SENTINEL-3 SLR YEARLY REPORT - 2017

SENTINELSPOD

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1.0	08/03/2018	22	First version
1.1	19/03/2018	21	Second version: - Section 2: Zimmerwald station passes included in the statistics - Section 3.1: Re-computation of the SLR residuals wrt QWG orbits from January 2017 until June 2017 using the PostSeismic deformation model and the SLRF2014 station coordinates. - Section 3.1: Statistics corrected after discarding outliers. - Section 3.2: Zimmerwald station passes included in the results - Section 3.2: Statistics corrected after discarding outliers. - Annex A: the table containing SLRF2008 coordinates was removed as finally it has not been used for the generation of this report. - Annex A: Zimmerwald station included in the SLRF2014 table

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1. INTRODUCTION

1.1. PURPOSE

This document describes the Sentinel-3 SLR Yearly Report - 2017, 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 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).

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. A new station placed in Zimmerwald (Switzerland) started tracking Sentinel 3A during 2017.

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

Figure 2-2 and Figure 2-3 represents the evolution of the S-3A total **number of passes per week** (during 2017 and since the beginning of the mission, respectively). As it can be seen, the average number of Sentinel-3A SLR tracking passes per week is around 80, which is in line with other similar missions, in terms of altitude and priority, like SWARM. On the other hand, Figure 2-4 and Figure 2-5 show the number of S-3A **passes per station** (during 2017 and since the beginning of the mission, respectively). 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.

