RD.1] and [RD.3]). It can be seen that an overall good geographical coverage is obtained given the available stations, with up to five stations in the southern hemisphere.

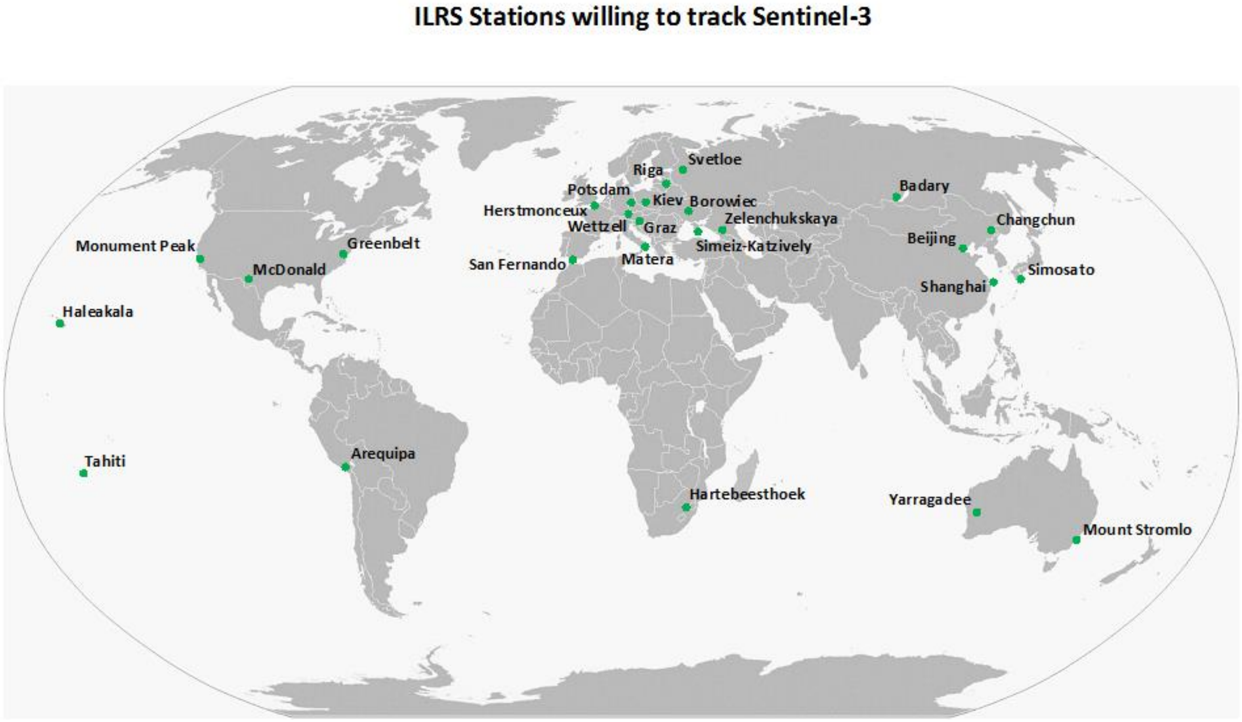

Figure 2-1: ILRS Stations allowed to track Sentinel-3

Figure 2-2 represents the evolution of the S-3A total number of passes per week since the beginning of the mission (this information was initially presented in [RD.4]). As it can be seen, regular SLR tracking of Sentinel-3A did not start until April 2016. Afterwards, it quickly reached the current stable level, which remains around 80 passes per week, which is in line with other similar missions, in terms of altitude and priority, like SWARM. On the other hand, Figure 2-3 shows the number of S-3A passes per station. The station of Yarragadee is the one with the largest number of passes followed by Changchun. Some stations like San Fernando or Tahiti have tracked little S-3A, probably due to some maintenance work on those stations. Further enquiries shall be carried out to figure out the reasons.

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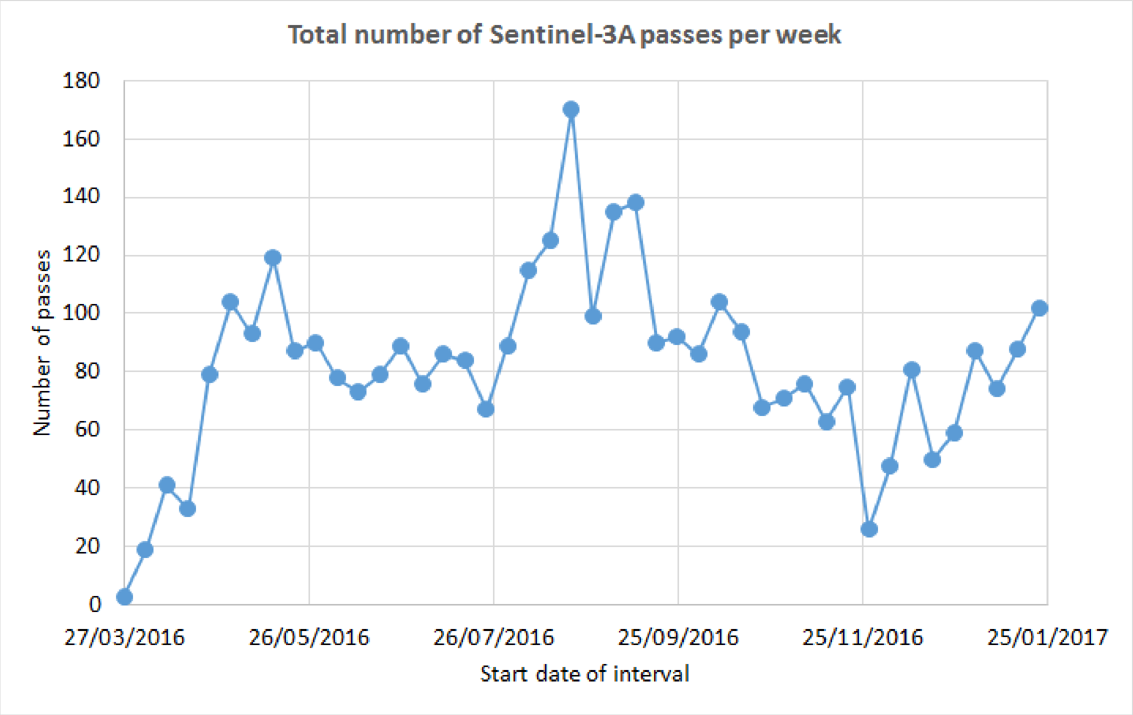

