SENTINEL-3 SLR YEARLY REPORT - 2019

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 - 2019**, 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 used by the 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 2019.

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 the ILRS, the results obtained from the SLR external validation and the Consolidated Prediction Files (CPFs) that the Copernicus POD (CPOD) Service provides to the ILRS laser stations in order to allow the tracking of the Sentinel-3 satellites.

1.3. DISCLAIMER

Sentinel-3 Mission, and in particular the CPOD 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 the 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

Acronyms used in this document and needing a definition are included in the following table:

Table 1-1: Acronyms

Acronym	Definition	Acronym	Definition
AIUB	Astronomical Institute University of Bern	LEO	Low Earth Orbit
CLS	Collecte Localisation Satellites	LRR	Laser Retro-reflector
CNES	Centre National d'Études Spatiales	NAPEOS	NAvigation Package for Earth Orbiting Satellites
CPF	Consolidated Prediction Format	OLCI	Ocean & Land Colour Instrument
CPOD	Copernicus POD	PDGS	Payload Data Ground Segment
DIL	Document Item List	POD	Precise Orbit Determination
DLR	Deutsche Zentrum für Luft- und Raumfahrt	QWG	Quality Working Group
DORIS	Doppler Orbytography and Radiopositioning Integrated by Satellite	RMS	Root Mean Square
ESA	European Space Agency	SAR	Synthetic Aperture Radar
ESOC	European Space Operation Centre	SINEX	Solution Independent Exchange

Acronym	Definition	Acronym	Definition
EUMETSAT	EUropean organisation for the exploitation of METeorological SATellites	SLR	Satellite Laser Ranging
FTP	File Transfer Protocol	SLSTR	Sea and Land Surface Temperature Radiometer
GFZ	Geo Forschungs Zentrum	SRAL	SAR Radar Altimeter
GNSS	Global Navigation Satellite System	STC	Short Time Critical
GPS	Global Positioning System	STD	Standard Deviation
IGS	International GNSS Service	TUD	Technische Universiteit Delft
ILRS	International Laser Ranging Service	TUM	Technische Universität München
ITRF	International Terrestrial Reference Frame	USA	United States of America
JPL	Jet Propulsion Laboratory		

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 1-2: Applicable Documents

Ref.	Title	Code	Version	Date
[AD.1]	Sentinel-3A Mission Support Request Form	ESTEC_ILRS_MSRF_Sentinel-3A	1	10/11/2015
[AD.2]	Sentinel-3B Mission Support Request Form	ESTEC_ILRS_MSRF_Sentinel-3B	3	15/01/2018

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 1-3: Reference Documents

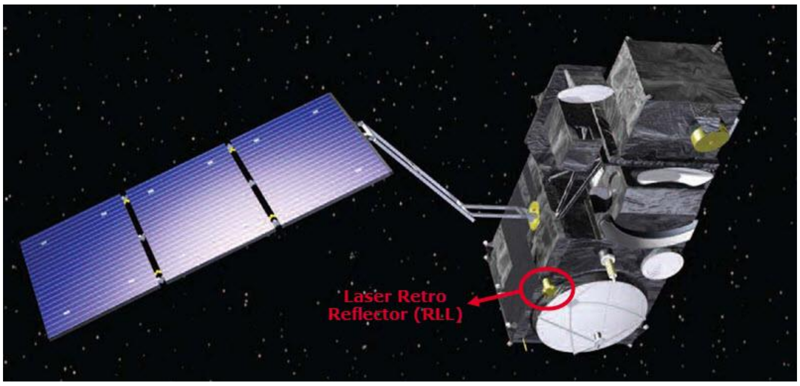
Ref.	Title	Code	Version	Date
[RD.1]	Analysis of elements for Sentinel-3 SLR tracking	GMV-GMESPOD-TN-0028	1.2	10/05/2018
[RD.2]	Copernicus POD Regular Service Review Oct 2019 - Jan 2020	GMV-GMESPOD-RSR-0016	1.0	04/03/2020
[RD.3]	Improved SLR orbit validation for Copernicus Sentinel-3 mission (poster) M. Fernández, J. Berzosa, J. Fernández, H. Peter, P. Féménias EGU General Assembly 2020, 4th-8th May 2020	N/A	N/A	05/05/2020

2. GENERAL OVERVIEW

The Copernicus Precise Orbit Determination (CPOD) Service is part of the Copernicus Payload Data Ground Segment (PDGS) of the Copernicus programme, which is an Earth observation programme coordinated and managed by the European Commission in partnership with the European Space Agency (ESA).

The Copernicus programme is in charge of the Sentinel missions, a series of satellites equipped with various Earth observation instruments in order to monitor, record and analyse environmental data and events around the globe. The monitoring of such events demands high levels of orbital accuracy, which requirements are satisfied by the CPOD Service, a consortium of different centres led by GMV. Thus, the CPOD Service is in charge of the provision of precise orbital products and auxiliary data files of the Sentinel satellites to the PDGS.

One of the Sentinel missions operated by the CPOD Service is the Sentinel-3 mission. This mission is currently using two satellites (Sentinel-3A and Sentinel-3B) to measure sea surface topography, sea and land surface temperature, and ocean and land surface colour with high accuracy and reliability. To that end, Sentinel-3 satellites are equipped with many instruments, among which there are an Ocean and Land Colour Instrument (OLCI), a Sea and Land Surface Temperature Radiometer (SLSTR), a SAR Radar Altimeter (SRAL), etc. In addition, the Sentinel-3 satellites are also equipped with a Laser Retro Reflector (LRR), which allows the tracking of the Sentinel-3 satellites by using a laser ranging from a network of Satellite Laser Ranging (SLR) stations belonging to the International Laser Ranging Service (ILRS). Figure 2-1 shows the location of the LRR reflector on the payload of the Sentinel-3 satellites. This figure also summarises a few properties of the orbit described by the Sentinel-3 satellites.



Properties of Sentinel-3 satellites

- Low Earth Orbit (LEO)
- Polar orbit
- Inclination: 98.65°
- Altitude: 814.5 km

Figure 2-1: Properties of Sentinel-3 satellites and location of the LRR

The observations provided by the SLR stations are very valuable for the CPOD Service since they are used as an alternative source for validating the precise orbit solutions the CPOD Service generates through the Global Navigation Satellite System (GNSS) signals, especially from those obtained by means of the Global Positioning System (GPS). For this, not only the CPOD Service but also ESA are very grateful for the support provided by the ILRS community, which helps at the long term validation and valorisation of the Sentinel-3 orbit and science products.

At the time of writing this document, there is a total of 25 SLR stations allowed to track the Sentinel-3 satellites. Not all the SLR stations may track both satellites since high levels of laser energy could damage some instrument on board the Sentinel-3 satellites (e.g., the OLCI receiver). Figure 2-2 shows the geographical location of these SLR stations based on an agreement signed upon power restrictions (see [AD.1], [AD.2] and [RD.1]). More information about the location name, the country and the location coordinates of the complete set of the SLR stations that have ever track any of the two Sentinel-3 satellites can be found in Table 7-1 of the annex.

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.

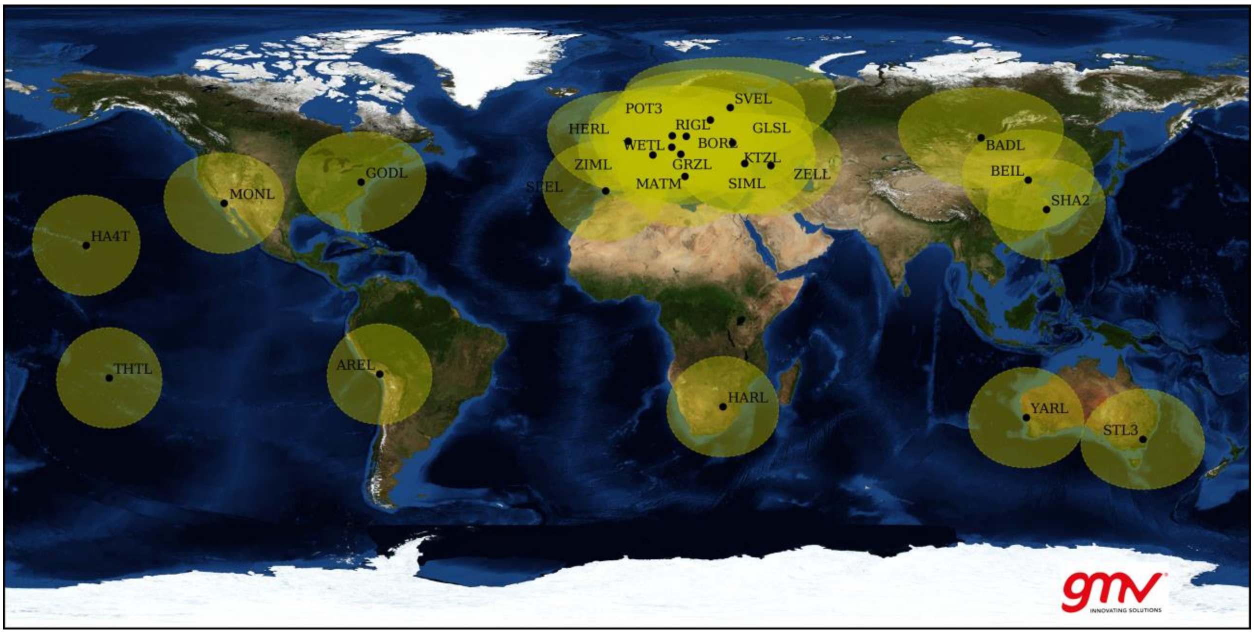


Figure 2-2: Geographical location of the set of the SLR Stations that are allowed to track the Sentinel-3 satellites

The list of SLR stations tracking the Sentinel-3 satellites has been reduced on the last months. On the one hand, a change on the laser configuration of the **SISL** station has led the station to exceed the allowed power restriction limits, and therefore, the SISL station has recently had to abandon the tracking of the Sentinel-3 satellites (as it also happened with CHAL station during 2018). On the other hand, the **MDOL** station has also stopped its tracking since it has been closed and it is consequently no longer operational.

It is worth to mention that there are some other SLR stations that, for one reason or another, have ceased their activity with the Sentinel-3 satellites in recent times. Such SLR stations are listed below:

- The **WETL** station has changed the system configuration of its laser, which is currently operating in the Infra-Red (IR) instead of the visible. It is still undecided whether the SLR stations can track Sentinel-3 satellites in the IR and, if they are, it is also unknown under which power restrictions. This fact is being analysed by ESA. Therefore, the WETL station has stopped, as a precautionary measure, the tracking of the Sentinel-3 satellites until receiving green light.
- The **ZELL** station has been inactive during the last months. The last piece of information received by the CPOD Service from the station was that it was being repaired, and therefore, it could not track the Sentinel-3 satellites.
- The **GLSL** and **BADL** are not tracking Sentinel-3 probably due to the change of the FTP server with the CPF predictions.

On the other hand, there are other SLR stations that have resumed the tracking of the Sentinel-3 satellites after a long time of inactivity. This is the case of **ZIML**, **SFEL** and **STL3** stations, which are currently tracking both satellites on a nominal basis.

The tracking of the satellites from the SLR stations follows a mission priority list established by the ILRS community. This information is summarised in Figure 2-3, which particularly highlights the positions that the Sentinel-3 satellites are occupying on the list at the time of writing this document. The complete priority list can be found in the official website of the ILRS community. As seen from the figure, Sentinel-3A and Sentinel-3B are on the 14^{th} and 13^{th} position, respectively, of all satellites considered by the ILRS community. Again, both ESA and the CPOD Service are very grateful that the ILRS community not only keeps tracking both satellites but continues to keep both satellites at this priority level.

Finally, this section concludes showing a general overview of the tracking of the Sentinel-3 satellites from the SLR stations. The statistics shown below have been subtracted from the *npt* files provided by the SLR stations on a daily basis. The figures will show the number of passes that the SLR stations have retrieved from the Sentinel-3 satellites during the entire satellite mission and also from the year 2019 in particular. It has been worth to add the statistics of another satellite (i.e., Jason-3) for crosscomparison purposes and to detect possible anomalies on the tracking of both Sentinel-3 satellites. Jason-3 is an altimetry satellite (as Sentinel-3 satellites) describing a LEO orbit with an altitude of 1336 km (more than 1.6 times the altitude of the Sentinel-3 satellites). This difference on altitude clearly benefits the tracking of the Jason-3 satellite mainly for two reasons: (a) it can be seen more times from the SLR stations, and (b) it can be tracked for a longer time period.

Priority	Mission	ILRS Name	COSPAR ID	SIC	Sponsor	Altitude (km)	Inclination (degrees)	Comments
1	GRACE-FO-1/2	gracefo1 gracefo2	1804701 1804702	0123 0124	NASA JPL and the German Research Centre for Geosciences (GFZ)	500	89	1-month campaign
2	ICESat-2	icesat2	1807001	6873	NASA	496	92	Restricted tracking; authorization required
3	CryoSat-2	cryosat2	1001301	8006	ESA	450-720	92	
⋮								⋮
13	Sentinel-3B	sentinel3b	1803901	8011	ESA/EUMETSAT	814.5	98.65	Restricted tracking; authorization required
14	Sentinel-3A	sentinel3a	1601101	8010	ESA/EUMETSAT	814.5	98.65	Restricted tracking; authorization required
⋮								⋮
21	Jason-3	jason3	1600201	4379	NASA, CNES, Eumetsat, NOAA	1,336	66.0	

Figure 2-3: ILRS mission priority list at the time of writing the document

Figure 2-4 and Figure 2-5 plot the temporal evolution on the **total number of satellite passes per GPS week** for the Sentinel-3A, Sentinel-3B and Jason-3 satellites. This temporal evolution is shown for the entire missions in Figure 2-4, whereas Figure 2-5 only pays attention on the year 2019.

As seen in the figures, the number of Sentinel-3 passes has remained quite constant (**between 50 and 100 passes**) during 2019. After the drop of passes occurred at the end of year 2018, the Sentinel-3 passes have achieved better figures mainly due to the resumption on the Sentinel-3 tracking from some SLR stations. However, there is still room for improvement in view of the results of previous years.

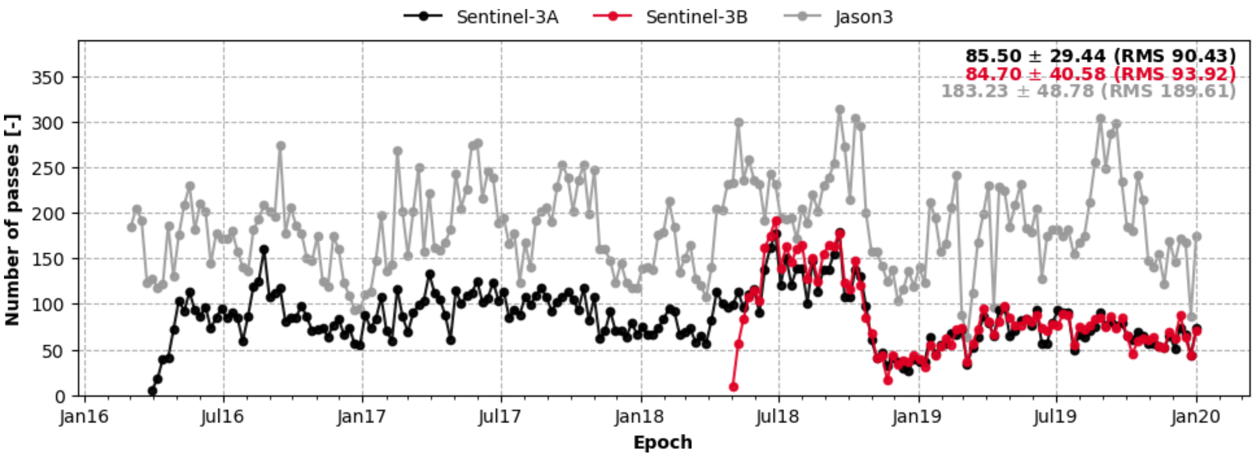


Figure 2-4: Total number of satellite passes per GPS week since the beginning of the satellite mission (Sentinel-3A, Sentinel-3B and Jason-3)

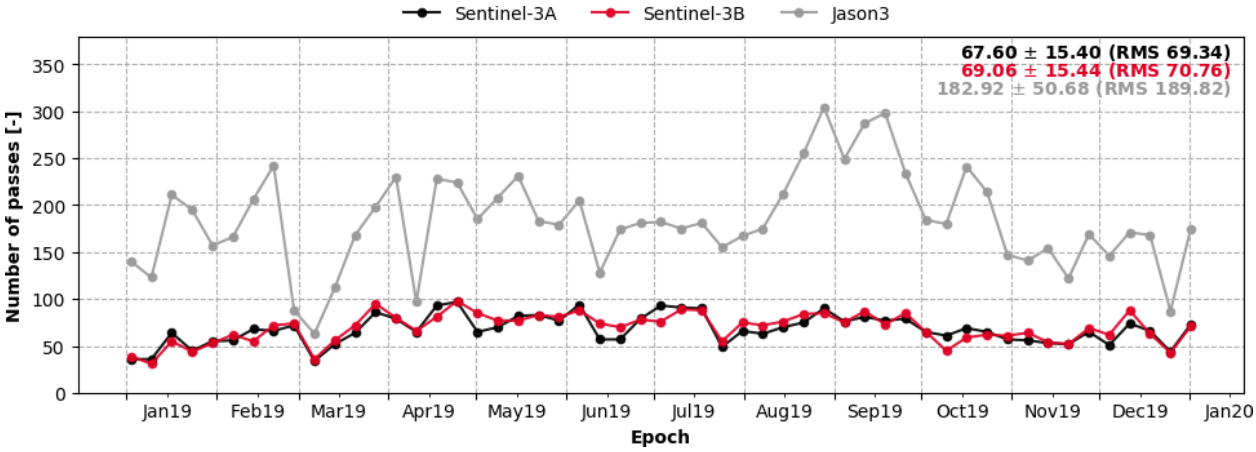


Figure 2-5: Total number of satellite passes per GPS week in 2019 (Sentinel-3A, Sentinel-3B and Jason-3)

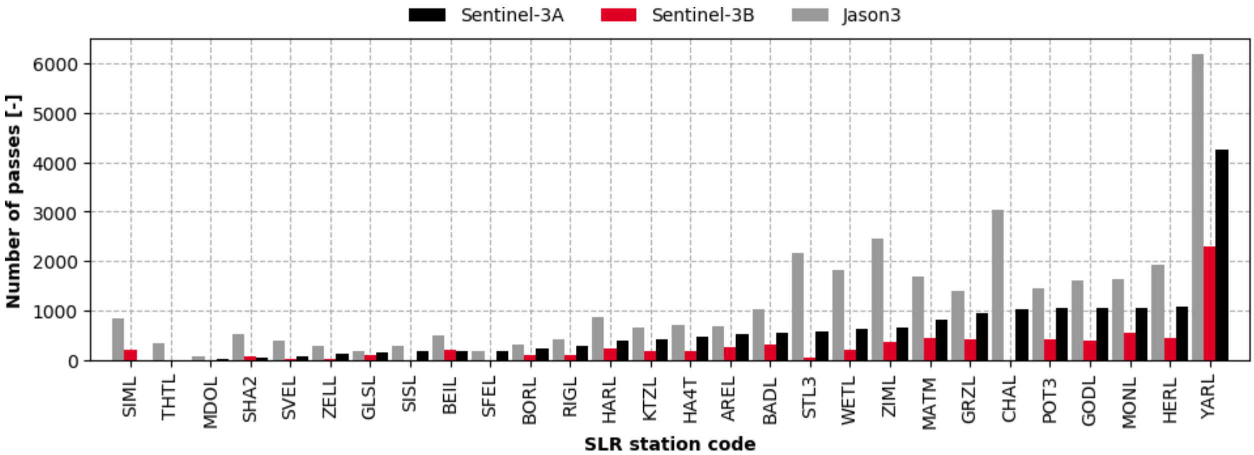


Figure 2-6: Total number of satellite passes per SLR station since the beginning of the satellite mission (Sentinel-3A, Sentinel-3B and Jason-3)

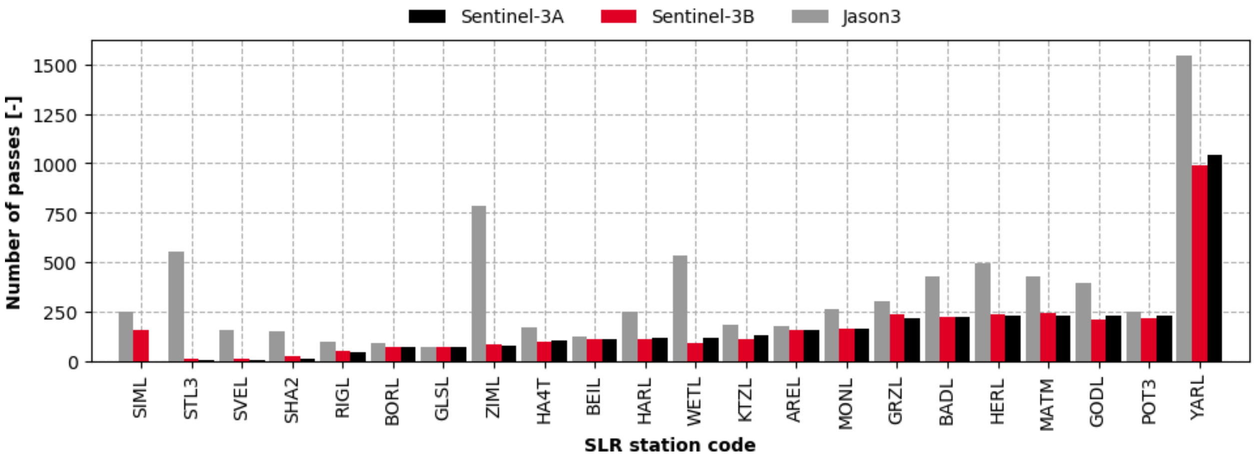


Figure 2-7: Total number of satellite passes per SLR station in 2019 (Sentinel-3A, Sentinel-3B and Jason-3)

On the other hand, Figure 2-6 and Figure 2-7 present the **total number of satellite passes per SLR station**. The results are given altogether for Sentinel-3A, Sentinel-3B and Jason-3 satellites, and they are shown for the entire mission of the three satellites (Figure 2-6), and solely for the year 2019 (Figure 2-7).

The plots keep showing that the **YARL** station is the one providing most satellite passes with great distance regarding the nominal figures obtained by the vast majority of the SLR stations. If Figure 2-7 is particularly analysed, it can be said that there is no significant difference between the outcome achieved by the Jason-3 and Sentinel-3 satellites, except for the results of **WETL**, **ZIML** and **STL3** stations. These stations have been inactive for a long time period on the tracking of the Sentinel-3 satellites during 2019 (as it will be seen in the figures of the following sections). Fortunately, ZIML and STL3 have recently resumed their activity, whereas the WETL station is still on-hold of ESA's decision.

3. VALIDATION OF THE SENTINEL-3 ORBIT SOLUTIONS

The SLR observations provided by the SLR stations have proven to be of high value in order to validate the precise Sentinel-3 orbit solutions being generated, for example, by the CPOD Service among others. However, not only the CPOD Service may benefit of an independent orbit validation given by the ILRS community but also the ILRS community itself may also receive some feedback in return about such validation, which may be used to improve the configuration network of the SLR stations.

This section has two main objectives: (a) validate the Sentinel-3 orbit solutions created on different centres, which do not make use of SLR data for generating their solutions, and (b) prove that including an estimated range bias on each SLR station may benefit the final validation outcome.

To that end, the section will be organized as follows:

- Firstly, a Sentinel-3 combined orbit solution for each satellite will be generated by merging appropriately all Sentinel-3 orbit solutions given by different centres.
- Secondly, an estimation of the range biases of each SLR station will be performed from the combined orbit solutions previously obtained.
- Finally, the validation of all Sentinel-3 orbit solutions will be evaluated by using the estimated range biases.

3.1. CALCULATION OF THE SENTINEL-3 COMBINED ORBIT SOLUTION

The Sentinel-3 orbit solutions are currently being computed by several centres that conform the Copernicus POD Quality Working Group (QWG), which is intended to ensure the good quality of the products generated by the CPOD Service.

Table 3-1 lists all centres providing Sentinel-3 orbit solutions to the QWG. These orbit solutions are based on very similar GNSS processing strategies, although using different processing schemes, models and software. For example, the CLS orbit solution (i.e., GRGG) is only based on DORIS data, whereas the CNES orbit solution includes DORIS observations along with the GPS data, or the CPOK orbit solution (from the CPOD Service) is a pure kinematic solution. None of the centres uses the SLR observations in the determination process, which allow the SLR data to be used as an independent means to validate the orbital accuracy of the orbit solutions of all centres. As seen in the table, not all centres only provide one orbit solution, there are a few centres which include a second or even a third orbit solution. However, despite being of the same centre, these orbit solutions are generated with noticeable differences between them.

Table 3-1: List of the centres providing orbit solutions for the generation of the combined orbit solution (labelled as COMB) of the Sentinel-3 satellites

Name of centre	Label/s of the orbit solution/s provided
Astronomical Institute of the University of Bern (AIUB)	AIUB AING (non-gravitational force modelling)
Collecte Localisation Satellites (CLS)	GRGG
Centre National d'Études Spatiales (CNES)	CNES
Copernicus Precise Orbit Determination (CPOD) Service	CPOD (operational solution) CPOF (ambiguity-fixed solution) CPOK (kinematic solution)
Deutsche Zentrum für Luft- und Raumfahrt (DLR)	DLRR
European Space Operation Centre (ESOC)	ESOC
European organisation for the exploitation of Meteorological Satellites (EUMETSAT)	EUMB (Bernese GNSS software) EUMM (NAPEOS software)
Deutsches GeoForschungsZentrum (GFZ)	GFZZ
Jet Propulsion Laboratory (JPL)	JPLL
Technische Universiteit Delft (TUD)	TUDG
Technische Universität München (TUM)	TUMM

The combined orbit solution (labelled as COMB) is then obtained from a combination of all orbit solutions listed in Table 3-1. These orbit solutions are properly weighted by following an IGS-like approach used by the International GNSS Service (IGS) to finally generate the COMB orbit solution.

Figure 3-1 and Figure 3-3 show the orbital comparisons (3D RMS) between the orbit solutions of all centres and the final COMB orbit solution calculated from them for Sentinel-3A and Sentinel-3B satellites, respectively. The statistical outcome of such comparisons has been gathered in Figure 3-2 and Figure 3-4 for the corresponding satellites. From the analysis of these figures, it can be said that the vast majority of the orbit solutions are close to the COMB orbit solution (between 0.5 and 2 cm in mean). There are only two orbit solutions that exceed the 2 cm in mean on both satellites, which are the GRGG and EUMM orbit solutions. In addition, most of the orbit solutions presents consistency over time throughout a low standard deviation value (below 0.5 cm). Thus, it can be concluded that all orbit solutions are of good quality.

Note that not all orbit solutions are provided for the whole year 2019 since not all centres have calculated their orbit solutions for the entire time period. Moreover, the time period analysed (or the time period where a COMB orbit has been generated) exceeds the year 2019 not only for the beginning but also for the end. This is due the fact that complete GPS weeks have been calculated. In this way, the time period evaluated starts on day 0 of GPS week 2034 (i.e., 30th December 2018) and ends on day 6 of GPS week 2086 (i.e., 4th January 2020).