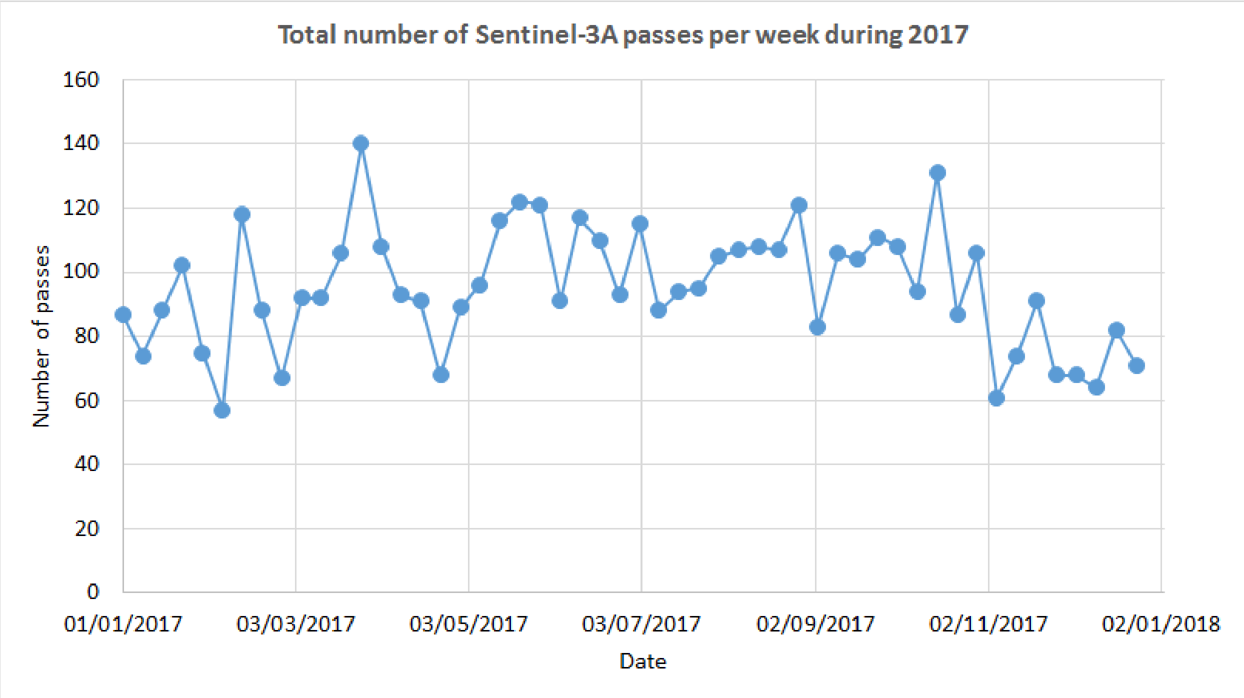

Figure 2-2: Total number of Sentinel-3A passes per week in 2017

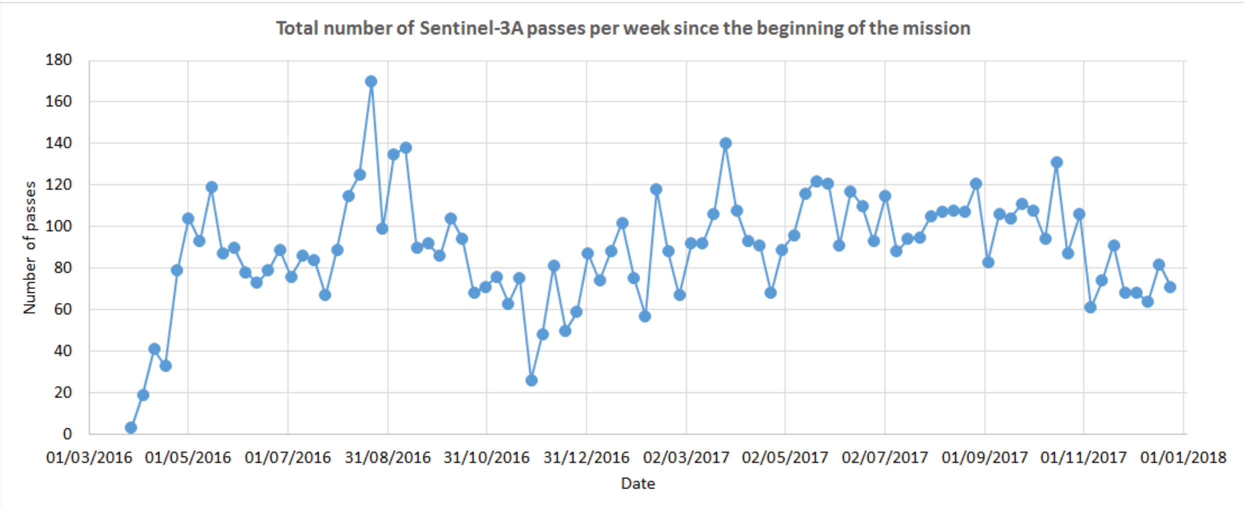

Figure 2-3: Total number of Sentinel-3A passes per week since the beginning of the mission

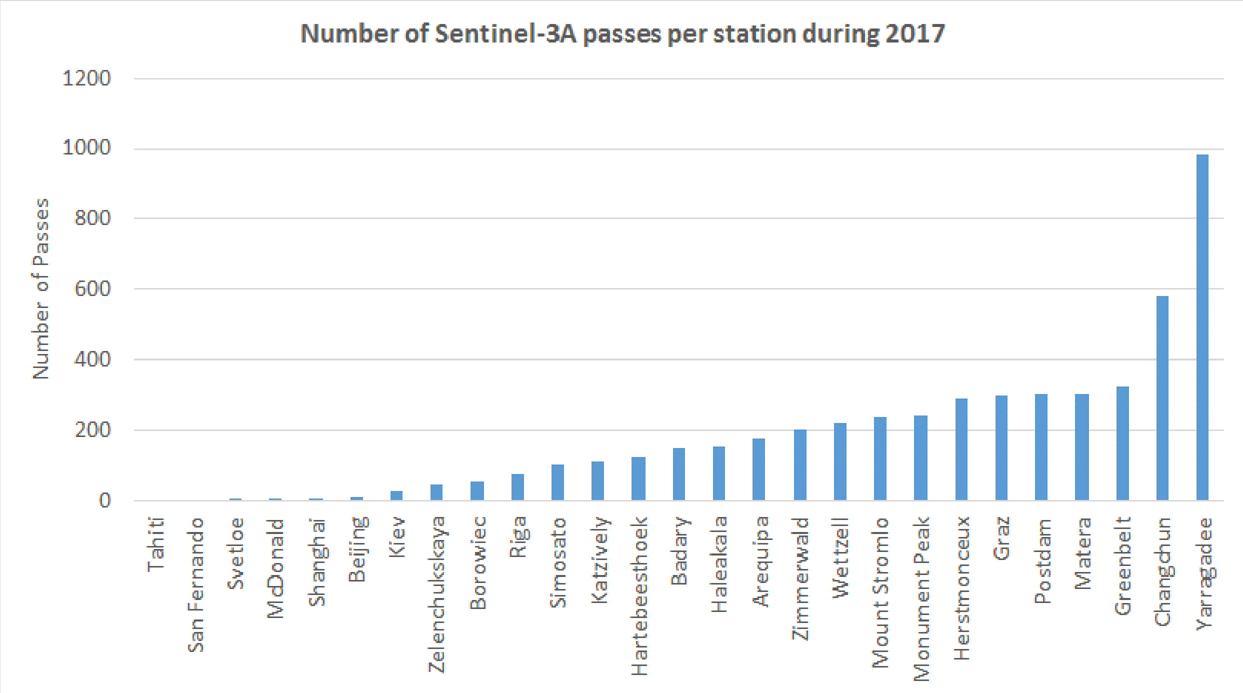

Figure 2-4: Total number of Sentinel-3A passes per station in 2017

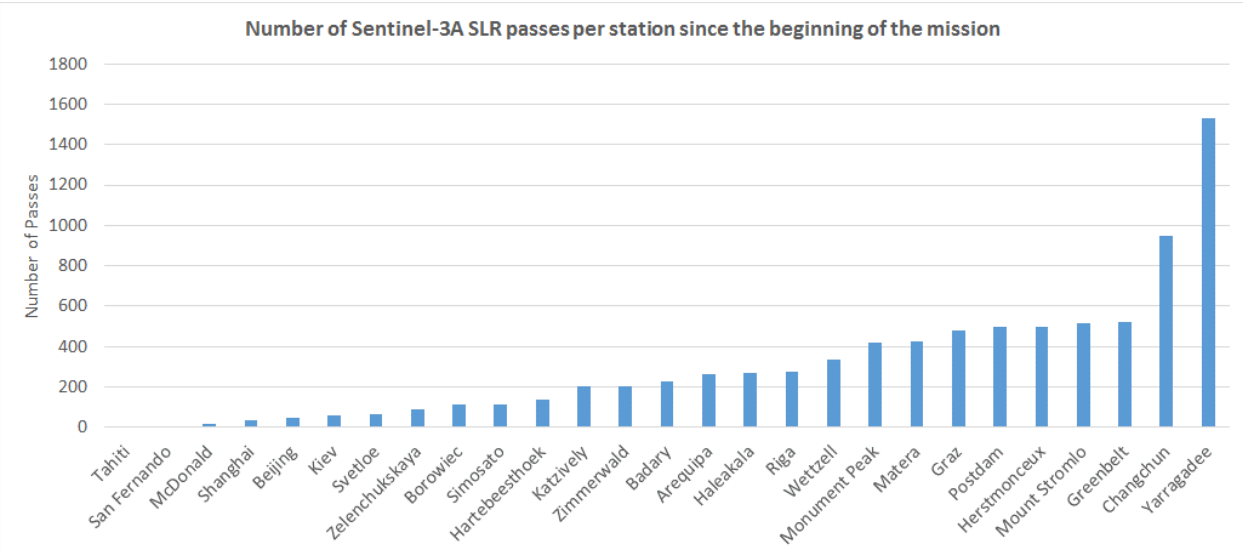

Figure 2-5: Total number of Sentinel-3A passes per station since the beginning of the mission