Figure 2-2: Total number of Sentinel-3A passes per week between April 2016 and January 2017

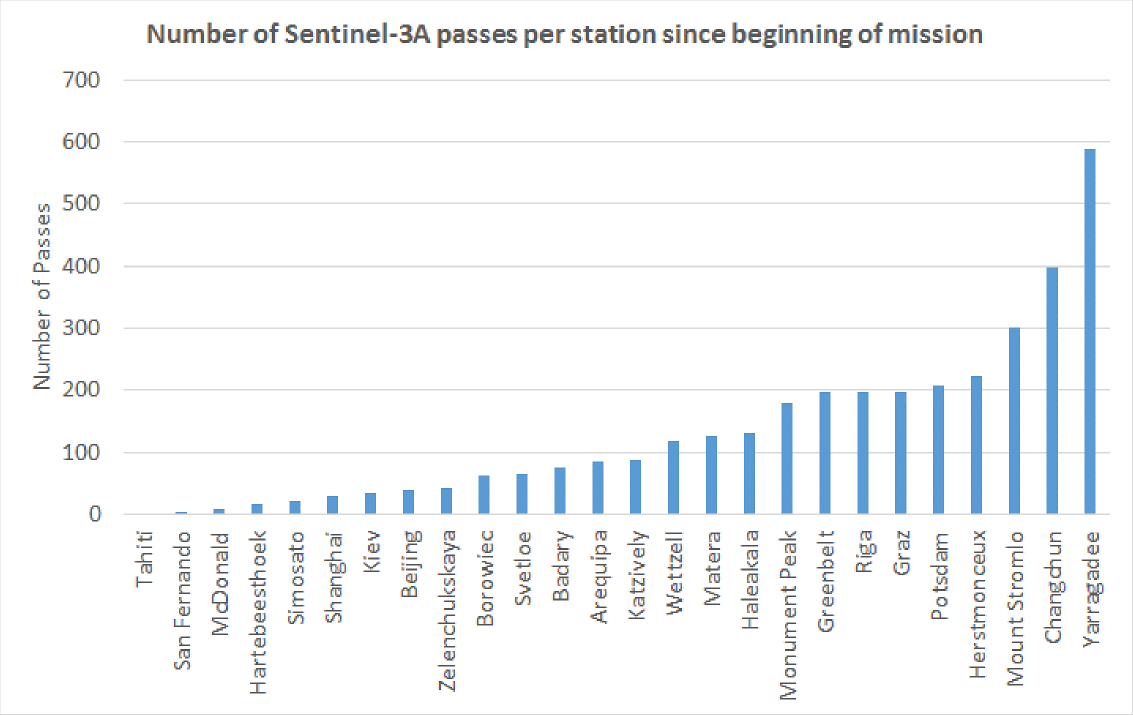

Figure 2-3: Total number of Sentinel-3A passes per station between April 2016 and January 2017

Figure 2-4 and Figure 2-5 show the geographical distribution of the S-3A passes. As could be inferred from the stations' layout, the majority of the passes are concentrated in the north hemisphere, remarking nonetheless the active contribution from Yarragadee station and Mount-Stromlo in Australia. The first figure shows the sum of the number of passes tracked in each geographical cell.

Taking into account that Sentinel-3 repeat cycle lasts 27 days, and that each selected cell covers approximately 2 consecutive orbits, the maximum number of passes from a single station for the selected period (9 months) can be up to 20 (as is the case for Yarragadee station). The second figure represents global coverage as a percentage of time in which a pass is available. A coverage of 100% means that every time that the satellite has flown over that region, it has been tracked by at least one SLR station.

Despite the irregularity of some stations or the heterogeneous geographical density of passes, the provided observations have proven to be sufficient for independent orbit validation.

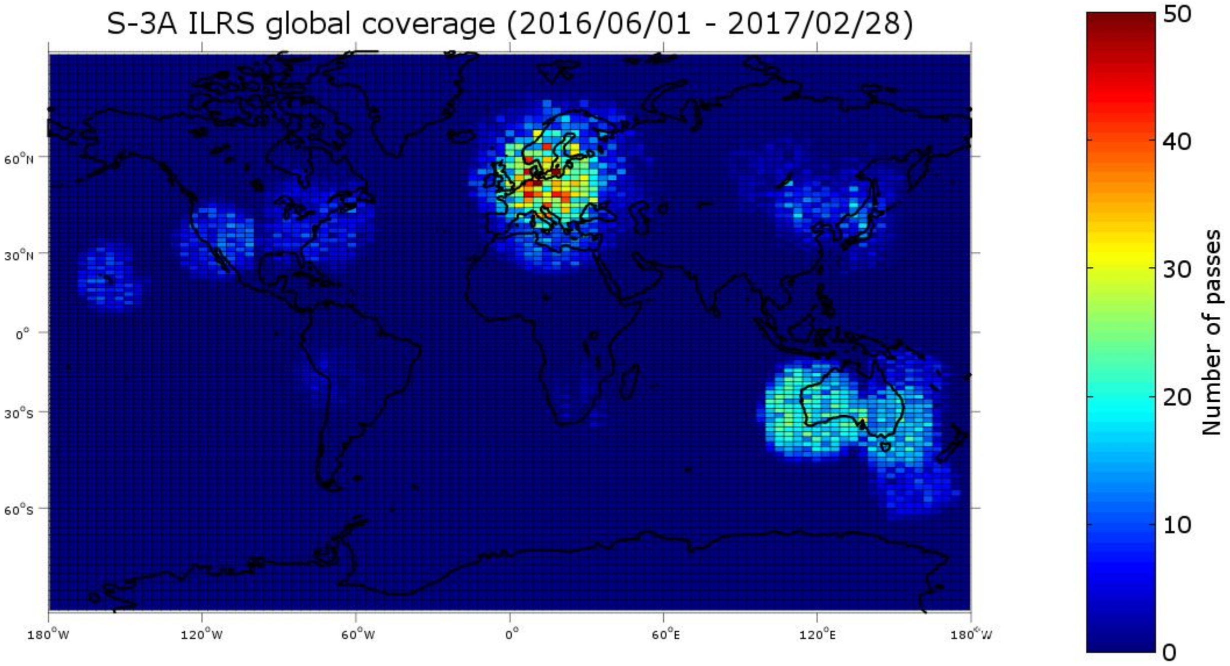

Figure 2-4: S-3A global distribution of ILRS number of passes between 2016/06/01 and 2017/02/28

