SENTINEL-3 SLR YEARLY REPORT - 2018

COPERNICUS SENTINEL-1, -2 AND -3 PRECISE ORBIT DETERMINATION SERVICE (SENTINELSPOD)

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1. INTRODUCTION

1.1. PURPOSE

This document called **Sentinel-3 SLR Yearly Report - 2018**, has been prepared in the frame of the project *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 and Sentinel-3B (in Routine Operational Phase [ROP] since August 2018) 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 the entire year 2018.

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 and S-3B. 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	1.2	10/05/2018
[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-3 satellites are equipped with a Laser Retro Reflector (LRR), which allows tracking the satellites 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-3 satellites based on an agreement signed upon power restrictions (see [RD.1] and [RD.3]). More information about the location name, the country and the location coordinates of these ILRS stations can be found in Table 6-1.

From the figure below, 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.

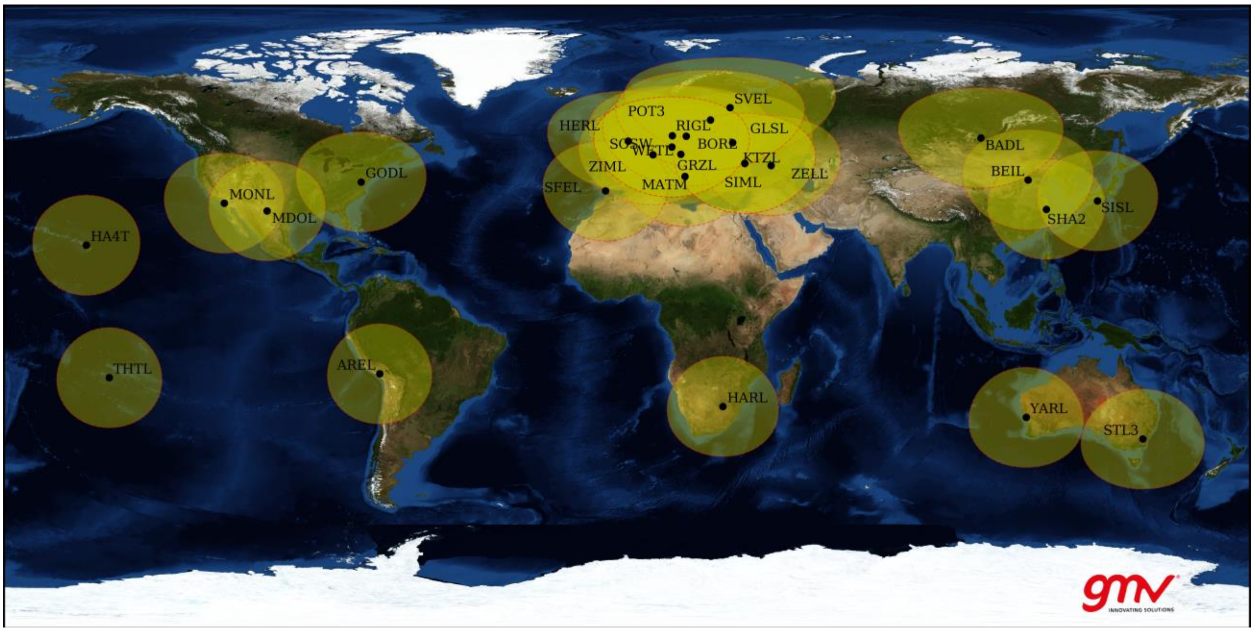


Figure 2-1: ILRS Stations allowed to track Sentinel-3 satellites

Figure 2-2 and Figure 2-3 plot the **total number of passes tracked per station** during 2018 and since the beginning of the S-3A mission, respectively, for both S-3A and S-3B. As seen from the figures, the station of Yarragadee, Australia (YARL) continues being the station with the largest number of passes of the year for both Sentinels with high differences with regard the other tracking stations. The second most tracking station, Changchum, China (CHAL), ceased tracking both Sentinels during 2018 since the power upgrade performed on its laser facilities might damage the on-board instrumentation of the Sentinels. At this point, it is remarkable to say that there are a few stations which have not tracked or have very little tracked both Sentinels during 2018. They are: Tahiti, French Polynesia (THTL), San Fernando, Spain (SFEL), Svetloe, Russia (SVEL), McDonald Observatory, Texas (MDOL), and Wettzell, Germany (SOSW). Maintenance works on these stations might be the reason of such lack of tracking; however, further enquiries shall be carried out to figure out the primary causes.

On the other hand, Figure 2-4 and Figure 2-5 show the evolution of the **total number of passes per week** during 2018 and since the beginning of the S-3A mission, respectively, for both S-3A and S-3B. In this case, the average number of tracking passes for S-3A follows the pattern of previous years, and, the behaviour of S-3B resembles the one of S-3A. Thus, it may be said that the Sentinels tracking has performed nominally. However, a **sudden decrease** on Sentinels tracking can be observed since the beginning of November 2018. Such decrease can also be observed when analysing another satellite out of Sentinels-3 missions (e.g., the Jason-3 satellite), but, after this decrease, the Jason-3 tracking regains nominal values whereas Sentinels-3 satellites do not. One likely explanation to this fact might be the consequence of the FTP change implemented by GMV on 31st October. ILRS requires to increase the security to access the CPF files of those satellites with restricted tracking, as it is Sentinel-3. As such, a new FTP was deployed, in which users are required to access using FTPS. This change might interfere the connection between some ILRS station and the new FTP as it can be seen in the figures shown in Table 2-1, where many stations stopped tracking both Sentinels since the beginning of November onwards. All stations in red in Table 2-1 have reduced the tracking of Sentinel-3 significantly since November, while many of them continues tracking Jason-3. Further enquiries will be performed to identify issues with those stations, in order to find a solution.

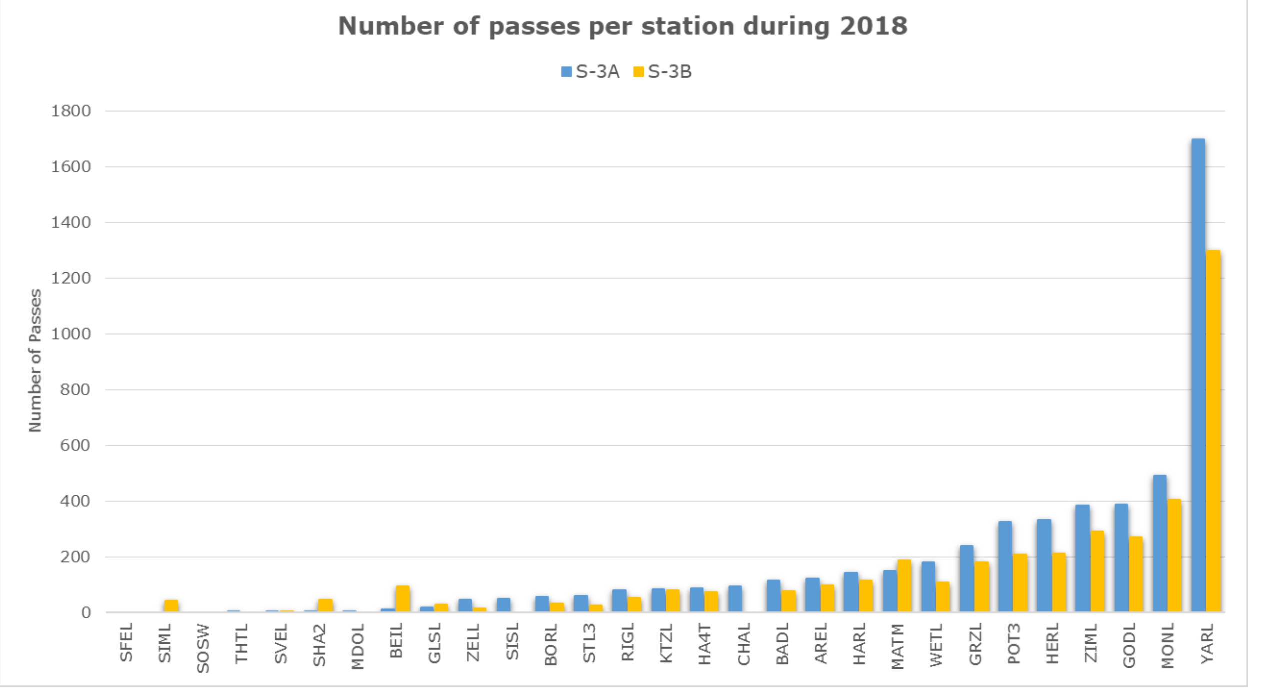


Figure 2-2: Total number of passes per station in 2018 (Sentinel-3A and Sentinel-3B)

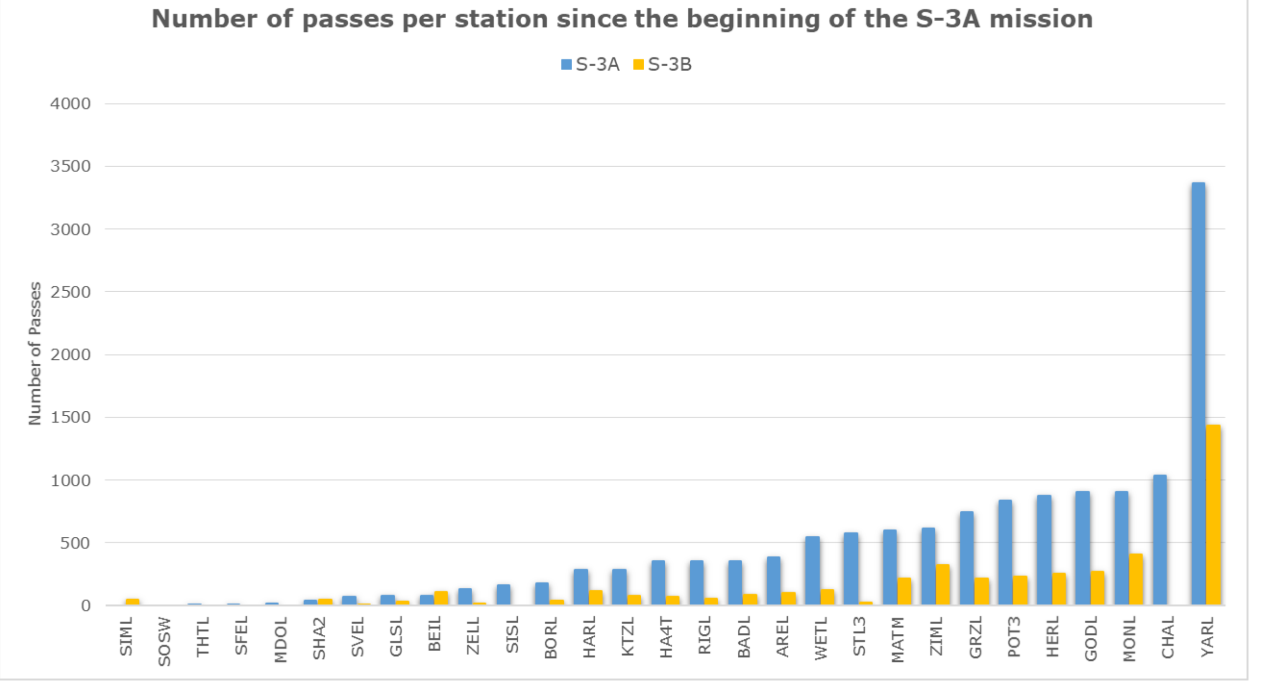


Figure 2-3: Total number of passes per station since the beginning of the S-3A mission (Sentinel-3A and Sentinel-3B)

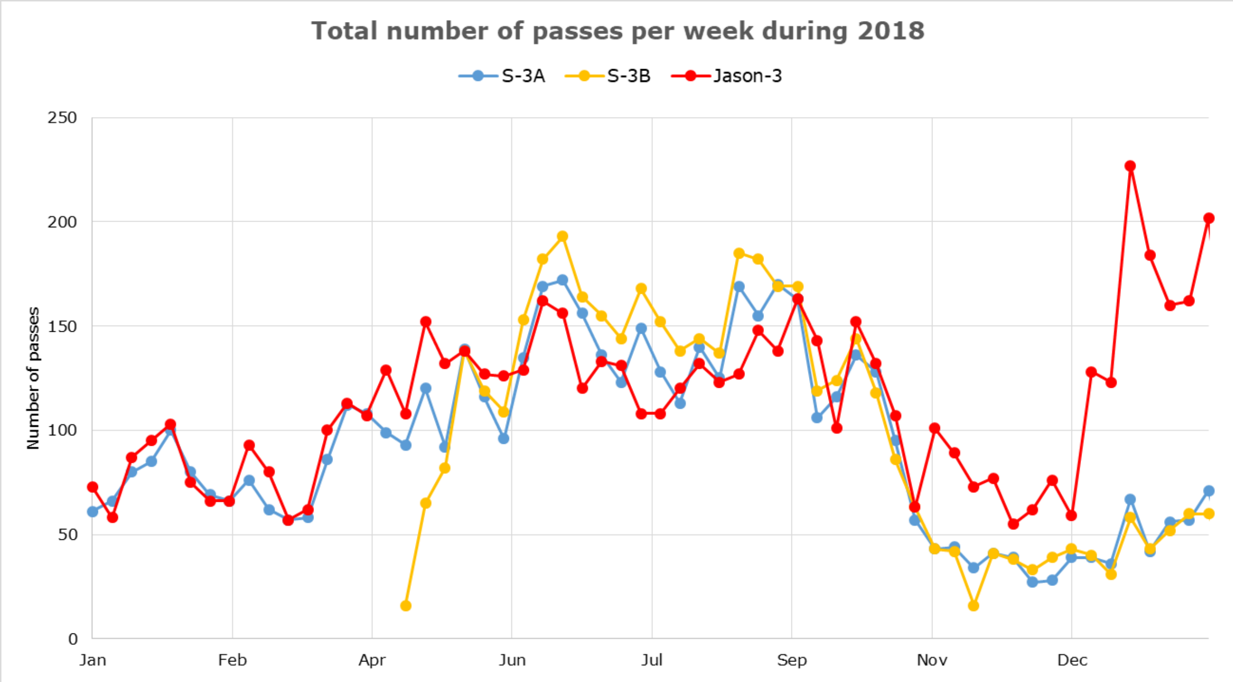


Figure 2-4: Total number of passes per week in 2018 (Sentinel-3A, Sentinel-3B and Jason-3)