3. ANALYSIS OF ACCURACY

3.1. INDEPENDENT SLR VALIDATION FOR SENTINEL-3A

The Sentinel-3A orbital solutions are currently been computed by several institutions that conform the POD Quality Working Group (QWG), which is intended to ensure the good quality of the Copernicus POD Service. The mentioned institutions are AIUB, CNES, DLR, ESOC, EUMETSAT, TU Delft, TU Munich, CLS (GRG) and the Copernicus POD Service itself. The computed solutions are based on very similar GNSS processing strategies, although using different processing schemes, models and SW. Actually, TU Delft provide two different solutions: one using GHOST and one using GIPSY. 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 data.

Figure 3-1 shows the number of accepted SLR observations per day by every centre along 2017, when a stable number of passes was available. It was generated by fixing the orbit of each centre and computing the SLR observation residuals. When the obtained residual was too high, the observation was considered rejected in order to avoid corrupting the statistics. 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.

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 ITRF14 coordinates, which are included in the annex.

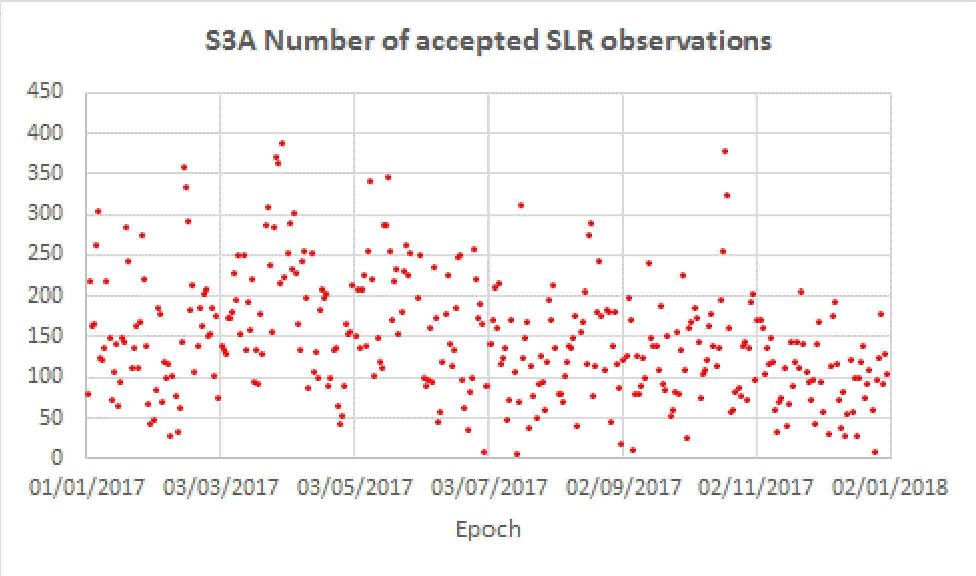

Figure 3-1: Number of SLR observations available in 2017

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 during 2017, where it can be seen that most of the solutions are highly consistent with RMS values below 2 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).

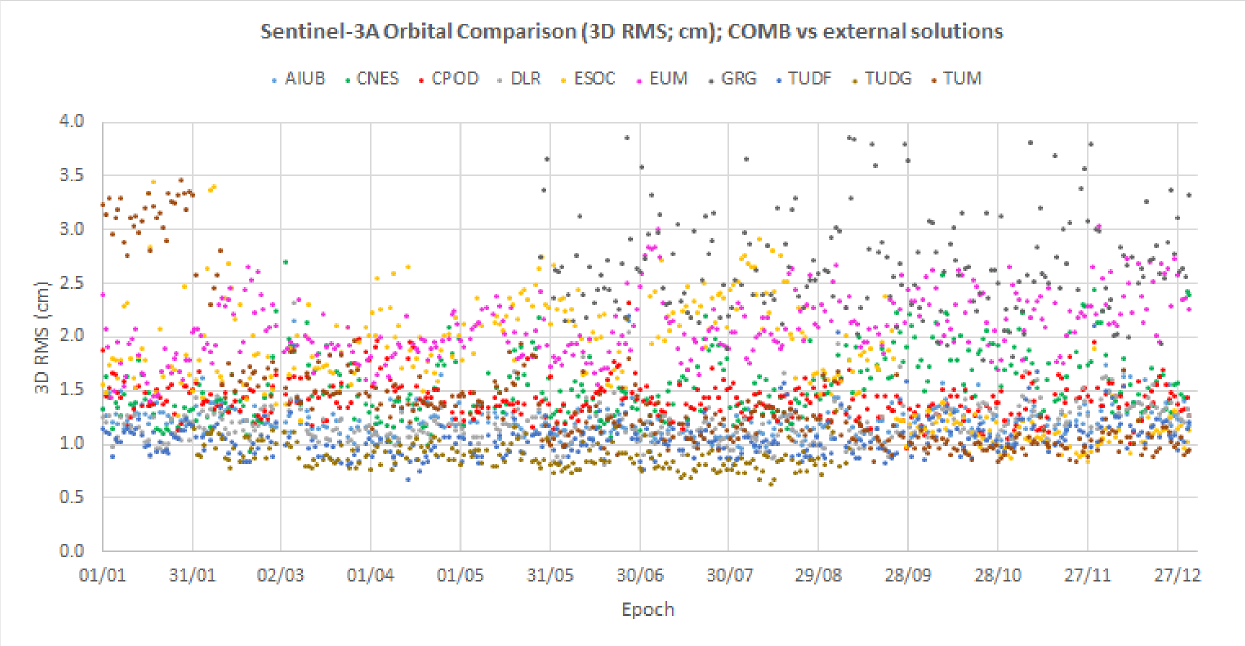

Figure 3-2: Sentinel-3A Orbital Comparisons: Combined solution against all centres in 2017