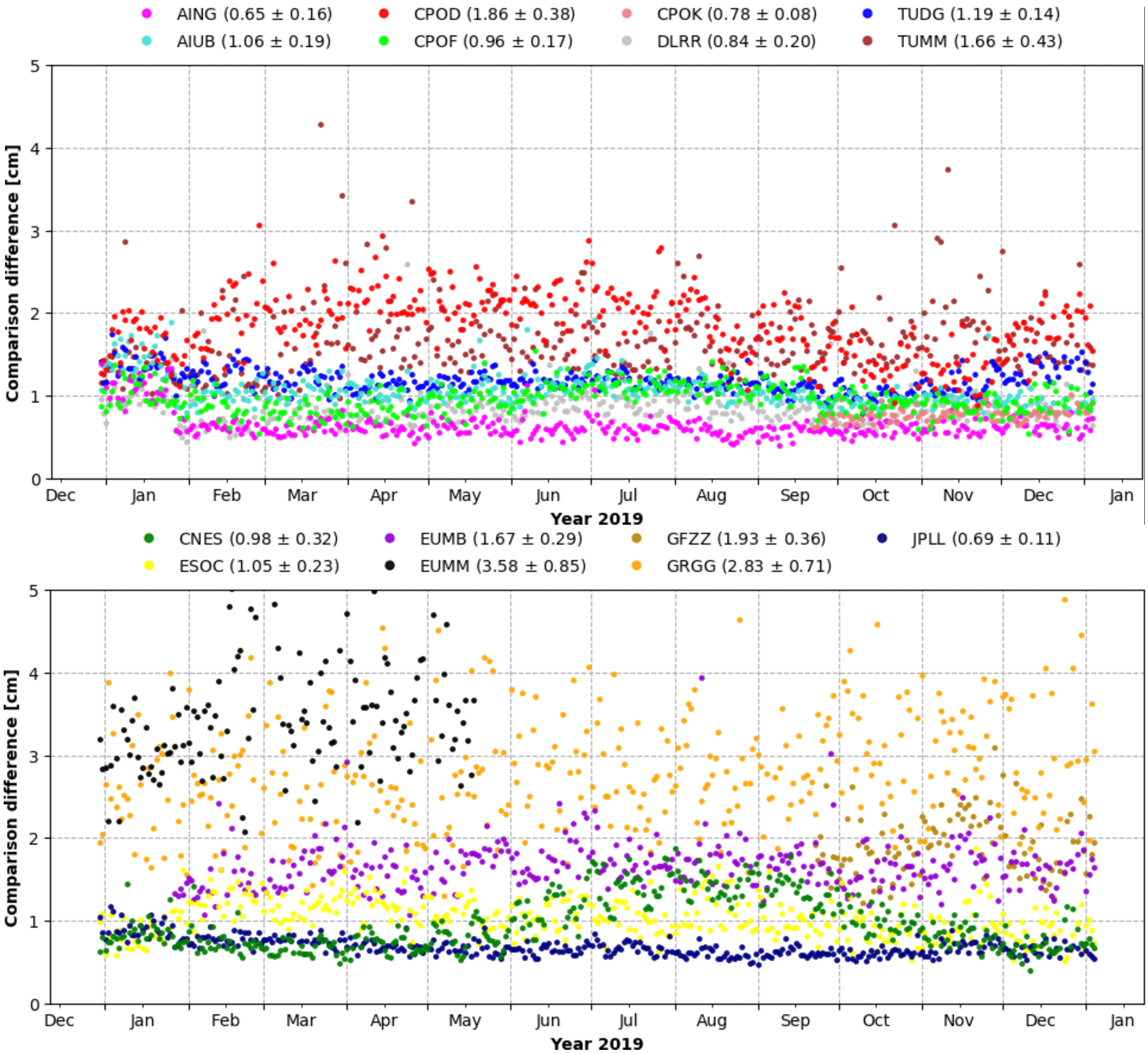


Figure 3-1: Orbital comparisons [3D RMS; cm] between each Sentinel-3A orbit solution and the Sentinel-3A combined orbit solution

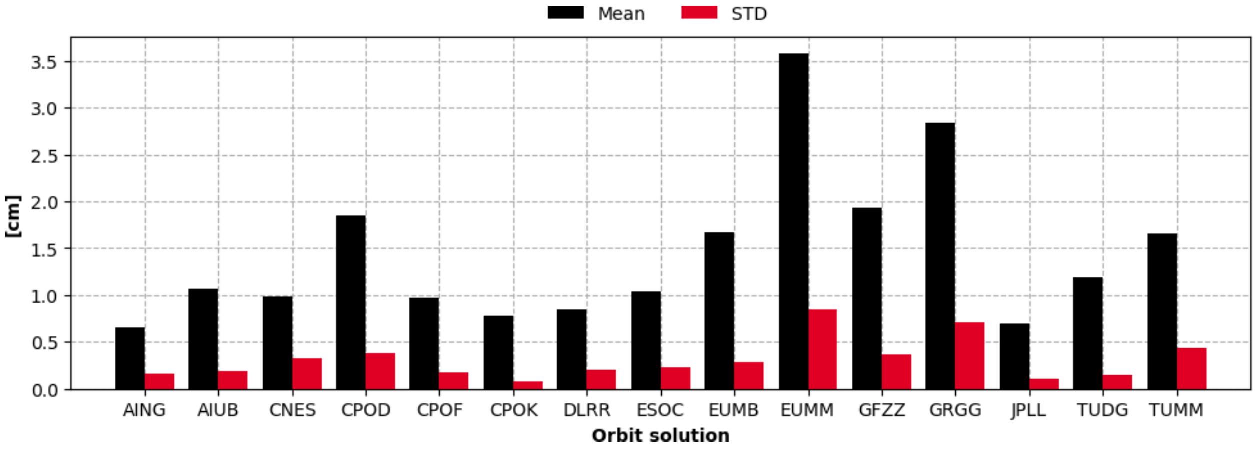


Figure 3-2: Mean and STD of the orbital comparisons [3D RMS; cm] between each Sentinel-3A orbit solution and the Sentinel-3A combined orbit solution

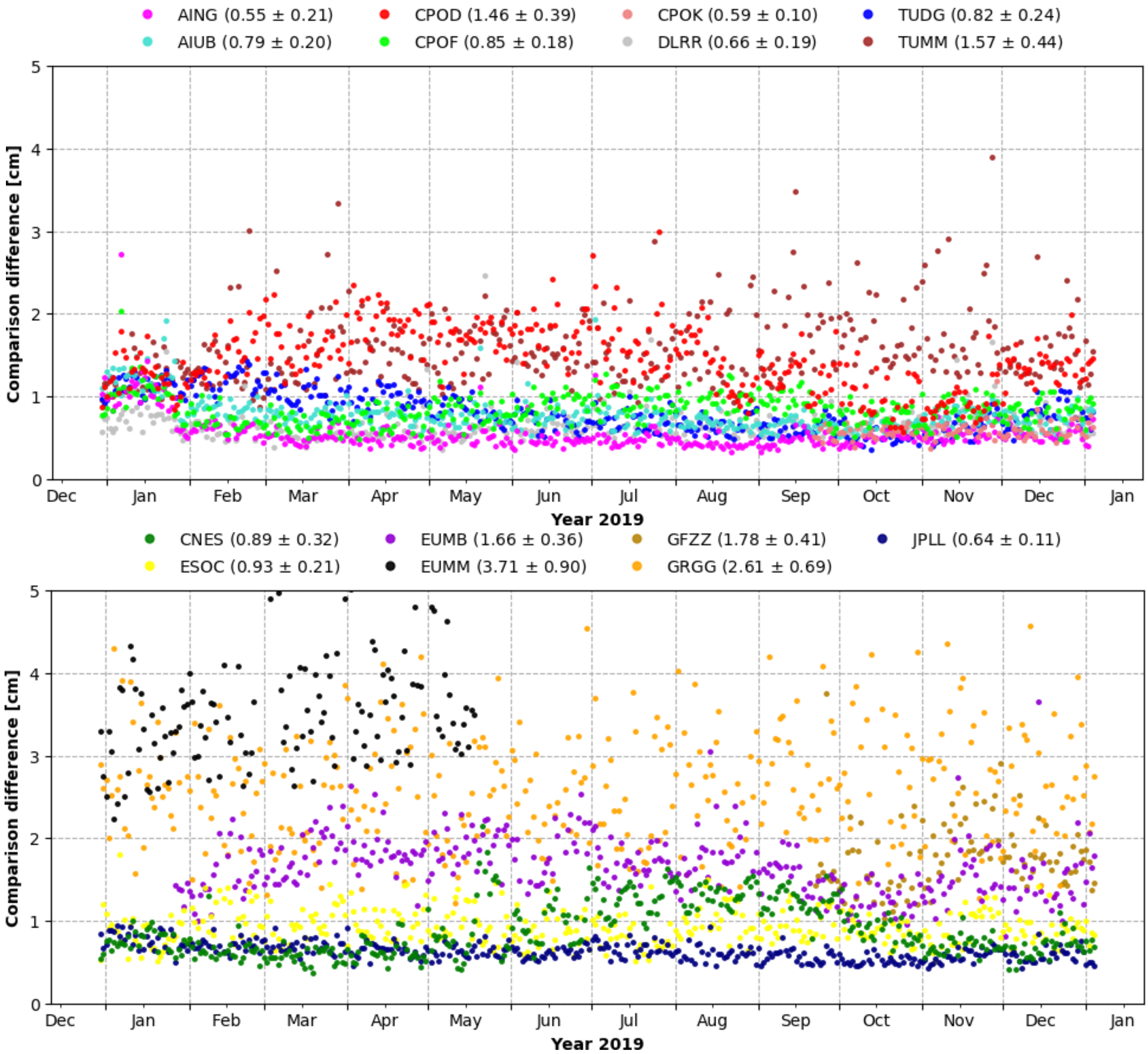


Figure 3-3: Orbital comparisons [3D RMS; cm] between each Sentinel-3B orbit solution and the Sentinel-3B combined orbit solution

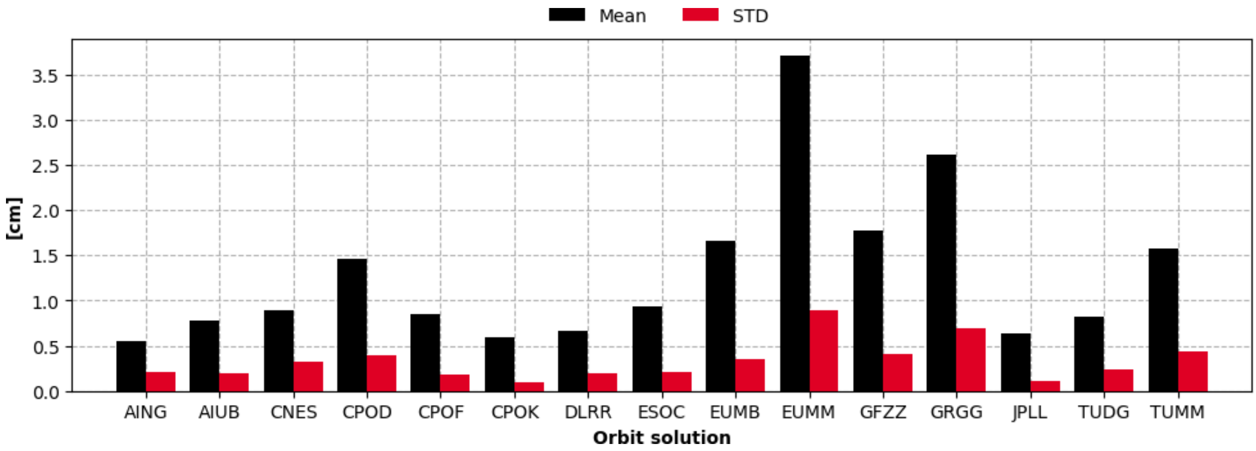


Figure 3-4: Mean and STD of the orbital comparisons [3D RMS; cm] between each Sentinel-3B orbit solution and the Sentinel-3B combined orbit solution

The following tables gather the statistical outcome of the previous figures adding the results for each satellite component. Note that the Sentinel-3 orbit solutions must present high accuracy on the radial component as the altimetry applications demand it.

Table 3-2: Summary of the mean, and STD values per satellite component of the orbital comparisons between each Sentinel-3A orbit solution and the Sentinel-3A combined orbit solution during 2019

Orbit solution	Sentinel-3A [cm]							
	Radial RMS		Along-track RMS		Cross-track RMS		3D RMS	
	Mean	STD	Mean	STD	Mean	STD	Mean	STD
AING	0.29	0.08	0.37	0.14	0.43	0.14	0.65	0.16
AIUB	0.72	0.12	0.42	0.15	0.63	0.21	1.06	0.19
CNES	0.42	0.14	0.75	0.29	0.45	0.15	0.98	0.32
CPOD	0.81	0.19	1.40	0.37	0.88	0.16	1.86	0.38
CPOF	0.33	0.07	0.63	0.18	0.64	0.11	0.96	0.17
CPOK	0.36	0.06	0.36	0.07	0.58	0.08	0.78	0.08
DLRR	0.36	0.12	0.54	0.18	0.51	0.17	0.84	0.20
ESOC	0.41	0.10	0.82	0.23	0.46	0.15	1.05	0.23
EUMB	0.92	0.18	0.94	0.25	1.00	0.25	1.67	0.29
EUMM	0.98	0.18	2.58	0.72	2.23	0.60	3.58	0.85
GFZZ	0.87	0.16	1.37	0.40	1.00	0.21	1.93	0.36
GRGG	0.66	0.20	2.16	0.65	1.58	0.69	2.83	0.71
JPLL	0.42	0.05	0.41	0.14	0.33	0.08	0.69	0.11
TUDG	0.85	0.11	0.56	0.15	0.58	0.17	1.19	0.14
TUMM	0.64	0.16	1.37	0.42	0.65	0.19	1.66	0.43
COMB	0.29	0.08	0.37	0.14	0.43	0.14	0.65	0.16

Table 3-3: Summary of the mean, and STD values per satellite component of the orbital comparisons between each Sentinel-3B orbit solution and the Sentinel-3B combined orbit solution during 2019

Orbit solution	Sentinel-3B [cm]							
	Radial RMS		Along-track RMS		Cross-track RMS		3D RMS	
	Mean	STD	Mean	STD	Mean	STD	Mean	STD
AING	0.21	0.08	0.37	0.17	0.33	0.14	0.55	0.21
AIUB	0.54	0.11	0.41	0.17	0.36	0.14	0.79	0.20
CNES	0.36	0.15	0.73	0.29	0.34	0.10	0.89	0.32
CPOD	0.60	0.18	1.22	0.37	0.48	0.15	1.46	0.39
CPOF	0.29	0.08	0.66	0.20	0.43	0.12	0.85	0.18
CPOK	0.34	0.07	0.37	0.09	0.30	0.06	0.59	0.10
DLRR	0.30	0.10	0.46	0.17	0.35	0.12	0.66	0.19
ESOC	0.36	0.11	0.73	0.21	0.43	0.13	0.93	0.21
EUMB	0.74	0.17	1.01	0.25	1.07	0.31	1.66	0.36
EUMM	0.97	0.20	2.87	0.75	2.10	0.62	3.71	0.90
GFZZ	0.84	0.17	1.40	0.41	0.65	0.20	1.78	0.41
GRGG	0.61	0.19	1.82	0.56	1.64	0.76	2.61	0.69
JPLL	0.29	0.04	0.46	0.13	0.31	0.06	0.64	0.11
TUDG	0.37	0.11	0.51	0.15	0.49	0.24	0.82	0.24
TUMM	0.46	0.15	1.34	0.42	0.65	0.21	1.57	0.44
COMB	0.21	0.08	0.37	0.17	0.33	0.14	0.55	0.21

Since all orbit solutions are computed using the same set of observations from GPS, an independent technique such as the SLR is needed to guarantee that the previous orbit solutions have no systematic biases affecting them all equally. An analysis of the SLR residuals can consequently be used to identify these possible biases. Keep in mind that the SLR residuals are nothing more than the differences between the SLR observations that would be obtained for a specific orbit solution and those SLR observations provided by the SLR stations themselves. Figure 3-5 shows the amount of the SLR observations delivered by the SLR stations during the time period evaluated.

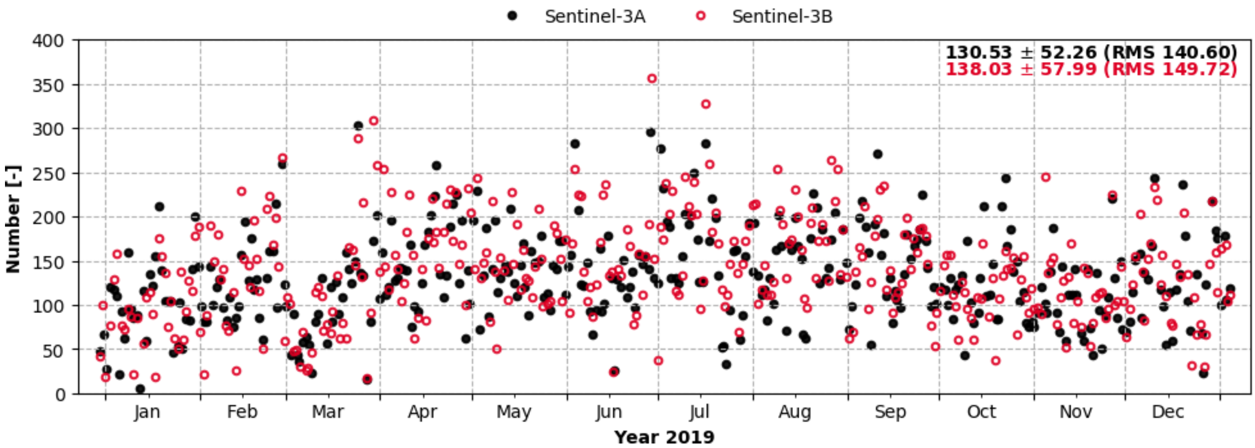


Figure 3-5: Daily total number of the accepted SLR observations of all SLR stations tracking Sentinel-3A and Sentinel-3B satellites in 2019

As seen from the previous figure, the SLR stations have generated a considerable amount of SLR observations, with an average value of over 130 SLR observations per day for both Sentinel-3 satellites.

Prior to the calculation of the SLR residuals, it has been deemed worth to estimate a range bias for each SLR station in order to improve the statistical outcome on the residuals.

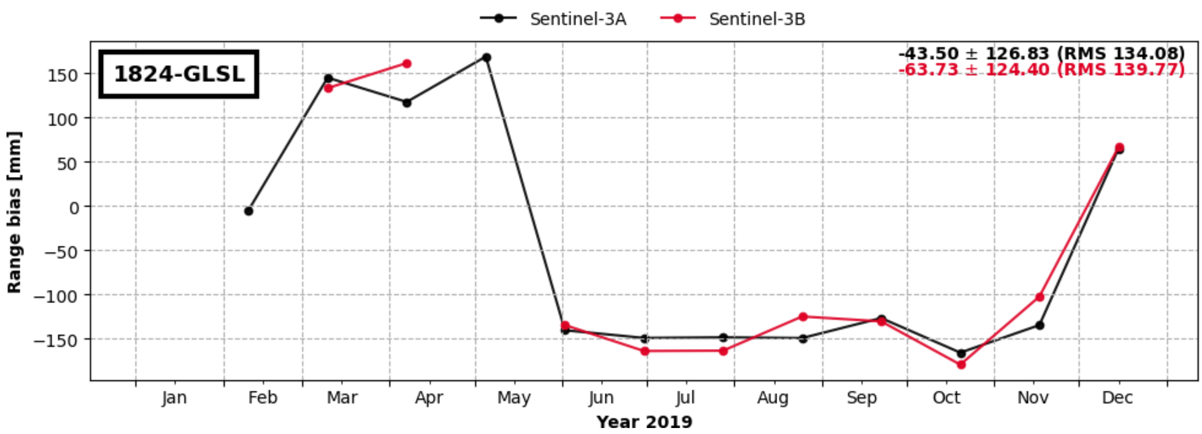
3.2. ESTIMATION OF THE RANGE BIASES FOR ALL SLR STATIONS

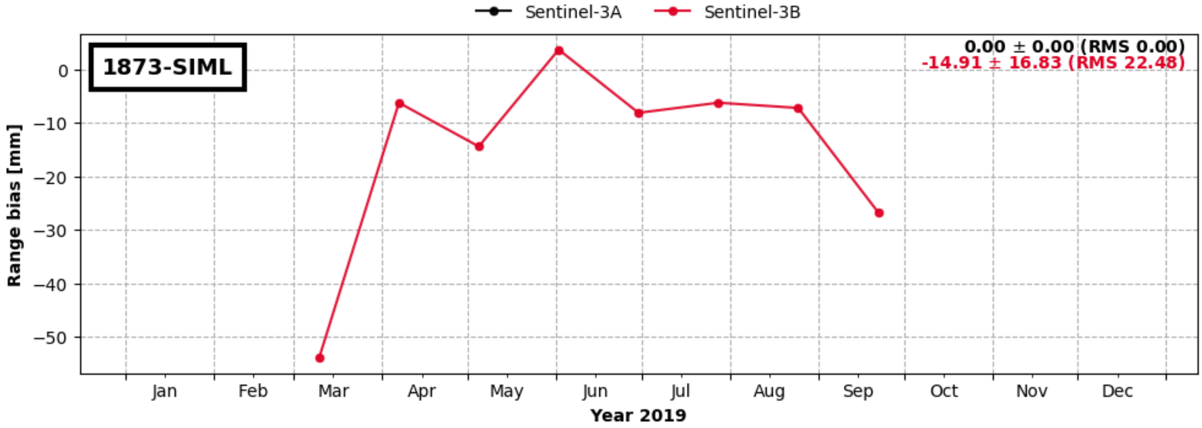
The selected way to reproduce a constant bias affecting both the Sentinel-3 orbit solutions and the SLR stations has been to calculate a certain error that each of the SLR stations may include on their SLR observations. This error has been calculated by fixing the Sentinel-3 orbit solution and by estimating the SLR observations that each of the SLR stations would have had to ideally deliver. From such error, a range bias of each SLR station has been derived.

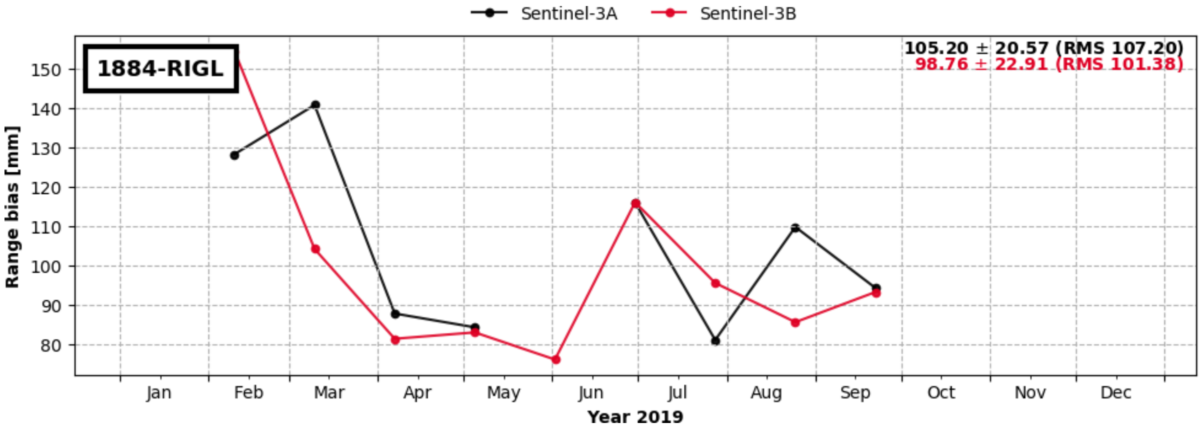
To make the outcome more reliable, first, the Sentinel-3 COMB orbit solution has been used as the fixed one, and second, the range biases have been calculated considering the entire time period evaluated on this document (i.e., from 30th December 2018 to 4th January 2020). In addition, instead of retrieving daily statistics on the range biases (that could somehow harm the statistics of those SLR stations providing less SLR observations), the range biases have been calculated from groups of four GPS weeks. Thus, a 4-GPS-week-long combined orbit solutions have been built, and, from them, a 4-GPS-week-long range biases of each SLR station have been estimated.

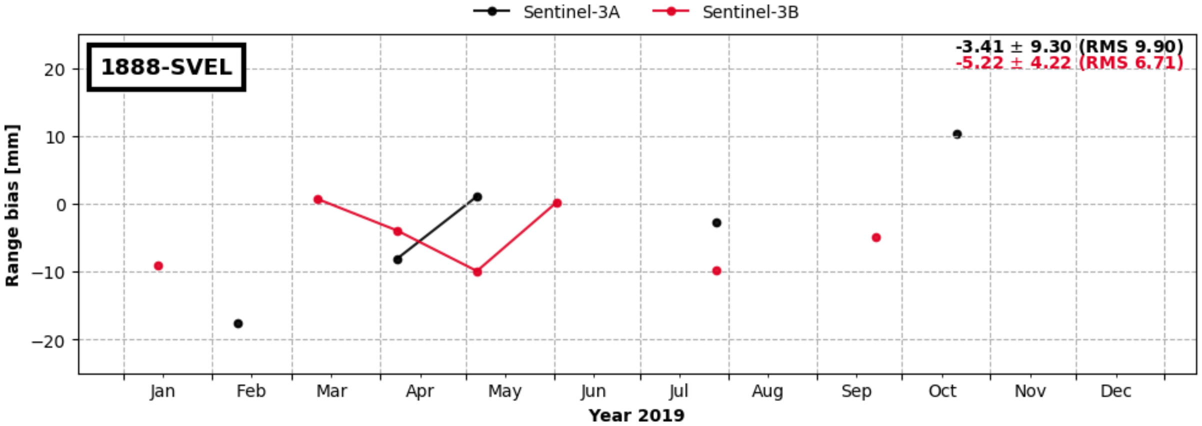
The following figure includes the plots of the temporal evolution of these estimated range biases for each SLR station assessed and discerning between Sentinel-3A and Sentinel-3B. From the plots of the figure, it can be seen that the vast majority of the SLR stations presents a quite constant evolution on the range biases, except for the cases of **GLSL**, **SIML**, **RIGL** and **BORL** stations, which values are more dispersive.

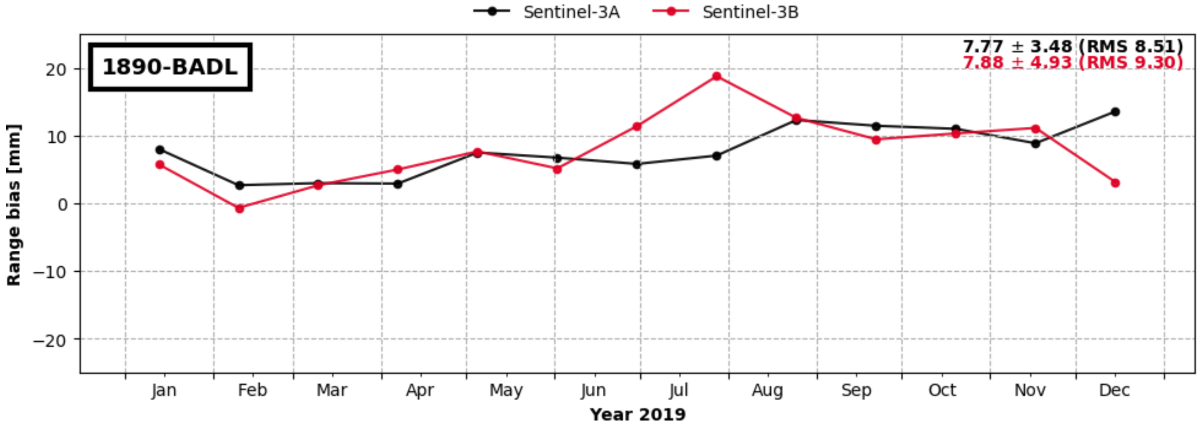
It must be taken into account that some outliers have been subtracted from the statistics of Figure 3-6 in order not to harm the final outcome of a few SLR stations.