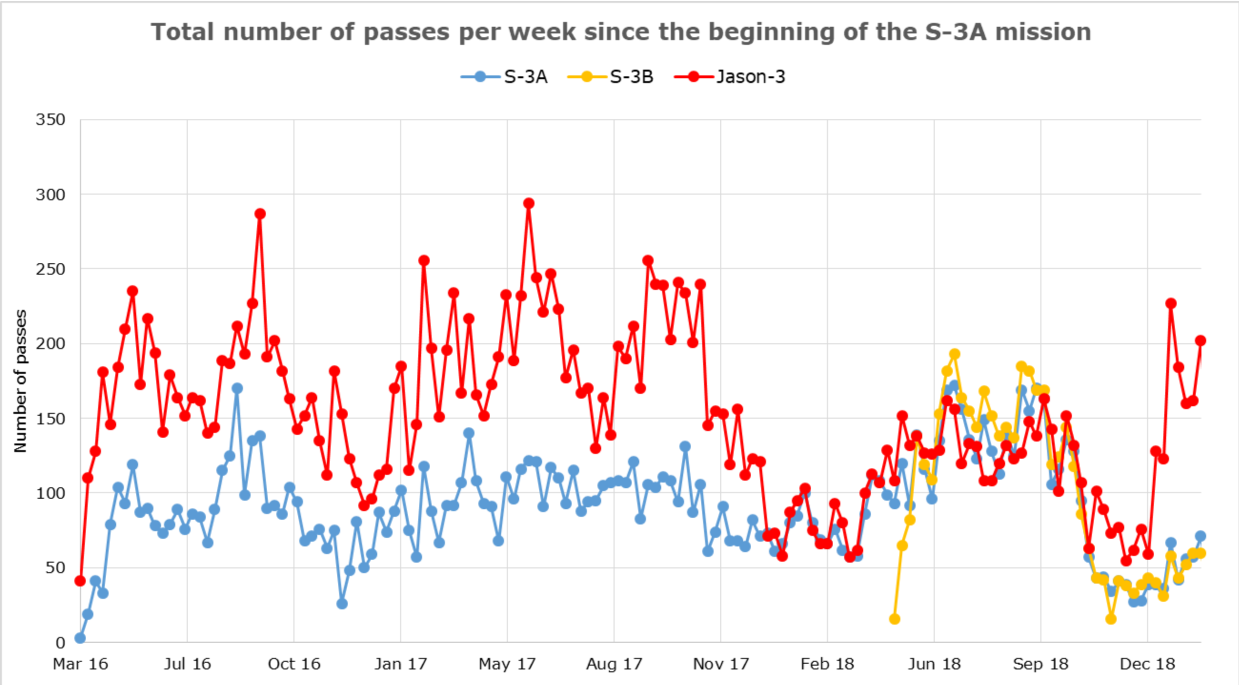


Figure 2-5: Total number of passes per week since the beginning of the S-3A mission (Sentinel-3A, Sentinel-3B and Jason-3)

Table 2-1: Number of passes per station considering two periods of time of 2018 (1st January to 31st October and 1st November to 31st December)

	Number of passes per station considering two periods of time of 2018														
	S3A					S3B					Jason-3				
	1st Jan - 31st Oct		1st Nov - 31st Dec		TOTAL 2018	1st May - 31st Oct		1st Nov - 31st Dec		TOTAL 2018	1st Jan - 31st Oct		1st Nov - 31st Dec		TOTAL 2018
	TOTAL	Av. per month	TOTAL	Av. per month		TOTAL	Av. per month	TOTAL	Av. per month		TOTAL	Av. per month	TOTAL	Av. per month	
THTL	1	0.10	0	0.00	1	0	0.00	0	0.00	0	116	11.60	5	2.50	121
SFEL	0	0.00	0	0.00	0	0	0.00	0	0.00	0	0	0.00	0	0.00	0
SVEL	0	0.00	1	0.50	1	2	0.33	0	0.00	2	99	9.90	8	4.00	107
MDOL	3	0.30	0	0.00	3	0	0.00	0	0.00	0	17	1.70	0	0.00	17
SHA2	1	0.10	0	0.00	1	46	7.67	0	0.00	46	0	0.00	0	0.00	0
BEIL	0	0.00	10	5.00	10	82	13.67	13	6.50	95	0	0.00	2	1.00	2
GLSL	14	1.40	1	0.50	15	27	4.50	0	0.00	27	0	0.00	0	0.00	0
ZELL	43	4.30	0	0.00	43	14	2.33	0	0.00	14	96	9.60	12	6.00	108
BORL	47	4.70	8	4.00	55	24	4.00	7	3.50	31	0	0.00	1	0.50	1
RIGL	79	7.90	0	0.00	79	51	8.50	0	0.00	51	0	0.00	0	0.00	0
SISL	49	4.90	0	0.00	49	0	0.00	0	0.00	0	66	6.60	5	2.50	71
KTZL	84	8.40	0	0.00	84	79	13.17	0	0.00	79	0	0.00	1	0.50	1
HARL	142	14.20	0	0.00	142	115	19.17	0	0.00	115	243	24.30	13	6.50	256
BADL	99	9.90	19	9.50	118	61	10.17	17	8.50	78	204	20.40	45	22.50	249
HA4T	80	8.00	0	0.00	80	73	12.17	0	0.00	73	116	11.60	15	7.50	131
AREL	117	11.70	2	1.00	119	98	16.33	0	0.00	98	154	15.40	30	15.00	184
WETL	174	17.40	5	2.50	179	100	16.67	7	3.50	107	481	48.10	65	32.50	546
STL3	58	5.80	0	0.00	58	25	4.17	0	0.00	25	0	0.00	14	7.00	14
MONL	485	48.50	0	0.00	485	403	67.17	0	0.00	403	308	30.80	43	21.50	351
HERL	301	30.10	32	16.00	333	187	31.17	27	13.50	214	0	0.00	5	2.50	5
GRZL	214	21.40	21	10.50	235	154	25.67	27	13.50	181	0	0.00	1	0.50	1
POT3	310	31.00	10	5.00	320	201	33.50	10	5.00	211	0	0.00	5	2.50	5
MATM	111	11.10	36	18.00	147	155	25.83	33	16.50	188	429	42.90	49	24.50	478
GODL	381	38.10	0	0.00	381	270	45.00	0	0.00	270	365	36.50	48	24.00	413
CHAL	86	8.60	0	0.00	86	0	0.00	0	0.00	0	0	0.00	25	12.50	25
YARL	1550	155.00	139	69.50	1689	1162	193.67	146	73.00	1308	1206	120.60	237	118.50	1443
ZIML	333	33.30	50	25.00	383	246	41.00	48	24.00	294	686	68.60	69	34.50	755

Number of passes per station considering two periods of time of 2018															
	S3A					S3B					Jason-3				
	1st Jan - 31st Oct		1st Nov - 31st Dec		TOTAL 2018	1st May - 31st Oct		1st Nov - 31st Dec		TOTAL 2018	1st Jan - 31st Oct		1st Nov - 31st Dec		TOTAL 2018
	TOTAL	Av. per month	TOTAL	Av. per month		TOTAL	Av. per month	TOTAL	Av. per month		TOTAL	Av. per month	TOTAL	Av. per month	
SIML	0	0.00	0	0.00	0	43	7.17	0	0.00	43	242	24.20	6	3.00	248
SOSW	0	0.00	0	0.00	0	0	0.00	0	0.00	0	0	0.00	0	0.00	0

LEGEND

- (white) **NO tracking**
- (red) **Tracking reduced to 0 or to very few observations**
- (orange) **Tracking reduced**
- (green) **Tracking increased**

3. ANALYSIS OF ACCURACY

In this section, the SLR residuals will be analysed for both Sentinels-3, firstly, comparing the solutions obtained by different external institutions and, secondly, considering the outcome provided by all tracking stations.

3.1. ANALYSIS OF RESIDUALS PER EXTERNAL INSTITUTION

The Sentinel-3 orbital solutions are currently been computed by several institutions that conform the Copernicus POD Quality Working Group (QWG), which is intended to ensure the good quality of the Copernicus POD (CPOD) Service. The mentioned institutions are AIUB, CNES, DLR, ESOC, EUMETSAT (EUM), TU Delft (TUDG), TU Munich (TUM), CLS (GRG) and CPOD Service itself. The computed solutions are based on very similar GNSS processing strategies, although using different processing schemes, models and software. For example, the CLS solution (using GRG ID) is only based on DORIS data and CNES solution includes DORIS observations along with the GPS data. Moreover, the AIUB and CPOD institutions also provide a second solution, labelled as AING and CPOF, respectively. The AING solution considers non-gravitational force models not taking into account in the AIUB solution, whereas the CPOF solution is based on ambiguity fixing algorithms not calculated in the CPOD solution. Finally, a combined solution (COMB), which joints all previous solutions adequately weighted into one solution, has also included within the analysis. Thus, a wide and an independent analysis of the SLR residuals has been performed.

It has to be mentioned that the availability of SLR measurements allow for an independent means to validate the orbital accuracy of the different institutions. To this end, SLR measurements are not used in the orbit determination process, but instead they are fitted to a fixed orbit based only on GPS data.

The following figures and tables are intended to ease the analysis of the SLR residuals for both Sentinels-3. Firstly, Figure 3-1 and Figure 3-2 show the orbital comparisons between all solutions provided by all institutions and the combined solution for S-3A and S-3B, respectively, during 2018. In this way, an overview on the "quality" of all different solutions is provided. Note that S-3B was in ROP since August 2018 and the orbital solutions of all institutions were started to be calculated a few days after. Thus, the orbital comparisons of S-3B (Figure 3-2) are computed since the end of September 2018 onwards.

As seen from the figures below, the vast majority of the orbital solutions are between 1 and 2 cm (or even better) from the combined solution, except for EUM and GRG solutions, which obtain worse results (between 2 and 4 cm). Despite this fact, it can be said that all solutions can be considered perfectly valid.

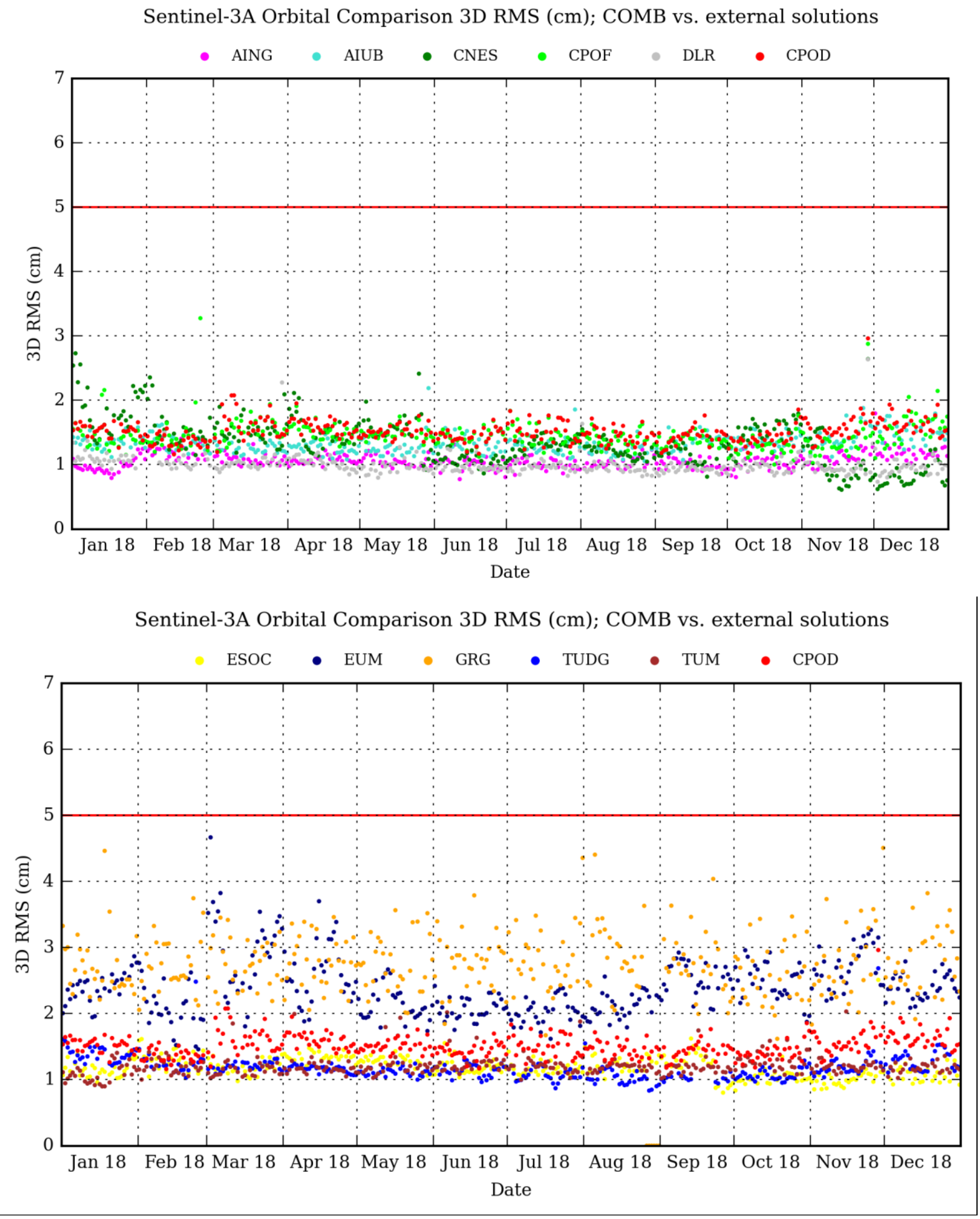
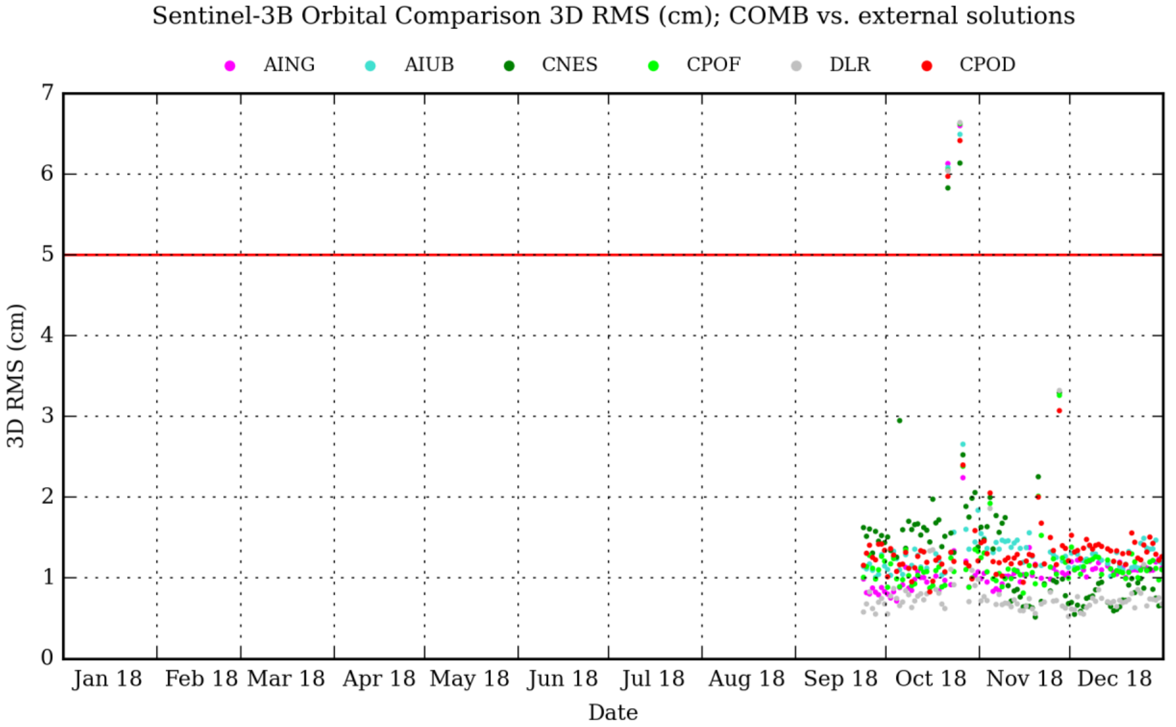