Figure 3-3 represents the RMS values of the SLR residuals computed against fixed orbit solutions obtained from the different centres using GPS data. It is observed that the agreement between the GPS solutions and the SLR observations is good. It can be appreciated that there is an improvement on the second half of the year. While the values of the first half of the year are around 1.5 cm, on the second half of the year they are around 1 cm, due to the application of the post-seismic deformation model and the new ITRF2014 coordinates in the analysis done from June onwards.

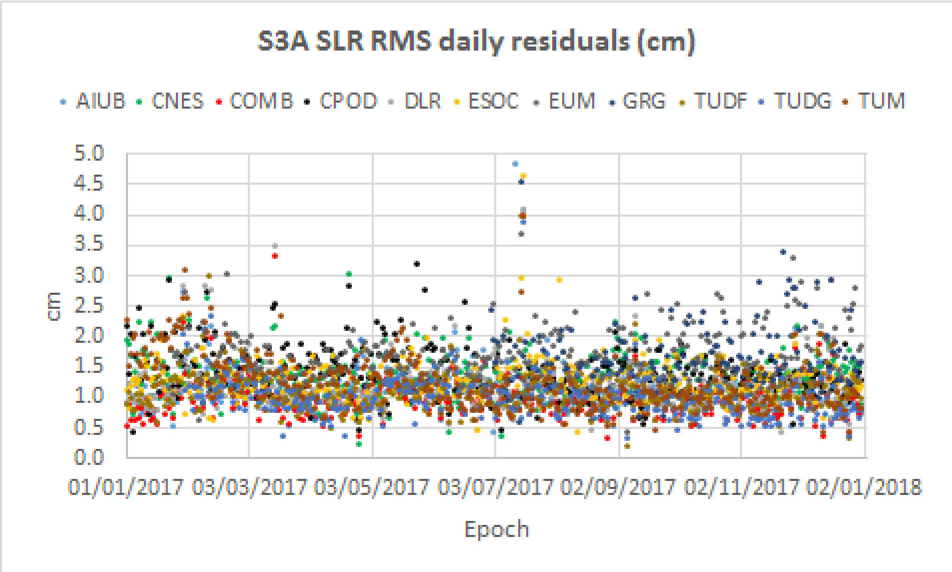

Figure 3-3: Daily SLR RMS of residuals in 2017

Figure 3-4 shows the mean value of the SLR residuals per centre. The values are mainly bounded within the interval [1.5 cm, -1 cm].

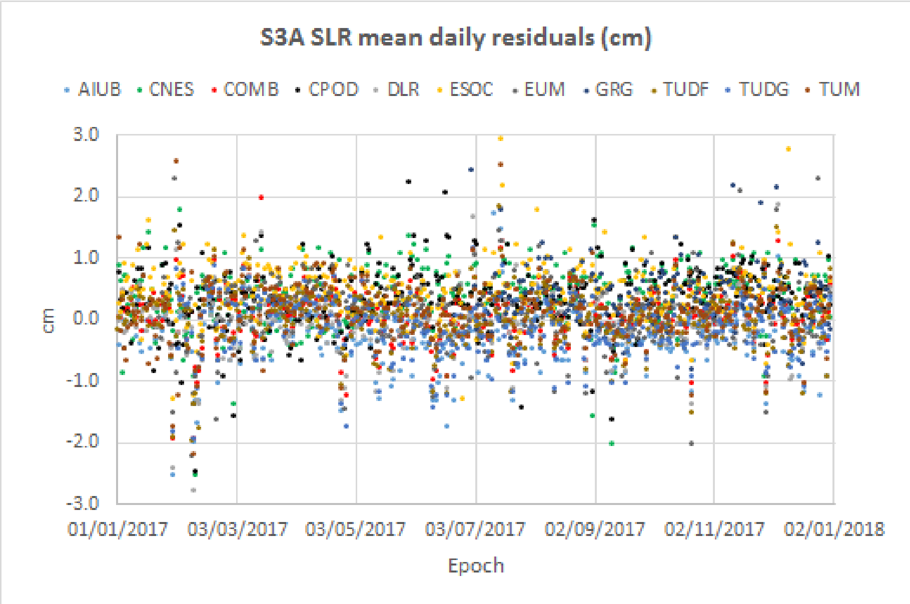

Figure 3-4: Daily SLR mean values of residuals in 2017

Another representative metric is the standard deviation shown in Figure 3-5. As it can be observed, it is of the same order of magnitude as the RMS due to the low biases observed with respect to laser residuals.