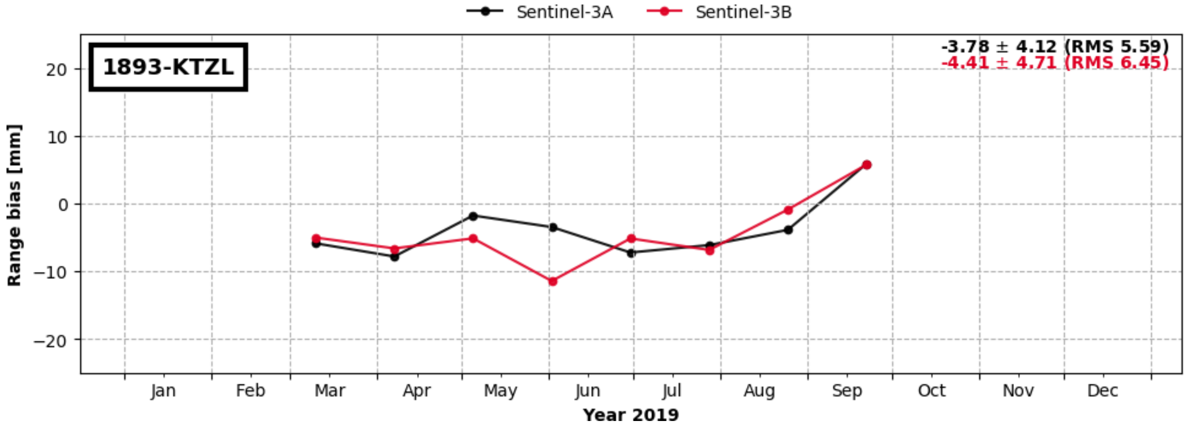


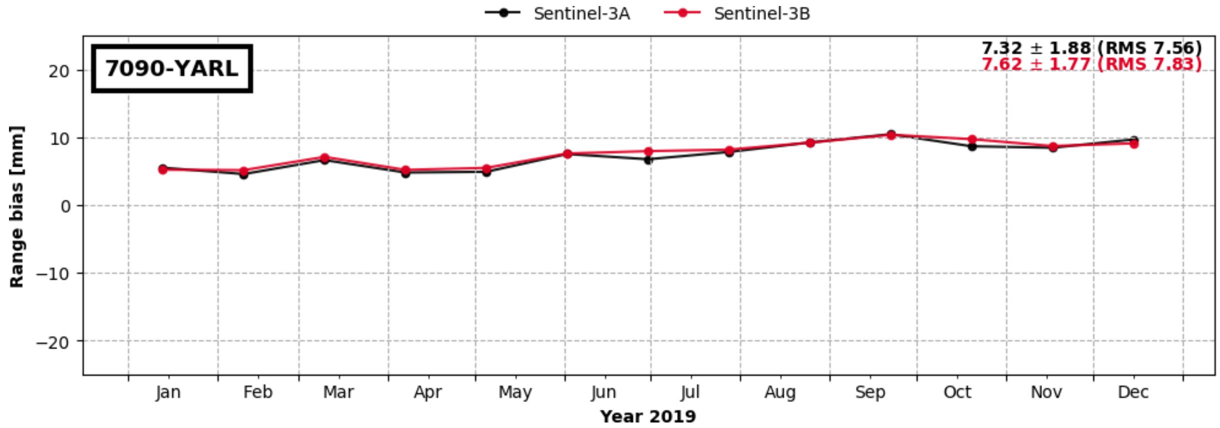


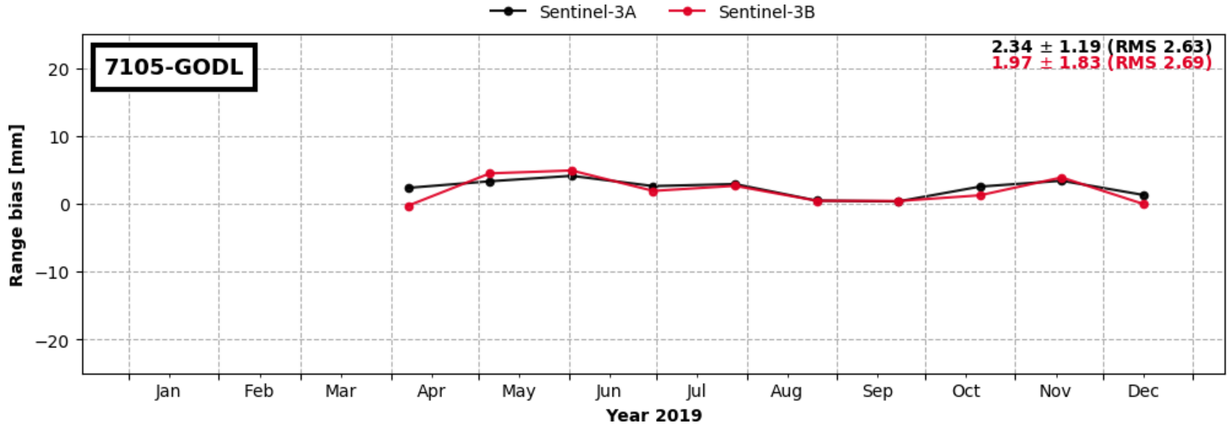

Sentinel-3A
Sentinel-3B
1884-RIGL
105.20 ± 20.57 (RMS 107.20)
98.76 ± 22.91 (RMS 101.38)
Range bias [mm]
Year 2019

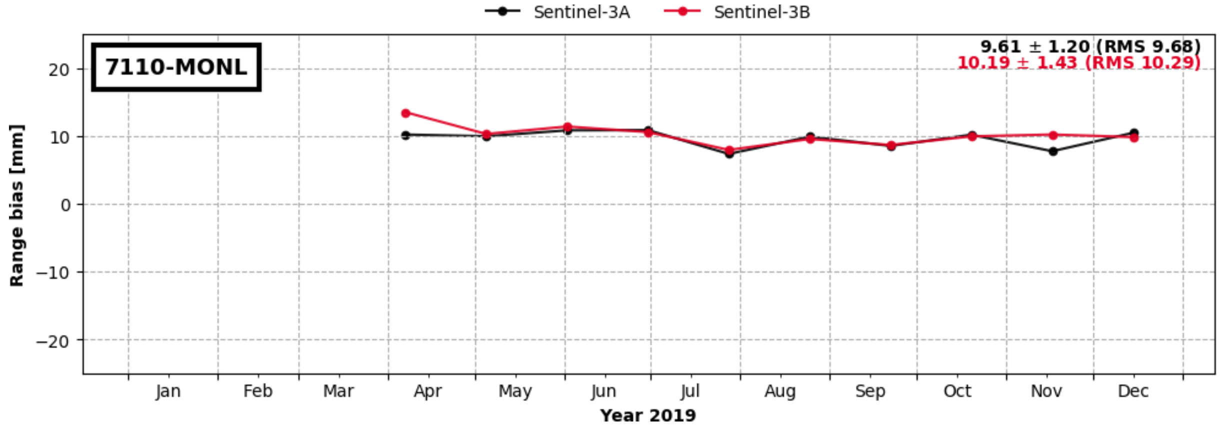

Sentinel-3A
Sentinel-3B
1888-SVEL
-3.41 ± 9.30 (RMS 9.90)
-5.22 ± 4.22 (RMS 6.71)
Range bias [mm]
Year 2019

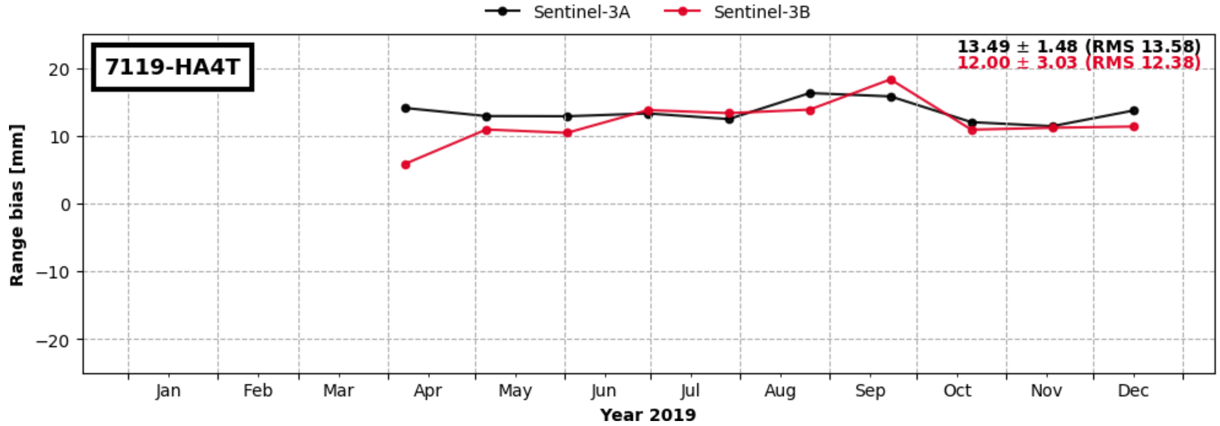

Sentinel-3A
Sentinel-3B
1890-BADL
7.77 ± 3.48 (RMS 8.51)
7.88 ± 4.93 (RMS 9.30)
Range bias [mm]
Year 2019

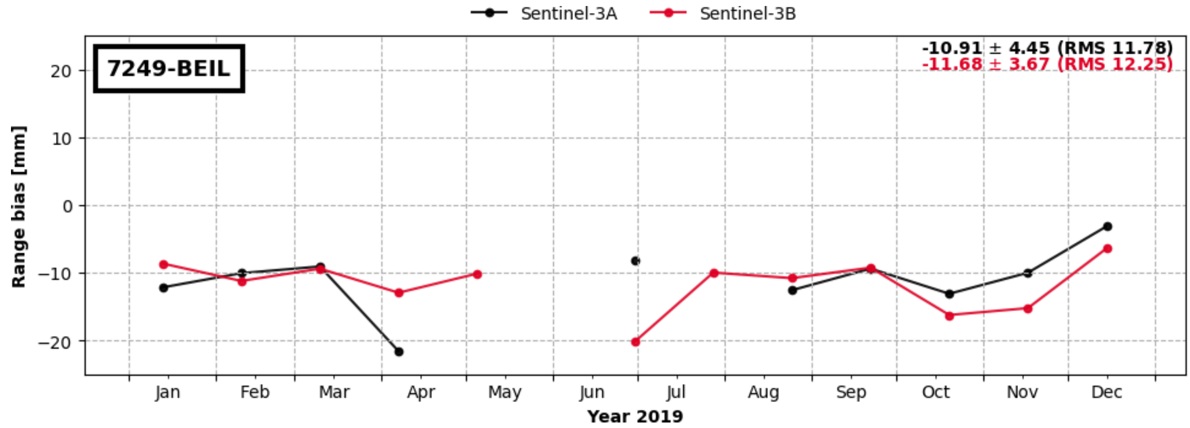

Sentinel-3A
Sentinel-3B
1893-KTZL
-3.78 ± 4.12 (RMS 5.59)
-4.41 ± 4.71 (RMS 6.45)
Range bias [mm]
Year 2019

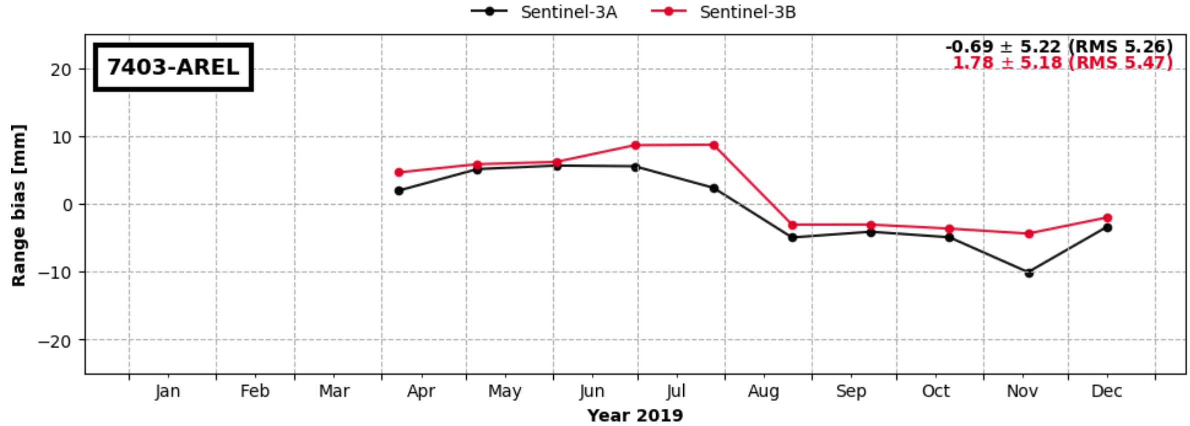

Sentinel-3A
Sentinel-3B
7090-YARL
7.32 ± 1.88 (RMS 7.56)
7.62 ± 1.77 (RMS 7.83)
Range bias [mm]
Year 2019

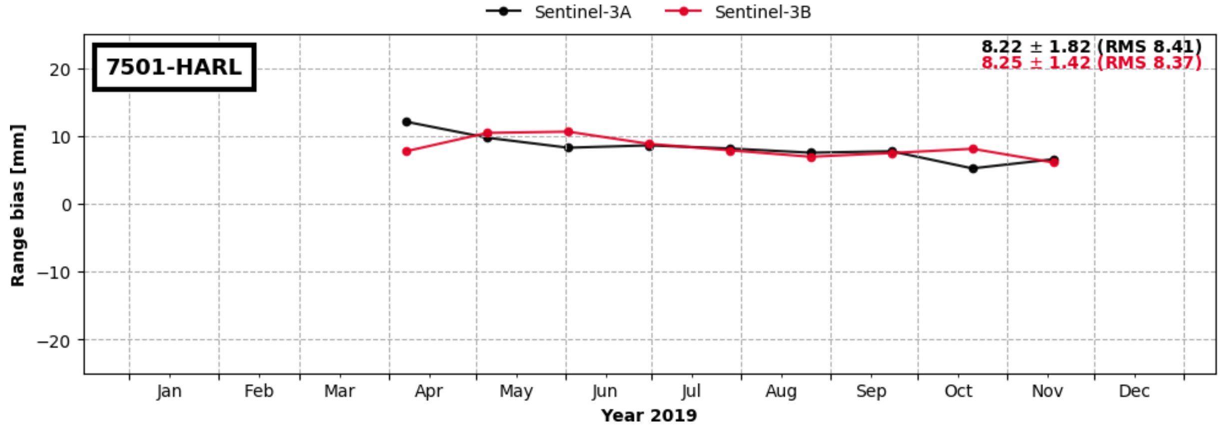

Sentinel-3A
Sentinel-3B
7105-GODL
2.34 ± 1.19 (RMS 2.63)
1.97 ± 1.83 (RMS 2.69)
Range bias [mm]
Year 2019

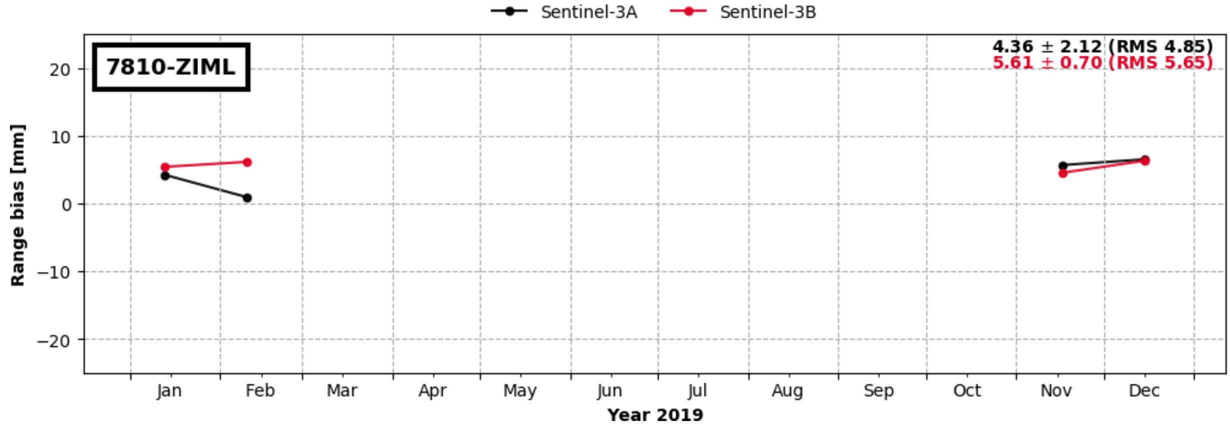

Sentinel-3A
Sentinel-3B
7110-MONL
9.61 ± 1.20 (RMS 9.68)
10.19 ± 1.43 (RMS 10.29)
Range bias [mm]
Year 2019

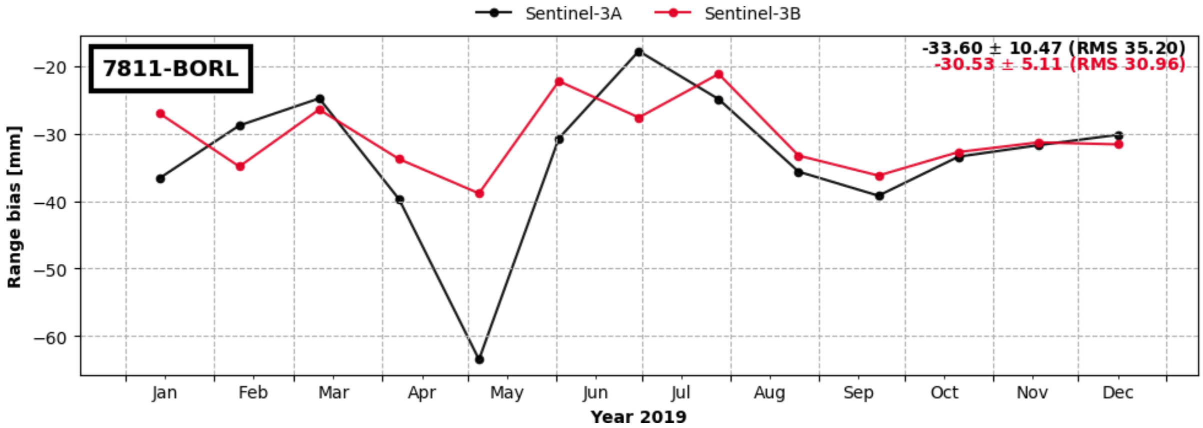

Sentinel-3A
Sentinel-3B
7119-HA4T
13.49 ± 1.48 (RMS 13.58)
12.00 ± 3.03 (RMS 12.38)
Range bias [mm]
Year 2019

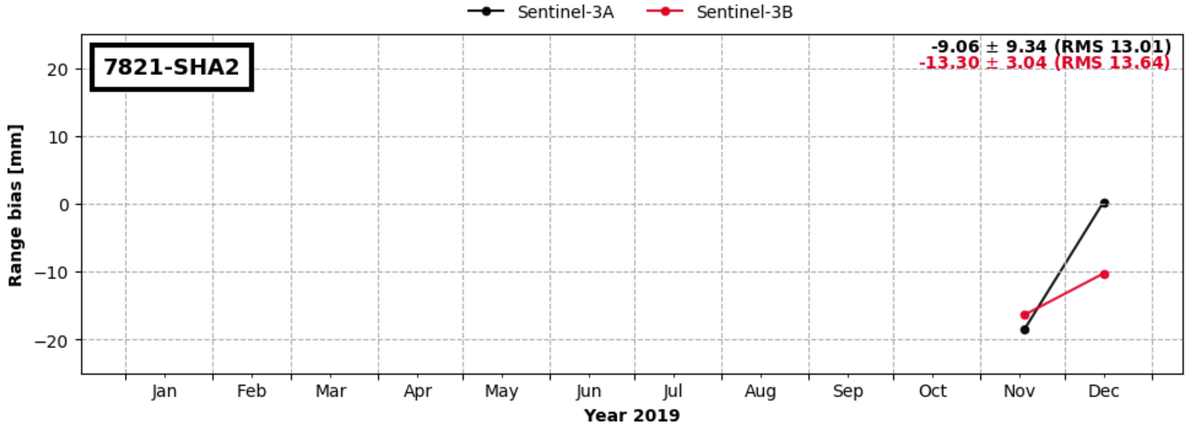

Sentinel-3A
Sentinel-3B
7249-BEIL
-10.91 ± 4.45 (RMS 11.78)
-11.68 ± 3.67 (RMS 12.25)
Range bias [mm]
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Year 2019

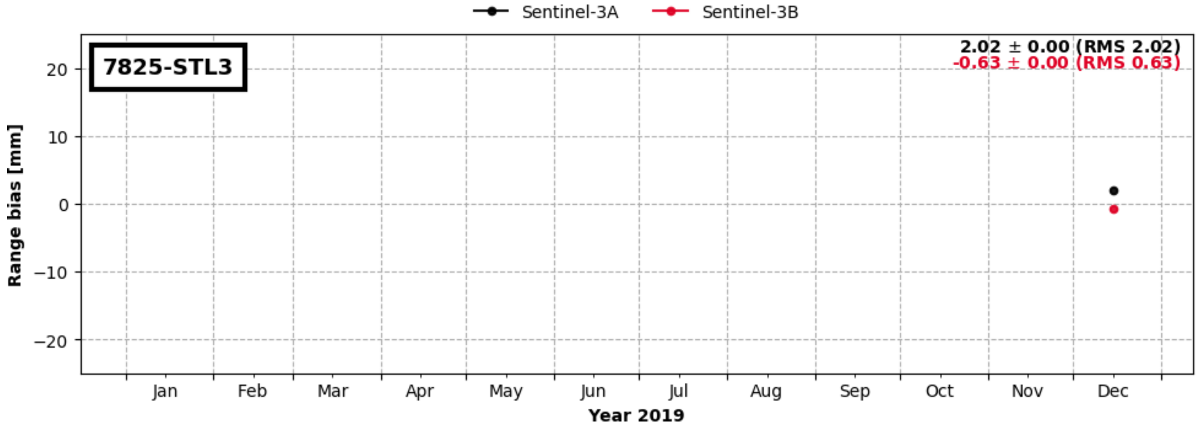

Sentinel-3A
Sentinel-3B
7403-AREL
-0.69 ± 5.22 (RMS 5.26)
1.78 ± 5.18 (RMS 5.47)
Range bias [mm]
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Year 2019

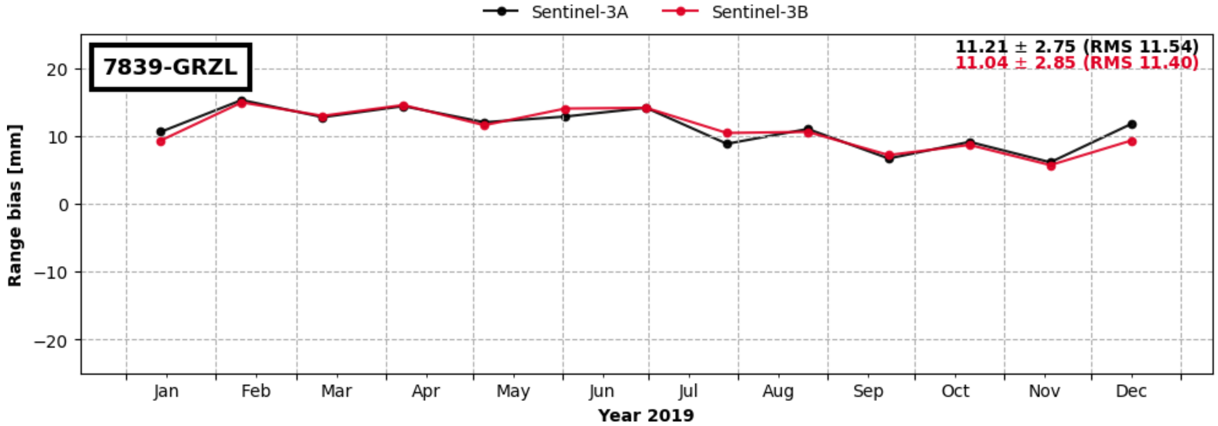

Sentinel-3A
Sentinel-3B
7501-HARL
8.22 ± 1.82 (RMS 8.41)
8.25 ± 1.42 (RMS 8.37)
Range bias [mm]
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Year 2019


Sentinel-3A
Sentinel-3B
7810-ZIML
4.36 ± 2.12 (RMS 4.85)
5.61 ± 0.70 (RMS 5.65)
Range bias [mm]
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Year 2019


Sentinel-3A
Sentinel-3B
7811-BORL
-33.60 ± 10.47 (RMS 35.20)
-30.53 ± 5.11 (RMS 30.96)
Range bias [mm]
Year 2019


Sentinel-3A
Sentinel-3B
7821-SHA2
-9.06 ± 9.34 (RMS 13.01)
-13.30 ± 3.04 (RMS 13.64)
Range bias [mm]
Year 2019


Sentinel-3A
Sentinel-3B
7825-STL3
2.02 ± 0.00 (RMS 2.02)
-0.63 ± 0.00 (RMS 0.63)
Range bias [mm]
Year 2019


Sentinel-3A
Sentinel-3B
7839-GRZL
11.21 ± 2.75 (RMS 11.54)
11.04 ± 2.85 (RMS 11.40)
Range bias [mm]
Year 2019

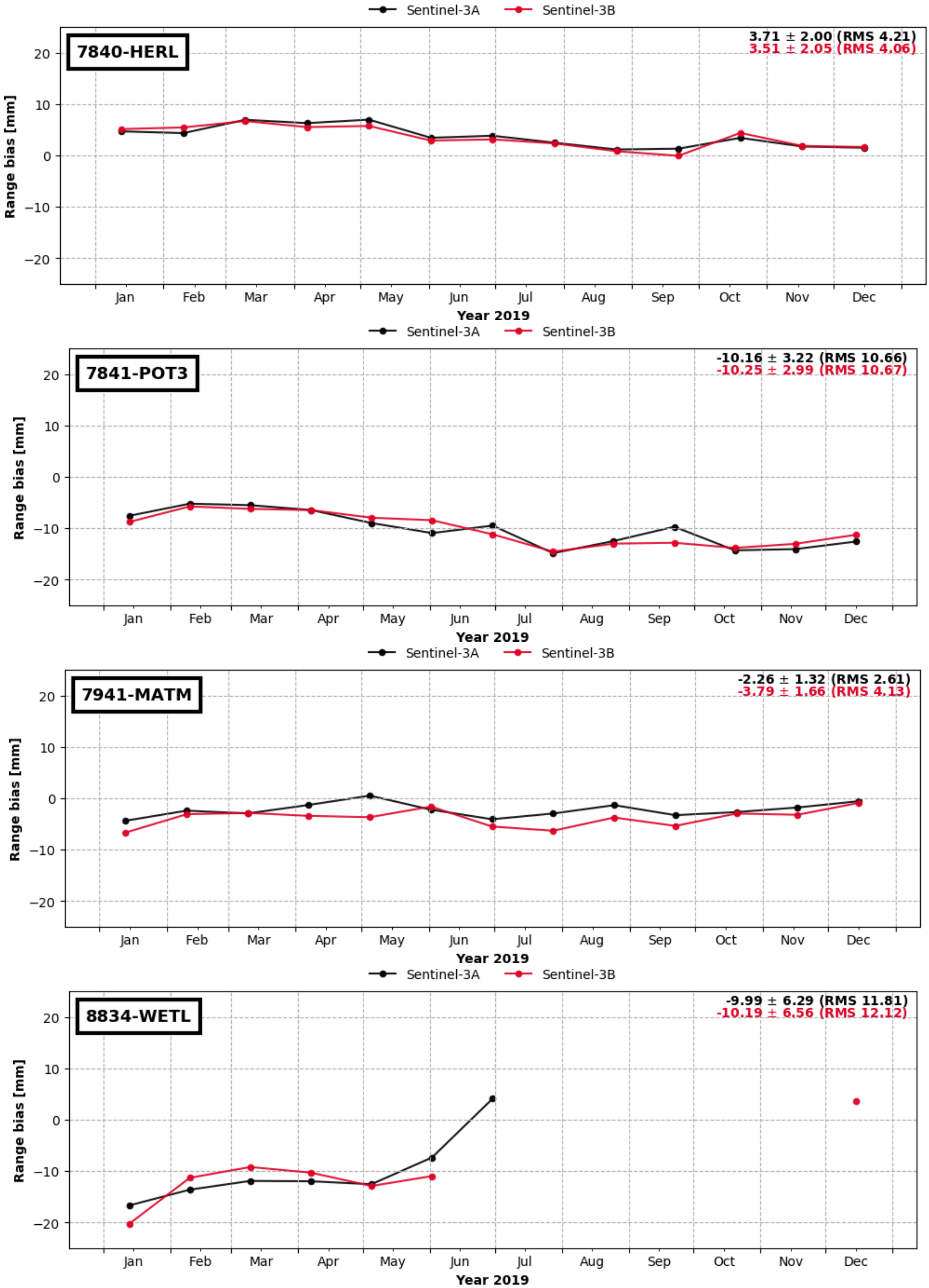


Figure 3-6: Evolution of the range biases [1-range; mm] calculated for each SLR station tracking Sentinel-3A and Sentinel-3B satellites in 2019

The outcome of Figure 3-6 is summarised in the following two figures, where the mean, standard deviation and root mean square statistics of the range biases estimated above are shown. As seen in the figures, the vast majority of the SLR stations obtains statistical figures below 1.5 cm (in absolute value). There are only three SLR stations that present unusual values, which might be caused as a result of a wrong definition of the SLR station coordinates.