Figure 3-1: Sentinel-3A orbital comparisons (3D RMS; cm) between COMB orbit and all orbit solutions



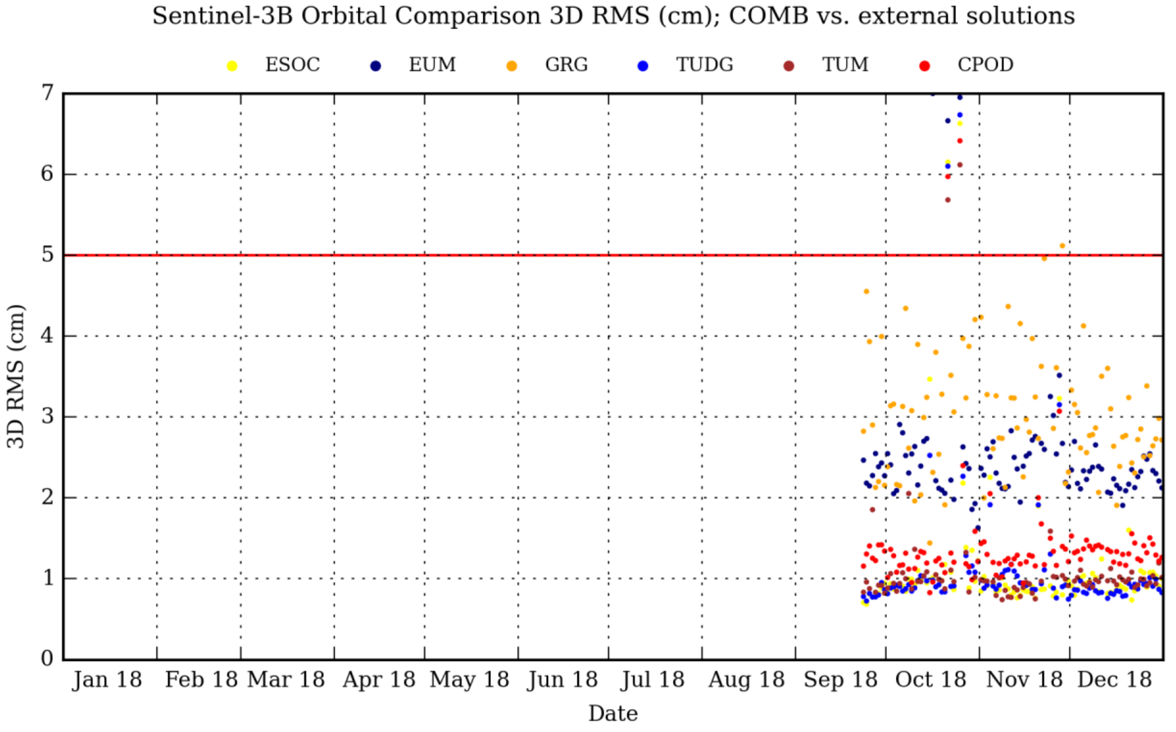


Figure 3-2: Sentinel-3B orbital comparisons (3D RMS; cm) between COMB orbit and all orbit solutions

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 previous solutions have no systematic biases affecting them all equally. In Figure 3-3 and Figure 3-4, the total number of accepted SLR observations is depicted for S-3A and S-3B, respectively. From the figures below, it can be seen that this number held between 25 and 100 observations per day for S-3A before the emergence of S-3B satellite. From this point on, the number of accepted observations has decreased to less than 50 in average for both Sentinels-3. In addition, such decrease is more accentuated when comparing these figures to previous years. For example, the number of accepted SLR observations for S-3A was between 50 and 200 during 2017, and these figures have reduced to between 10 and 60 observations during 2018. Some other issues than the emergence of S3-B have harmed the tracking of both satellites. Possibly, the required changes in the FTP providing the CPF files, to request secure FTP protocols, is causing problems to some stations (see Table 2-1)

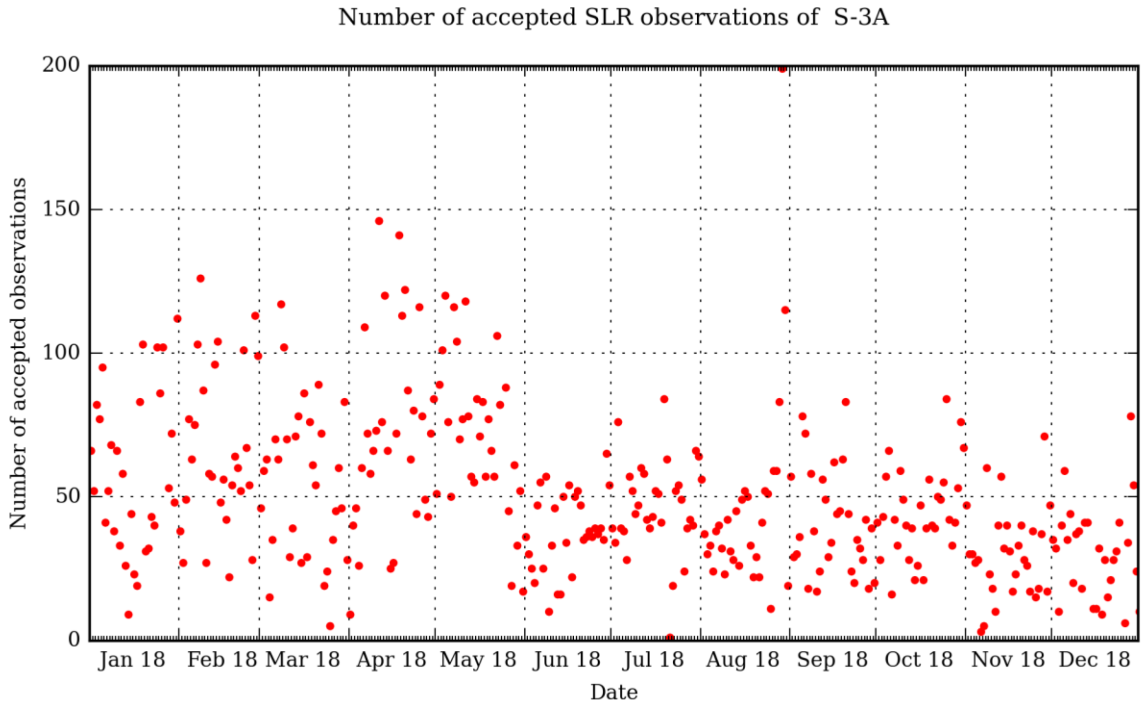


Figure 3-3: Number of accepted SLR observations for Sentinel-3A during 2018

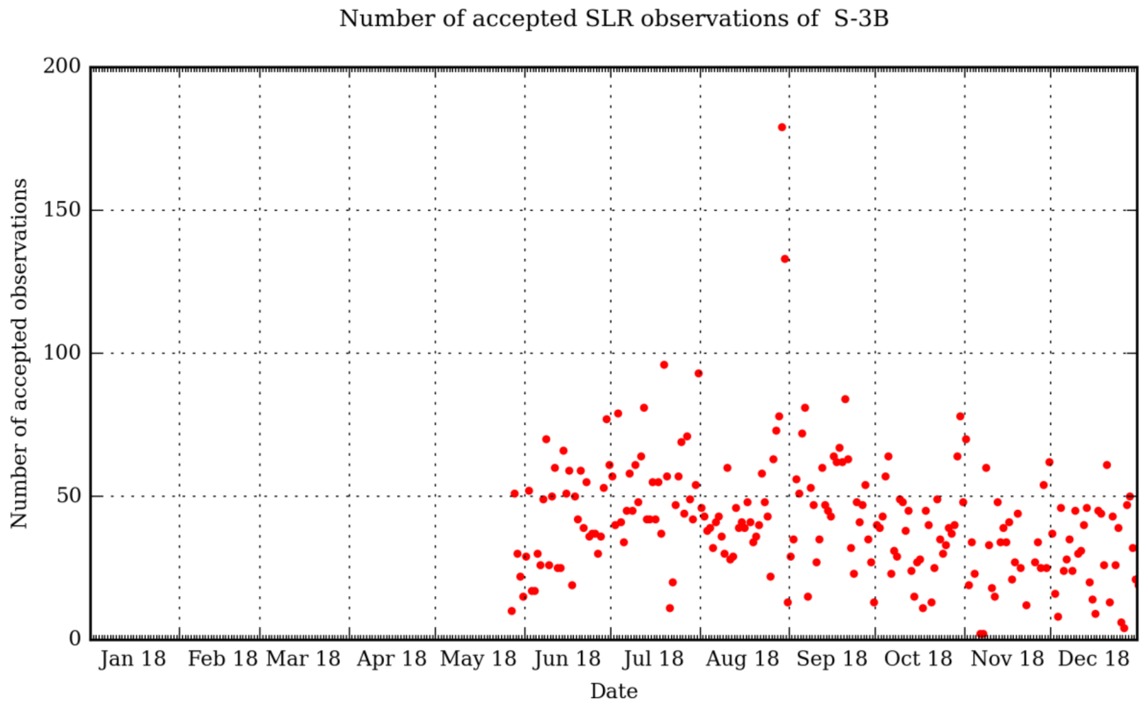


Figure 3-4: Number of accepted SLR observations for Sentinel-3B during 2018

The following figures present the SLR residuals of each orbital solution for S-3A and S-3B, respectively. As seen from the figures below, the provision of S-3B residuals of each orbital solution start before or after depending on the orbit solution availability. Not all the institutions provided their S-3B orbital solution from the same date. Regarding the outcome, most of the residuals are found to be less than 4 cm in absolute value. EUM and GRG residuals are the ones with highest dispersion, which is related to the orbital accuracy obtained in Figure 3-1 and Figure 3-2. It has to be highlighted that the white gaps shown in the plots of the residuals correspond to missing computed orbits due to manoeuvres or gaps of data on that specific dates.

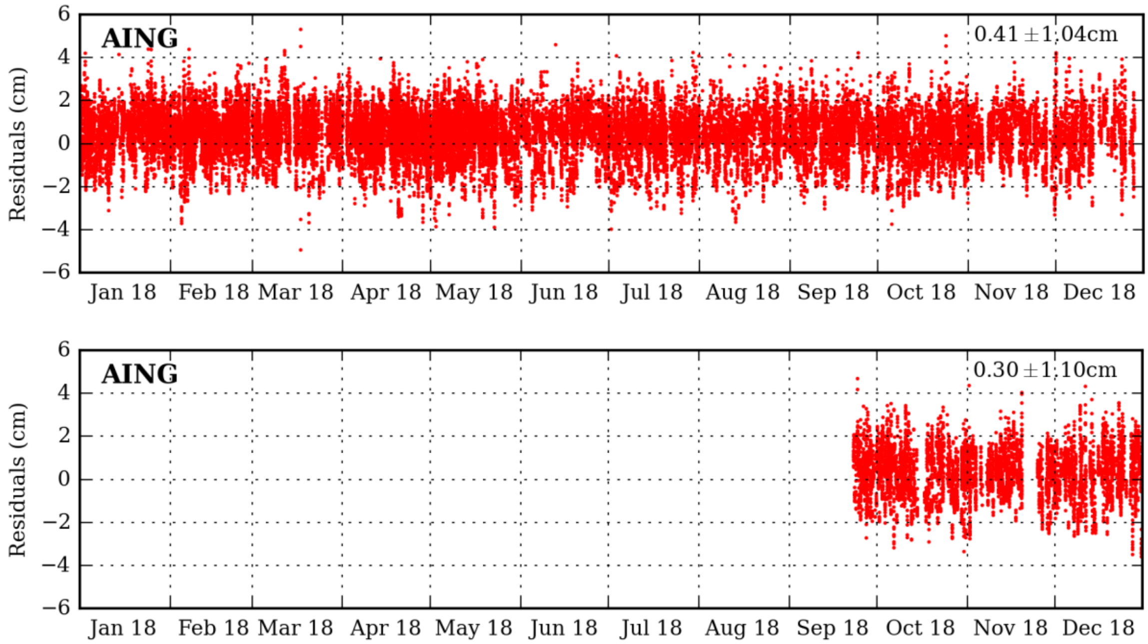


Figure 3-5: SLR observation residuals of AING solution for Sentinel-3A (above) and Sentinel-3B (below) during 2018

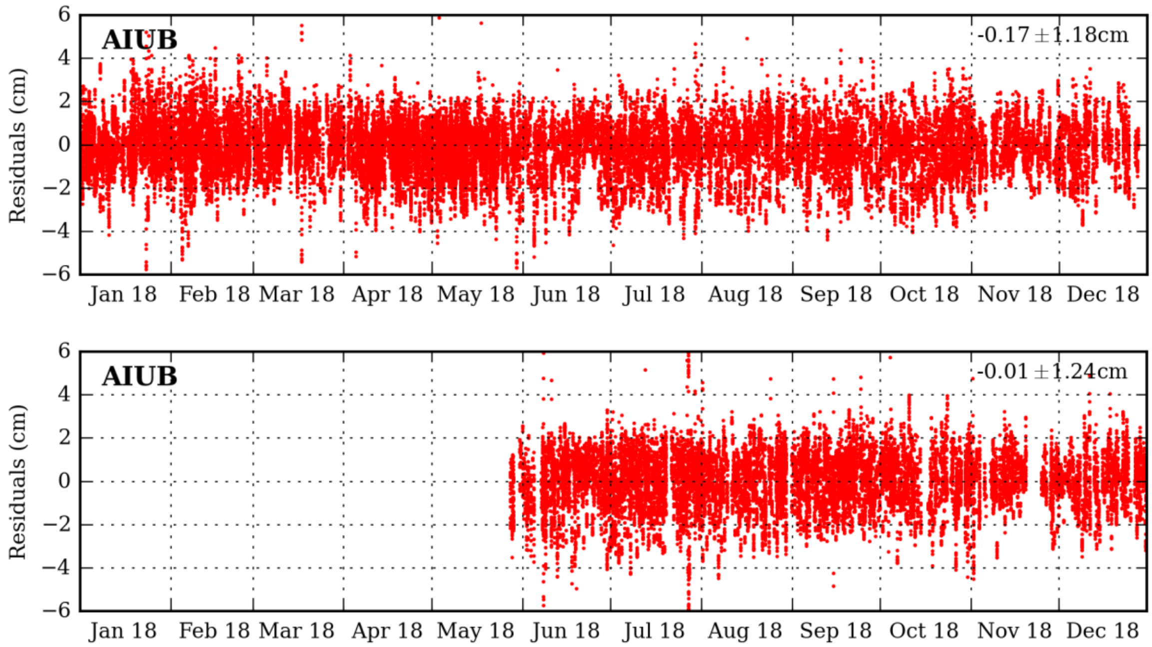


Figure 3-6: SLR observation residuals of AIUB solution for Sentinel-3A (above) and Sentinel-3B (below) during 2018