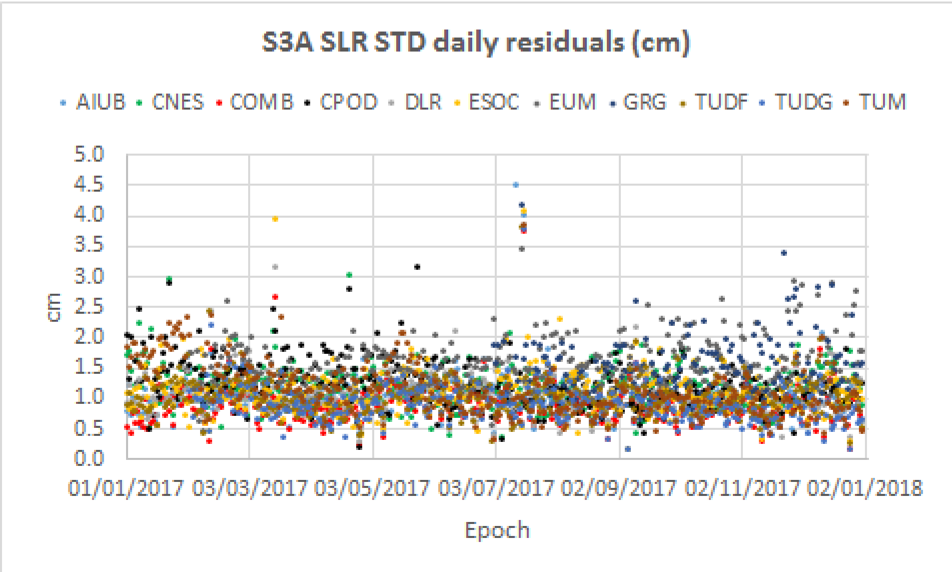

Figure 3-5: Daily SLR standard deviations of residuals in 2017

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 in most cases.

Table 3-1: SLR average metrics of residuals (cm) in 2017

	AIUB	CNES	COMB	CPOD	DLR	ESOC	EUM	GRG	TUDF	TUDG	TUM
Mean (cm)	-0.20	0.40	0.12	0.36	0.00	0.46	0.12	0.42	0.02	-0.11	0.17
RMS (cm)	1.16	1.37	1.00	1.39	1.18	1.30	1.65	1.65	1.10	1.02	1.25
STD (cm)	1.03	1.19	0.90	1.22	1.06	1.10	1.54	1.39	1.00	0.92	1.10

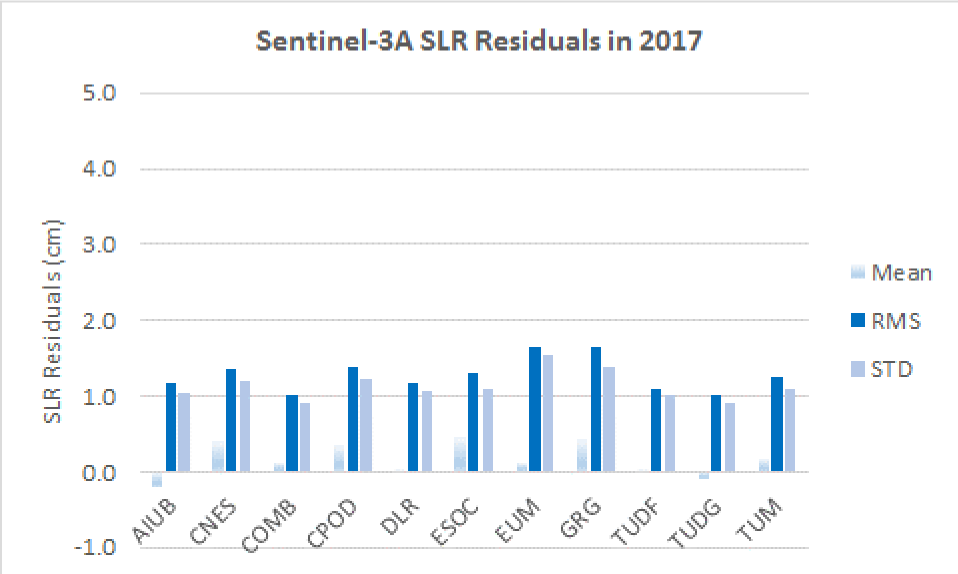

Figure 3-6: SLR average metrics of residuals in 2017

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 to 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 observations per station. Again, 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.