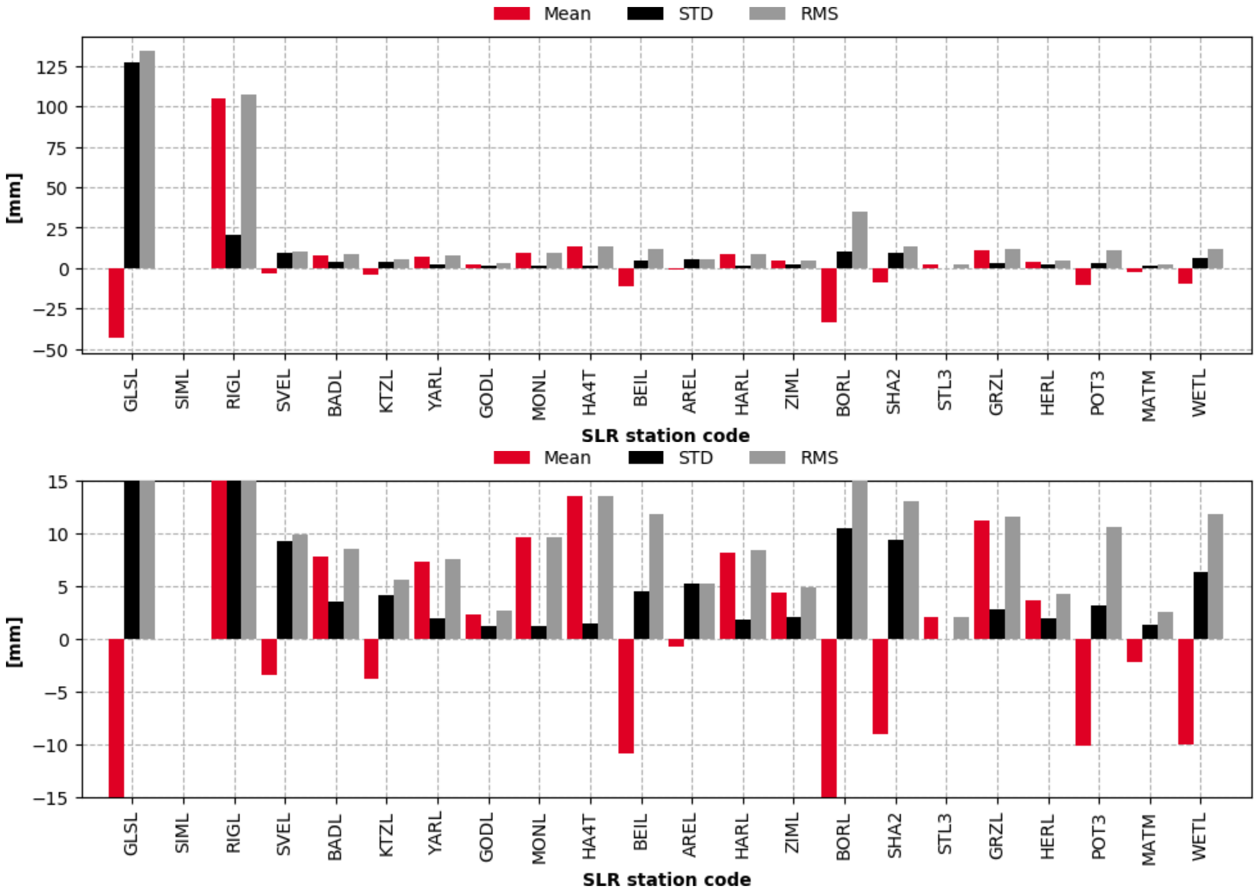
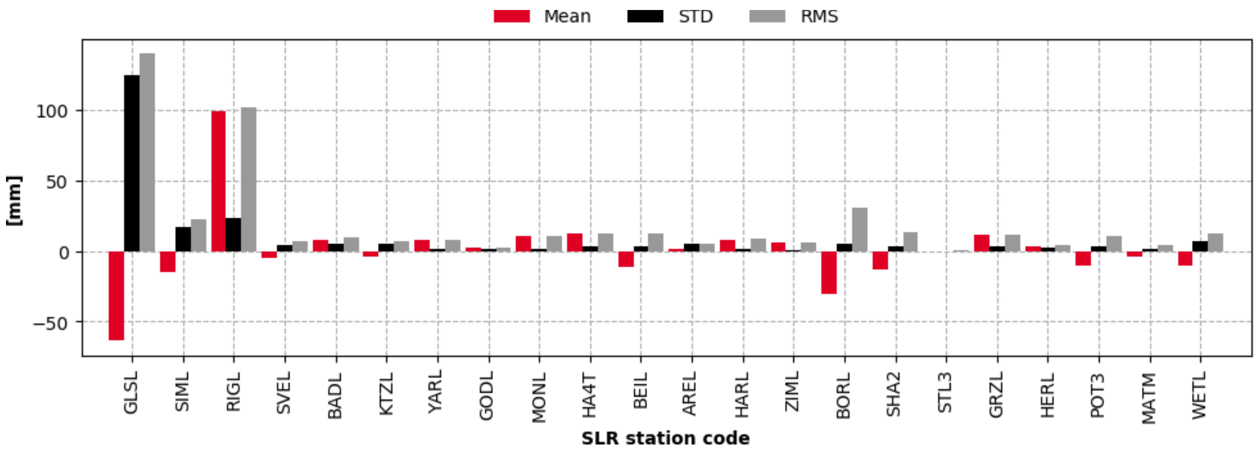


Figure 3-7: Mean, STD and RMS of the Sentinel-3A range biases [1-range; mm] of each SLR station (the figure below is a zoomed-in of the figure above)



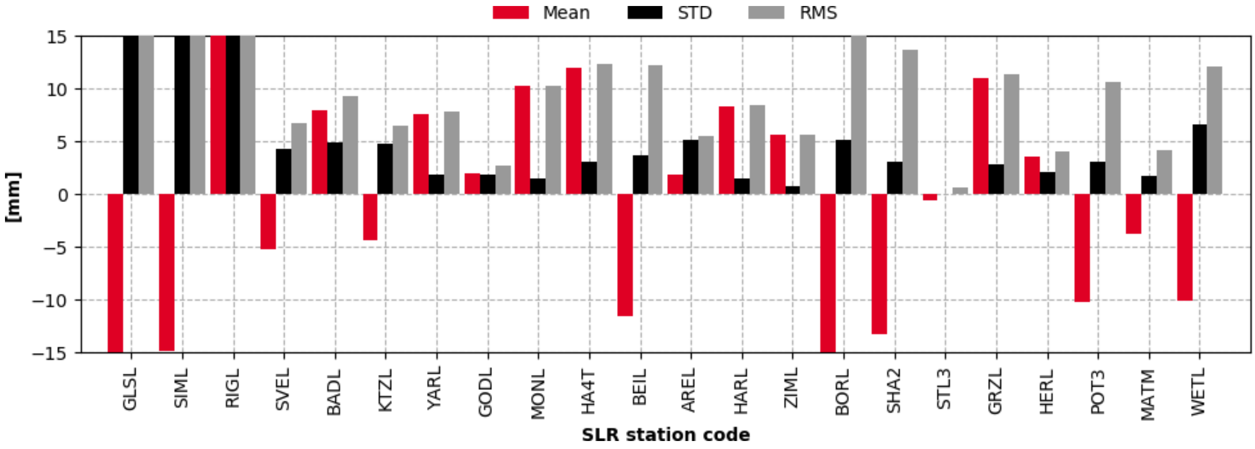


Figure 3-8: Mean, STD and RMS of the Sentinel-3B range biases [1-range; mm] of each SLR station (the figure below is a zoomed-in of the figure above)

Finally, Table 3-4 gathers the mean value of the range biases estimated for each SLR station and Sentinel-3 satellite. These values have been fixed together with the corresponding COMB orbit solution on the processing to retrieve the SLR residuals shown in the following sub section.

Table 3-4: Mean value of the range biases [1-range; mm] of each SLR station tracking Sentinel-3A and Sentinel-3B satellites in 2019 used to calculate the SLR residuals

SLR station		Mean value [mm]	
Monument	Code	Sentinel-3A	Sentinel-3B
1824	GLSL	-43.50	-63.73
1873	SIML	-	-14.91
1884	RIGL	105.20	98.76
1888	SVEL	-3.41	-5.22
1890	BADL	7.77	7.88
1893	KTZL	-3.78	-4.41
7090	YARL	7.31	7.62
7105	GODL	2.34	1.97
7110	MONL	9.61	10.19
7119	HA4T	13.49	12.00
7249	BEIL	-10.91	-11.68
7403	AREL	-0.69	1.78
7501	HARL	8.21	8.25
7810	ZIML	4.36	5.61
7811	BORL	-33.60	-30.53
7821	SHA2	-9.06	-13.30
7825	STL3	2.02	-0.63
7839	GRZL	11.21	11.04
7840	HERL	3.71	3.51
7841	POT3	-10.16	-10.25
7941	MATM	-2.26	-3.79
8834	WETL	-9.99	-10.19

3.3. SLR RESIDUALS PER ORBIT SOLUTION

The aim of this sub section is to validate all orbit solutions provided by the different centres of the QWG. However, this sub section also wants to prove the effect of removing the range biases previously estimated from the calculation of the SLR residuals. Consider removing the biases as fixing them during the extraction of the SLR residuals.

The following figures will depict the SLR residuals obtained per each orbit solution of Table 3-1 and per Sentinel-3 satellite. Each of the plots will contain the SLR residuals before and after having removed the range biases from all SLR stations. Thus, it will be shown the effect of considering these range biases or not. In addition, a filtering criterion has been applied to the calculation of the SLR residuals in order not to harm the final statistics obtained for each orbit solution. If there are white gaps of data on particular days in any plot, it is as a result of missing orbit solutions due to either manoeuvres or gaps of data.

From the analysis of the figures below, it can be said that removing the range biases has a positive effect on the standard deviation and root mean square statistics of all orbit solutions. After having fixed them, all orbit solutions have obtained reduced figures on such statistics. In addition, removing the range biases has led the mean value of the different orbit solutions to alternate more between positive and negative values. Note that the vast majority of the mean values are only positive if the range biases are not fixed.

Therefore, it can be concluded that the validation of the different Sentinel-3 orbit solutions improves if the range biases of the SLR stations are fixed. However, further studies must be done to better locate the origin of the error since possible orbit biases or station coordinate uncertainties are being hidden into the estimation of the range biases.

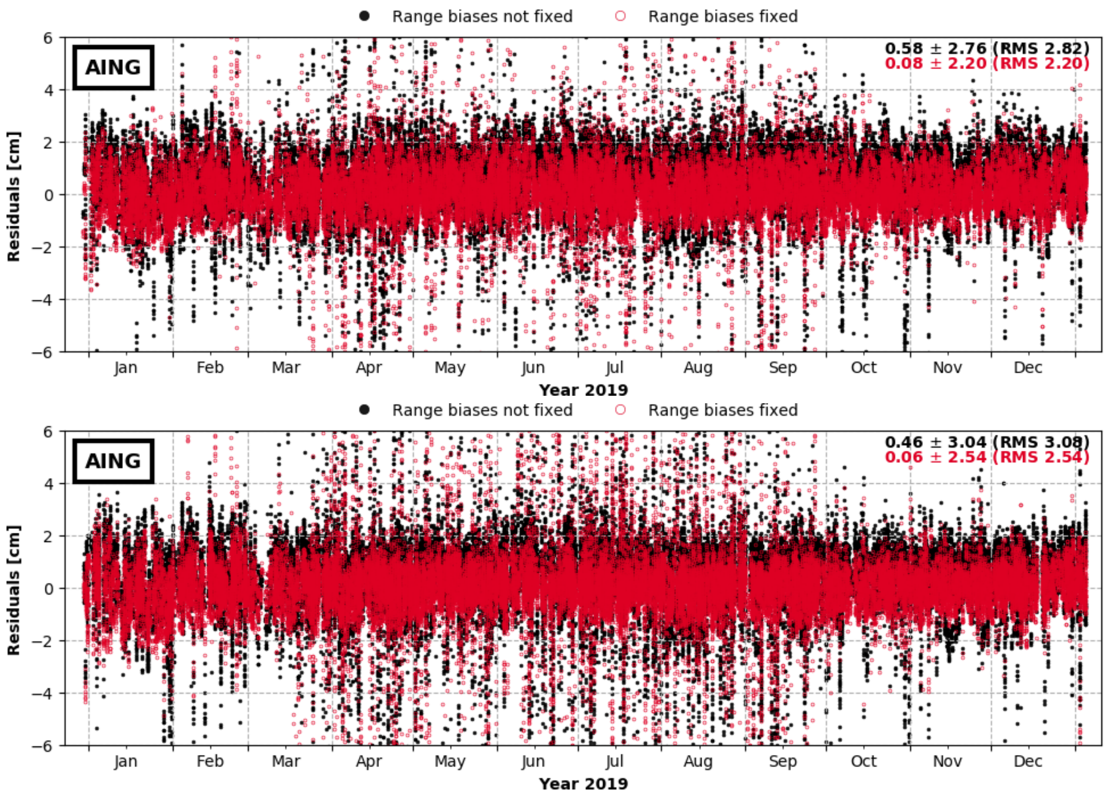


Figure 3-9: SLR observation residuals [1-range; cm] obtained for AING orbit solution in 2019 (above Sentinel-3A, and below Sentinel-3B)

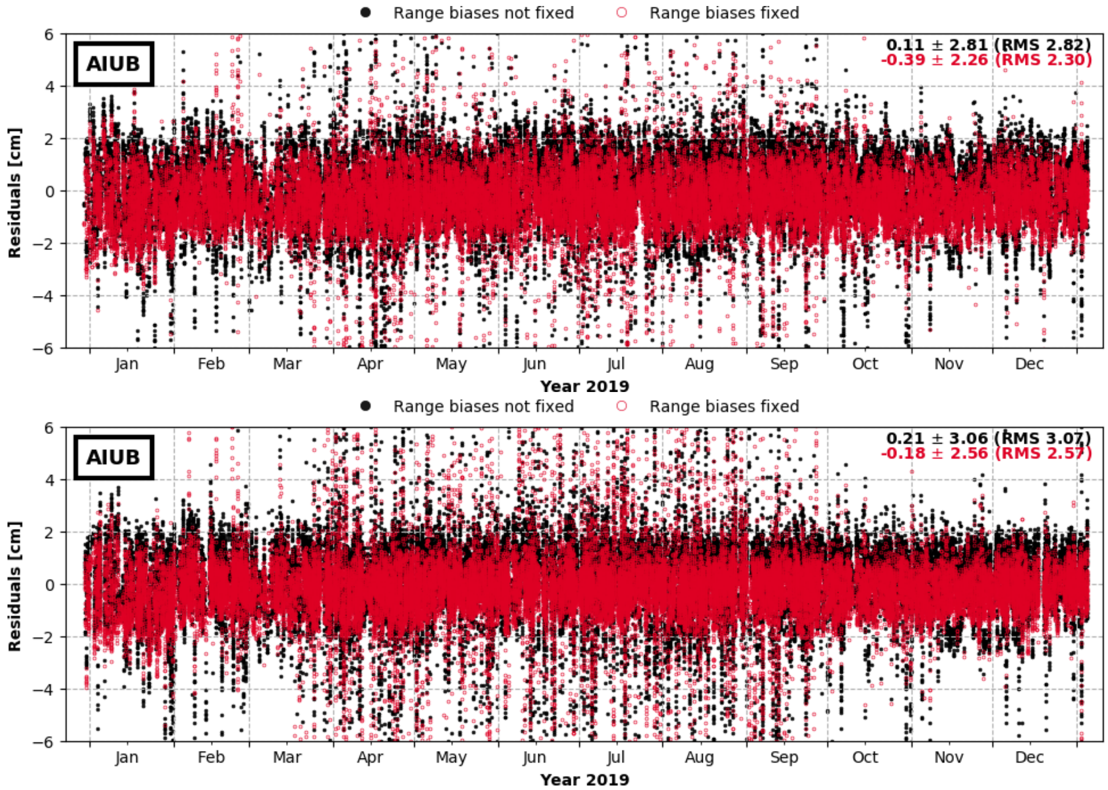


Figure 3-10: SLR observation residuals [1-range; cm] obtained for AIUB orbit solution in 2019 (above Sentinel-3A, and below Sentinel-3B)

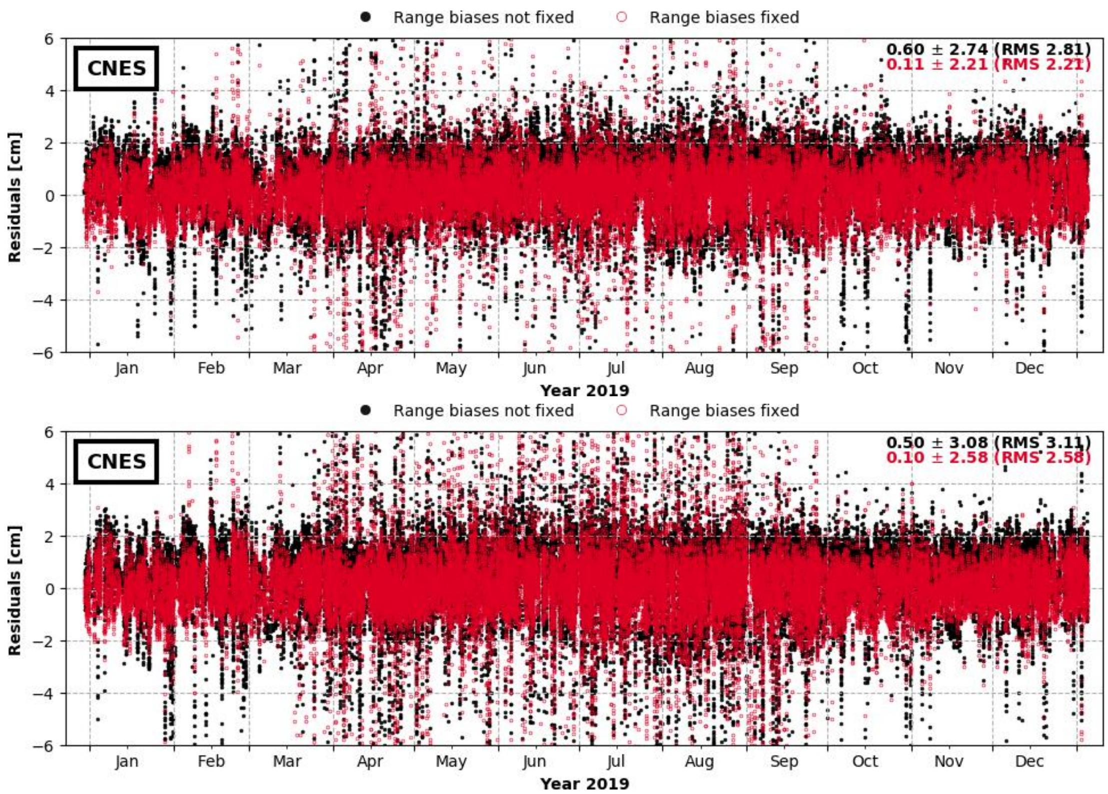


Figure 3-11: SLR observation residuals [1-range; cm] obtained for CNES orbit solution in 2019 (above Sentinel-3A, and below Sentinel-3B)

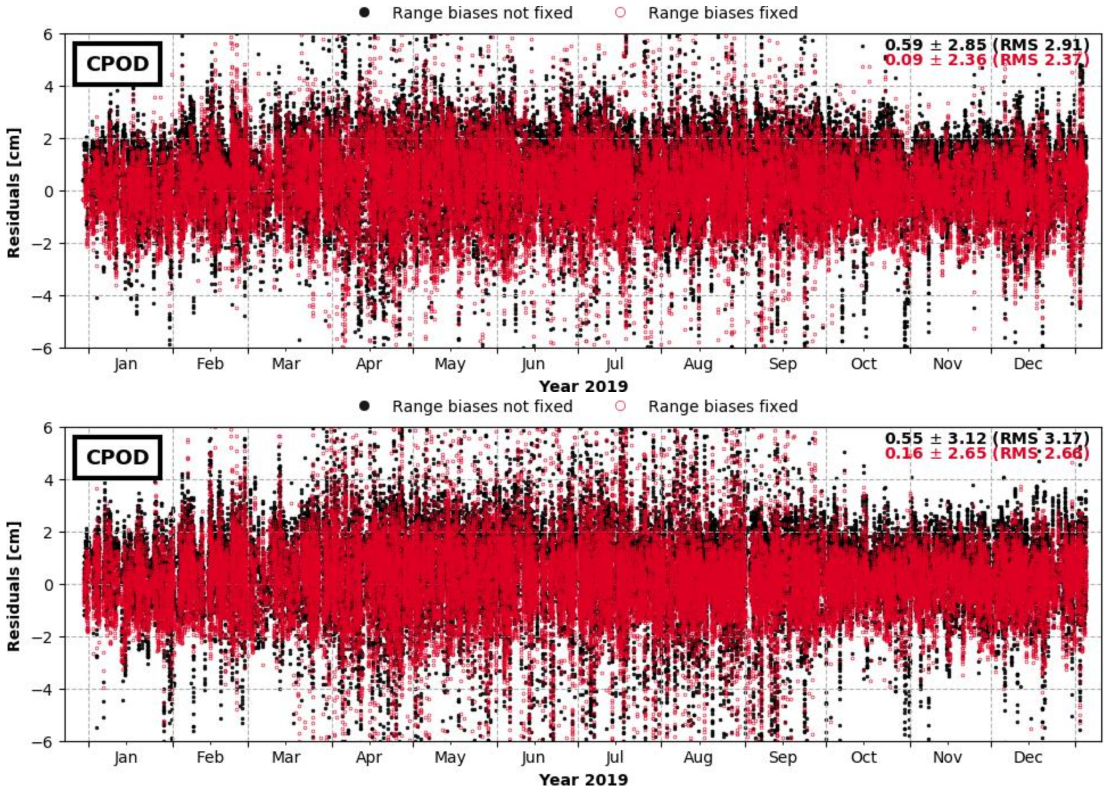


Figure 3-12: SLR observation residuals [1-range; cm] obtained for CPOD orbit solution in 2019 (above Sentinel-3A, and below Sentinel-3B)

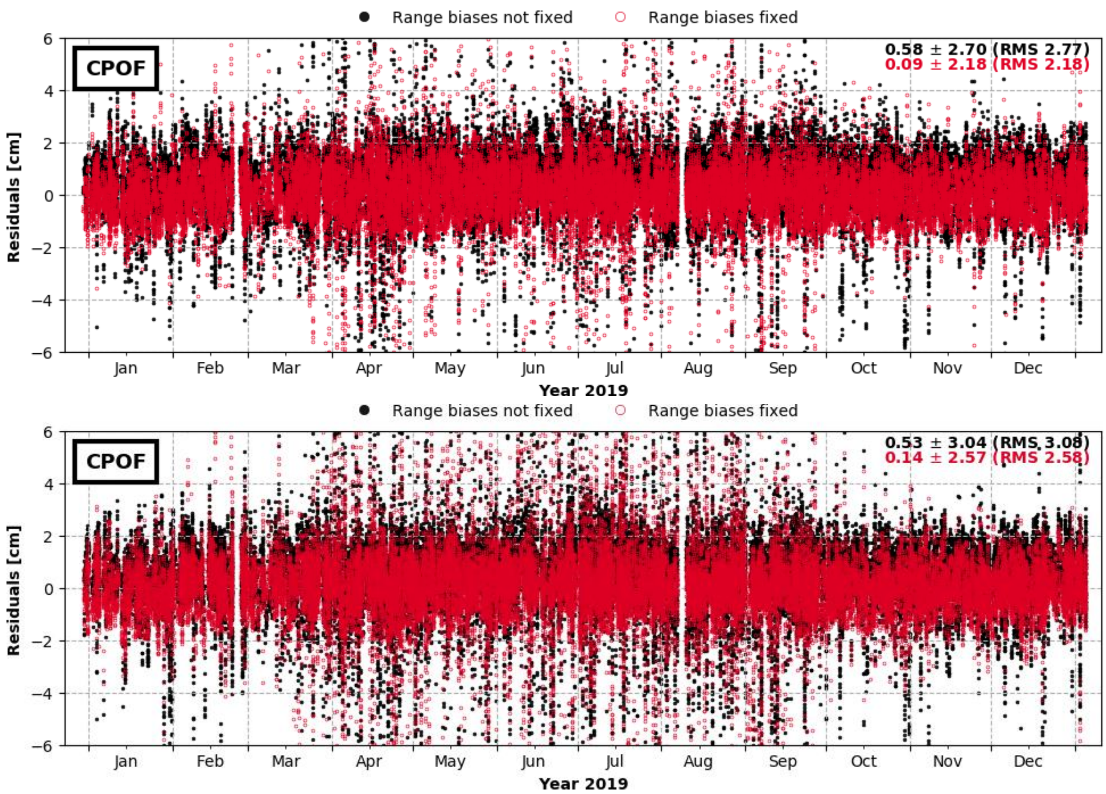


Figure 3-13: SLR observation residuals [1-range; cm] obtained for CPOF orbit solution in 2019 (above Sentinel-3A, and below Sentinel-3B)