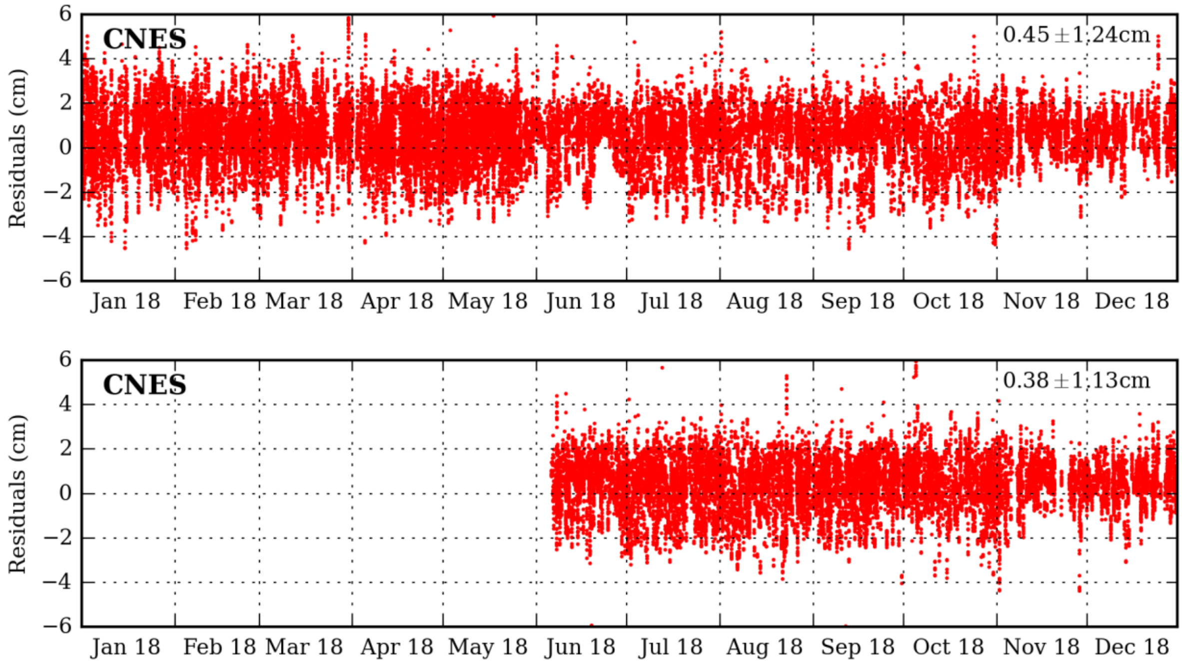


Figure 3-7: SLR observation residuals of CNES solution for Sentinel-3A (above) and Sentinel-3B (below) during 2018

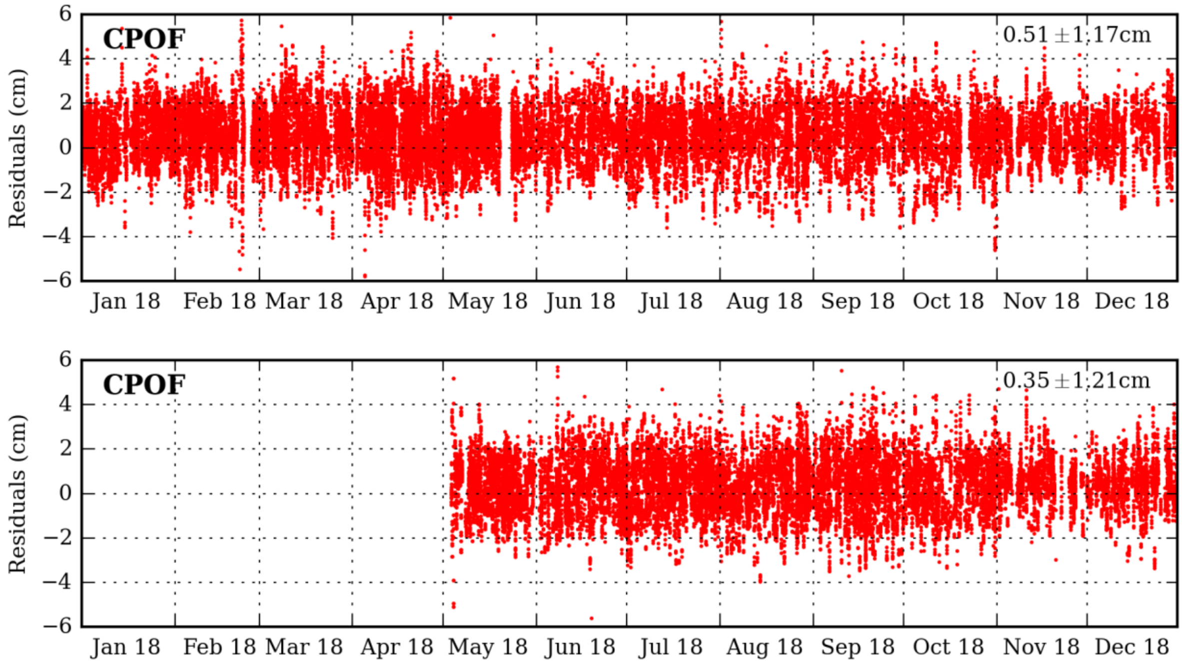


Figure 3-8: SLR observation residuals of CPOF solution for Sentinel-3A (above) and Sentinel-3B (below) during 2018

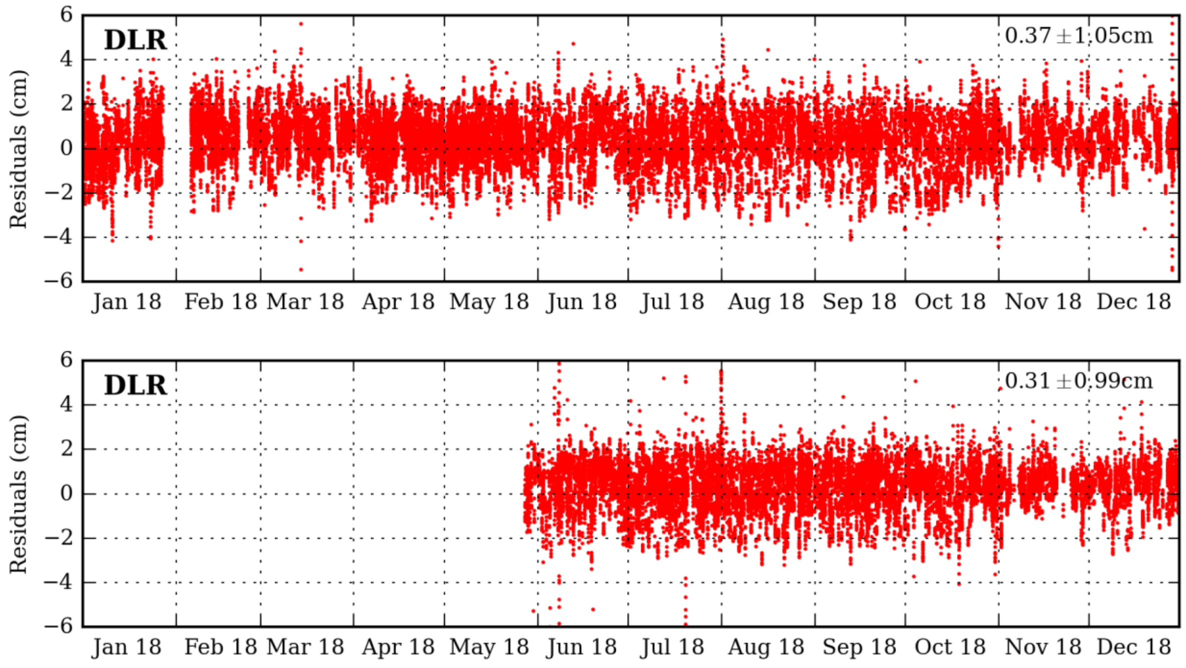


Figure 3-9: SLR observation residuals of DLR solution for Sentinel-3A (above) and Sentinel-3B (below) during 2018

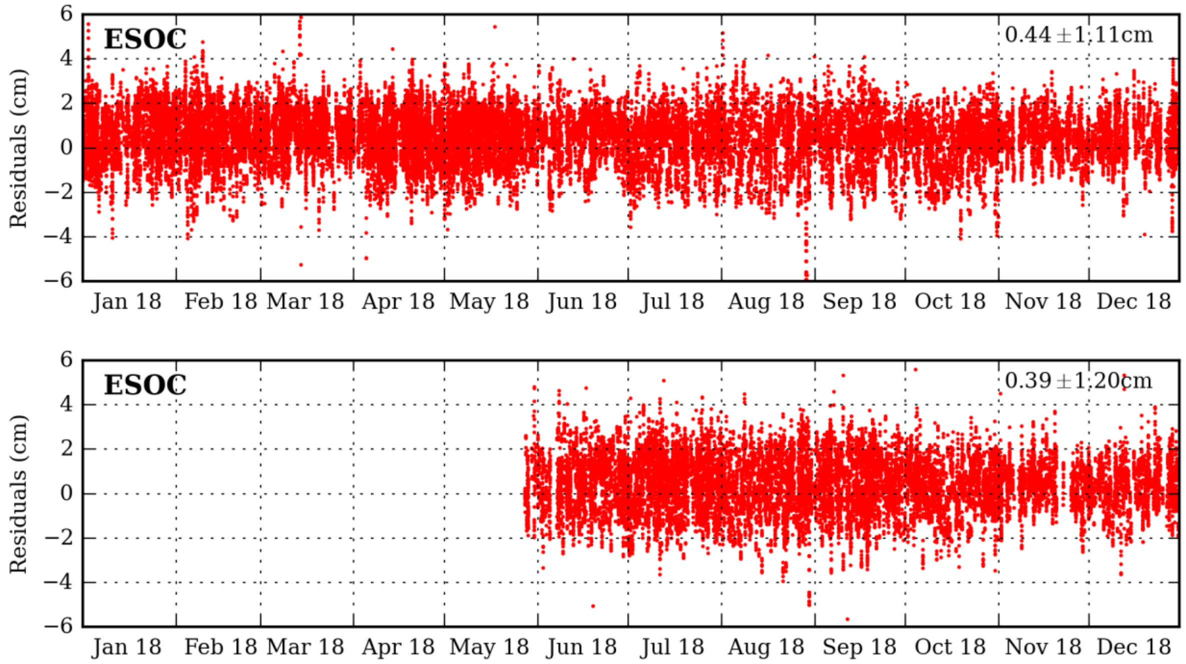


Figure 3-10: SLR observation residuals of ESOC solution for Sentinel-3A (above) and Sentinel-3B (below) during 2018

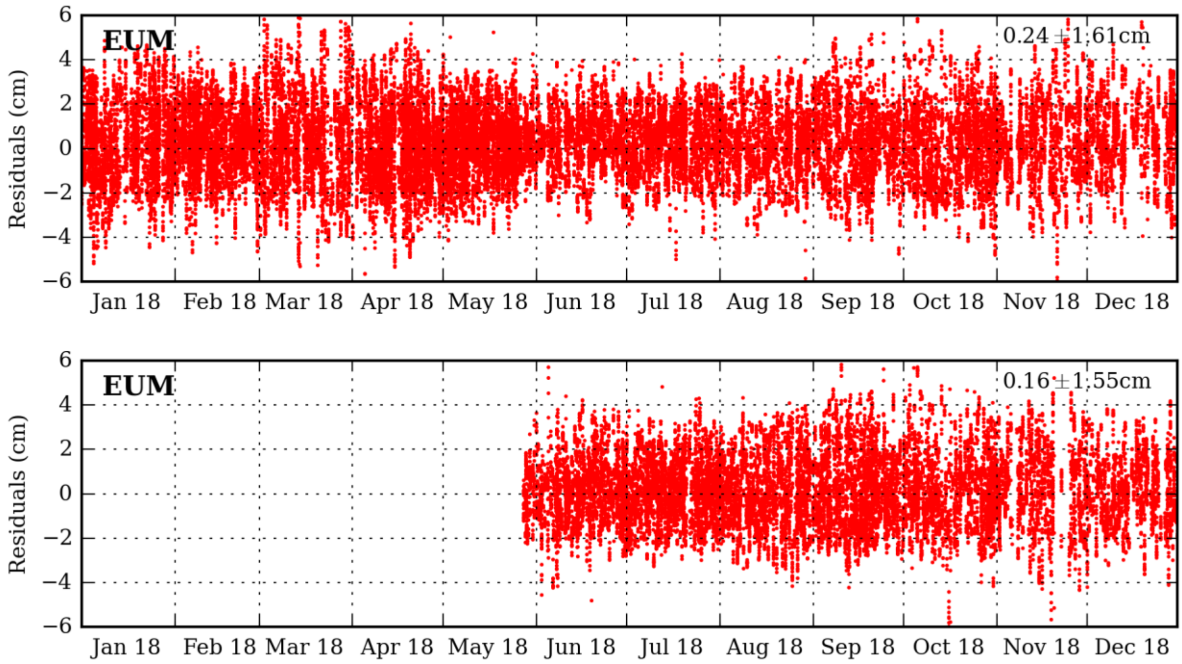


Figure 3-11: SLR observation residuals of EUM solution for Sentinel-3A (above) and Sentinel-3B (below) during 2018