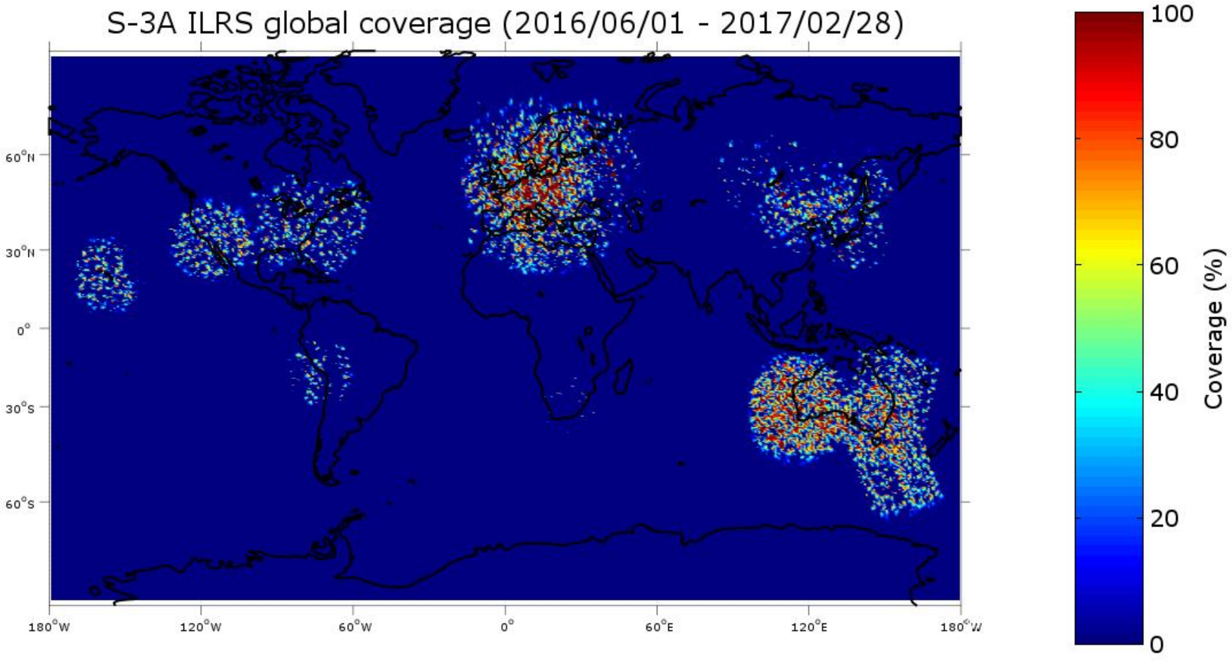

Figure 2-5: S-3A time percentage of global ILRS coverage between 2016/06/01 and 2017/02/28

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3. ANALYSIS OF ACCURACY

3.1. INDEPENDENT SLR VALIDATION FOR SENTINEL-3A

The Sentinel-3A orbital solutions computed by the institutions conforming the POD Quality Working Group (QWG), which currently are: AIUB, CNES, ESOC, DLR, EUMETSAT, TUM, TU Delft, and Copernicus POD Service, and which is intended to ensure the good quality of the Copernicus POD service, are based on very similar GNSS processing strategies, although using different processing schemes, models and SW. In the case of Sentinel-3, the availability of SLR measurements allow for an independent means to validate the orbital accuracy of the different centres. In order to accomplish this goal, SLR measurements are not used in the orbit determination process, but instead are fitted to a fixed orbit based only on GPS (or GPS+DORIS) data.

Figure 3-1 shows the number of accepted and rejected measurements per day and per centre since June 2016, when a stable number of passes was available. It has been computing fixing the orbit of each centre and computing the SLR observation residuals; when the residual is too high, the observation is rejected to avoid corrupting the statistics. The first figure shows the number of observations accepted per day while the second figure shows the number of observations rejected per day; it is not possible to see clearly the effect per centre (dots with different colours) as all centres (i.e. all independent orbital solutions) have similar performances in terms of accepted and rejected SLR observations, so dots overlap in the plots. It can be seen that these numbers are represented as a point-cloud with the same level of accepted observations for all the centres (overlapping points), ranging from 50 to 250. Note that the number of rejected observations is zero in the vast majority of the days, except for some isolate ones that remains typically below 25. The rejection criteria is based on the averaged residuals obtained for the passes of a given station. As mentioned in the Disclaimer (see Section 1.3), rejected observations do not necessarily imply that they are systematically degraded. Temporal issues with stations or wrongly configured station coordinates at the POD processing might also be responsible for this behaviour. In particular, the presented results are based on ITRF08 coordinates, which are included in the annex so that it can be verified whether there is any mistake related to their coordinates (see Annex A: Stations Coordinate List). Further action involving an update to ITRF14 (including station coordinates) shall be carried out in the near future, where residuals per station shall be analysed again to check for any systematic error or unexpected higher residuals.

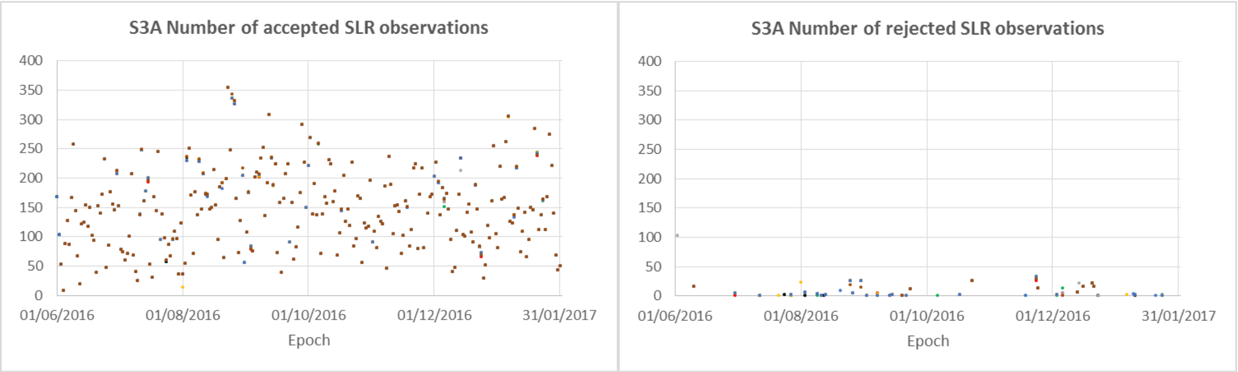

Figure 3-1: Number of accepted/rejected SLR observations between June 2016 and January 2017 – no legend included since all centres typically present overlapping markers