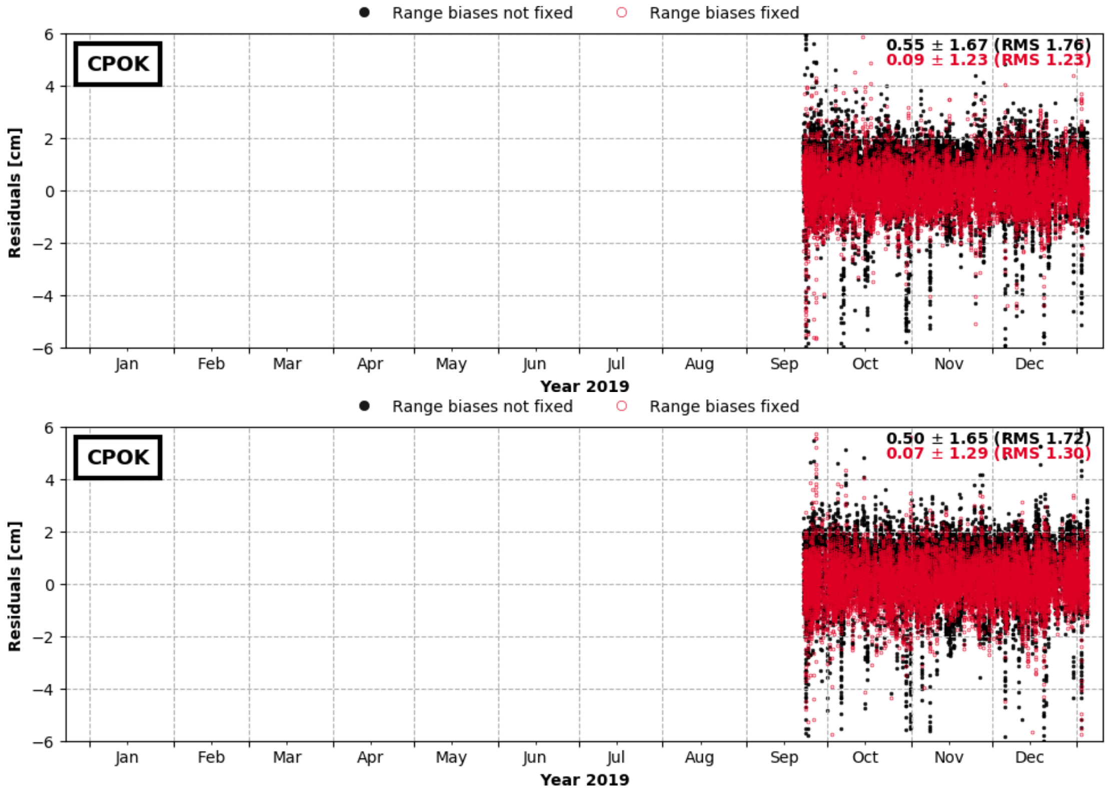


Figure 3-14: SLR observation residuals [1-range; cm] obtained for CPOK orbit solution in 2019 (above Sentinel-3A, and below Sentinel-3B)

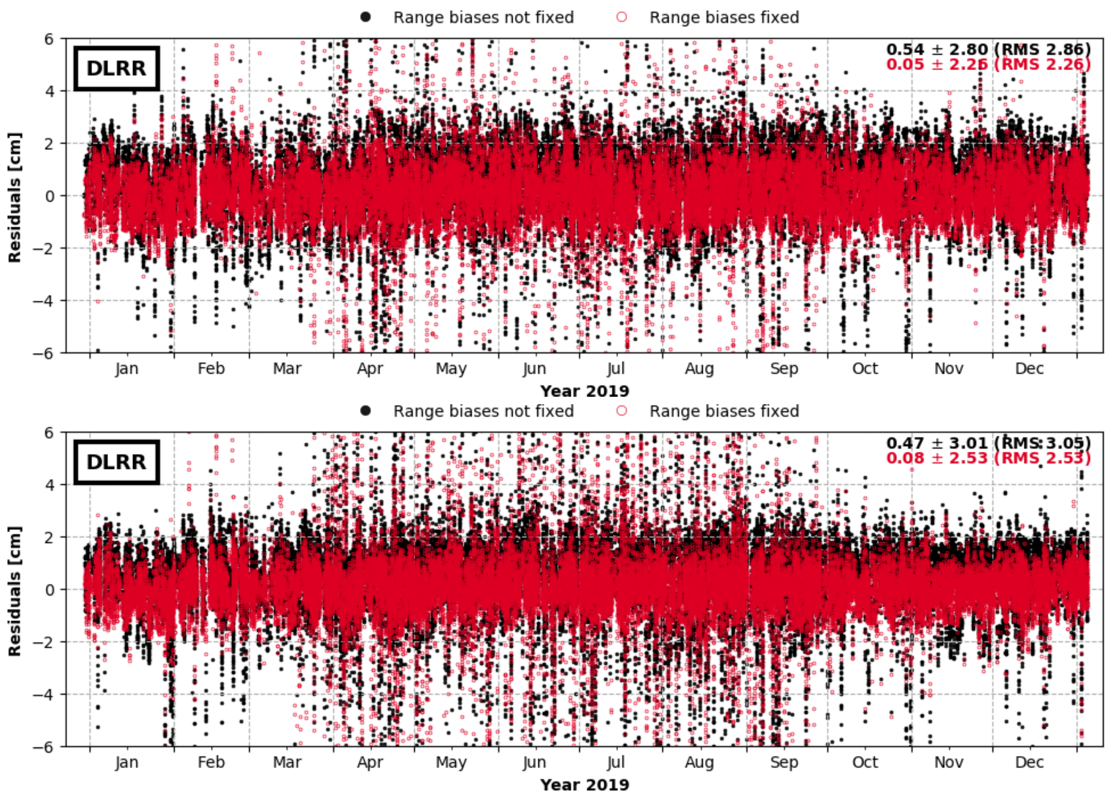


Figure 3-15: SLR observation residuals [1-range; cm] obtained for DLRR orbit solution in 2019 (above Sentinel-3A, and below Sentinel-3B)

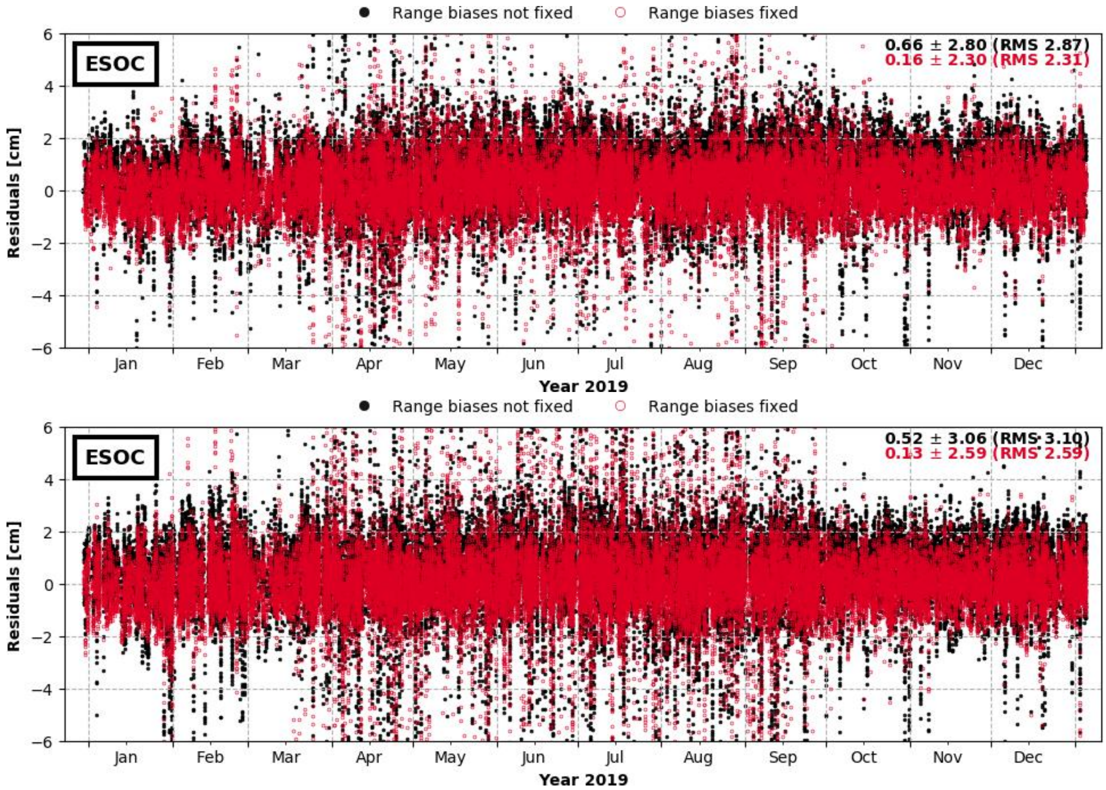


Figure 3-16: SLR observation residuals [1-range; cm] obtained for ESOC orbit solution in 2019 (above Sentinel-3A, and below Sentinel-3B)

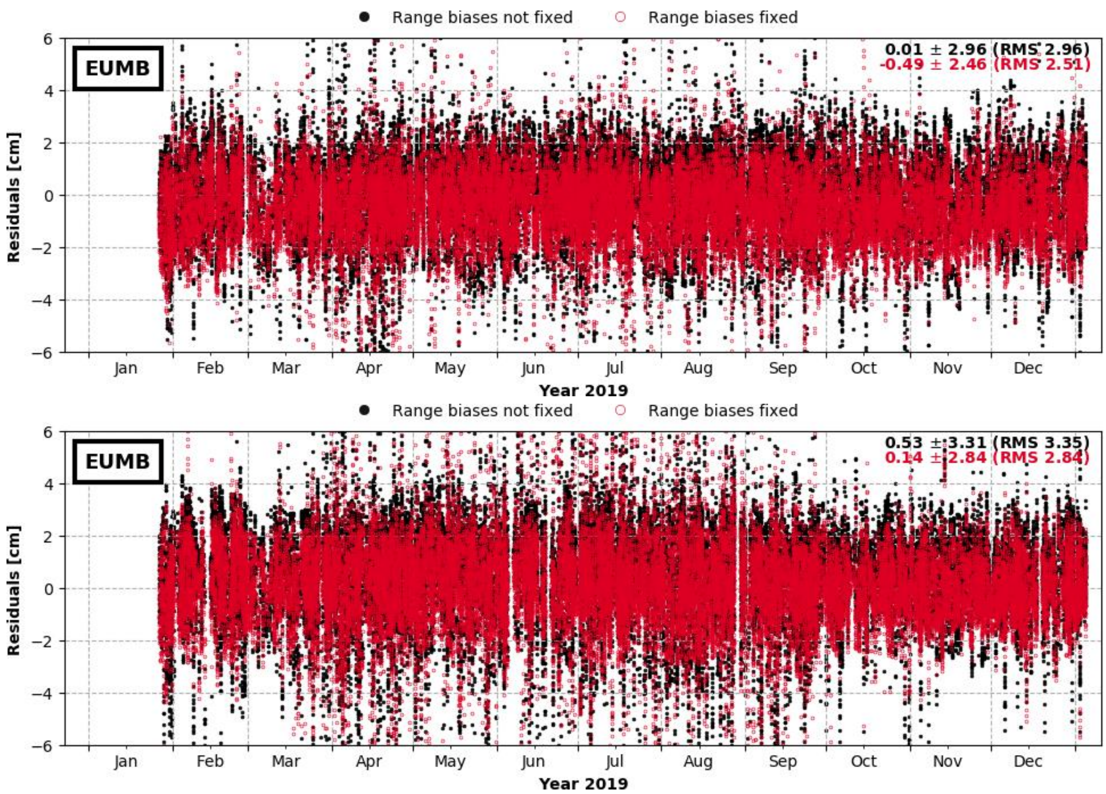


Figure 3-17: SLR observation residuals [1-range; cm] obtained for EUMB orbit solution in 2019 (above Sentinel-3A, and below Sentinel-3B)

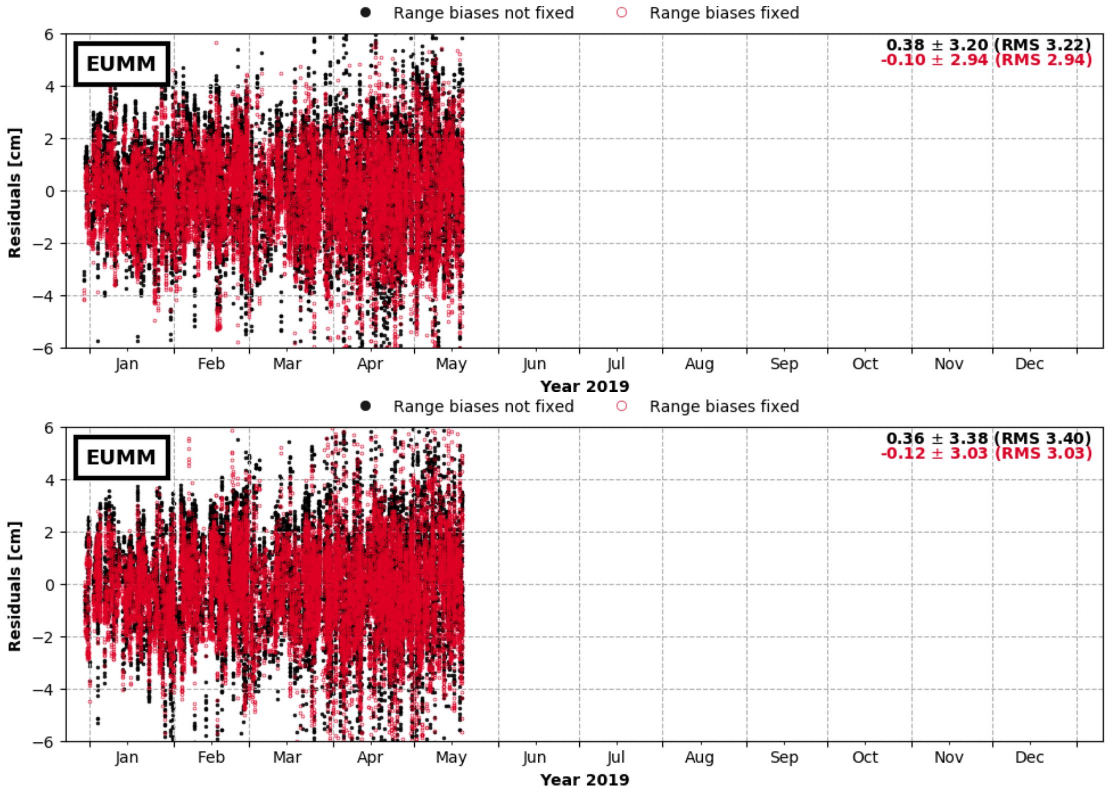


Figure 3-18: SLR observation residuals [1-range; cm] obtained for EUMM orbit solution in 2019 (above Sentinel-3A, and below Sentinel-3B)

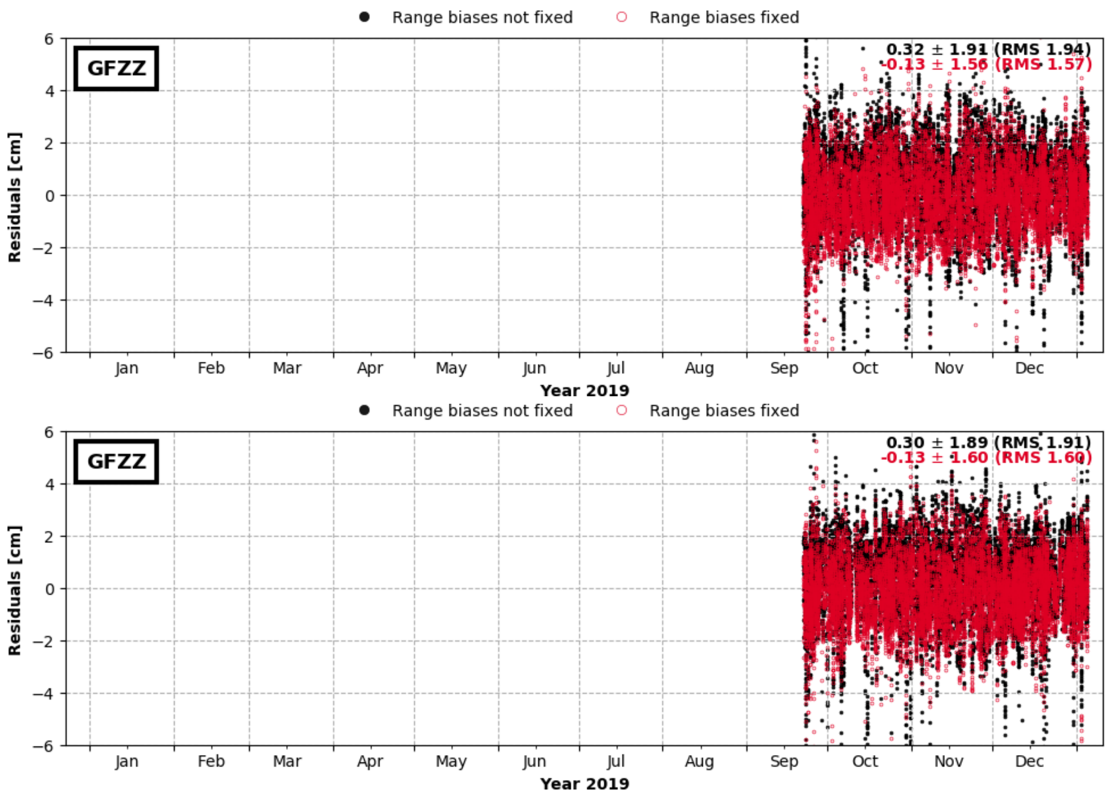


Figure 3-19: SLR observation residuals [1-range; cm] obtained for GFZZ orbit solution in 2019 (above Sentinel-3A, and below Sentinel-3B)

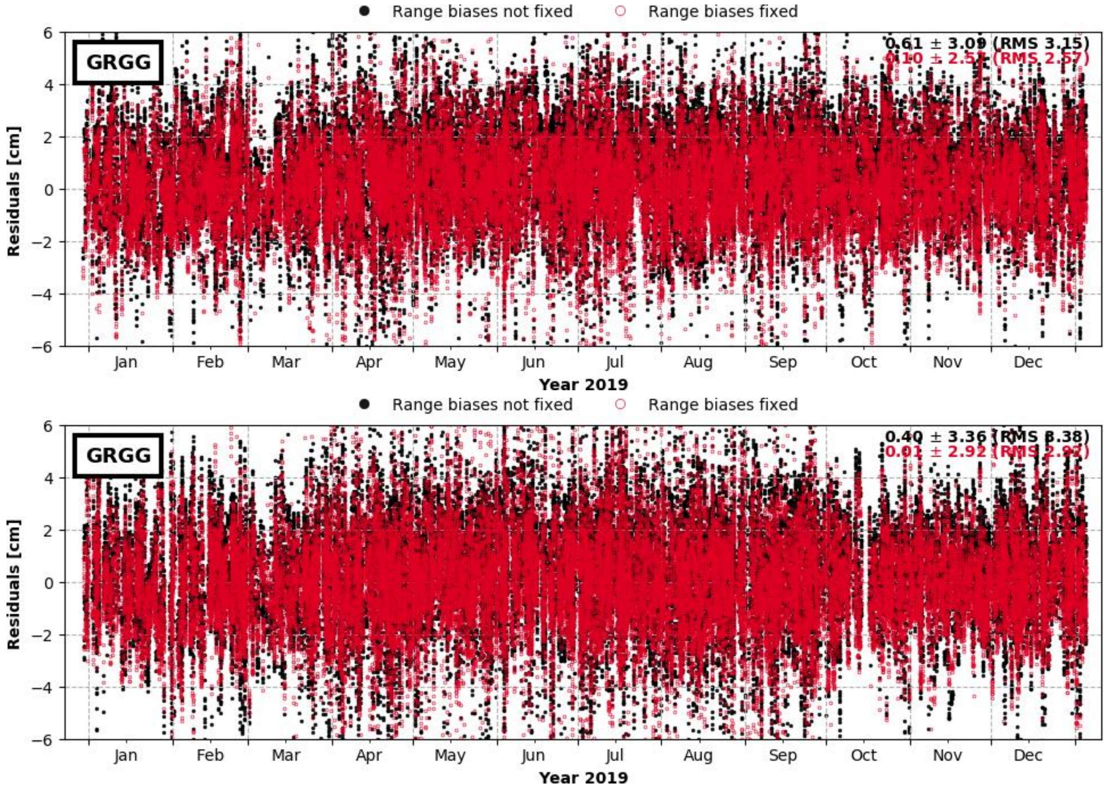


Figure 3-20: SLR observation residuals [1-range; cm] obtained for GRGG orbit solution in 2019 (above Sentinel-3A, and below Sentinel-3B)

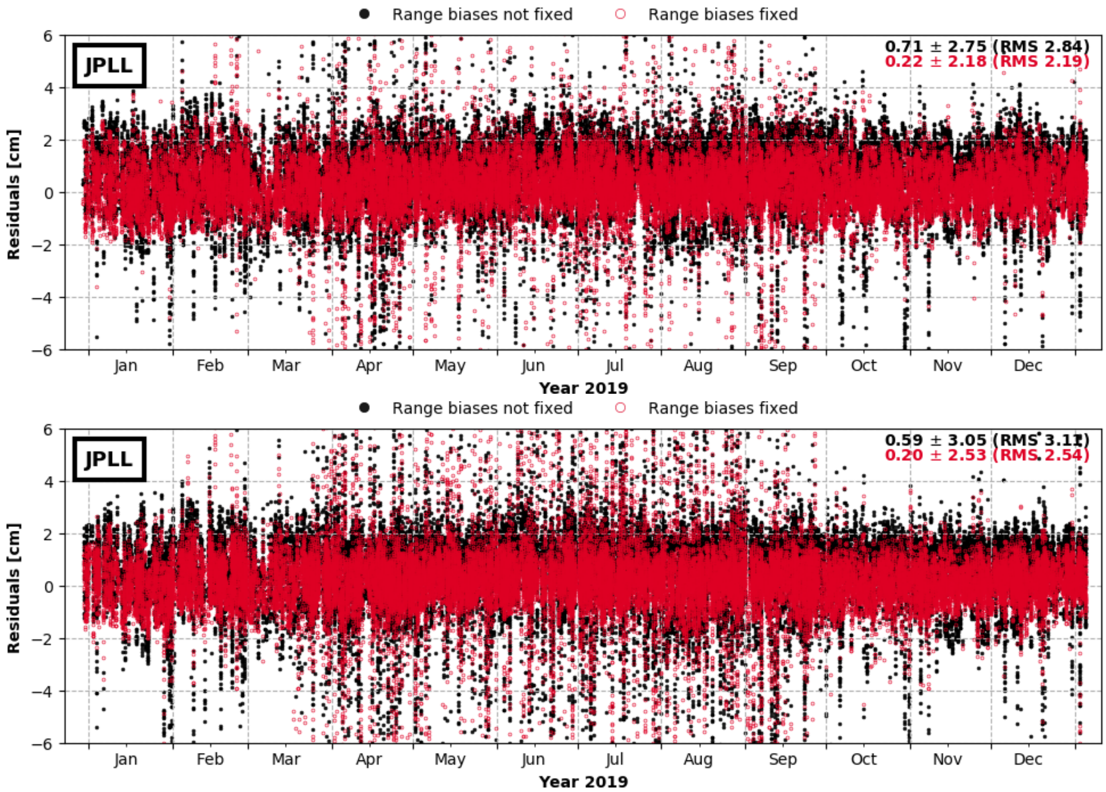


Figure 3-21: SLR observation residuals [1-range; cm] obtained for JPLL orbit solution in 2019 (above Sentinel-3A, and below Sentinel-3B)

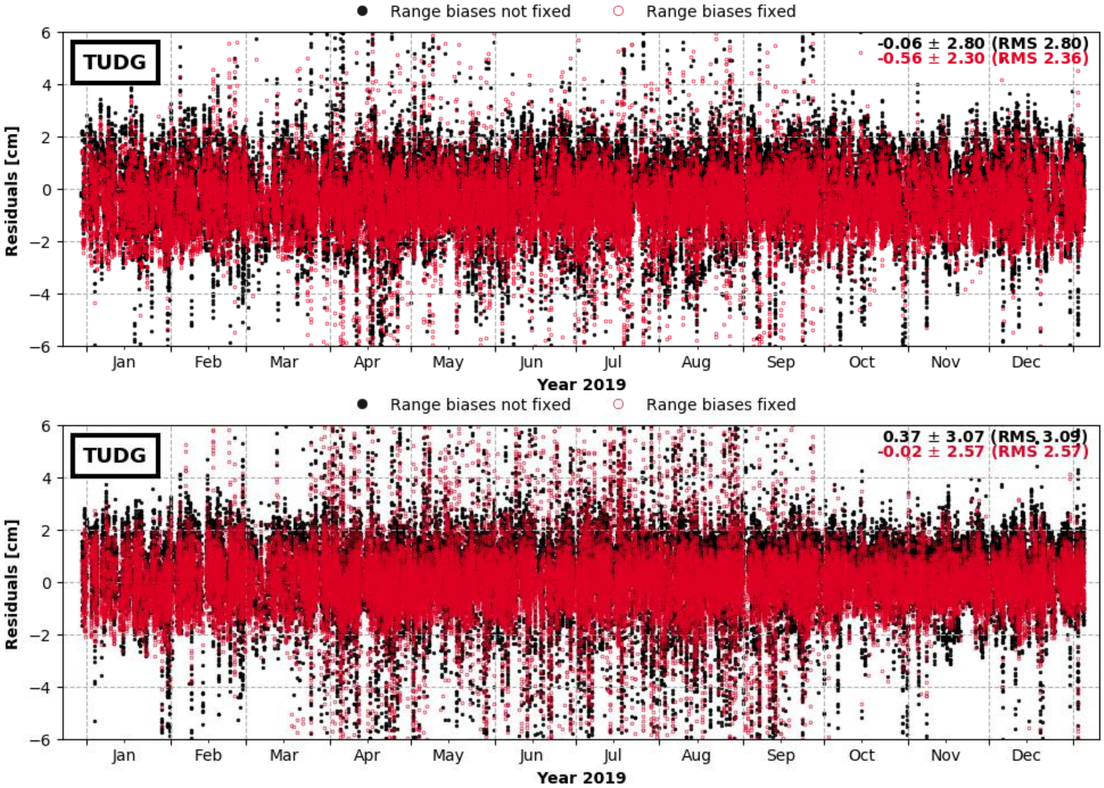


Figure 3-22: SLR observation residuals [1-range; cm] obtained for TUDG orbit solution in 2019 (above Sentinel-3A, and below Sentinel-3B)

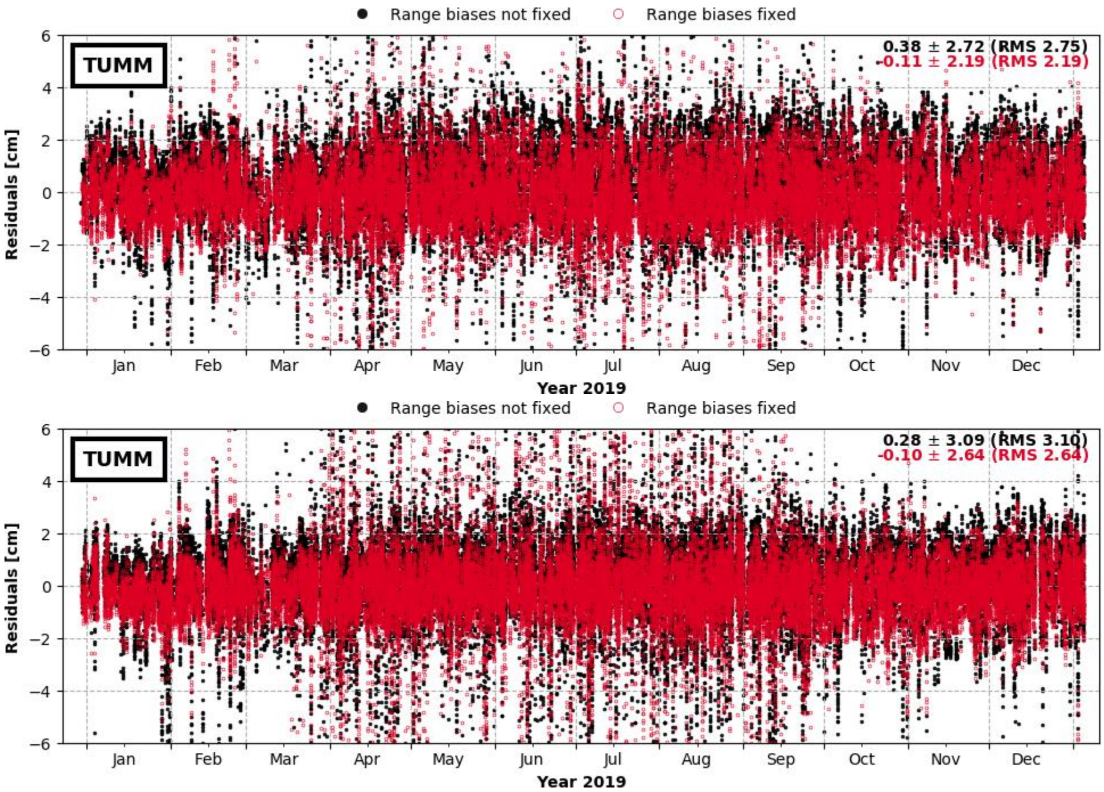


Figure 3-23: SLR observation residuals [1-range; cm] obtained for TUMM orbit solution in 2019 (above Sentinel-3A, and below Sentinel-3B)