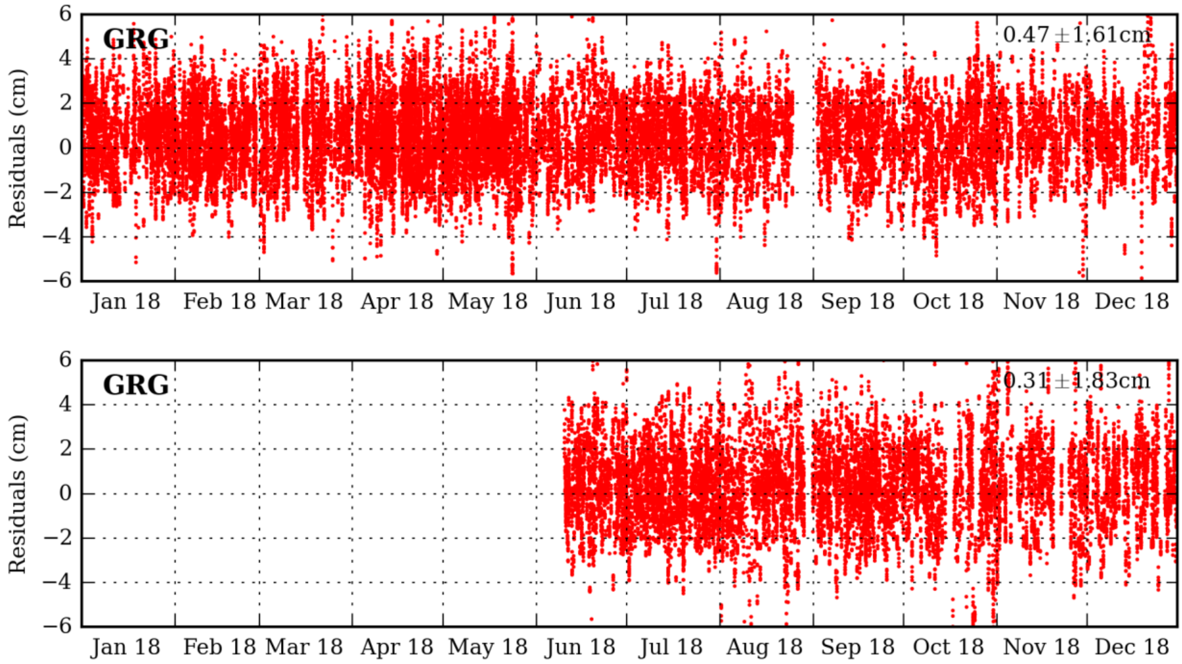


Figure 3-12: SLR observation residuals of GRG solution for Sentinel-3A (above) and Sentinel-3B (below) during 2018

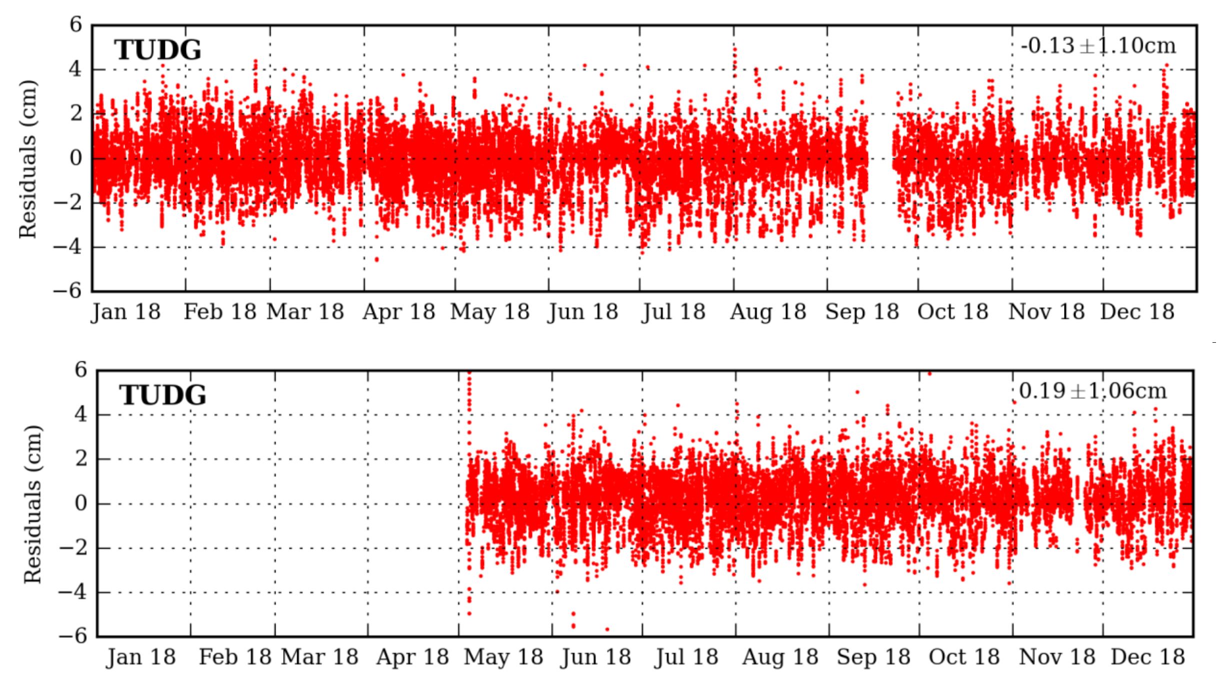


Figure 3-13: SLR observation residuals of TUDG solution for Sentinel-3A (above) and Sentinel-3B (below) during 2018

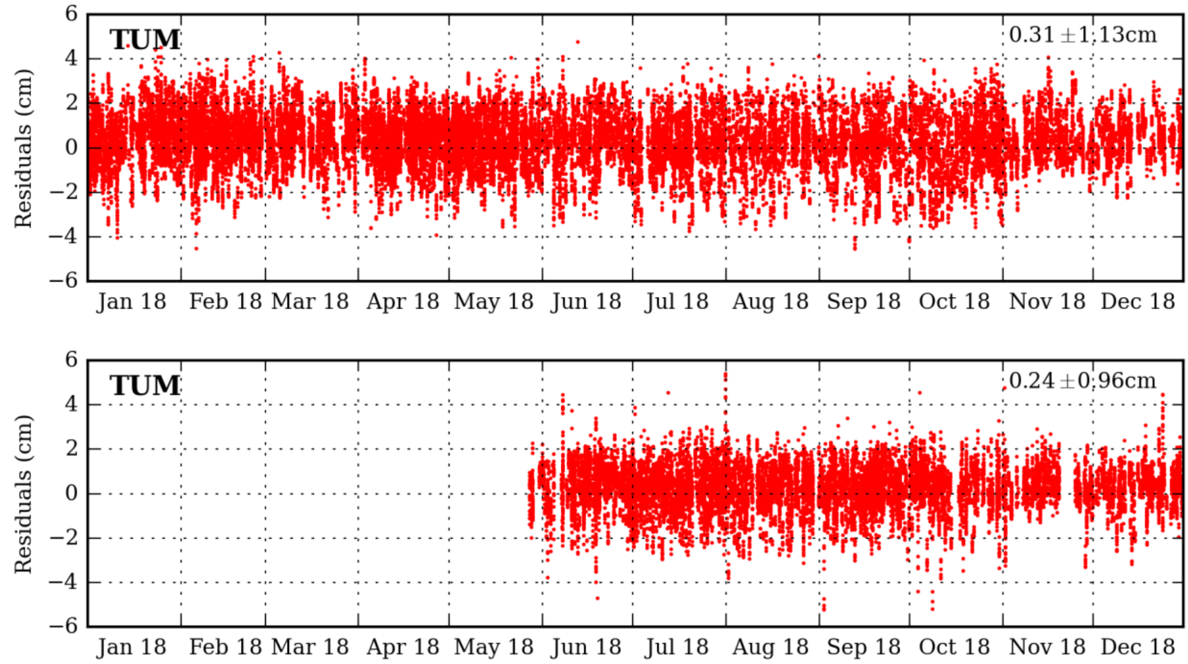


Figure 3-14: SLR observation residuals of TUM solution for Sentinel-3A (above) and Sentinel-3B (below) during 2018

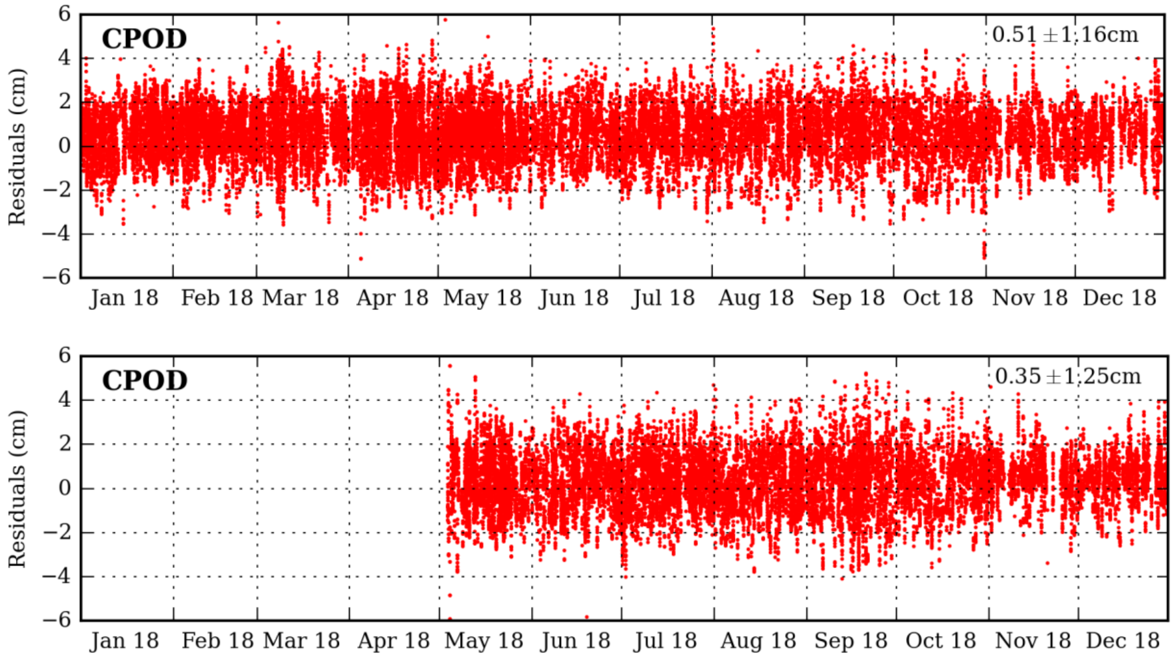


Figure 3-15: SLR observation residuals of CPOD solution for Sentinel-3A (above) and Sentinel-3B (below) during 2018

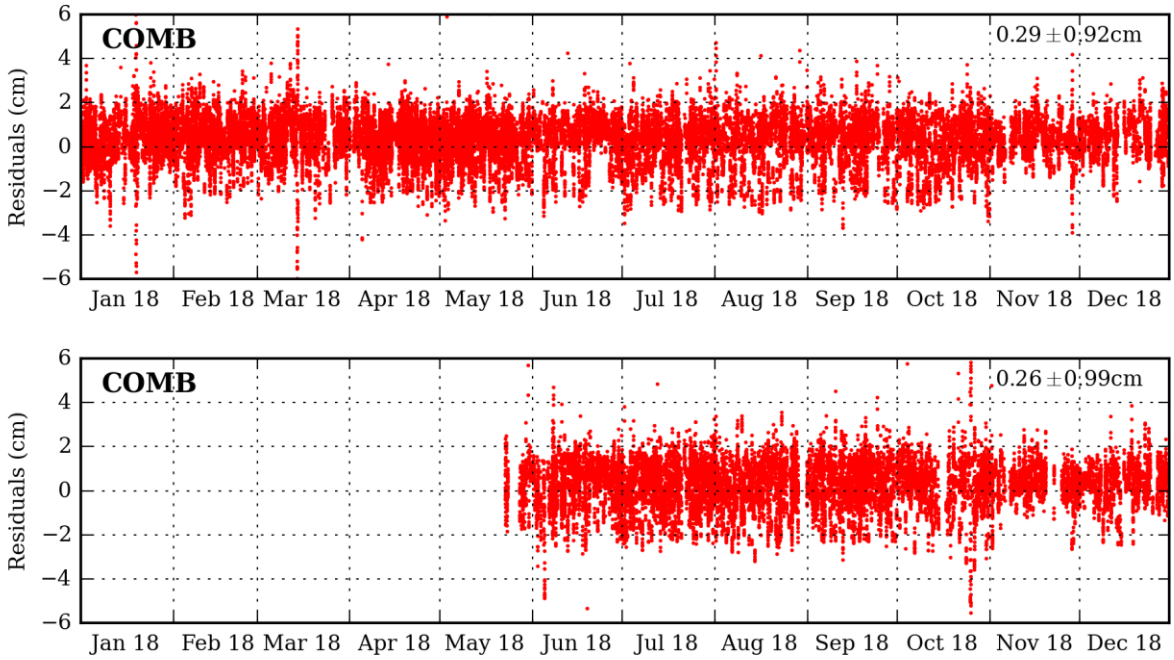


Figure 3-16: SLR observation residuals of COMB solution for Sentinel-3A (above) and Sentinel-3B (below) during 2018

Finally, the information of the residuals presented above is summarised in the following two figures and two tables, where the mean, the standard deviation and the root mean square (RMS) are calculated for all residuals. From these figures, it can be observed that the RMS of all residuals are below 1.5 cm except for the EUM and GRG solutions, which are a little bit higher. Therefore, there is a good agreement between the orbital solutions, mostly based on GPS data, computed by all institutions and the orbit calculated from SLR observations in both cases, S-3A and S-3B.