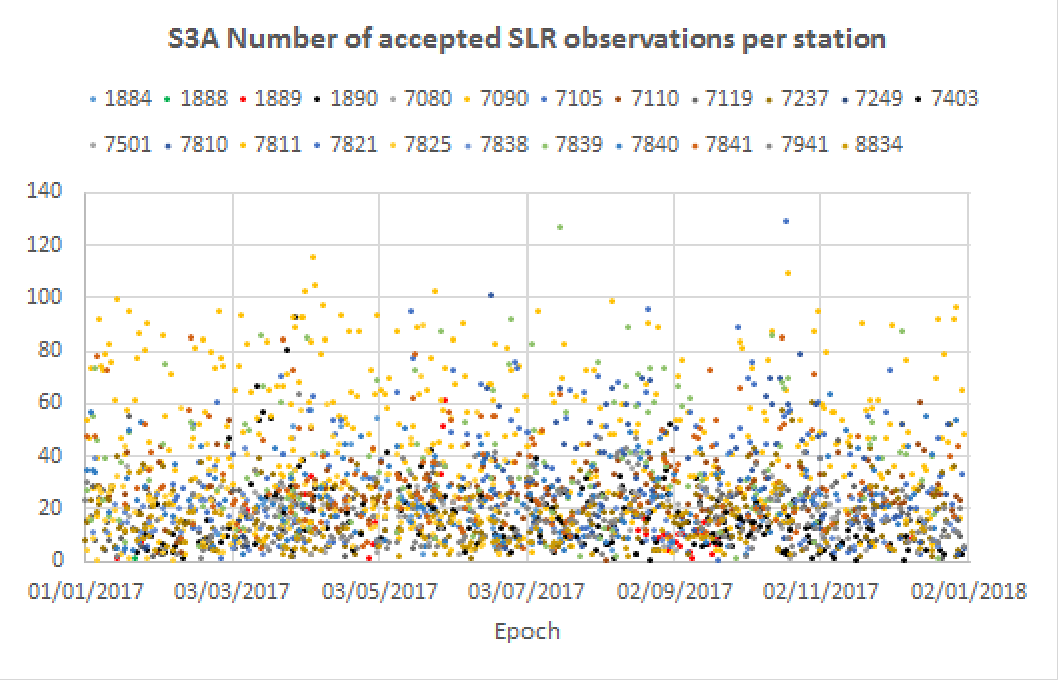

Figure 3-7: Number of accepted/rejected SLR observations during 2017

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.