The most important application of the SLR observations is to validate the orbits obtained based on GPS processing. These orbits are routinely validated by performing cross-comparisons between the different solutions provided by the POD QWG. Figure 3-2 shows the 3D RMS of the orbit cross-comparison against an IGS-like combined solution between October 2016 and January 2017, where it can be seen that the solutions are highly consistent with RMS values below 1.5 cm. Since all orbits are computed using the same set of observations from GPS, an independent technique such as SLR is needed to guarantee that the solutions have no systematic biases affecting them all equally (which would not be seen in these cross-comparisons at this level of accuracy).

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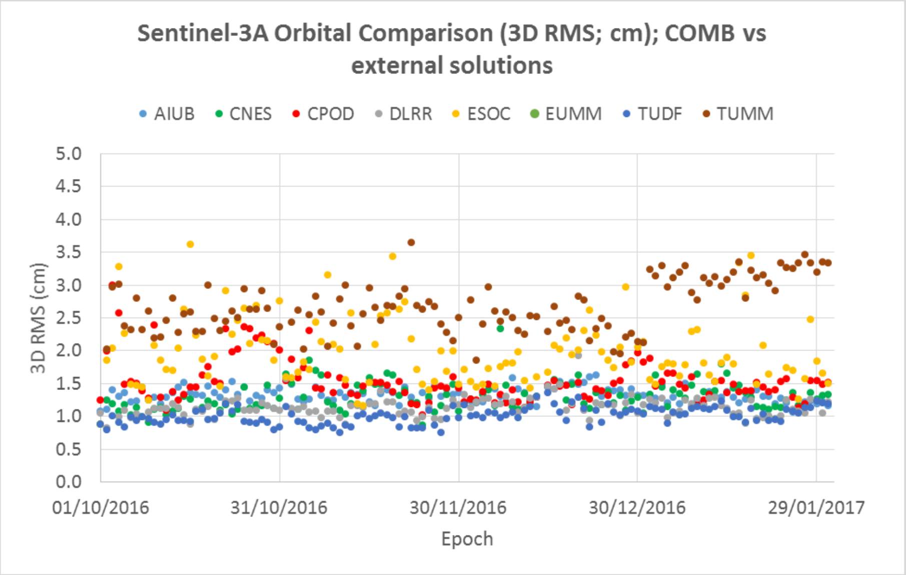

Figure 3-2: Sentinel-3A Orbital Comparisons: Combined solution against all centres between October 2016 and January 2017

Figure 3-3 represents the SLR residuals computed against fixed orbit solutions obtained from GPS data. It is observed that the agreement between the GPS solutions and the SLR observations is reasonably good, with an RMS value around 1.5 cm. Figure 3-4 shows the mean value of the residuals per centre, typically around 0.5 cm. Another representative metric is the standard deviation shown in Figure 3-5. As shown, it is of the same order of magnitude as the RMS due to the low biases observed with respect to laser residuals.

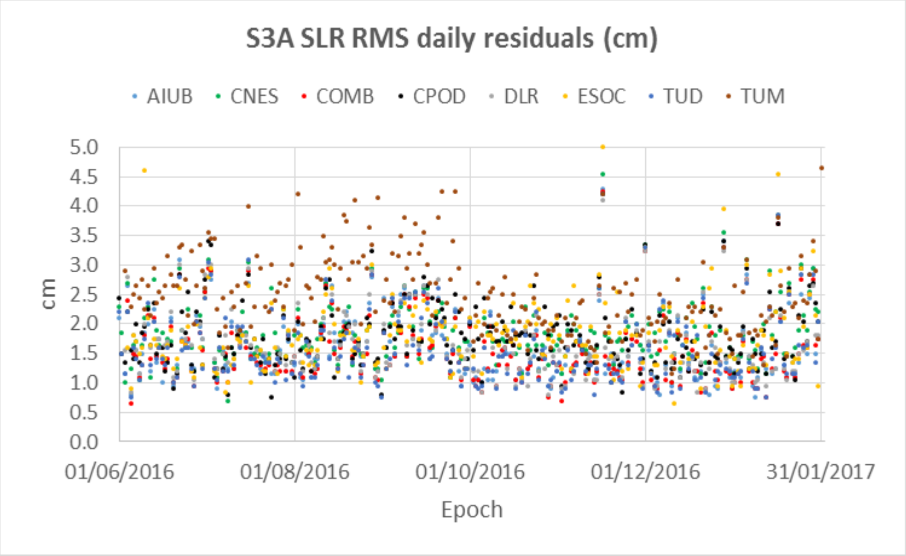

Figure 3-3: Daily SLR RMS of residuals between June 2016 and January 2017

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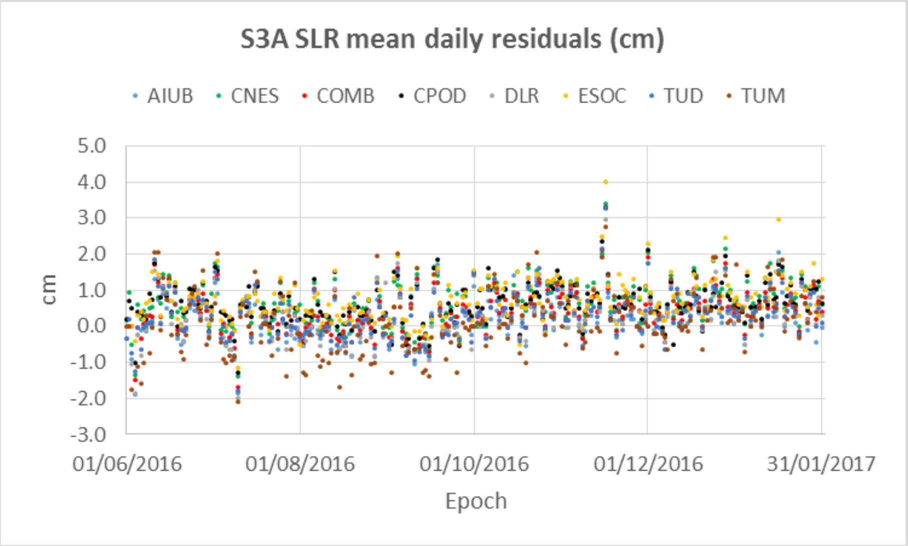