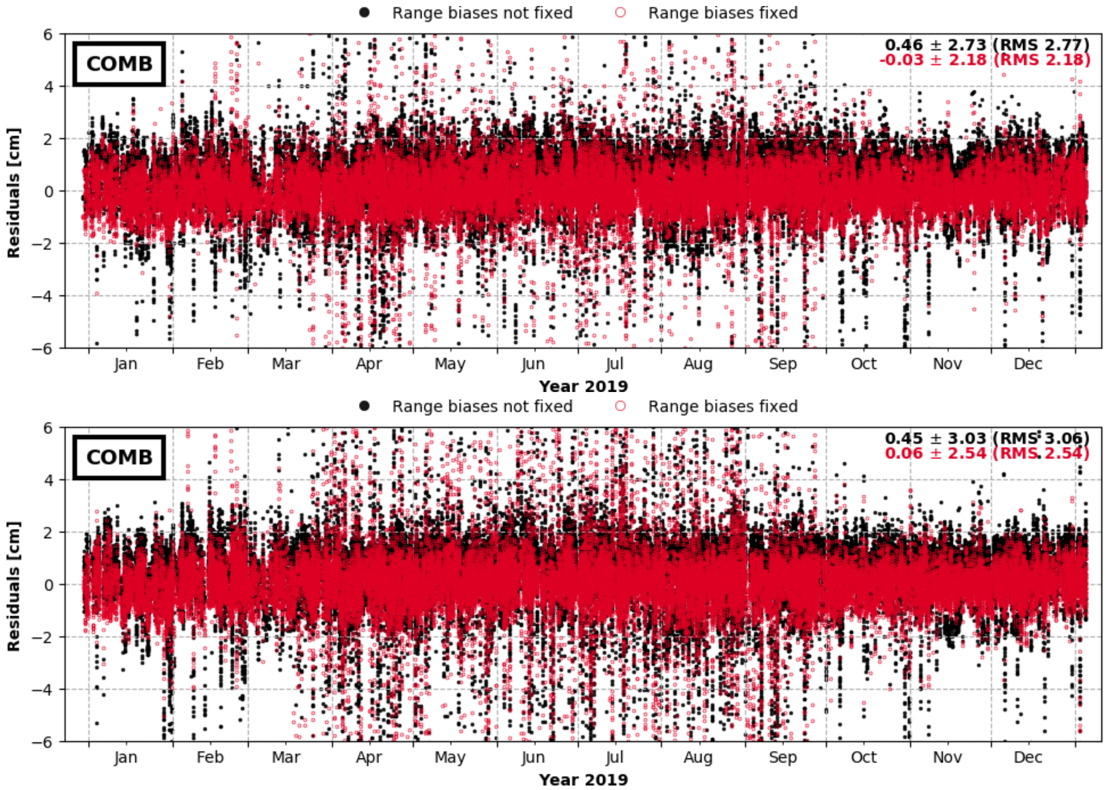
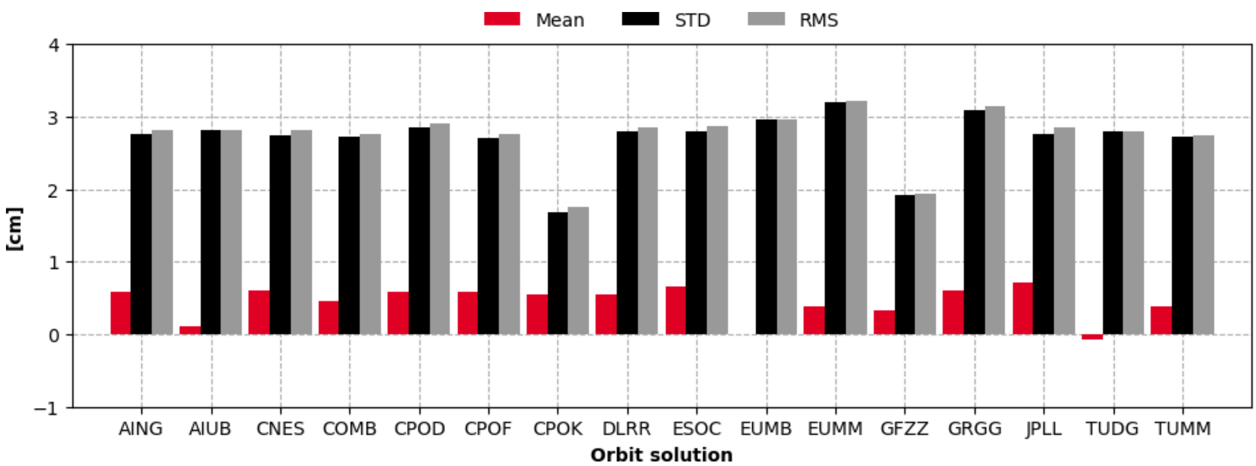


Figure 3-24: SLR observation residuals [1-range; cm] obtained for COMB orbit solution in 2019 (above Sentinel-3A, and below Sentinel-3B)

Finally, the information of the SLR residuals presented above has been summarised in the following two figures and Table 3-5 by showing the mean, standard deviation and root mean square statistics altogether per Sentinel-3 satellite.

A seen from the figures below, the obtained standard deviation and root mean square values remain between 2 and 3 cm for all orbit solutions, except for the CPOK and GFZZ orbit solutions. Indeed, these orbit solutions have not provided orbit solutions for the entire time period, which might be the root cause of these reduced statistical values.

One can find validation studies with more precision in the outcome in [RD.2] and [RD.3], where only a subset of all SLR stations studied within this section has been used. These studies present statistical figures below 1 cm both on the standard deviation and root mean square values.



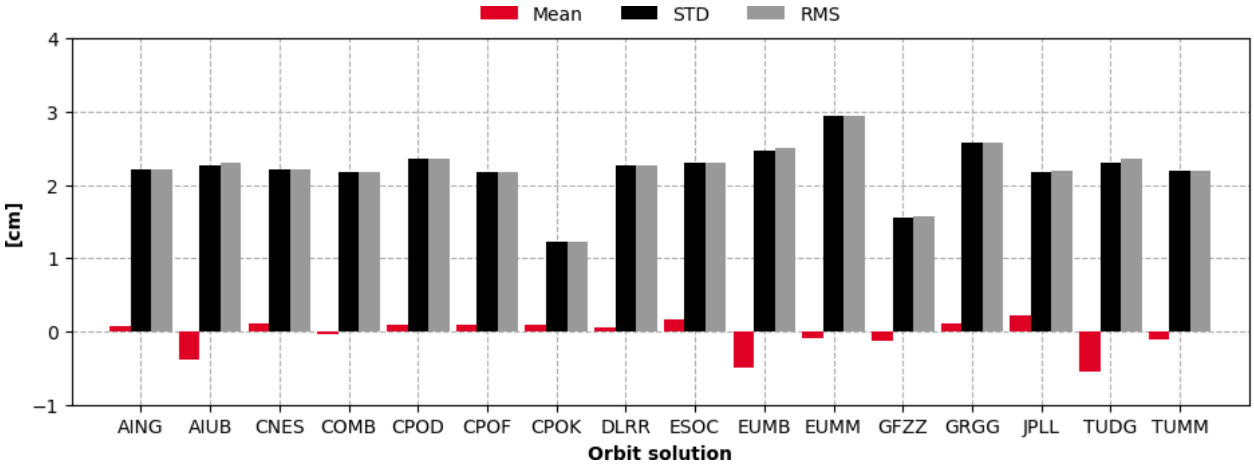


Figure 3-25: Mean, STD and RMS of the Sentinel-3A SLR observation residuals [1-range; cm] from all orbit solutions in 2019 (above the range biases have not been fixed, below the range biases have been fixed)

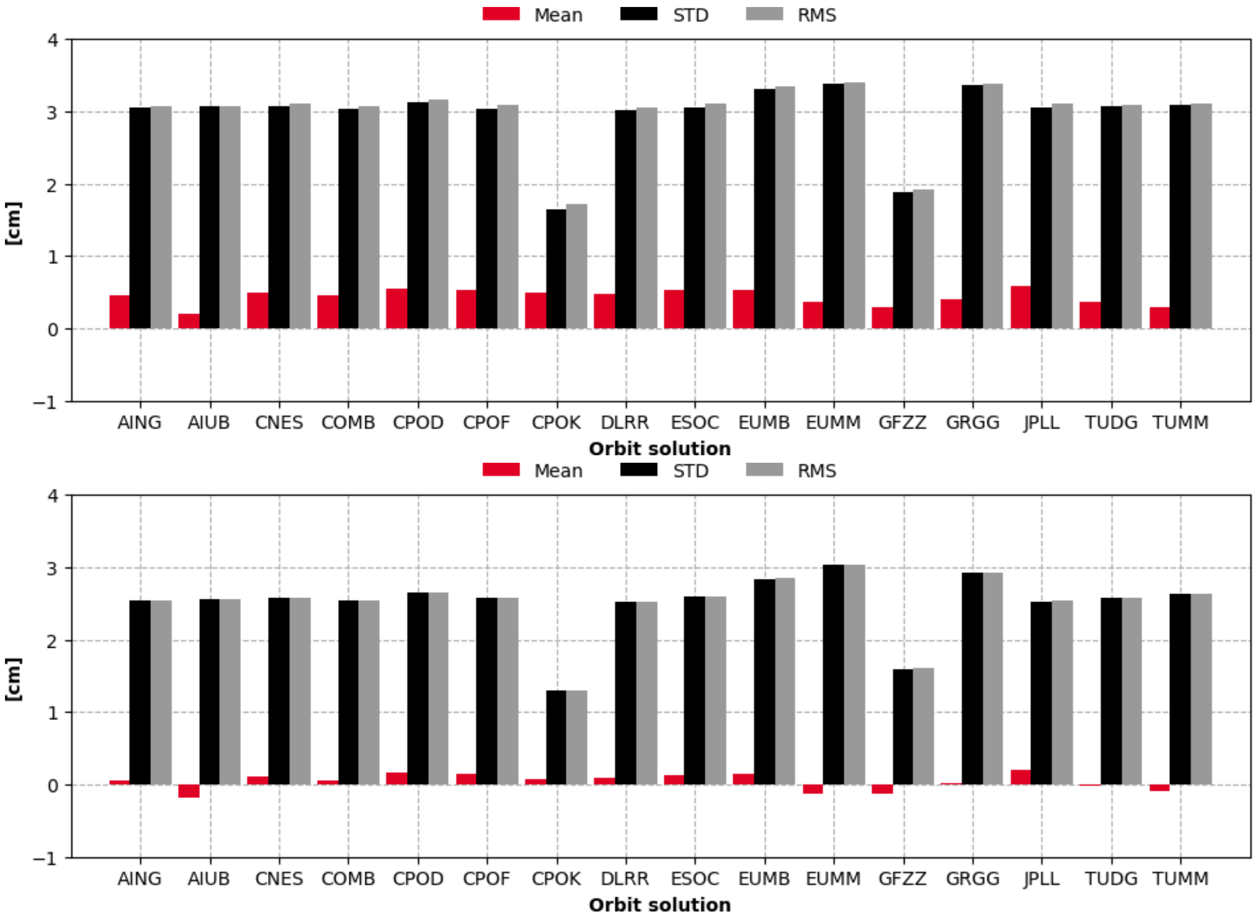


Figure 3-26: Mean, STD and RMS of the Sentinel-3B SLR observation residuals [1-range; cm] from all orbit solutions in 2019 (above the range biases have not been fixed, below the range biases have been fixed)

Finally, all the statistics of the sub section have been gathered in Table 3-5.

Table 3-5: Summary of the mean, STD and RMS of the Sentinel-3A and Sentinel-3B SLR observation residuals [1-range; cm] obtained from all orbit solutions in 2019

Orbit solution	Sentinel-3A [1-range; cm]						Sentinel-3B [1-range; cm]					
	Mean		STD		RMS		Mean		STD		RMS	
	Range biases not fixed	Range biases fixed	Range biases not fixed	Range biases fixed	Range biases not fixed	Range biases fixed	Range biases not fixed	Range biases fixed	Range biases not fixed	Range biases fixed	Range biases not fixed	Range biases fixed
AING	0.58	0.08	2.76	2.20	2.82	2.20	0.46	0.06	3.04	2.54	3.08	2.54
AIUB	0.11	-0.39	2.81	2.26	2.82	2.30	0.21	-0.18	3.06	2.56	3.07	2.57
CNES	0.60	0.11	2.74	2.21	2.81	2.21	0.50	0.10	3.08	2.58	3.11	2.58
CPOD	0.59	0.09	2.85	2.36	2.91	2.37	0.55	0.16	3.12	2.65	3.17	2.66
CPOF	0.58	0.09	2.70	2.18	2.77	2.18	0.53	0.14	3.04	2.57	3.08	2.58
CPOK	0.55	0.09	1.67	1.23	1.76	1.23	0.50	0.07	1.65	1.29	1.72	1.30
DLRR	0.54	0.05	2.80	2.26	2.86	2.26	0.47	0.08	3.01	2.53	3.05	2.53
ESOC	0.66	0.16	2.80	2.30	2.87	2.31	0.52	0.13	3.06	2.59	3.10	2.59
EUMB	0.01	-0.49	2.96	2.46	2.96	2.51	0.53	0.14	3.31	2.84	3.35	2.84
EUMM	0.38	-0.10	3.20	2.94	3.22	2.94	0.36	-0.12	3.38	3.03	3.40	3.03
GFZZ	0.32	-0.13	1.91	1.56	1.94	1.57	0.30	-0.13	1.89	1.60	1.91	1.60
GRGG	0.61	0.10	3.09	2.57	3.15	2.57	0.40	0.01	3.36	2.92	3.38	2.92
JPLL	0.71	0.22	2.75	2.18	2.84	2.19	0.59	0.20	3.05	2.53	3.11	2.54
TUDG	-0.06	-0.56	2.80	2.30	2.80	2.36	0.37	-0.02	3.07	2.57	3.09	2.57
TUMM	0.38	-0.11	2.72	2.19	2.75	2.19	0.28	-0.10	3.09	2.64	3.10	2.64
COMB	0.46	-0.03	2.73	2.18	2.77	2.18	0.45	0.06	3.03	2.54	3.06	2.54

4. ANALYSIS OF THE SLR DATA PER SLR STATION

This section is intended to address the performance of each SLR station that has tracked the Sentinel-3 satellites during the year 2019. To evaluate such performance the Sentinel-3 COMB orbit solutions (calculated on the previous section) and the SLR observations provided by the SLR stations during 2019 will be used. The station coordinates used can be found in Table 7-1 of the annex.

Some plots shown in past sections will be presented again within this section but considering the statistics of a single SLR station instead of the whole set of SLR stations. In addition, some statistics related to the SLR residuals per SLR station will also be shown. Keep in mind that the SLR residuals are the result of the difference between the SLR observations derived from an orbit solution (in the case of the study the COMB orbit solution) and the SLR observations provided by the SLR stations themselves.

The following bullet points summarise all data presented within this section:

- A table gathering some processing statistics (e.g., satellite passes, number of observations processed or filtered out, activity of the SLR station, etc.).
- Two figures showing the temporal evolution of the satellite passes of the SLR station (one for the entire mission, and the other for the time period evaluated).
- The evolution on the number of accepted SLR observations during the time period evaluated.
- Figures presenting the daily mean, standard deviation and root mean square of the SLR residuals during the time period evaluated.

All figures shown within this section will be depicted containing data of both Sentinel-3 satellites, and, whenever possible, taking into account the removal or not of the range biases calculated on the previous section (see values in Table 3-4). The analysis will include a few more days at the beginning and end of the year 2019 in order to complete GPS weeks. Therefore, the time period evaluated will start on 30th December 2018 and will end on 4th January 2020 (i.e., a total of 371 days).

Finally, the last sub section will summarise some of the individual statistics presented within this section.

4.1. SLR STATION 1824 (GLSL)

Table 4-1: Summary of the processing statistics of the SLR station 1824 (GLSL)

		Sentinel-3A	Sentinel-3B	Jason3
Number of satellite passes (*.npt* files)	All mission	146	96	187
	"Year 2019" (20340-20866)	70	69	70
Days processed(*)	Total	366	366	-
Active days	Total	59	58	-
	% (w.r.t. the total days processed)	16.12 %	15.85 %	-
Number of satellite passes processed	Total	70	69	-
	% (w.r.t. the *.npt* files)	100.00 %	100.00 %	-
Number of observations processed	Total	544	604	-
Number of observations per satellite pass	Mean	7.77	8.75	-
Number of observations filtered out	Total	5	28	-
	% (w.r.t. the total obs. processed)	0.92 %	4.64 %	-

(*) The total number of days processed does not coincide with the total number of days evaluated in "year 2019" (i.e., 371 days) since the combined orbit solution has not been generated on a few days as a result of either long manoeuvres or large gaps of data or other issues.

The SLR station Golosiiv (1824 - GLSL) has been active (i.e., providing daily SLR observations of the Sentinel-3 satellites) during ~16 % of the time period evaluated for both Sentinel-3 satellites. From a general overview, the GLSL station has similarly tracked the Sentinel-3 satellites since similar figures have been obtained on all the fields of Table 4-1. A mean value of ~8-9 SLR observations per satellite pass and a significant number of filtered-out SLR observations (especially on the Sentinel-3B satellite case) are also points to be highlighted of the GLSL station. The first point reveals a medium-low tracking value (considering this same value of other SLR stations), and the second point might lead to some station misconfiguration during the processing of the GLSL observations.

From Figure 4-1 and Figure 4-2, the following issues of GLSL station can be identified: (a) the station shows a seasonal pattern, (b) the station has increased the number of Sentinel-3 passes during this time period evaluated, and (c) there are almost no tracking differences between the Sentinel-3 and Jason-3 satellites despite the different orbit altitudes they have.

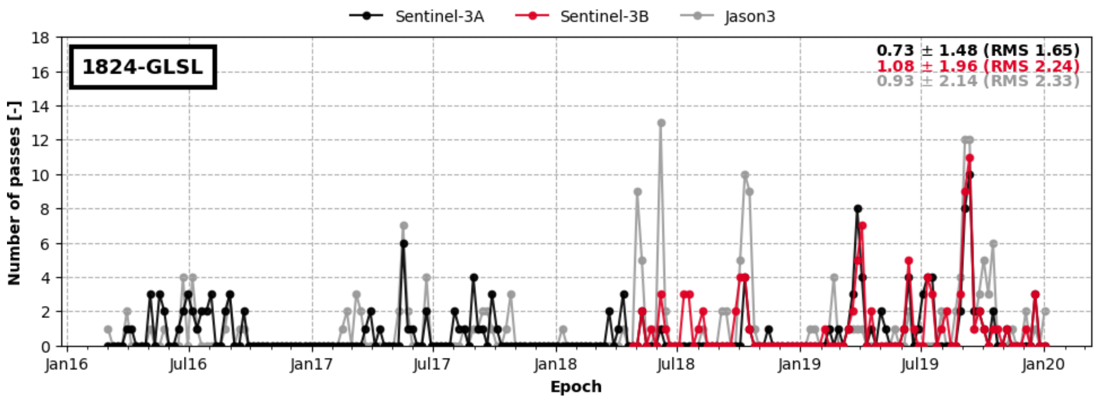


Figure 4-1: Total number of satellite passes per GPS week of the SLR station 1824 (GLSL) since the beginning of the satellite mission (Sentinel-3A, Sentinel-3B and Jason-3)

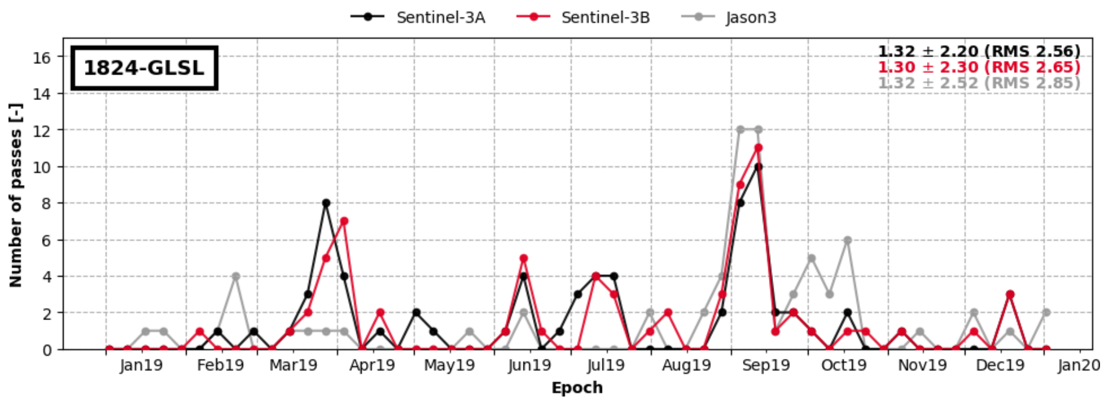


Figure 4-2: Total number of satellite passes per GPS week of the SLR station 1824 (GLSL) in 2019 (Sentinel-3A, Sentinel-3B and Jason-3)

If the total number of observations and the statistics of the residuals are addressed, the GLSL station shows an irregular pattern during 2019. The SLR observations are more concentrated at the end of March and during September, being this last month the time interval where the SLR observations seem to be more reliable. From the figures below, it can be seen that the best statistics on the SLR residuals are achieved during September. The rest of the months show more dispersive statistics, which increases the difficulty of drawing conclusions from them.

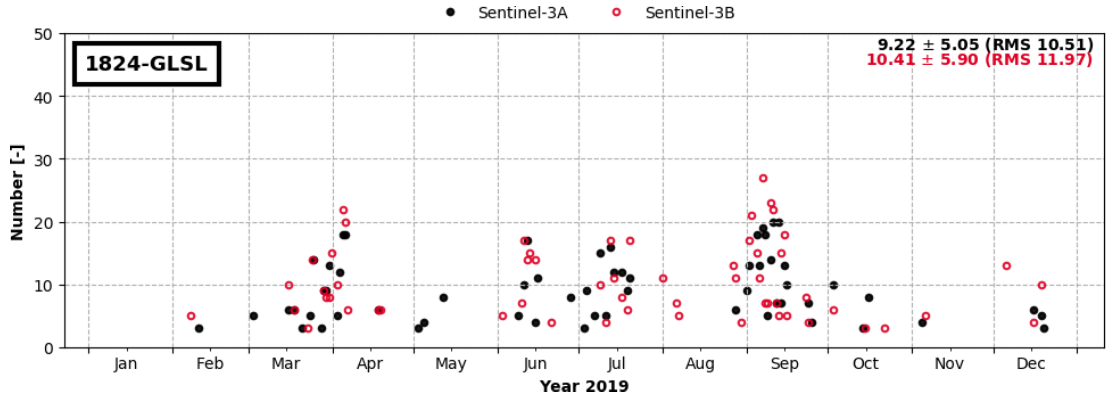


Figure 4-3: Daily total number of the accepted SLR observations of the SLR station 1824 (GLSL) in 2019 (Sentinel-3A and Sentinel-3B)

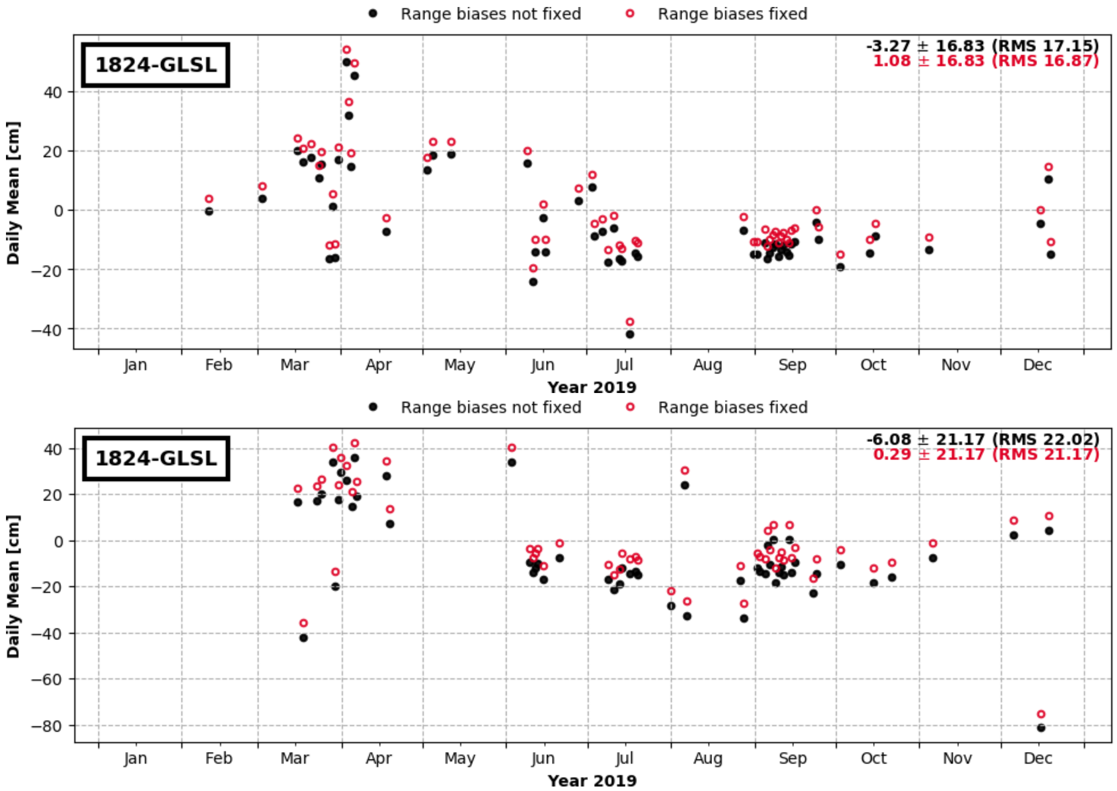
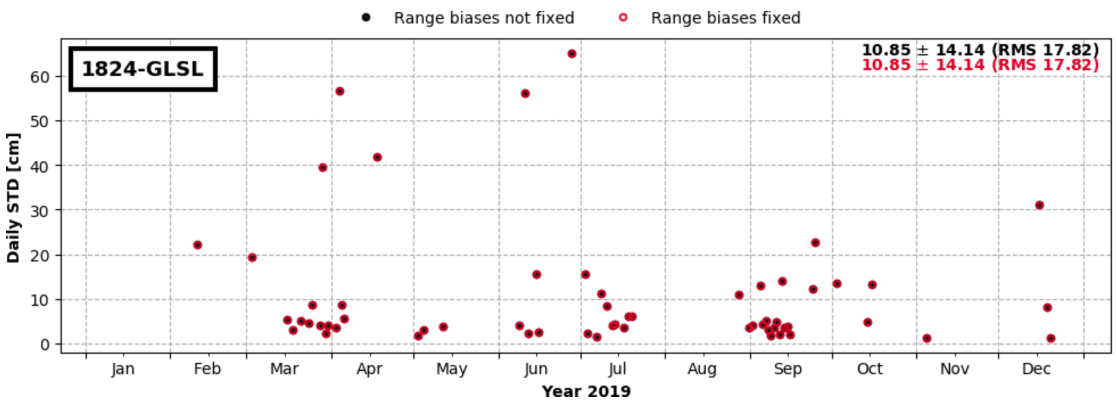