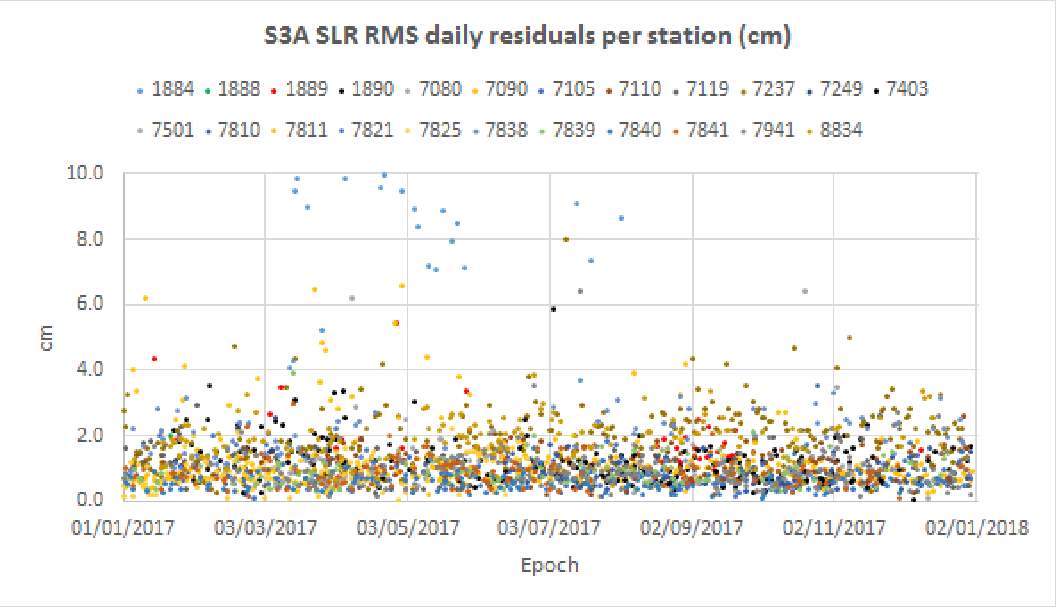

Figure 3-8: Daily SLR RMS of residuals per station during 2017

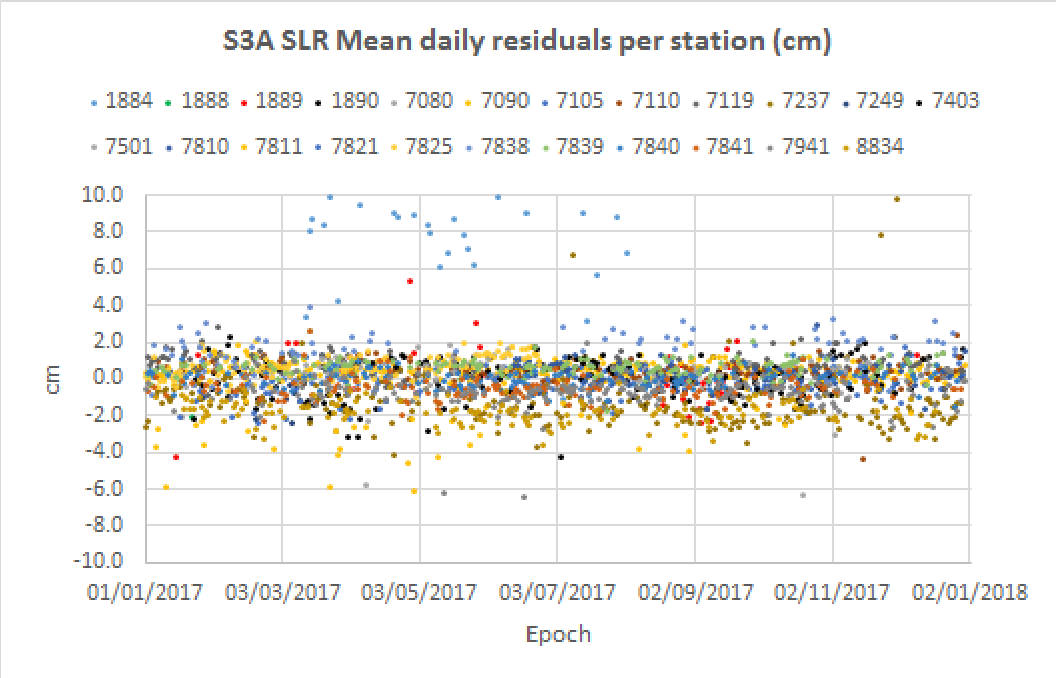

Figure 3-9: Daily SLR mean residuals per station during 2017

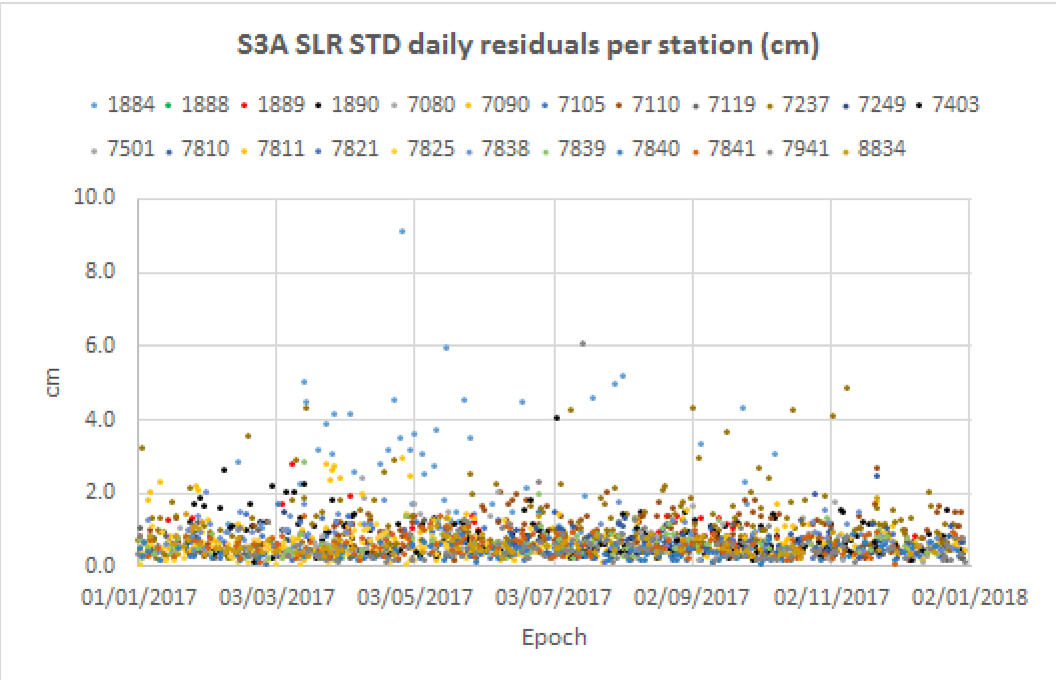

Figure 3-10: Daily SLR standard deviation of residuals during 2017

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 7.68 cm in the case of the station 1884 (Golosiiv, Ukraine) to less than 1 cm in the case of the station 7090 (Yarragadee, Australia). According to this, the stations with the largest biases are the following (sorting in descending order): 1884, 7080, and 7811. These stations are also highlighted in the following tables.

Table 3-2: SLR average metrics per station during 2017

	1884	1888	1889	1890	7080	7090	7105	7110	7119	7237	7249
Mean (cm)	7.32	-2.05	0.24	-0.28	-3.39	0.57	-0.12	0.51	0.88	-1.24	-1.16
RMS (cm)	7.68	2.05	1.86	1.54	4.11	0.88	0.89	1.23	1.06	2.03	1.53
STD (cm)	3.02	0.00	1.09	1.08	1.79	0.60	0.65	1.02	0.50	1.18	0.80

Table 3-3: SLR average metrics per station during 2017

	7403	7501	7810	7811	7821	7825	7838	7839	7840	7841	7941	8834
Mean (cm)	0.23	0.49	0.21	-2.58	-1.17	0.65	1.50	0.60	-0.05	-0.51	-0.74	-1.82
RMS (cm)	0.92	0.93	0.90	3.10	1.26	0.96	1.96	0.92	0.58	0.93	0.99	1.92
STD (cm)	0.60	0.63	0.69	1.50	0.42	0.58	0.90	0.61	0.42	0.61	0.55	0.60

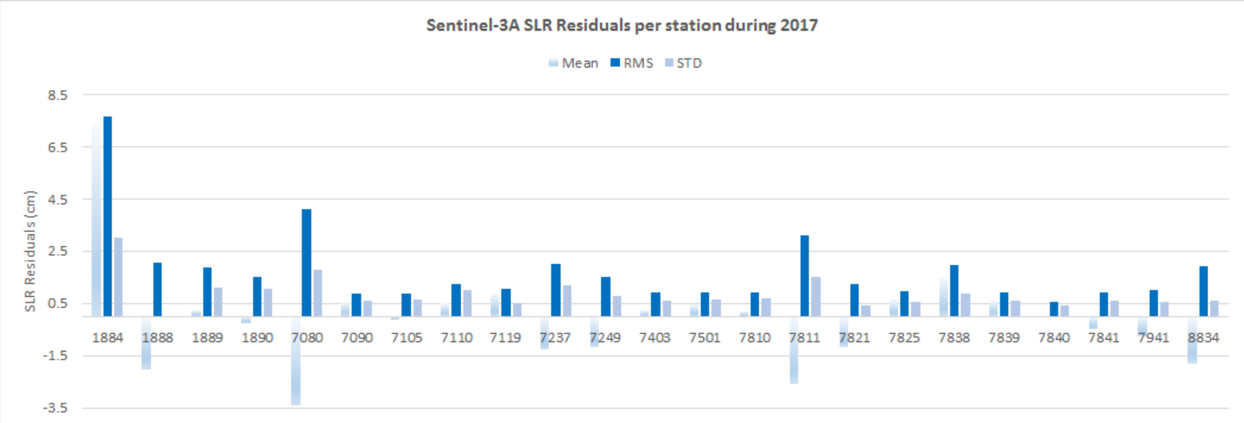

Figure 3-11: SLR comparison per station during 2017

4. CPF PREDICTIONS

To allow the SLR tracking of Sentinel-3, the 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 365. 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:

- 2017/02/23
- 2017/03/15
- 2017/04/22
- 2017/04/27
- 2017/05/23
- 2017/07/12
- 2017/09/27
- 2017/10/20
- 2017/11/29
- 2017/12/13

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.