Figure 3-4: Daily SLR mean values of residuals between June 2016 and January 2017

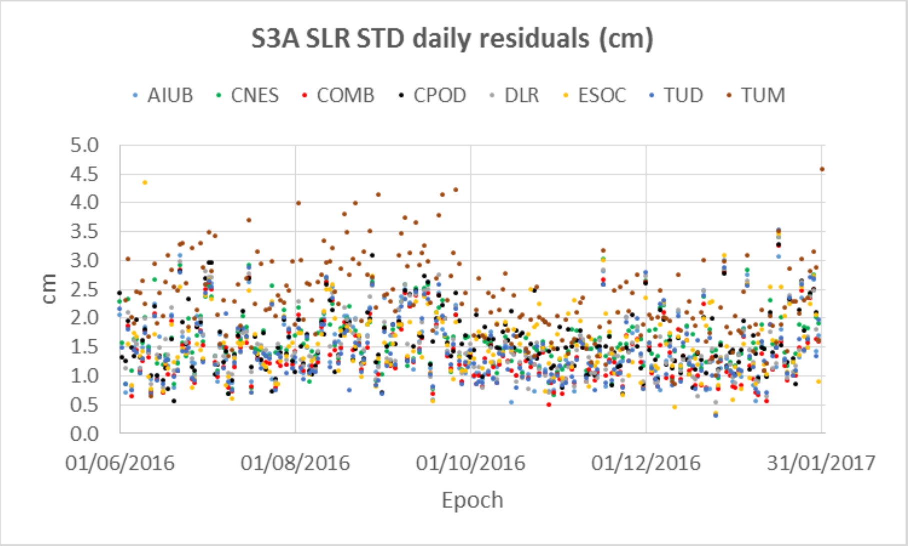

Figure 3-5: Daily SLR standard deviations of residuals between June 2016 and January 2017

Table 3-1 and Figure 3-6 summarize the information of the metrics above by averaging the whole data. The good agreement between the solutions computed by the different centres based on GPS, and the SLR observations, can be observed with the average bias below 1 cm for all centres and the RMS remaining below 2 cm.

Table 3-1: SLR average metrics of residuals (cm) between June 2016 and January 2017

	AIUB	CNES	COMB	CPOD	DLR	ESOC	TUDF	TUM
Mean (cm)	0.23	0.67	0.44	0.62	0.30	0.76	0.32	0.15
RMS (cm)	1.62	1.85	1.58	1.80	1.70	1.84	1.60	2.52
STD (cm)	1.49	1.64	1.40	1.61	1.55	1.59	1.45	2.33

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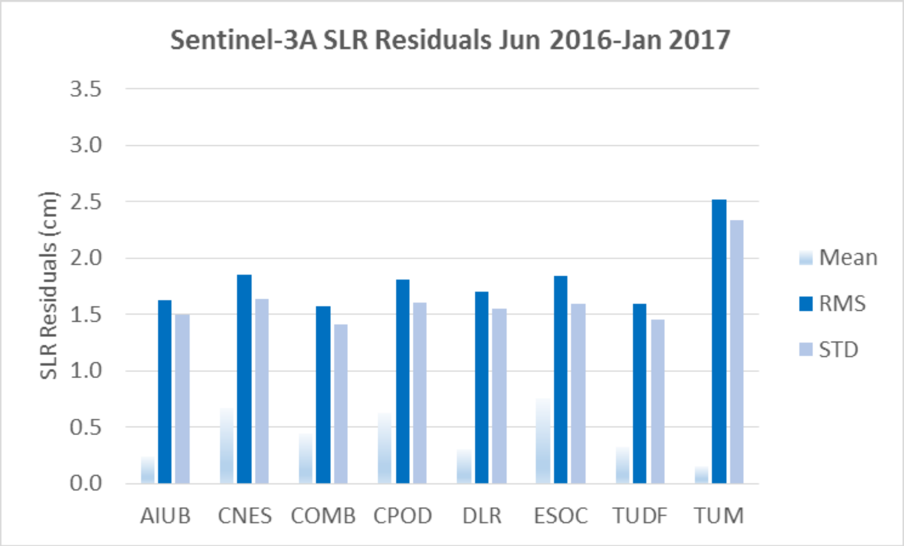

Figure 3-6: SLR average metrics of residuals between June 2016 and January 2017

3.2. ANALYSIS OF RESIDUALS PER STATION

In this section, the SLR measurements obtained by each station (four stations excluded due to lack of data or high residuals which are pending of further analysis), are used to compute observation residuals using a combined orbital solution obtained from weighting the different orbits provided by the members of the POD QWG. First of all, note that each station will be referred by its monument number, instead of its location. These numbers can be identified at the ILRS official webpage (see [RD.2]).

Figure 3-7 shows the accepted and rejected observations per station. It can be seen again that the number of rejected observations is typically 0 except for some isolate days. As explained before, the criteria for rejecting observations is subject to several factors which might be related to any wrongly configured station coordinates or momentary issues with the stations. Again, further calibration shall be carried out after switching to ITRF14.