Figure 4-4: Daily mean of the SLR observation residuals [1-range; cm] of the SLR station 1824 (GLSL) in 2019 (above Sentinel-3A, and below Sentinel-3B)



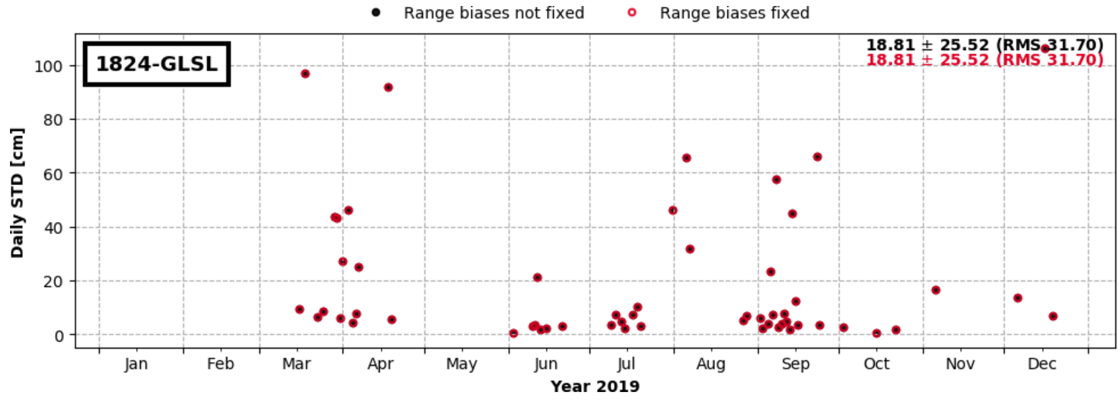


Figure 4-5: Daily STD of the SLR observation residuals [1-range; cm] of the SLR station 1824 (GLSL) in 2019 (above Sentinel-3A, and below Sentinel-3B)

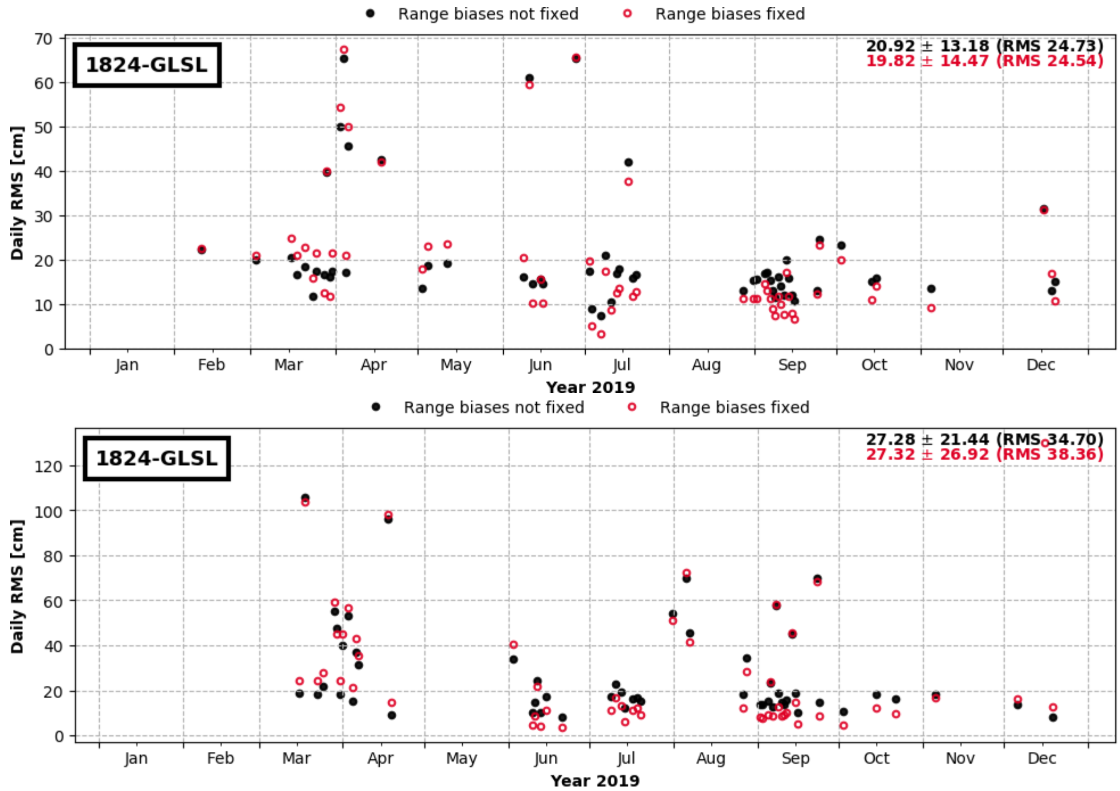


Figure 4-6: Daily RMS of the SLR observation residuals [1-range; cm] of the SLR station 1824 (GLSL) in 2019 (above Sentinel-3A, and below Sentinel-3B)

4.2. SLR STATION 1873 (SIML)

The SLR station Simeiz (1873 - SIML) has only tracked Sentinel-3B satellite during the reported time period, or even more precisely, the SIML station has never tracked the Sentinel-3A satellite. This fact has recently reverted after having contacted the SIML station. At the time of writing this document, the SIML station is tracking both Sentinel-3 satellites without issues.

From Table 4-2, it can be said that SIML station has been active during almost a third of the time period evaluated providing a large number of SLR observations (mean value of ~17) from every satellite pass. On the downside, some SLR observations have been filtered-out from the processing of the SLR residuals.

Table 4-2: Summary of the processing statistics of the SLR station 1873 (SIML)

		Sentinel-3A	Sentinel-3B	Jason3
Number of satellite passes (*.npt* files)	All mission	-	199	837
	"Year 2019" (20340-20866)	-	156	250
Days processed(*)	Total	-	366	-
Active days	Total	-	112	-
	% (w.r.t. the total days processed)	-	30.60 %	-
Number of satellite passes processed	Total	-	154	-
	% (w.r.t. the *.npt* files)	-	98.72 %	-
Number of observations processed	Total	-	2624	-
Number of observations per satellite pass	Mean	-	17.04	-
Number of observations filtered out	Total	-	38	-
	% (w.r.t. the total obs. processed)	-	1.45 %	-

(*) The total number of days processed does not coincide with the total number of days evaluated in "year 2019" (i.e., 371 days) since the combined orbit solution has not been generated on a few days as a result of either long manoeuvres or large gaps of data or other issues.

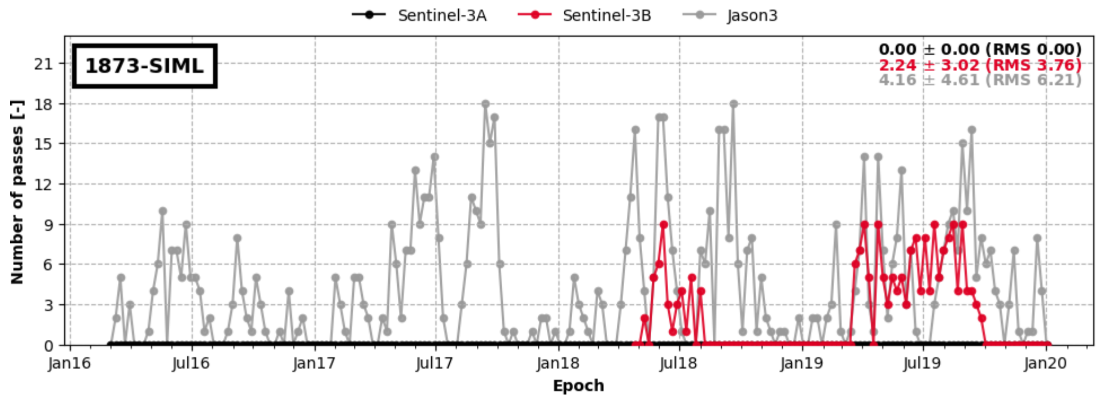


Figure 4-7: Total number of satellite passes per GPS week of the SLR station 1873 (SIML) since the beginning of the satellite mission (Sentinel-3A, Sentinel-3B and Jason-3)

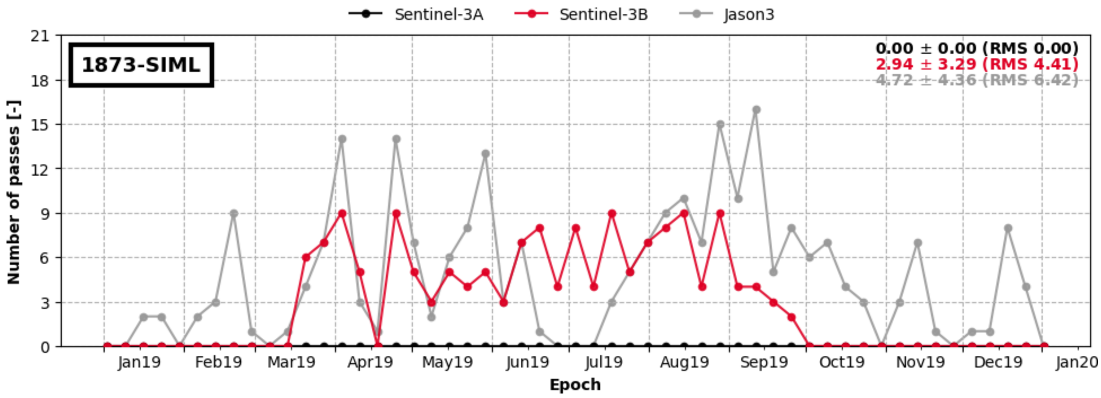


Figure 4-8: Total number of satellite passes per GPS week of the SLR station 1873 (SIML) in 2019 (Sentinel-3A, Sentinel-3B and Jason-3)

The figures above show a seasonal pattern of the SIML station, which clearly provides less SLR observations during winter time (northern hemisphere). On the other hand, the Sentinel-3B satellite passes have significantly increased its number during 2019. These figures are now closer to those achieved by the Jason-3 satellite.

All Sentinel-3B observations from the time period evaluated are concentrated between March and September. From the analysis of the SLR residuals, it could be said that they present better mean value than standard deviation or root mean square values. However, there is a clear dispersion on all the statistics, which reveals a dispersive nature on the SLR observations provided by the SIML station.

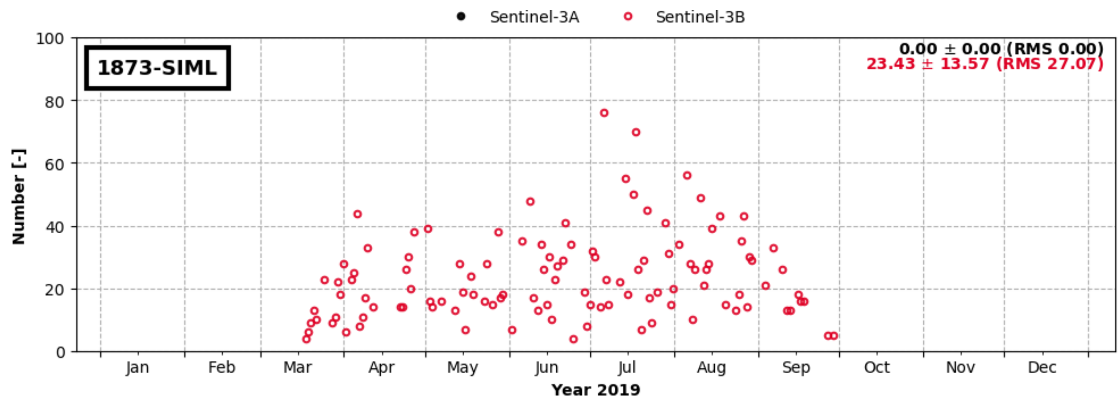


Figure 4-9: Daily total number of the accepted SLR observations of the SLR station 1873 (SIML) in 2019 (Sentinel-3A and Sentinel-3B)

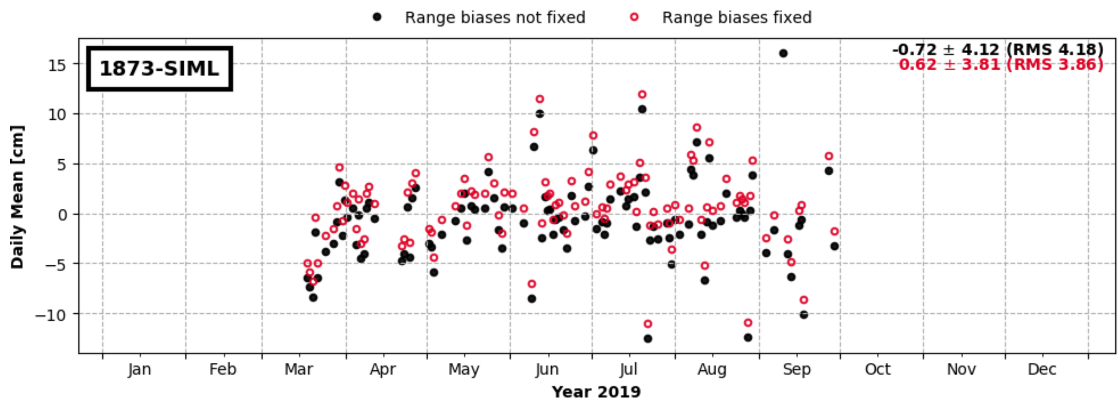


Figure 4-10: Daily mean of the SLR observation residuals [1-range; cm] of the SLR station 1873 (SIML) in 2019 (only Sentinel-3B)

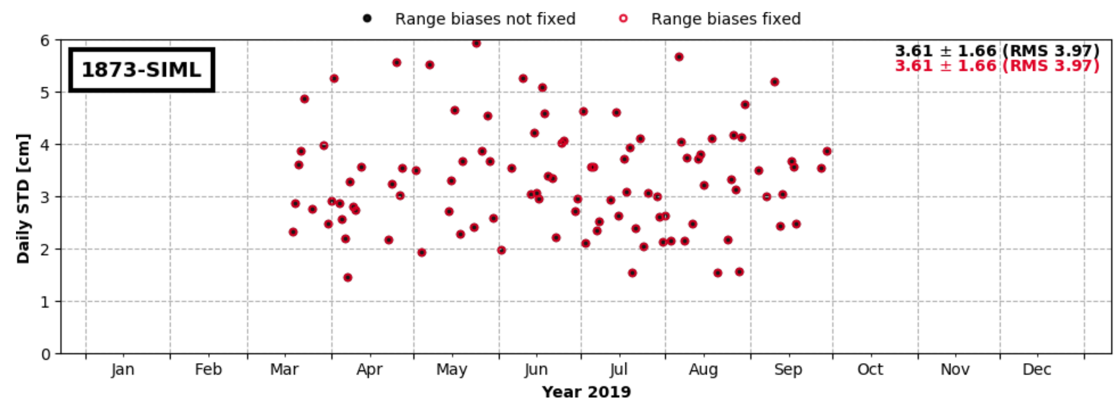


Figure 4-11: Daily STD of the SLR observation residuals [1-range; cm] of the SLR station 1873 (SIML) in 2019 (only Sentinel-3B)

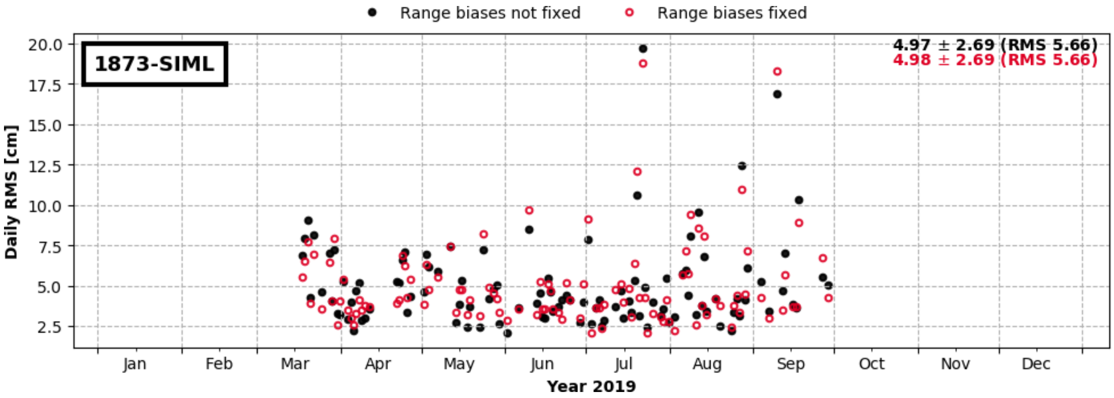


Figure 4-12: Daily RMS of the SLR observation residuals [1-range; cm] of the SLR station 1873 (SIML) in 2019 (only Sentinel-3B)

4.3. SLR STATION 1854 (RIGL)

The SLR station Riga (1854 - RIGL) has been tracking both Sentinel-3 satellites during ~11 % of the time period evaluated. Although the number of satellite passes is not high, the RIGL station provides a large number of SLR observations from each satellite pass (a mean value of ~19-20 SLR observations). Both Sentinel-3 satellites have been equally tracked by the station, and no outliers have been found during the processing of the SLR statistics.

Table 4-3: Summary of the processing statistics of the SLR station 1884 (RIGL)

		Sentinel-3A	Sentinel-3B	Jason3
Number of satellite passes (*.npt* files)	All mission	272	100	406
	"Year 2019" (20340-20866)	47	49	98
Days processed(*)	Total	366	366	-
Active days	Total	39	40	-
	% (w.r.t. the total days processed)	10.66 %	10.93 %	-
Number of satellite passes processed	Total	47	48	-
	% (w.r.t. the *.npt* files)	100.00 %	97.96 %	-
Number of observations processed	Total	879	954	-
Number of observations per satellite pass	Mean	18.70	19.88	-
Number of observations filtered out	Total	0	0	-
	% (w.r.t. the total obs. processed)	0.00 %	0.00 %	-

(*) The total number of days processed does not coincide with the total number of days evaluated in "year 2019" (i.e., 371 days) since the combined orbit solution has not been generated on a few days as a result of either long manoeuvres or large gaps of data or other issues.

The RIGL station also shows a seasonal pattern as it can be seen in Figure 4-13 and Figure 4-14. The vast majority of the satellite passes have been concentrated from March to September. However, the station presented an unexpected behaviour during June, with a reduced number of satellite passes. Comparing the statistics of Sentinel-3 and Jason-3 satellites, it can be found similarity on most of the time period evaluated, except for August and September where Jason-3 achieved a clearly large number on the satellite passes.

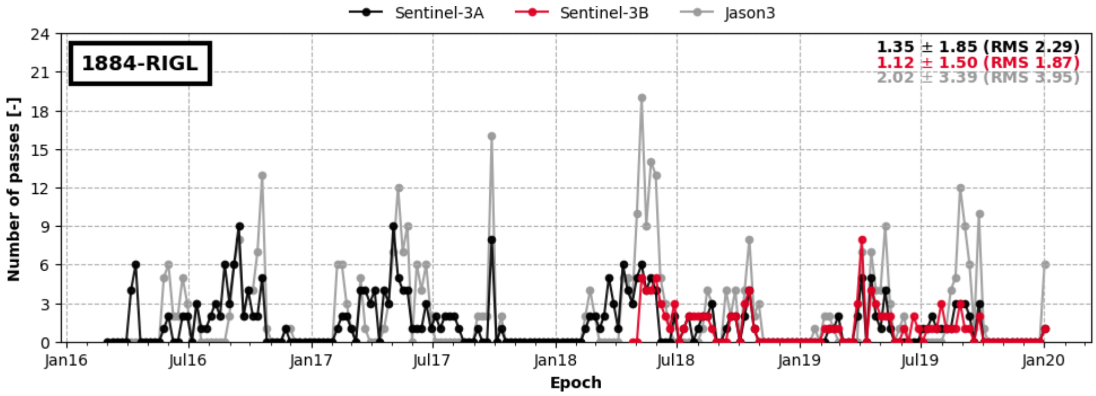


Figure 4-13: Total number of satellite passes per GPS week of the SLR station 1884 (RIGL) since the beginning of the satellite mission (Sentinel-3A, Sentinel-3B and Jason-3)

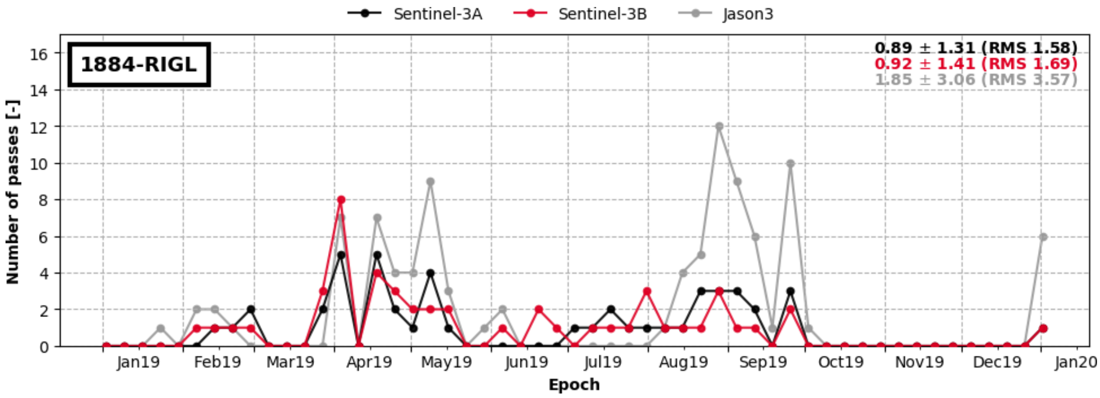


Figure 4-14: Total number of satellite passes per GPS week of the SLR station 1884 (RIGL) in 2019 (Sentinel-3A, Sentinel-3B and Jason-3)

The number of SLR observations shows a peak of activity on April, and, for the rest of the months, the mean value has been maintained around 20 SLR observations per day. In this case, the statistics on the SLR residuals of the RIGL station significantly benefit from the removal of the range biases. Not only the mean values have greatly reduced but also the root mean square values have. However, the figures below are quite dispersive, which shows some bad performance affecting the SLR observations delivered by the RIGL station.

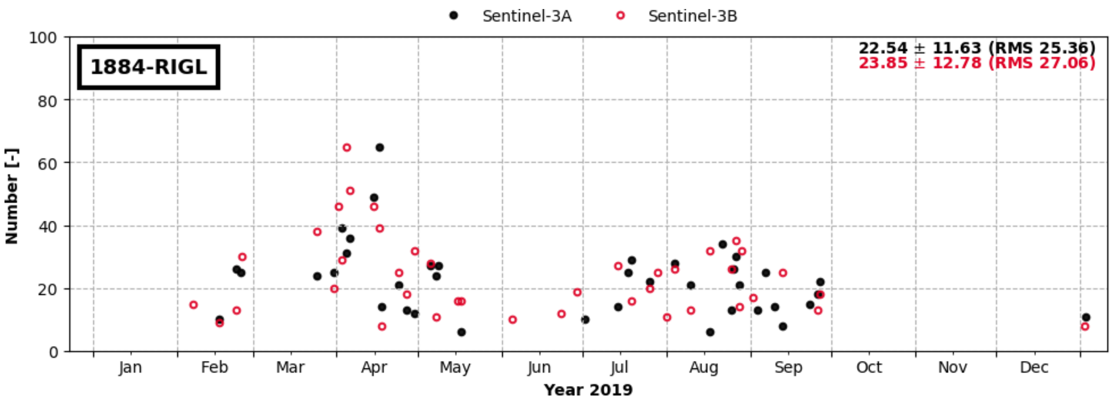


Figure 4-15: Daily total number of the accepted SLR observations of the SLR station 1884 (RIGL) in 2019 (Sentinel-3A and Sentinel-3B)

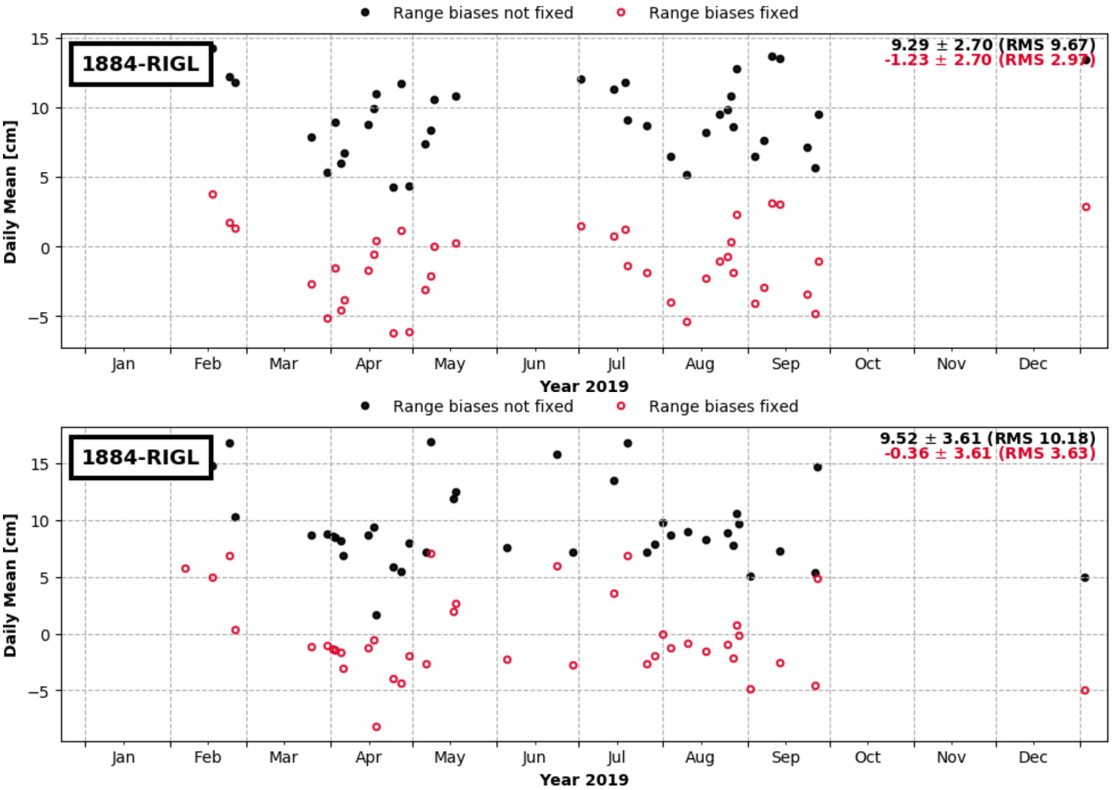


Figure 4-16: Daily mean of the SLR observation residuals [1-range; cm] of the SLR station 1884 (RIGL) in 2019 (above Sentinel-3A, and below Sentinel-3B)