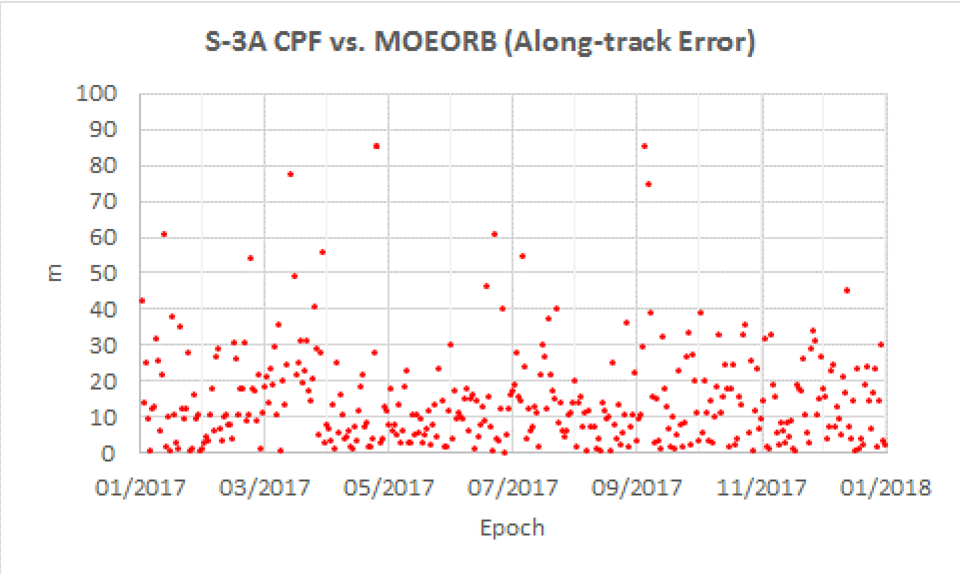

Figure 4-1: CPF files vs MOEORB during 2017

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	Jan 2017 – Dec 2017
< 1 m	4.1 %
< 5 m	24.9 %
< 10 m	43.2 %
< 20 m	74.6 %
< 40 m	94.5 %

5. CONCLUSIONS

This document gathers the 2017 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 mean to validate the orbital accuracy of the POD orbits. The comparisons have revealed a good agreement between them (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.

ANNEX A: STATIONS COORDINATE LIST

The following table shows the coordinates of the stations used by the POD team for the generation of this report (the year 2017); they are extracted from the file SLRF2014.

Table A- 1: Geographical location and coordinates of all Sentinel-3 SLR tracking stations (SLRF2014)

Monument	Code	Location Name, Country	X (m)	Y (m)	Z (m)
1824	GLSL	Golosiiv/Kiev, Ukraine	3512989.111	2068968.912	4888817.398
1884	RIGL	Riga, Latvia	3183895.637	1421497.208	5322803.793
1888	SVEL	Svetloe, Russia	2730138.911	1562328.755	5529998.665
1889	ZELL	Zelenchukskya, Russia	3451135.973	3060335.220	4391970.306
1890	BADL	Badary, Russia	-838299.971	3865738.847	4987640.893
1893	KTZL	Katzively, Ukraine	3785944.345	2550780.789	4439461.397
7080	MDOL	McDonald Observatory, Texas	-1330021.233	-5328401.842	3236480.717
7090	YARL	Yarragadee, Australia	-2389007.534	5043329.447	-3078524.223
7105	GODL	Greenbelt, Maryland	1130719.438	-4831350.580	3994106.573
7110	MONL	Monument Peak, California	-2386278.627	-4802353.816	3444881.772
7119	HA4T	Haleakala, Hawaii	-5466065.553	-2404338.024	2242108.390
7124	THTL	Tahiti, French Polynesia	-5246407.299	-3077284.309	-1913813.757
7237	CHAL	Changchum, China	-2674387.081	3757189.194	4391508.287
7249	BEIL	Beijing, China	-2148760.760	4426759.548	4044509.606
7403	AREL	Arequipa, Peru	1942807.795	-5804069.723	-1796915.614
7501	HARL	Hartebeesthoek, South Africa	5085401.092	2668330.330	-2768688.650
7810	ZIML	Zimmerwald, Switzerland	4331283.311	567549.958	4633140.235
7811	BORL	Borowiec, Poland	3738332.592	1148246.687	5021816.135
7821	SHA2	Shanghai, China	-2830744.597	4676580.229	3275072.784
7824	SFEL	San Fernando, Spain	5105473.580	-555110.494	3769892.761
7825	STL3	Mt Stromlo, Australia	-4467064.778	2683034.887	-3667007.319
7838	SISL	Simosato, Japan	-3822388.317	3699363.635	3507573.048
7839	GRZL	Graz, Austria	4194426.293	1162694.265	4647246.785
7840	HERL	Herstmonceux, United Kingdom	4033463.542	23662.700	4924305.303
7841	POT3	Potsdam, Germany	3800432.096	881692.172	5029030.173
7941	MATM	Matera, Italy	4641978.617	1393067.723	4133249.623
8834	WETL	Wettzell, Germany	4075576.651	931785.679	4801583.698

END OF DOCUMENT