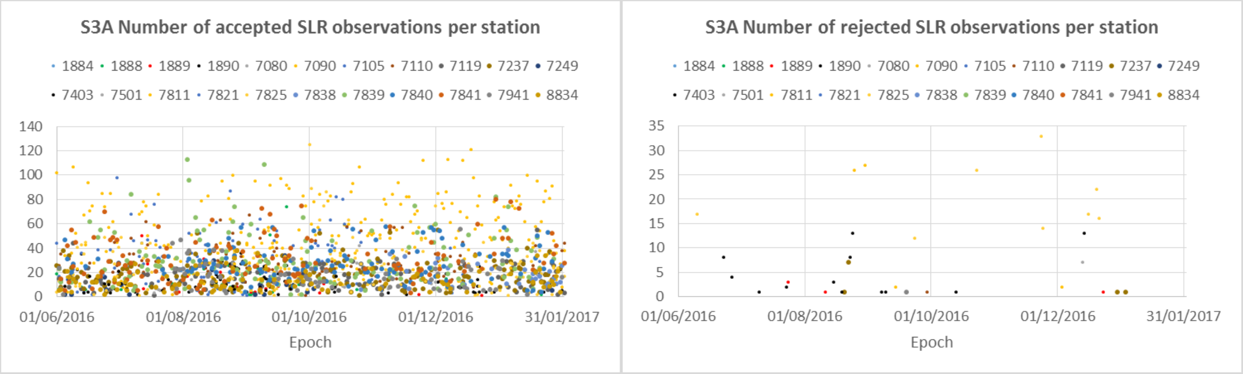

Figure 3-7: Number of accepted/rejected SLR observations between June 2016 and January 2017

The following figures, Figure 3-8, Figure 3-9 and Figure 3-10, show the RMS, mean and standard deviation of the residuals. As can be inferred, a wide dispersion appears because of the large number of stations used. However, these comparisons typically represent a high level of agreement between the measurements of the stations and the combined orbit.

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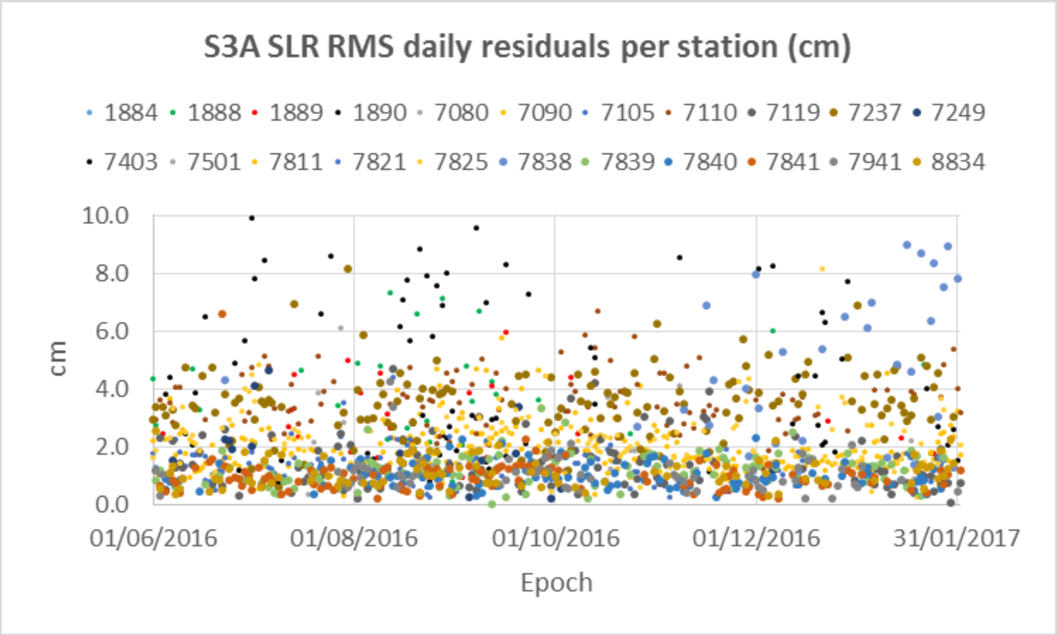

Figure 3-8: Daily SLR RMS of residuals per station between June 2016 and January 2017

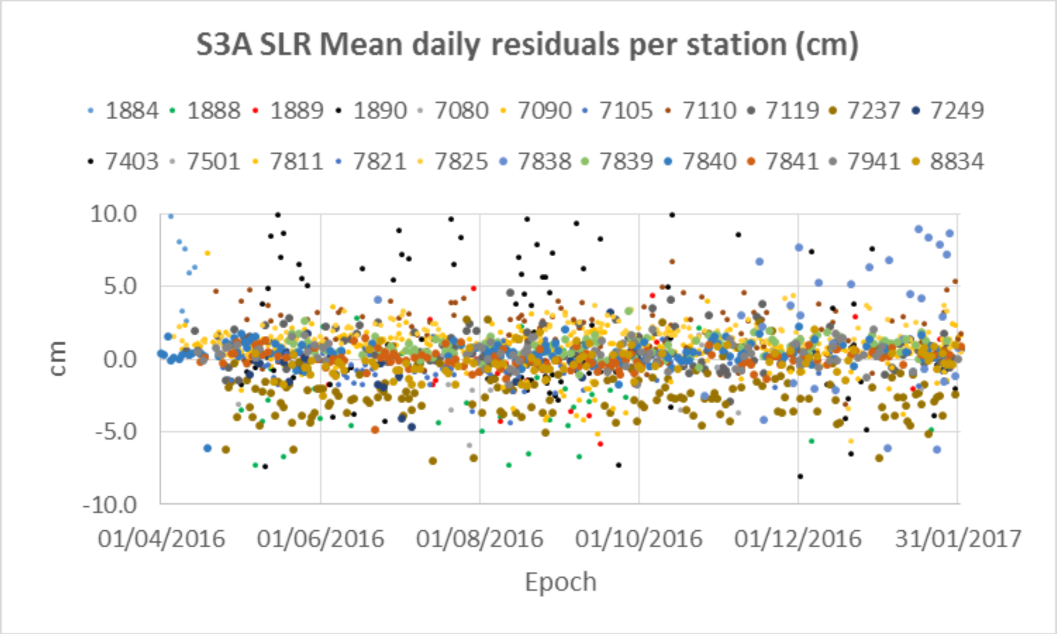

Figure 3-9: Daily SLR mean residuals per station between June 2016 and January 2017