Table 3-1: Residuals average, standard deviation and RMS of SLR observations in Sentinel-3A with respect to all orbital solutions during 2018 (figures)

	AING	AIUB	CNES	CPOF	DLR	ESOC	EUM	GRG	TUDG	TUM	CPOD	COMB
Mean (cm)	0.41	-0.17	0.45	0.51	0.37	0.44	0.24	0.47	**-0.08**	0.31	0.51	0.29
Std Dev (cm)	**1.04**	1.18	1.24	1.17	1.05	1.11	1.61	1.61	1.17	1.13	1.16	0.92
RMS (cm)	**1.11**	1.20	1.32	1.28	**1.11**	1.19	1.62	1.68	1.17	1.18	1.27	0.97

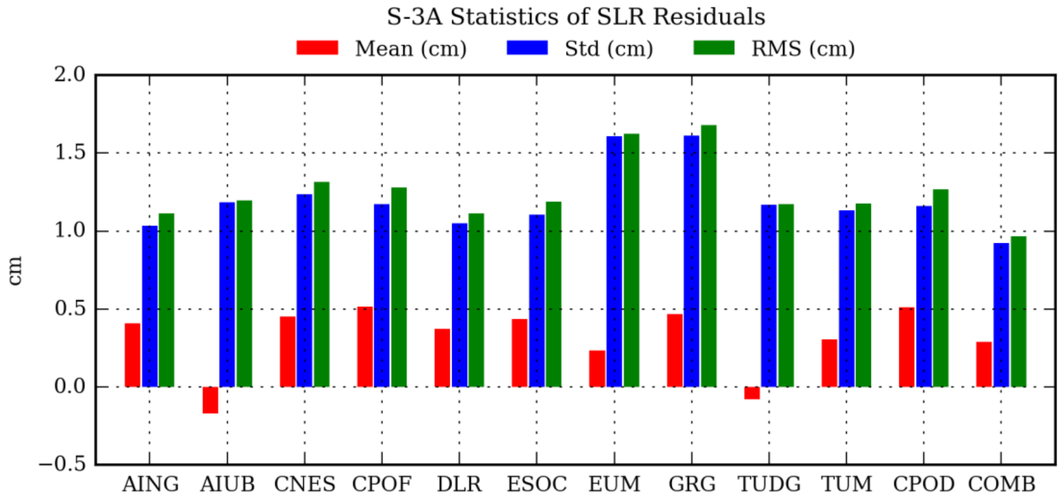


Figure 3-17: Residuals average, standard deviation and RMS of SLR observations in Sentinel-3A with respect to all orbital solutions during 2018 (plot)

Table 3-2: Residuals average, standard deviation and RMS of SLR observations in Sentinel-3B with respect to all orbital solutions during 2018 (figures)

	AING	AIUB	CNES	CPOF	DLR	ESOC	EUM	GRG	TUDG	TUM	CPOD	COMB
Mean (cm)	0.3	**-0.01**	0.38	0.35	0.31	0.39	0.16	0.31	0.19	0.24	0.35	0.26
Std Dev (cm)	1.1	1.24	1.13	1.21	0.99	1.2	1.55	1.83	1.06	**0.96**	1.25	0.99
RMS (cm)	1.14	1.24	1.19	1.26	1.03	1.27	1.56	1.86	1.08	**0.99**	1.3	1.03

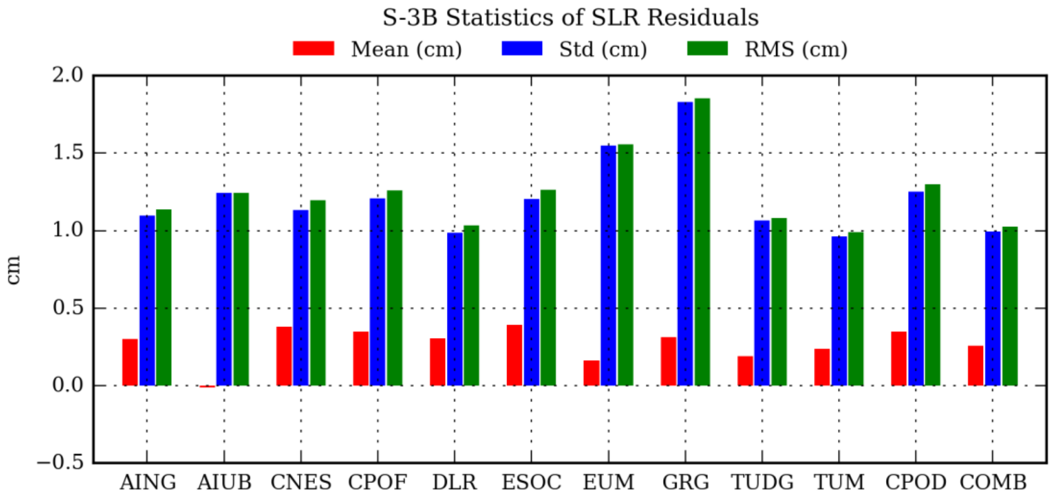


Figure 3-18: Residuals average, standard deviation and RMS of SLR observations in Sentinel-3B with respect to all orbital solutions during 2018 (plot)

3.2. ANALYSIS OF RESIDUALS PER STATION

In this section, the SLR residuals obtained by each station from the CPOD orbital solution will be analysed. All figures and tables presented into this section will refer to all stations tracking Sentinel-3 satellites by its code. Consult Table 6-1 for more information about the stations.

Firstly, Figure 3-19 and Figure 3-20 show the number of accepted observations per station and day during 2018 for S-3A and S-3B, respectively. As seen from the figures below, the usual range of accepted observations for both Sentinels-3 is somewhere between 0 and 50 observations. It has to be mentioned that, previously to the emergence of S-3B, there are a few stations (e.g., YARL and GODL) with an increased number of accepted observations (between 50 and 100 approximately per day) for S-3A. In addition, it can be observed that the cloud of points is less dense since the beginning of November 2018. This fact, affecting both Sentinels-3, might be related to the connection between the station and the new FTP explained in Section 2 and more detailed in Table 2-1.

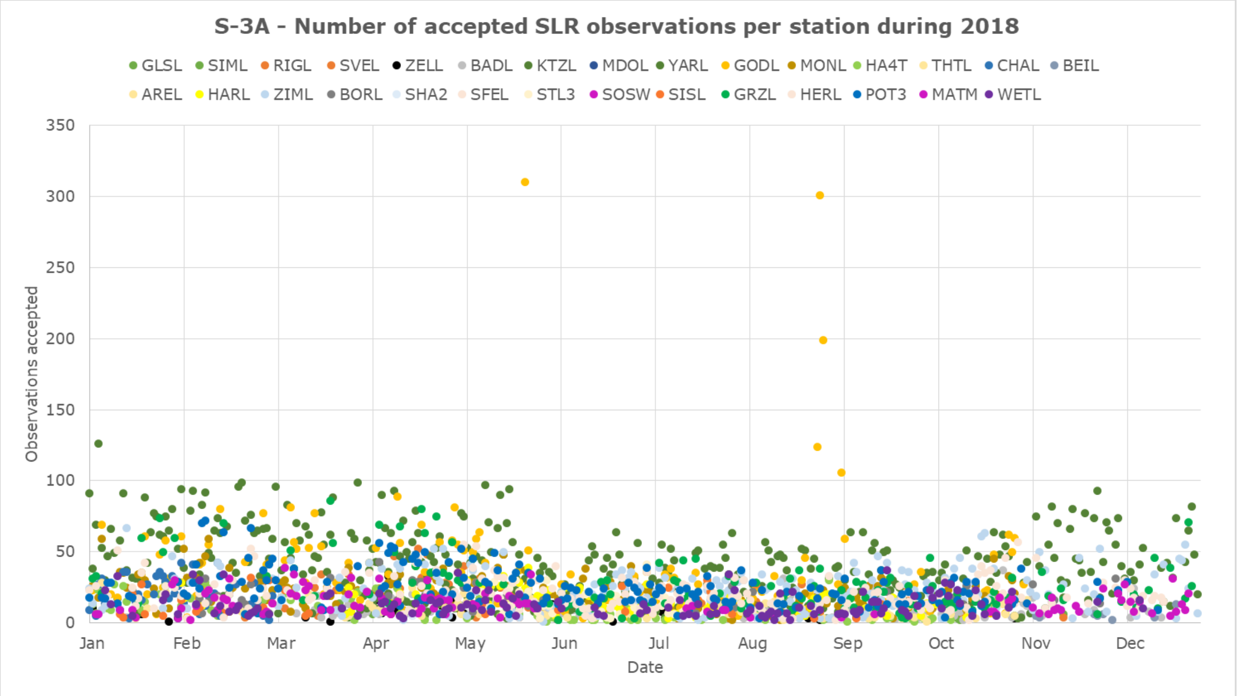


Figure 3-19: Number of accepted SLR observations per station during 2018 (Sentinel-3A)

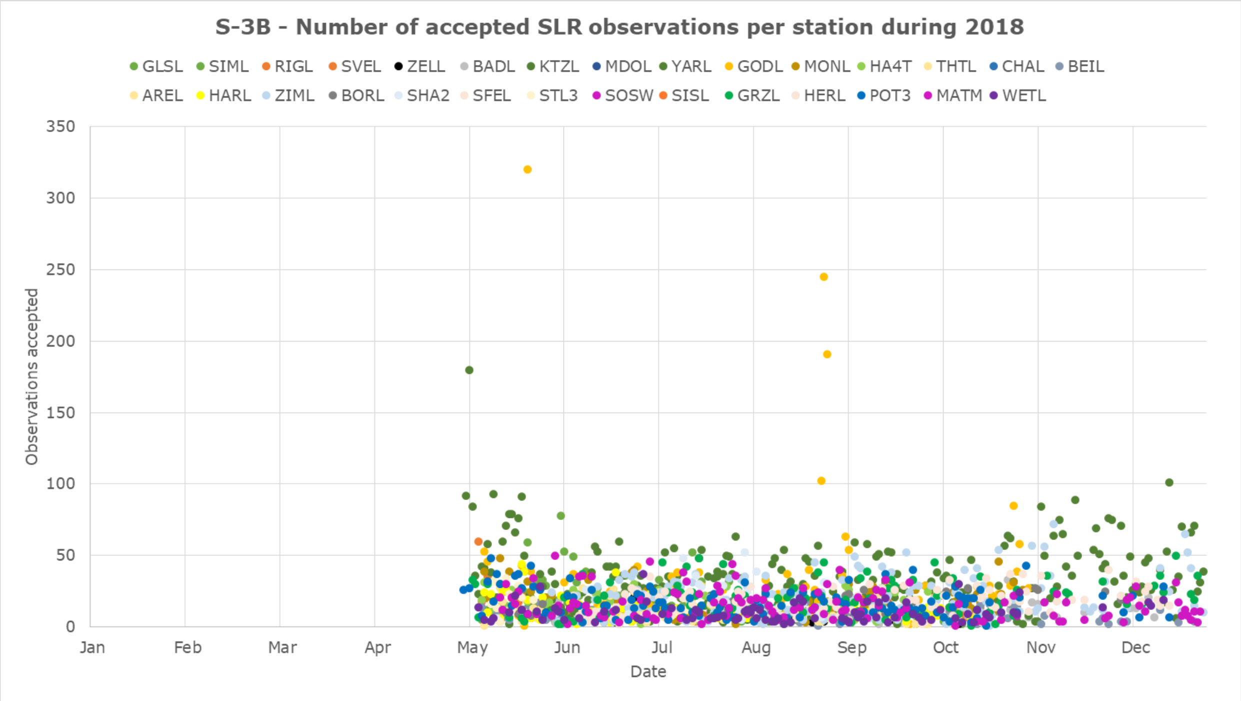


Figure 3-20: Number of accepted SLR observations per station during 2018 (Sentinel-3B)

Secondly, the following figures plot the mean, the standard deviation and the RMS of the residuals for S-3A and S-3B. If the statistics of any obtained residuals are resulted to be high, the observation has been considered rejected in order not to corrupt the statistics. These 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 such behaviour (see Section 1.3). In particular, the presented outcome is based on ITRF14 coordinates, which are included in Table 6-1.

As seen from the figures below, most of the statistics present a mean below 2 cm in absolute value, a standard deviation below 2 cm, and an RMS below 3 cm for both Sentinels-3 during 2018. However, it must be highlighted that there are a few stations (e.g., GLSL and RIGL) that show a wider dispersion on their outcome.

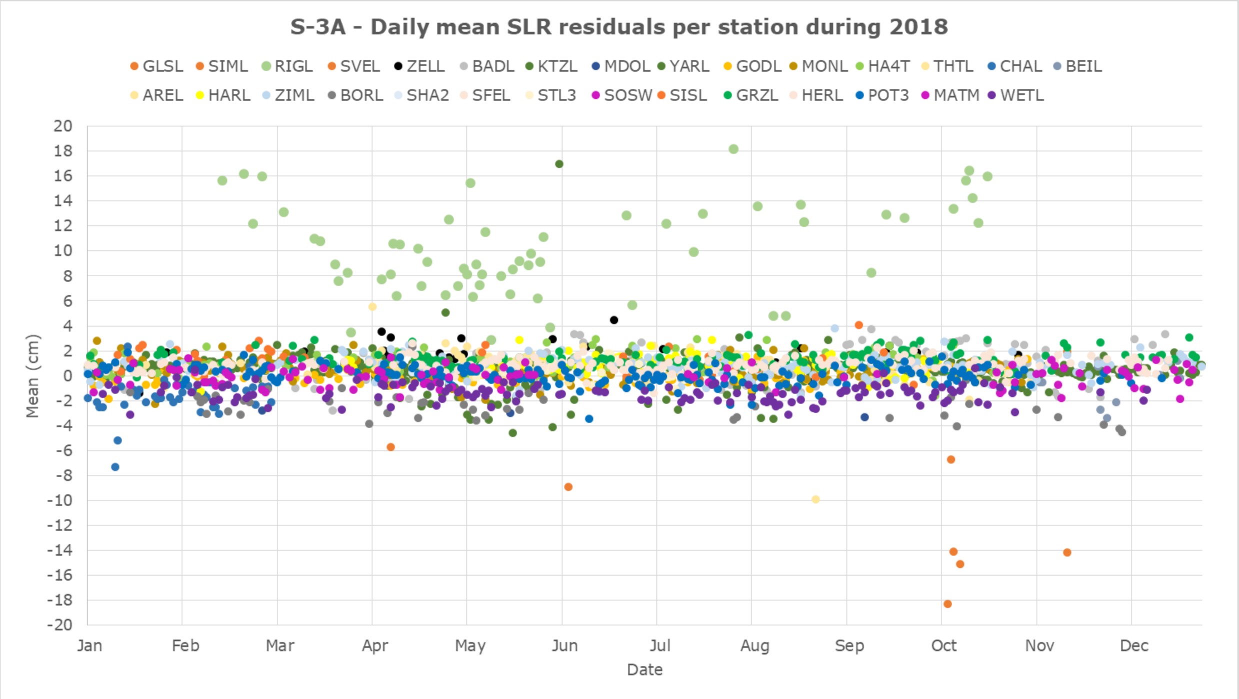


Figure 3-21: Daily mean SLR residuals per station during 2018 (Sentinel-3A)

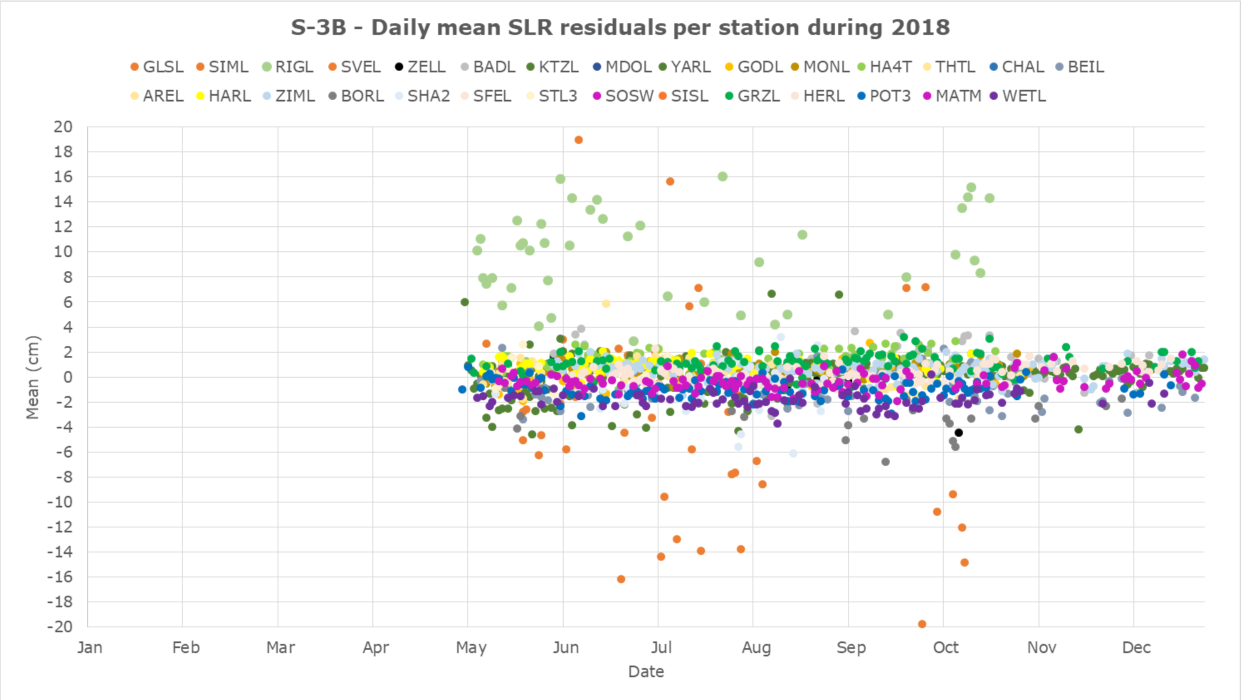


Figure 3-22: Daily mean SLR residuals per station during 2018 (Sentinel-3B)