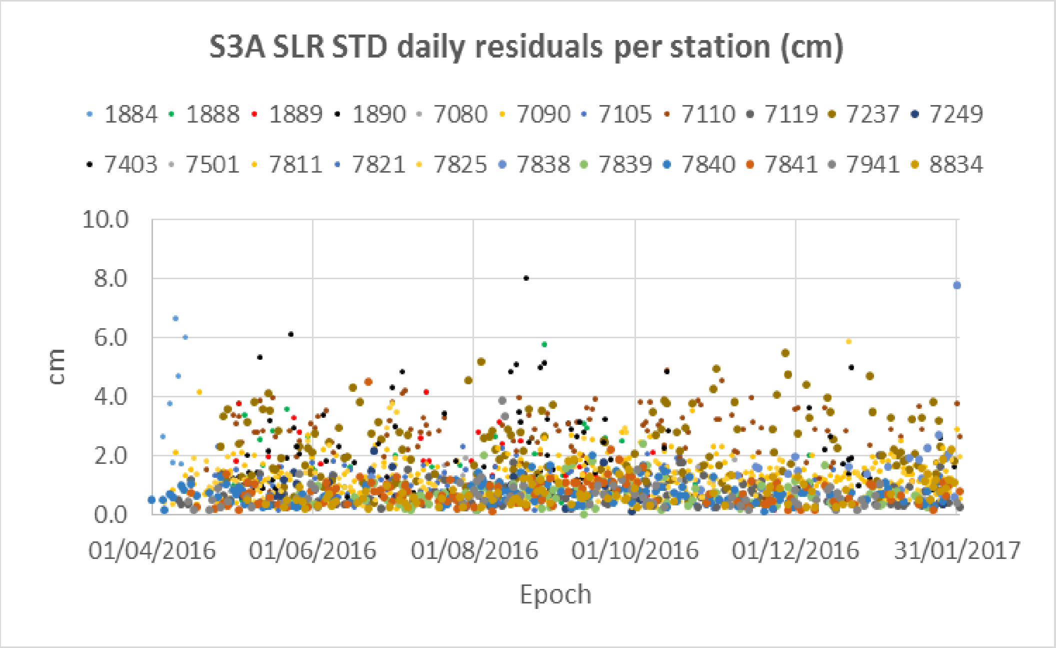

Figure 3-10: Daily SLR standard deviation of residuals per station between June 2016 and January 2017

To make this information more readable, Table 3-2, Table 3-3 and Figure 3-11 summarize these metrics by averaging the whole dataset. It can be seen that the residuals range between a relatively wide interval, from 8.33 cm in the case of the station 1884 (Golosiiv, Ukraine) to less than 1 cm in the case of the station 7841 (Potsdam, Germany). According to this, the stations with the largest biases are the following (sorting in descending order): 1884, 7403, 7080, 7838, 7237 and 1888. These stations are also highlighted in the following tables.

Table 3-2: SLR comparison per station between June 2016 and January 2017

	1884	1888	1889	1890	7080	7090	7105	7110	7119	7237	7249
Mean (cm)	7.13	-2.20	-0.25	-0.83	-3.19	1.10	-0.46	1.86	0.81	-2.33	-0.45
RMS (cm)	8.33	3.73	2.91	2.13	3.62	1.78	1.36	3.56	1.42	3.52	1.49
STD (cm)	0.09	0.23	0.18	0.26	0.04	1.02	0.35	1.01	0.27	1.13	0.09

Table 3-3: SLR comparison per station between June 2016 and January 2017 (cont.)

	7403	7501	7811	7821	7825	7838	7839	7840	7841	7941	8834
Mean (cm)	4.87	0.27	-1.45	-0.94	1.65	2.52	0.90	0.40	0.02	0.43	-0.24
RMS (cm)	7.20	1.15	2.59	1.45	2.13	4.56	1.24	1.02	0.97	1.08	1.09
STD (cm)	0.46	0.04	0.23	0.02	0.59	0.16	0.28	0.32	0.32	0.16	0.24

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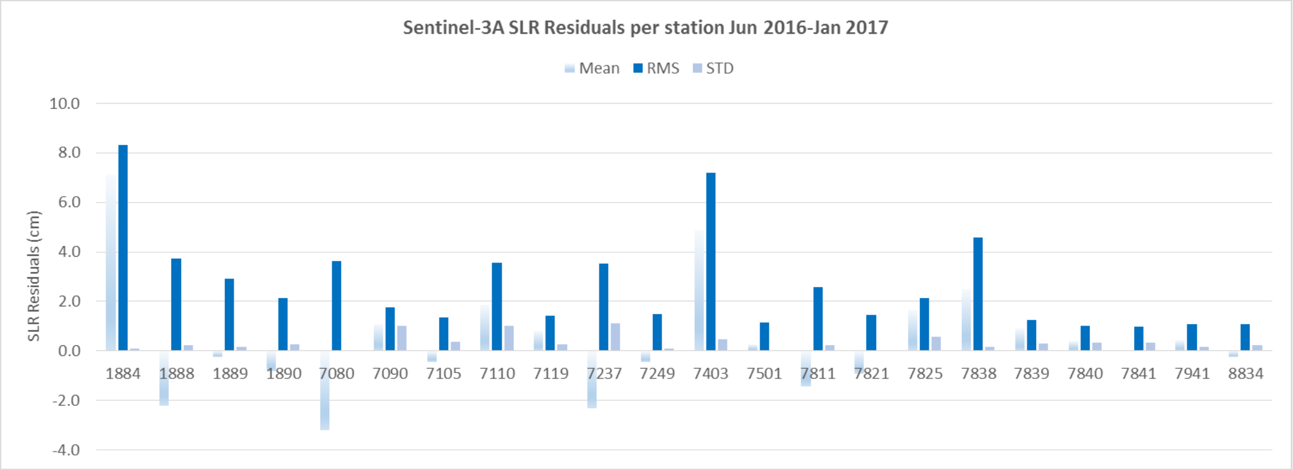

Figure 3-11: SLR comparison per station between June 2016 and January 2017

4. CPF PREDICTIONS

To allow the SLR tracking of Sentinel-3, Copernicus POD makes available to the stations the so-called **Consolidated Prediction Files (CPFs)**, which contain the orbital prediction of the Sentinel-3 satellites. These files are generated daily at the same time as the Medium Orbit Accuracy (MOEORB) product and contain a 7 day prediction with respect to the generation time. During the reported period, the number of generated CPFs amounts to 368. It is important to point out that the CPOD Service informs the ILRS community about possible degraded CPFs due to manoeuvres because of a likely loss of accuracy in the prediction which might pose a difficulty for tracking the satellite. Such service interruptions occurred in the following days:

- 2016/04/13
- 2016/04/19
- 2016/06/02
- 2016/07/21
- 2016/08/31
- 2016/09/22
- 2016/11/01
- 2016/12/01
- 2016/12/14

Figure 4-1 shows the accuracy obtained with the CPFs (orbital predictions) against the MOEORB products (orbit determinations), whose accuracy requirement is 2 cm in radial RMS. It has been depicted the along-track residual since, besides representing the main source of error being almost the 100% of the total 3D RMS, it is the most critical direction for the SLR tracking. As can be seen, the comparison is typically below 40 m. Note that the increment of dispersion found after 10/11/2016 was caused by a modification in the timeliness of the MOEORB products (according to other requirements of the service), and the time interval compared.

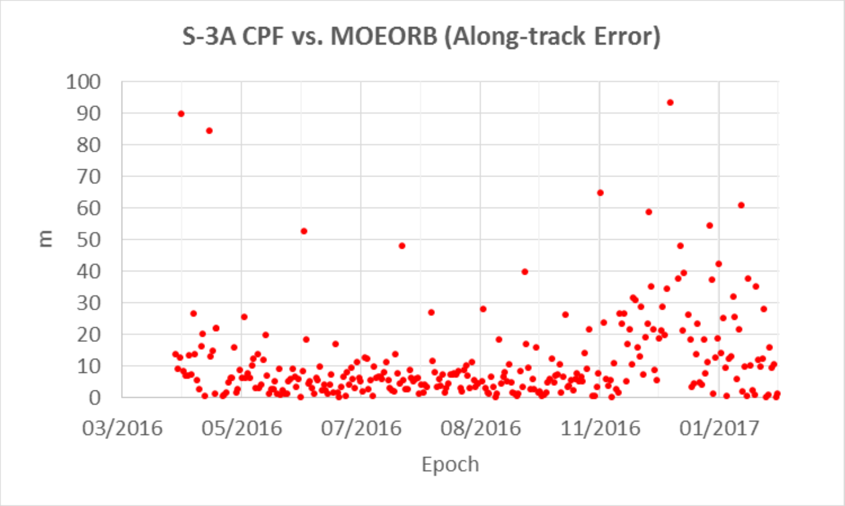

Figure 4-1: CPF files vs MOEORB between February 2016 and February 2017

Table 4-1 shows the percentiles of 3D RMS for CPF files.

Table 4-1: Percentiles of 3D RMS for CPF files

Accuracy 3D RMS	Feb 2016 – Jan 2017
< 1 m	5.3 %
< 5 m	35.2 %
< 10 m	63.8 %
< 20 m	80.8 %
< 40 m	92.8 %

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5. CONCLUSIONS

This document gather the first yearly results related to SLR tracking for Sentinel-3A. It is meant to stress the importance of the ILRS Community in the frame of the Sentinel-3 mission. The main aspects to highlight are:

- The ILRS stations cooperate with the Copernicus POD Service and its QWG by tracking the Sentinel-3A and supplying ranging measurements. Due to the amount of available stations, an overall good geographical coverage is attained.
- The observations provided by the ILRS stations are used by the QWG as an independent means to validate the orbital accuracy of the POD orbits. The comparisons have revealed a good agreement between both (keeping the RMS of the residuals around 2 cm), which improves the reliability of the CPOD products.
- The combined solution of the orbits of all the centres has been compared as well against the SLR observations provided by each station. The obtained comparisons also show a good agreement but with a wider dispersion, pointing to discrepancies with respect to some stations.
- To allow the tracking of Sentinel-3A, CPOD provides CPF files to the stations. These files contain the orbital prediction of the satellite with accuracy typically below 40 m in 3D RMS.

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ANNEX A: STATIONS COORDINATE LIST

The following table shows the coordinates of the stations used by the POD teams. They are extracted from the file IERS08-TRF-ILRS.SNX.

Monument	Code	Location Name, Country	X (m)	Y (m)	Z (m)
1824	GLSL	Golosiiv/Kiev, Ukraine	3512989.226	2068968.891	4888817.379
1884	RIGL	Riga, Latvia	3183895.758	1421497.147	5322803.792
1888	SVEL	Svetloe, Russia	2730138.945	1562328.765	5529998.670
1889	ZELL	Zelenchukskya, Russia	3451136.048	3060335.088	4391970.333
1890	BADL	Badary, Russia	-838299.799	3865738.847	4987640.905
1893	KTZL	Katzively, Ukraine	3785944.434	2550780.706	4439461.394
7080	MDOL	McDonald Observatory, Texas	-1330021.166	-5328401.838	3236480.741
7090	YARL	Yarragadee, Australia	-2389007.301	5043329.404	-3078524.479
7105	GODL	Greenbelt, Maryland	1130719.512	-4831350.574	3994106.560
7110	MONL	Monument Peak, California	-2386278.455	-4802353.941	3444881.725
7119	HA4T	Haleakala, Hawaii	-5466065.489	-2404338.330	2242108.230
7124	THTL	Tahiti, French Polynesia	-5246407.094	-3077284.569	-1913813.925
7237	CHAL	Changchum, China	-2674386.933	3757189.227	4391508.318
7249	BEIL	Beijing, China	-2148760.596	4426759.567	4044509.634
7403	AREL	Arequipa, Peru	1942807.597	-5804069.760	-1796915.753
7501	HARL	Hartebeesthoek, South Africa	5085401.100	2668330.232	-2768688.734
7811	BORL	Borowiec, Poland	3738332.687	1148246.615	5021816.098
7821	SHA2	Shanghai, China	-2830744.445	4676580.293	3275072.843
7824	SFEL	San Fernando, Spain	5105473.630	-555110.546	3769892.714
7825	STL3	Mt Stromlo, Australia	-4467064.597	2683034.882	-3667007.547
7838	SISL	Simosato, Japan	-3822388.317	3699363.604	3507573.081
7839	GRZL	Graz, Austria	4194426.377	1162694.176	4647246.730
7840	HERL	Herstmonceux, United Kingdom	4033463.609	23662.617	4924305.250
7841	POT3	Potsdam, Germany	3800432.180	881692.094	5029030.127
7941	MATM	Matera, Italy	4641978.714	1393067.630	4133249.550
8834	WETL	Wettzell, Germany	4075576.737	931785.596	4801583.655

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