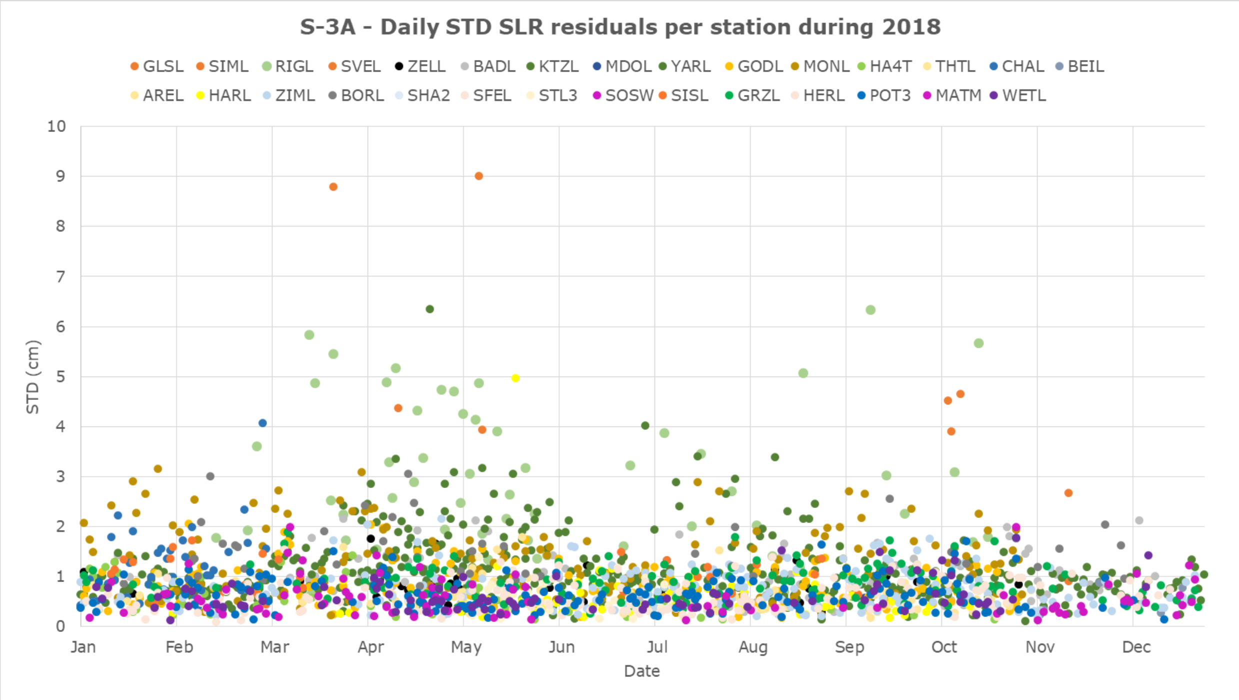


Figure 3-23: Daily standard deviation SLR residuals per station during 2018 (Sentinel-3A)

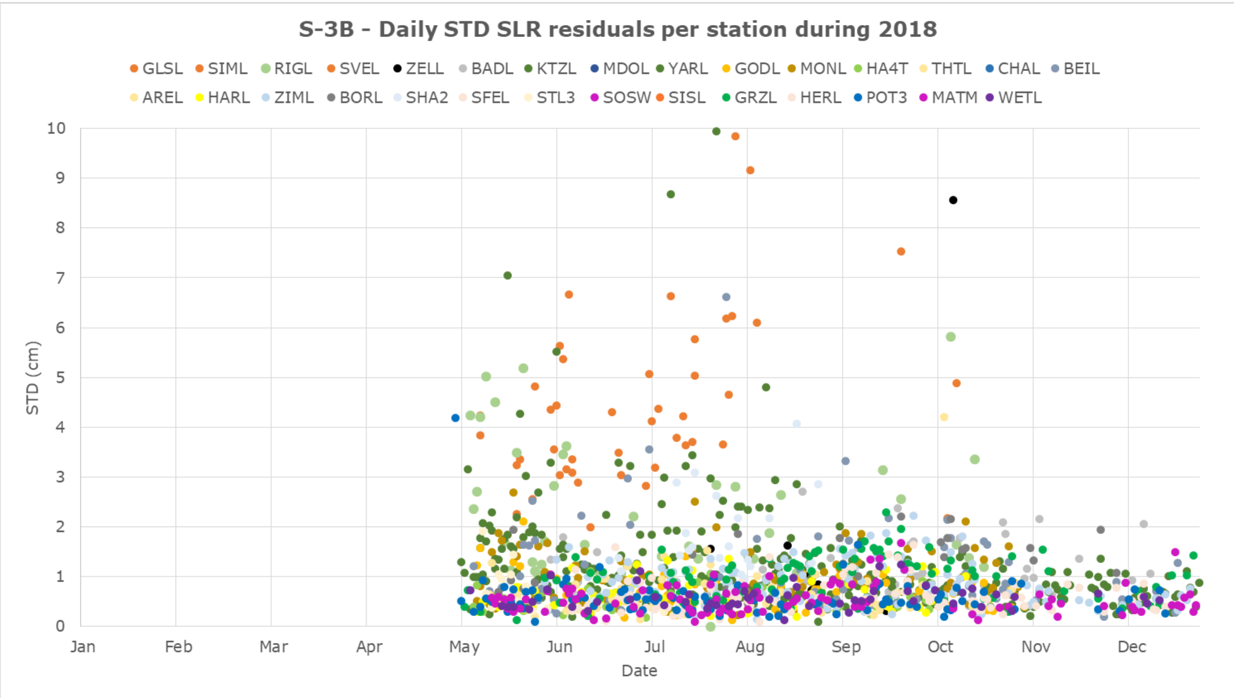


Figure 3-24: Daily standard deviation SLR residuals per station during 2018 (Sentinel-3B)

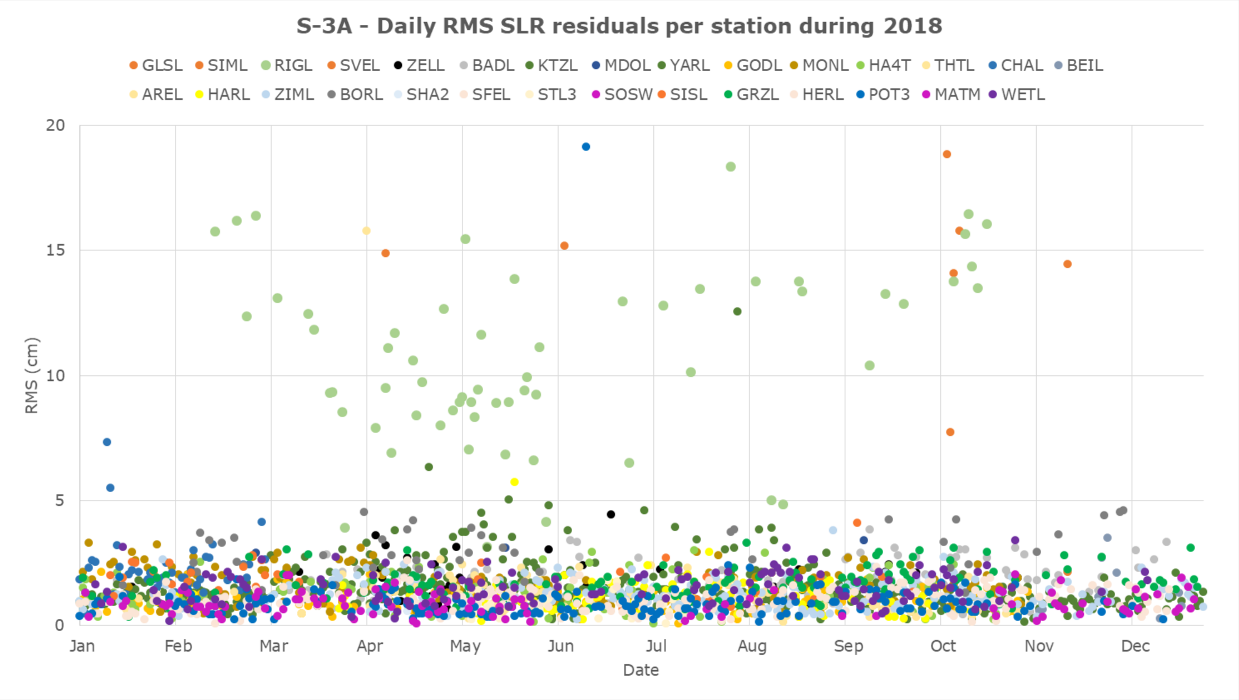


Figure 3-25: Daily RMS SLR residuals per station during 2018 (Sentinel-3A)

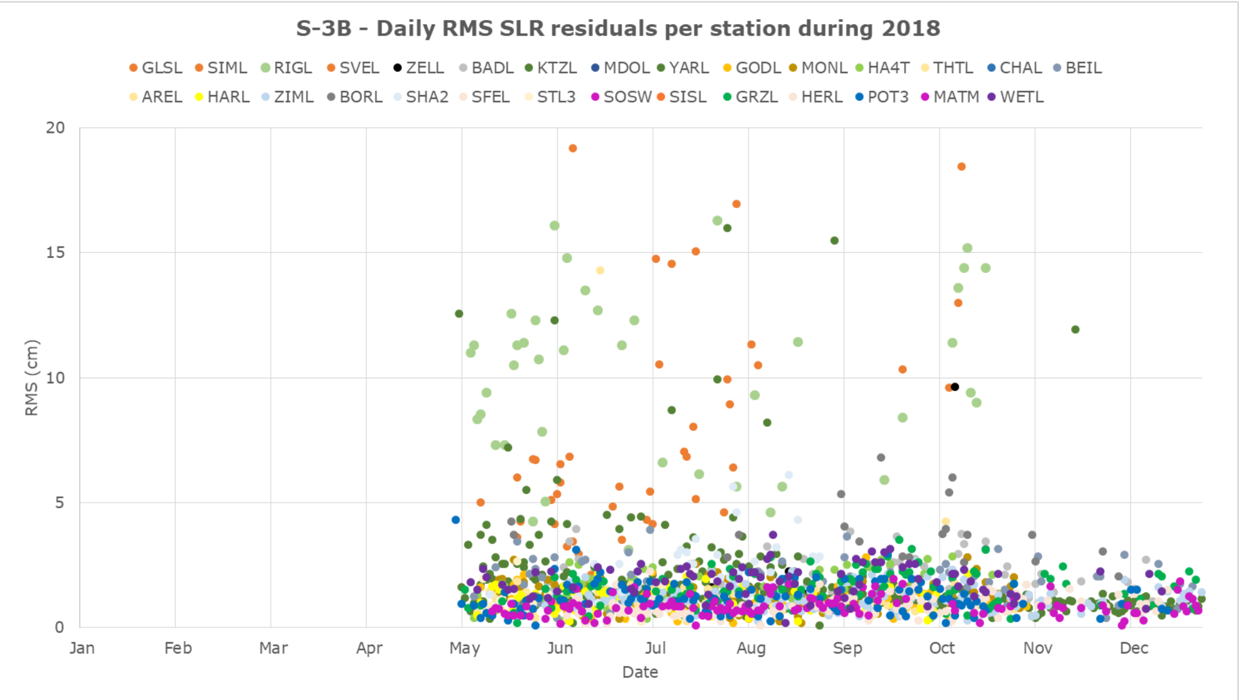


Figure 3-26: Daily RMS SLR residuals per station during 2018 (Sentinel-3B)

To make the information of previous figures more readable, the following tables and figures summarise all the above metrics by averaging the whole dataset. From them, it can be seen that the stations which provide better RMS residuals are SHA2 and HERL for S-3A and S-3B, respectively. On the other hand, the poorer RMS residuals are obtained by GLSL for both Sentinels-3.

Table 3-3: Residuals average, standard deviation and RMS of SLR observations with respect to all stations tracking Sentinel-3A during 2018 (figures)

	GLSL	SIML	RIGL	SVEL	ZELL	BADL	KTZL	MDOL	YARL	GODL	MONL	HA4T	THTL	CHAL	BEIL
Mean (cm)	-7.12	-	7.13	1.95	1.55	0.81	-0.68	-3.05	0.67	0.18	0.49	1.06	-1.00	-1.62	-0.83
Std Dev (cm)	5.23	-	2.92	0.91	0.87	1.01	2.08	0.71	0.93	0.84	1.37	0.55	1.05	1.20	0.55
RMS (cm)	7.75	-	7.56	2.15	1.92	1.85	2.70	3.13	1.23	1.02	1.63	1.28	1.45	2.27	1.46

	AREL	HARL	ZIML	BORL	SHA2	SFEL	STL3	SOSW	SISL	GRZL	HERL	POT3	MATM	WETL
Mean (cm)	0.70	0.95	0.79	-2.39	0.30	-	0.29	-	1.38	1.38	0.81	**0.06**	-0.07	-1.41
Std Dev (cm)	0.59	0.63	0.75	1.50	**0.52**	-	0.55	-	1.02	0.88	0.58	0.63	0.58	0.62
RMS (cm)	1.17	1.19	1.26	2.99	**0.60**	-	0.82	-	1.87	1.67	1.05	0.87	0.88	1.55

Table 3-4: Residuals average, standard deviation and RMS of SLR observations with respect to all stations tracking Sentinel-3B during 2018 (figures)

	GLSL	SIML	RIGL	SVEL	ZELL	BADL	KTZL	MDOL	YARL	GODL	MONL	HA4T	THTL	CHAL	BEIL
Mean (cm)	-3.02	-1.36	6.29	-	**-0.23**	1.07	-0.83	-	0.56	0.41	0.62	1.43	-	-	-0.89
Std Dev (cm)	5.32	4.03	2.41	-	1.59	1.06	2.35	-	0.84	0.71	1.01	**0.54**	-	-	1.17
RMS (cm)	7.38	5.36	6.67	-	1.99	1.96	3.06	-	1.14	1.02	1.29	1.52	-	-	1.84

	AREL	HARL	ZIML	BORL	SHA2	SFEL	STL3	SOSW	SISL	GRZL	HERL	POT3	MATM	WETL
Mean (cm)	0.32	0.89	0.64	-3.05	-1.14	-	0.33	-	-	1.22	0.28	-0.95	-0.36	-1.80
Std Dev (cm)	0.66	0.62	0.85	1.37	1.65	-	0.70	-	-	0.98	0.60	0.58	0.55	0.58
RMS (cm)	1.08	1.16	1.18	3.39	2.52	-	1.14	-	-	1.62	**0.85**	1.19	0.86	1.88

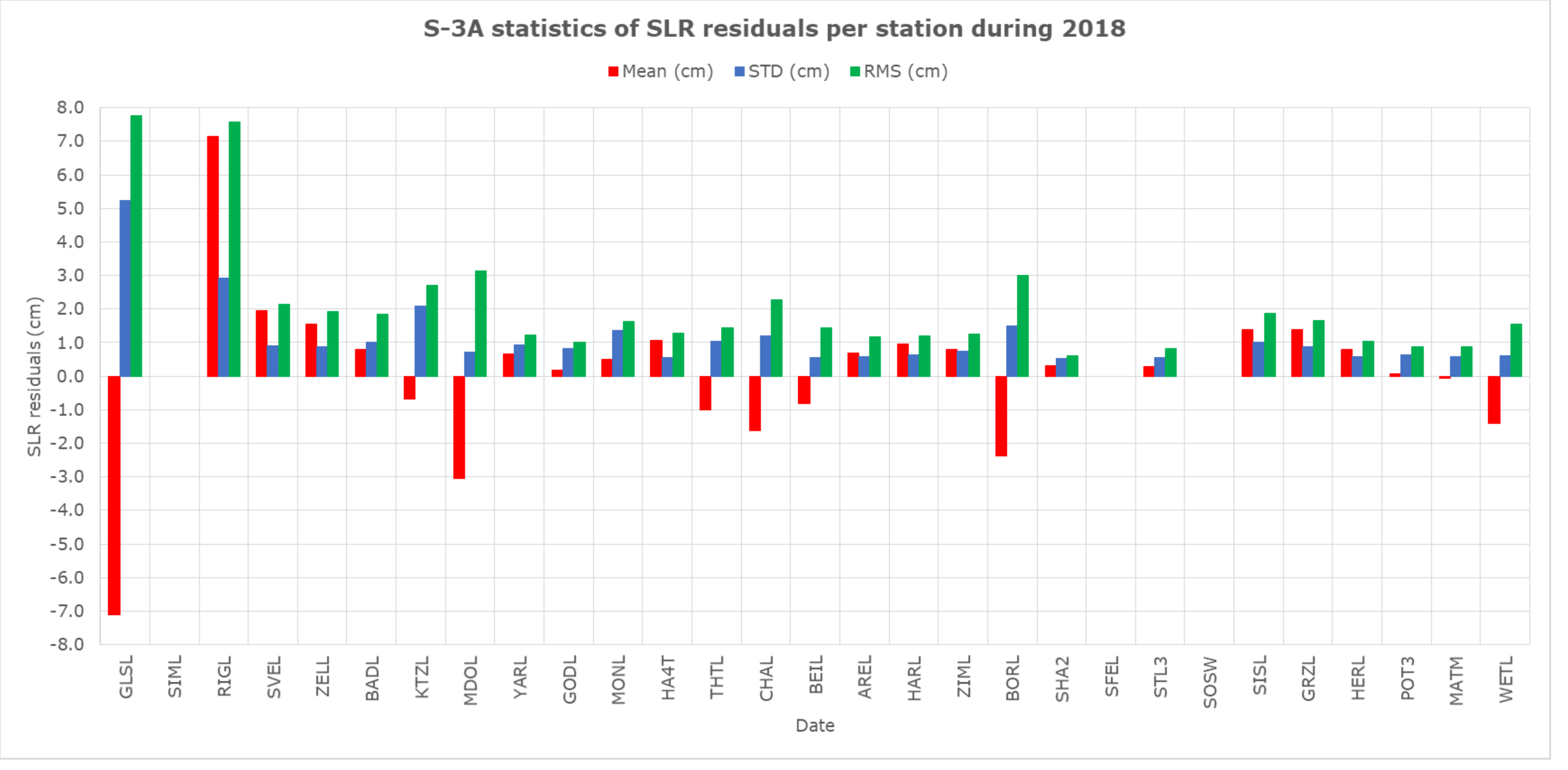


Figure 3-27: Residuals average, standard deviation and RMS of SLR observations with respect to all stations tracking Sentinel-3A during 2018 (plot)

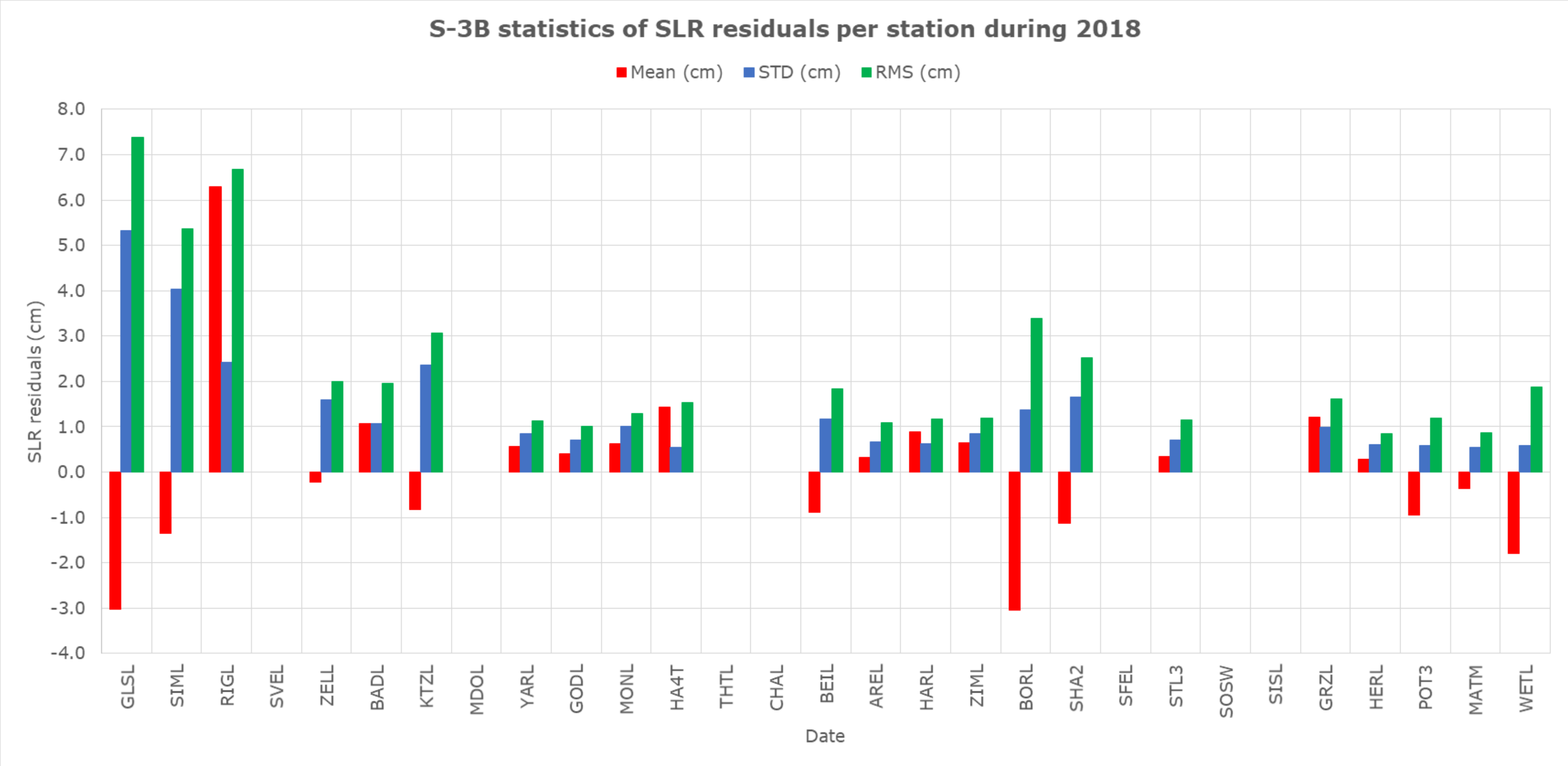


Figure 3-28: Residuals average, standard deviation and RMS of SLR observations with respect to all stations tracking Sentinel-3B during 2018 (plot)

Finally, Table 3-5 reports the best-, middle-, worst- and non-tracking stations during 2018 for S-3A and S-3B based on the statistics of previous tables. In this table, it is highlighted the stations which share same behaviour on both Sentinels-3.

Table 3-5: Best-, middle-, worst- and non-tracking stations during 2018 (Sentinel-3A and Sentinel-3B)

Best-tracking stations		Middle-tracking stations		Worst-tracking stations		Non-tracking stations	
S-3A	**S-3B**	**S-3A**	**S-3B**	**S-3A**	**S-3B**	**S-3A**	**S-3B**
YARL	YARL	SVEL	ZELL	GLSL	GLSL	SIML	SVEL
GODL	GODL	ZELL	BADL	RIGL	SIML	SFEL	MDOL
MONL	MONL	BADL	HA4T	MODL	RIGL	SOSW	THTL
HA4T	AREL	KTZL	BEIL	BORL	KTZL		CHAL
THTL	HARL	CHAL	SHA2		BORL		SFEL
BEIL	ZIML	SISL	GRZL				SOSW
AREL	STL3	GRZL	WETL				SISL
HARL	HERL	WETL					
ZIML	POT3						
SHA2	MATM						
STL3							
HERL							
POT3							
MATM							

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 and 244 for S-3A and S-3B, respectively. 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 on the days shown in Table 4-1.

Table 4-1: CPOD Service interruptions due to manoeuvres (Sentinel-3A and Sentinel-3B)

Sentinel-3A	Sentinel-3B
2018/02/28	2018/05/01 (2)
2018/03/14	2018/05/02
2018/05/24	2018/05/04
2018/08/01	2018/05/08
2018/08/29	2018/05/08
2018/11/28	2018/05/10
2018/12/19	2018/05/24
	2018/05/29
	2018/05/30
	2018/06/05
	2018/06/05
	2018/06/06
	2018/08/10
	2018/08/23
	2018/08/23
	2018/08/30
	2018/10/15
	2018/10/16
	2018/10/24
	2018/10/29
	2018/11/04
	2018/11/04
	2018/11/20
	2018/11/22
	2018/11/23
	2018/11/27
	2018/12/12

Figure 4-1 shows the accuracy obtained with the CPFs files (orbital predictions) against the MOEORB products (orbit determinations). It has been depicted the along-track residual instead of the 3D RMS residual since the along track is the most critical direction for the SLR tracking. As it can be seen in the figure below, the comparisons are typically below 40 m. This fact can be better observed in Table 4-2, where the percentiles of along RMS for CPF files are calculated.

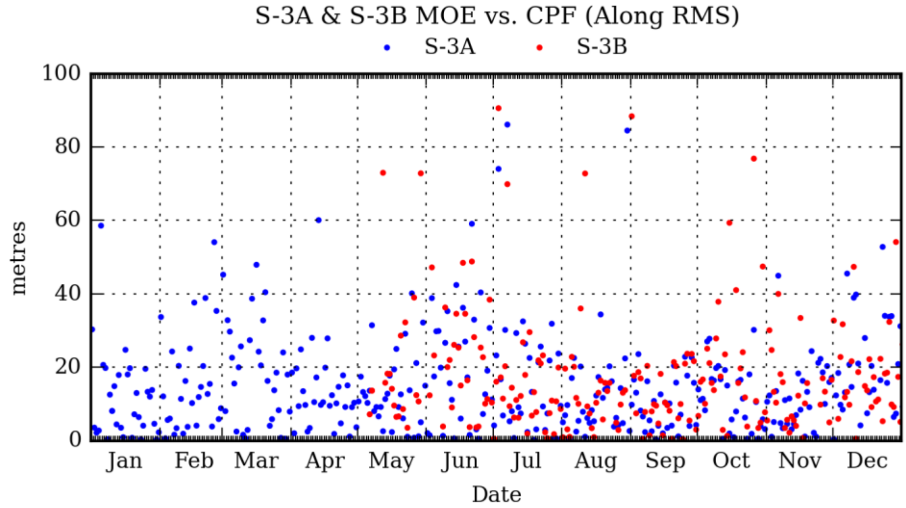


Figure 4-1: Along RMS for the CPF files vs. MOEORB products during 2018 (Sentinel-3A and Sentinel-3B)

Table 4-2: Percentiles of the along RMS for CPF files (Sentinel-3A and Sentinel-3B)

Accuracy (Along RMS)	2018	
	Sentinel-3A	Sentinel-3B
< 1 m	6.5%	3.7%
< 5 m	25.6%	14.3%
< 10 m	42.8%	31.2%
< 20 m	73.3%	60.7%
< 40 m	94.6%	80.7%

5. CONCLUSIONS

This document gathers the 2018 yearly results related to SLR tracking for Sentinel-3A and Sentinel-3B, which has been in Routine Operational Phase (ROP) since August 2018. The document is meant to stress the importance of the ILRS Community in the frame of the Sentinel-3 mission. The main aspects to be highlighted are:

- The ILRS stations cooperate with the Copernicus POD Service and its QWG by tracking both Sentinels-3 and supplying ranging measurements. Due to the amount of available stations, an overall good geographical coverage is attained.
- The total number of passes during 2018 has shown nominal values except since the beginning of November, where such number has suffered an accentuated decrease, not observed on other missions (e.g., Jason-3), probably due to change on the FTP providing the CPF files, which requires now secure FTP connections, as request by ILRS. If this is the case, it will be cross-checked with ILRS to find a solution.
- 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 below 2 cm), which improves the reliability of the CPOD products.
- An analysis of the SLR residuals obtained per each station against de CPOD solution has also been performed. Such analysis has shown which stations are best performed the tracking of Sentinel-3 satellites and which do not. In addition, it has been highlighted the stations that do not track both satellites during 2018 and the loss of tracking of few stations since the beginning of November as commented before.
- To allow the tracking of Sentinel-3A and Sentinel-3B, CPOD provides CPF files to the stations. These files contain the orbital prediction of the satellite which accuracies are typically below 40 m in along RMS.

6. ANNEX: STATIONS COORDINATE LIST

The following table shows the coordinates of the stations used by the POD team for the generation of this report on 2018. They are extracted from the file SLRF2014.

Table 6-1: 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
1873	SIML	Simeiz, Ukraine	3783902.507	2551404.979	4441257.696
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
7827	SOSW	Wettzell, Germany	4075531.073	931781.841	4801619.951
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 WLRS, Germany	4075576.651	931785.679	4801583.698

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