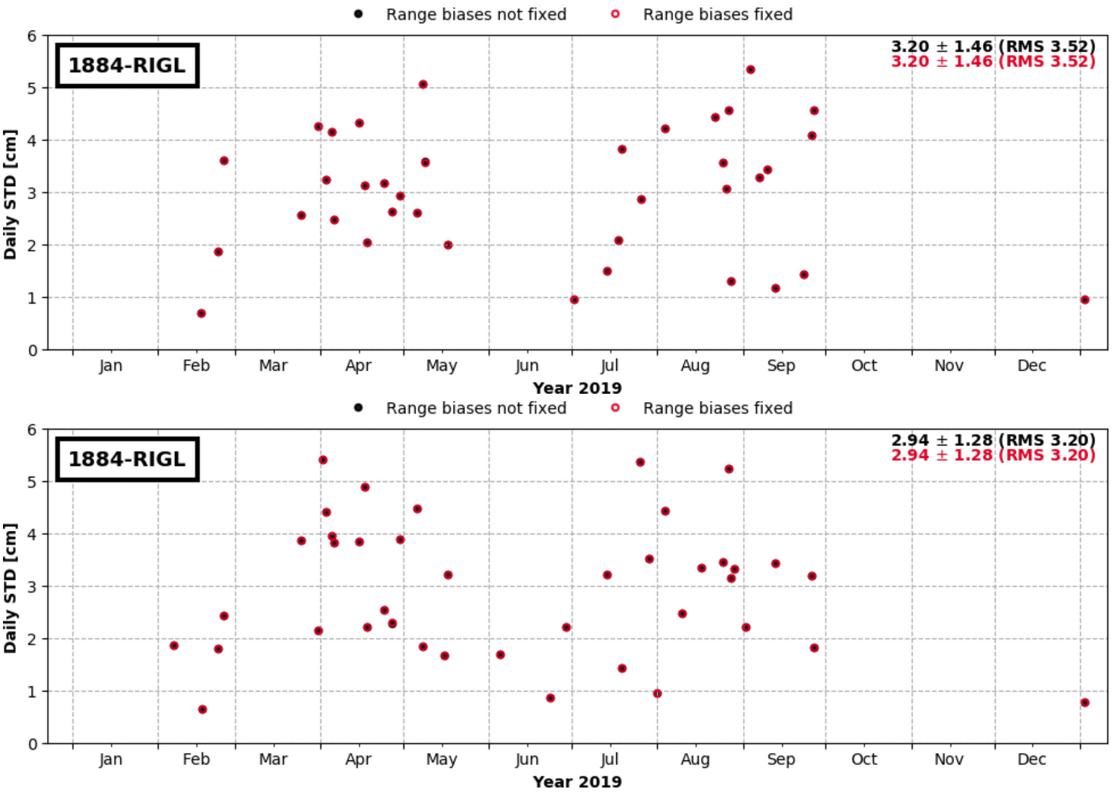


Figure 4-17: Daily STD of the SLR observation residuals [1-range; cm] of the SLR station 1884 (RIGL) in 2019 (above Sentinel-3A, and below Sentinel-3B)

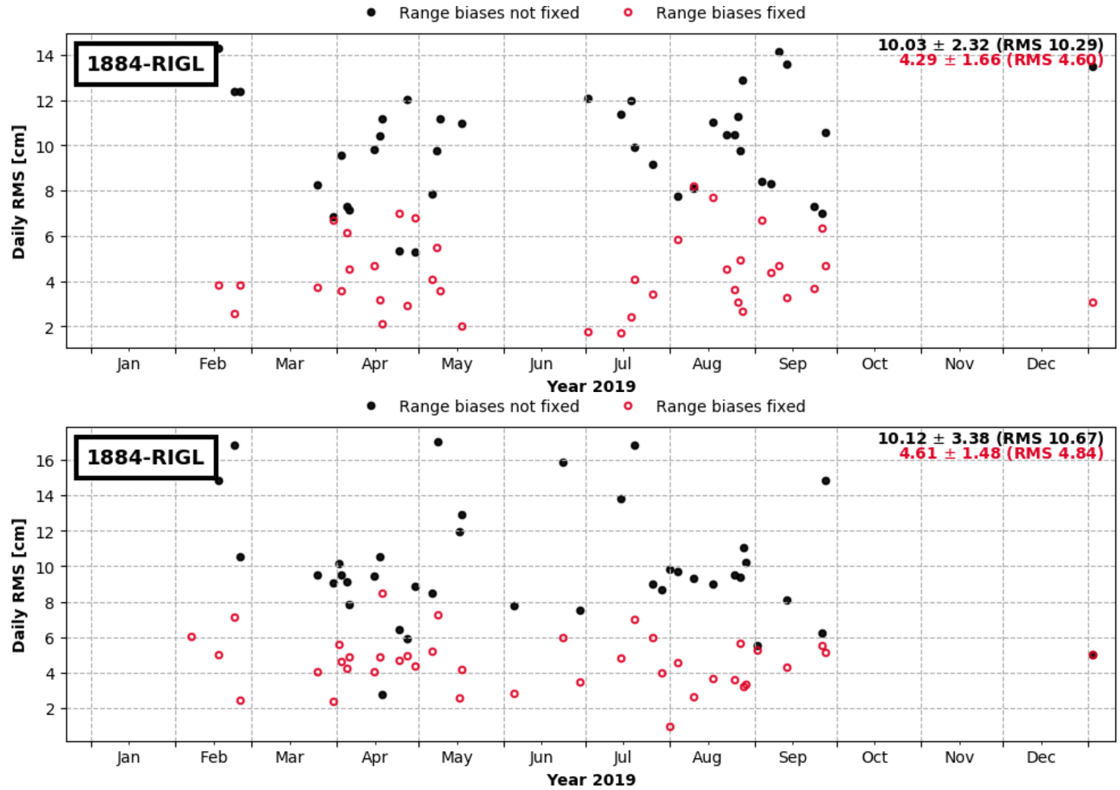


Figure 4-18: Daily RMS of the SLR observation residuals [1-range; cm] of the SLR station 1884 (RIGL) in 2019 (above Sentinel-3A, and below Sentinel-3B)

4.4. SLR STATION 1888 (SVEL)

Table 4-4: Summary of the processing statistics of the SLR station 1888 (SVEL)

		Sentinel-3A	Sentinel-3B	Jason3
Number of satellite passes (*.npt* files)	All mission	72	12	376
	"Year 2019" (20340-20866)	7	10	155
Days processed(*)	Total	366	366	-
Active days	Total	6	9	-
	% (w.r.t. the total days processed)	1.64 %	2.46 %	-
Number of satellite passes processed	Total	6	10	-
	% (w.r.t. the *.npt* files)	85.71 %	100.00 %	-
Number of observations processed	Total	40	66	-
Number of observations per satellite pass	Mean	6.67	6.60	-
Number of observations filtered out	Total	0	0	-
	% (w.r.t. the total obs. processed)	0.00 %	0.00 %	-
(*) The total number of days processed does not coincide with the total number of days evaluated in "year 2019" (i.e., 371 days) since the combined orbit solution has not been generated on a few days as a result of either long manoeuvres or large gaps of data or other issues.				

The SLR station Svetloe (1888 - SVEL) has been inactive most of the time period analysed. This fact makes it difficult to draw conclusions from the data obtained by this station. From Table 4-4, it can be highlighted that the SVEL station provides a medium-low number of SLR observations form each satellite pass (i.e., a mean value of ~7 SLR observations), and no outliers have been identified during the processing of the SLR residuals.

In this case, there is a clear difference on the number of satellite passes between Sentinel-3 and Jason-3 satellites. Figure 4-19 and Figure 4-20 reveal much more tracking on the Jason-3 satellite, especially during the last two years. In addition, the SVEL station seems that lost connectivity at the end of year 2019; however, it is currently tracking (i.e., at the time of writing this document) the three satellites without issues.

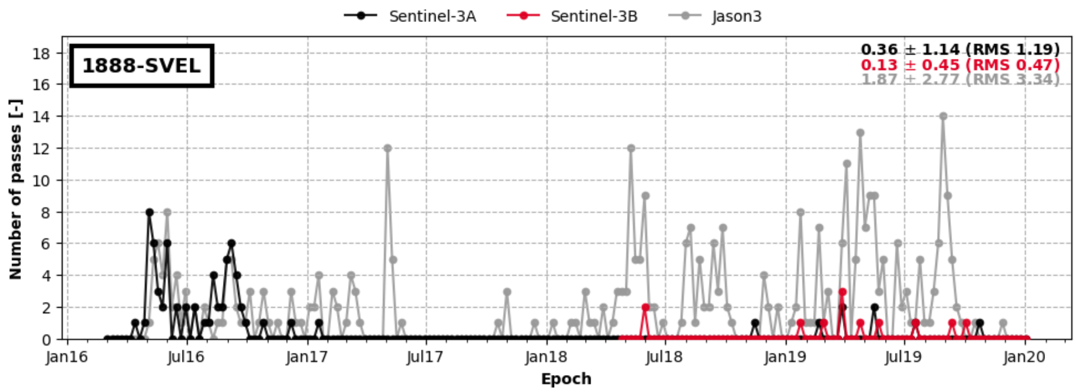


Figure 4-19: Total number of satellite passes per GPS week of the SLR station 1888 (SVEL) since the beginning of the satellite mission (Sentinel-3A, Sentinel-3B and Jason-3)

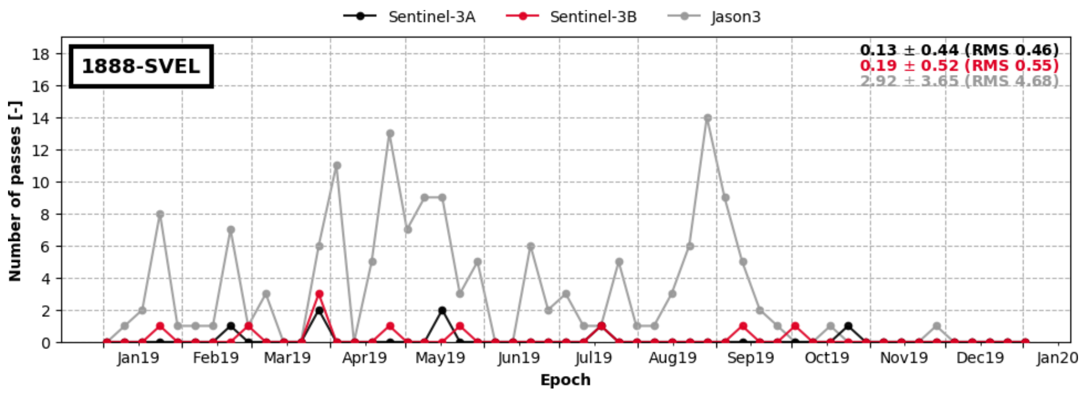


Figure 4-20: Total number of satellite passes per GPS week of the SLR station 1888 (SVEL) in 2019 (Sentinel-3A, Sentinel-3B and Jason-3)

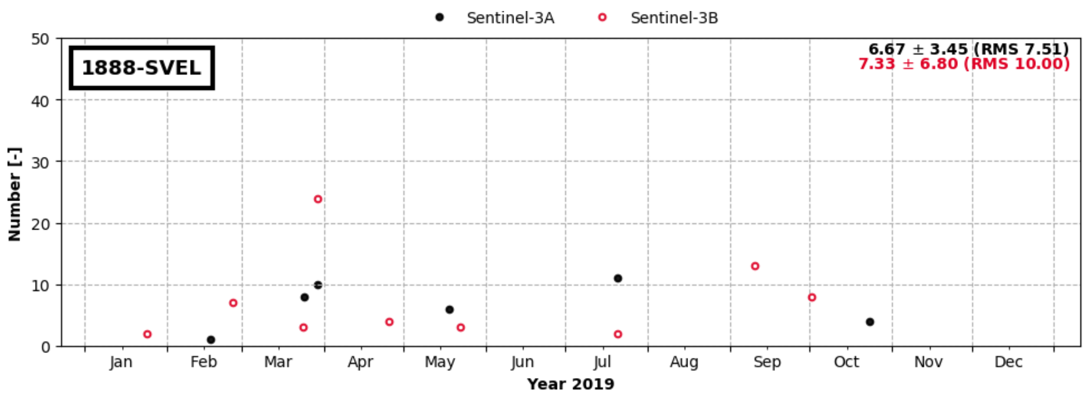


Figure 4-21: Daily total number of the accepted SLR observations of the SLR station 1888 (SVEL) in 2019 (Sentinel-3A and Sentinel-3B)

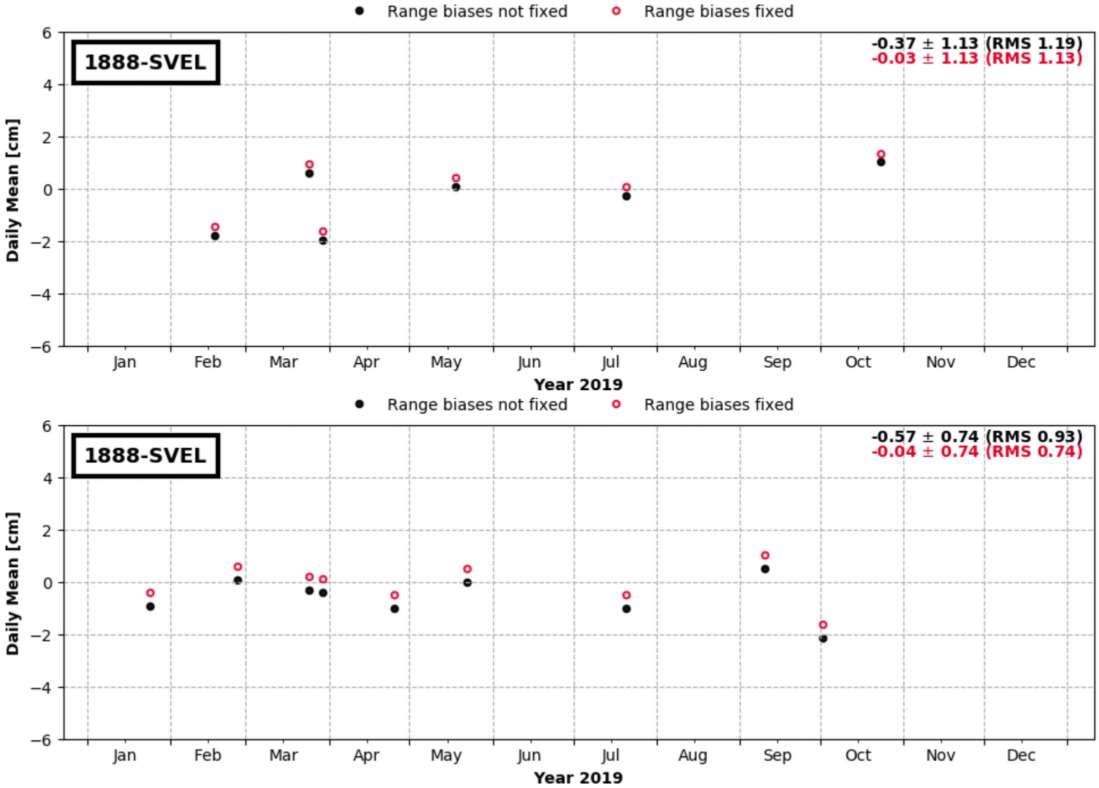


Figure 4-22: Daily mean of the SLR observation residuals [1-range; cm] of the SLR station 1888 (SVEL) in 2019 (above Sentinel-3A, and below Sentinel-3B)

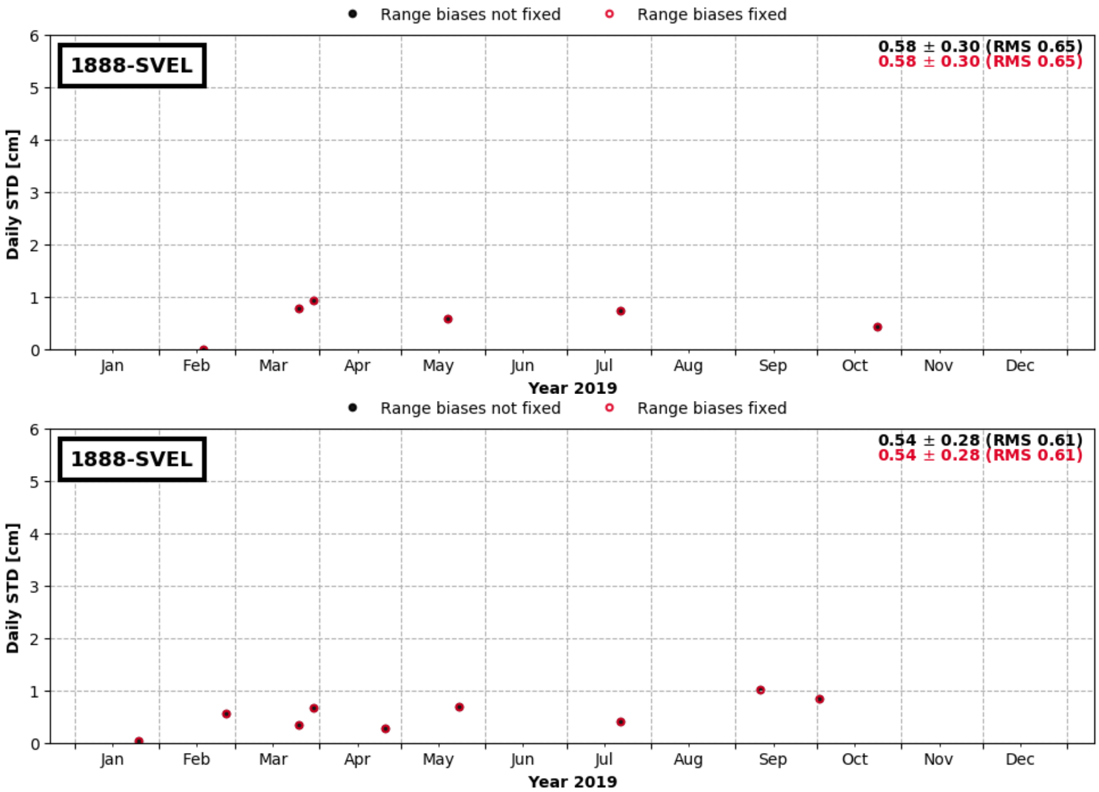


Figure 4-23: Daily STD of the SLR observation residuals [1-range; cm] of the SLR station 1888 (SVEL) in 2019 (above Sentinel-3A, and below Sentinel-3B)

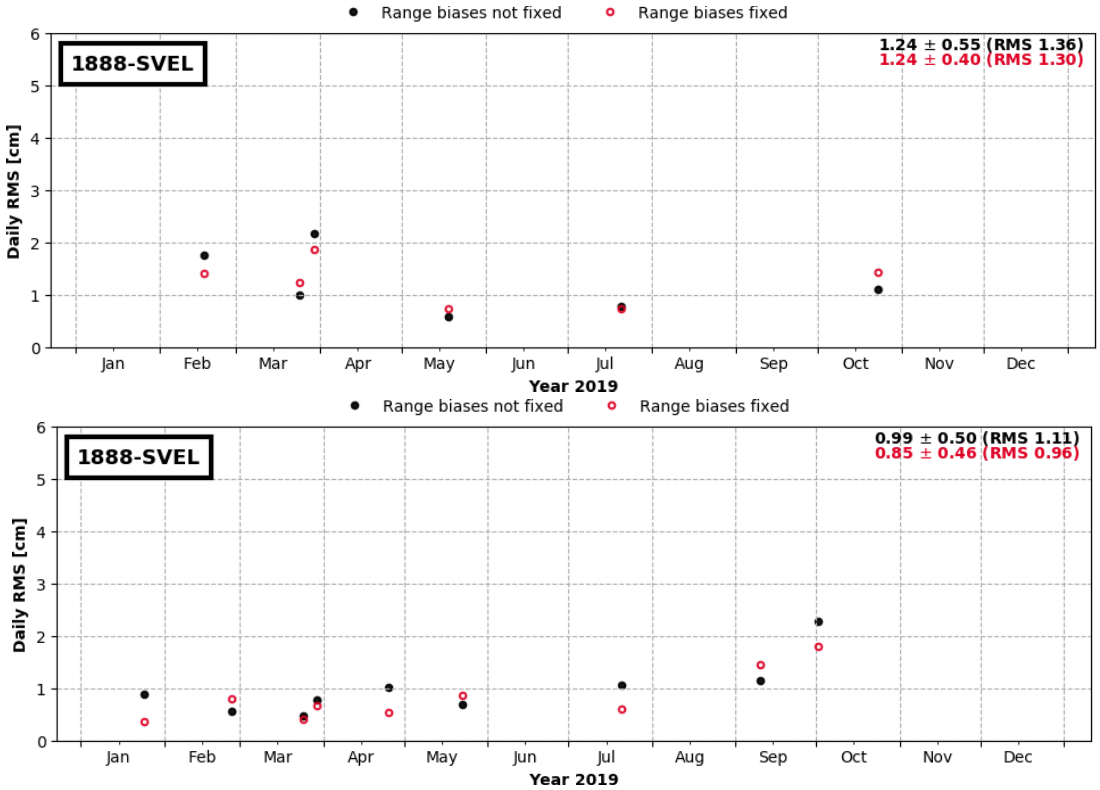


Figure 4-24: Daily RMS of the SLR observation residuals [1-range; cm] of the SLR station 1888 (SVEL) in 2019 (above Sentinel-3A, and below Sentinel-3B)

As commented at the beginning of this sub section, it is difficult to analyse the data if only a few observations are available. From these little data (see figures above), it could be said though that the SVEL station delivers SLR observations with a mean value tending to 0 and they are a little dispersive.

4.5. SLR STATION 1890 (BADL)

Table 4-5: Summary of the processing statistics of the SLR station 1890 (BADL)

		Sentinel-3A	Sentinel-3B	Jason3
Number of satellite passes (*.npt* files)	All mission	559	299	1031
	"Year 2019" (20340-20866)	220	224	426
Days processed$^{(*)}$	Total	366	366	-
Active days	Total	147	144	-
	% (w.r.t. the total days processed)	40.16 %	39.34 %	-
Number of satellite passes processed	Total	216	223	-
	% (w.r.t. the *.npt* files)	98.18 %	99.55 %	-
Number of observations processed	Total	1844	1914	-
Number of observations per satellite pass	Mean	8.54	8.58	-
Number of observations filtered out	Total	4	18	-
	% (w.r.t. the total obs. processed)	0.22 %	0.94 %	-

$^{(*)}$ The total number of days processed does not coincide with the total number of days evaluated in "year 2019" (i.e., 371 days) since the combined orbit solution has not been generated on a few days as a result of either long manoeuvres or large gaps of data or other issues.

The SLR station Badary (1890 - BADL) is one of the SLR stations showing most activity when tracking both Sentinel-3 satellites. Near a 40 % of the time, the BADL station delivers SLR observations from both satellites. Moreover, there are no significant differences on the tracking between the Sentinel-3 satellites since similar figures are obtained on all fields evaluated on Table 4-5. From this table, it can be highlighted that the BADL station gives 8-9 SLR observations from each satellite pass, which is an average value compared to the rest of the SLR stations.

Figure 4-25 and Figure 4-26 show that the BADL station has increased the number of satellite passes during these last months, not only over Sentinel-3 satellites but also on Jason-3. However, it seems that the Jason-3 satellite has been more benefited from this last fact.

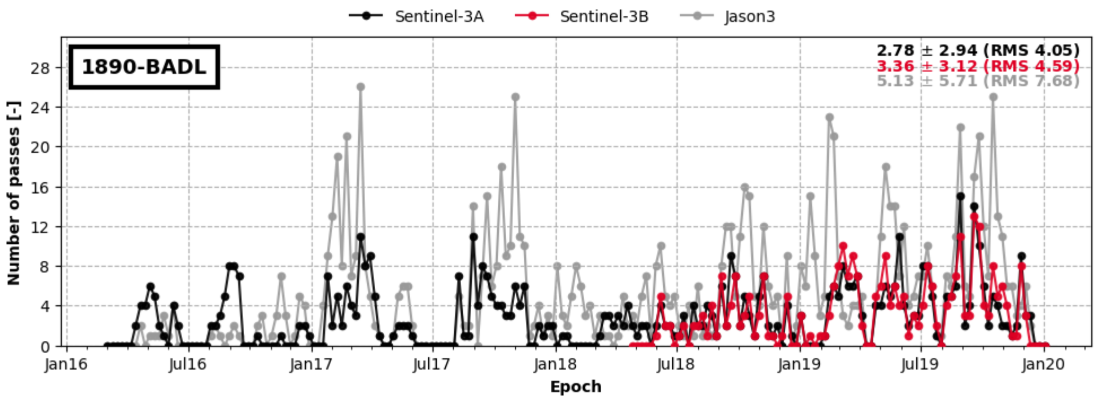


Figure 4-25: Total number of satellite passes per GPS week of the SLR station 1890 (BADL) since the beginning of the satellite mission (Sentinel-3A, Sentinel-3B and Jason-3)

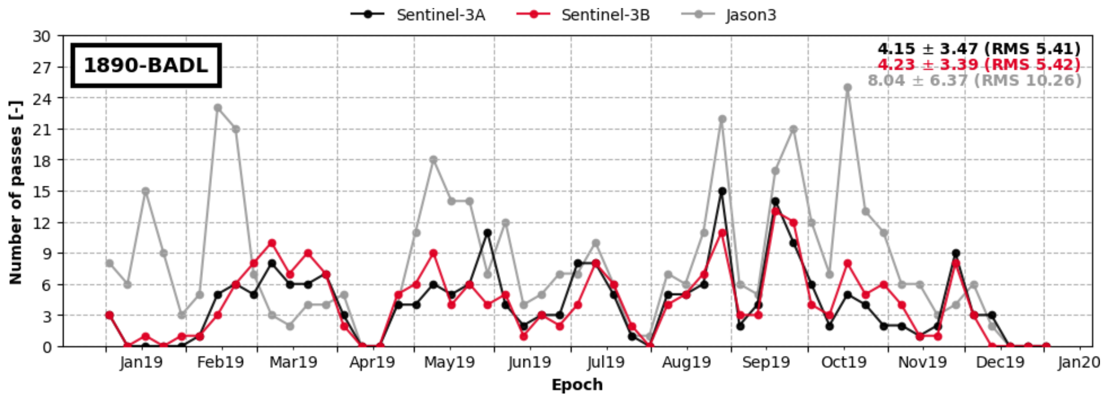


Figure 4-26: Total number of satellite passes per GPS week of the SLR station 1890 (BADL) in 2019 (Sentinel-3A, Sentinel-3B and Jason-3)

As seen in Figure 4-27, the BADL station has provided a great number of SLR observations during 2019 with a peak at the end of August and two time periods with a reduced number or a lack of SLR observations (i.e., January and April).

Analysing the SLR residuals, the mean value of these residuals is very close to zero, and both the standard deviation and root mean square values present low or very low figures. However, these statistics still show a little more dispersion with respect to the outcome of those SLR stations showing the best figures.

Finally there is a comment to be highlighted from the BADL station. At the time of writing this document, this station has lost the connectivity of the Sentinel-3 satellites since it is not currently retrieving the CPF predictions from the new FTP server of the CPOD Service. Some contact attempts to the people in charge of the station have been performed but there is still no answer from them. The CPOD Service will continue working to resume the tracking of BADL as soon as possible.

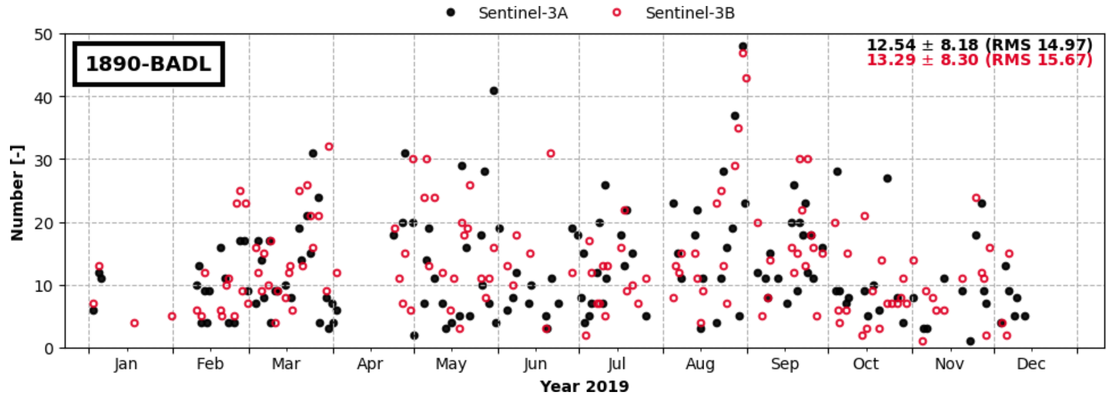


Figure 4-27: Daily total number of the accepted SLR observations of the SLR station 1890 (BADL) in 2019 (Sentinel-3A and Sentinel-3B)

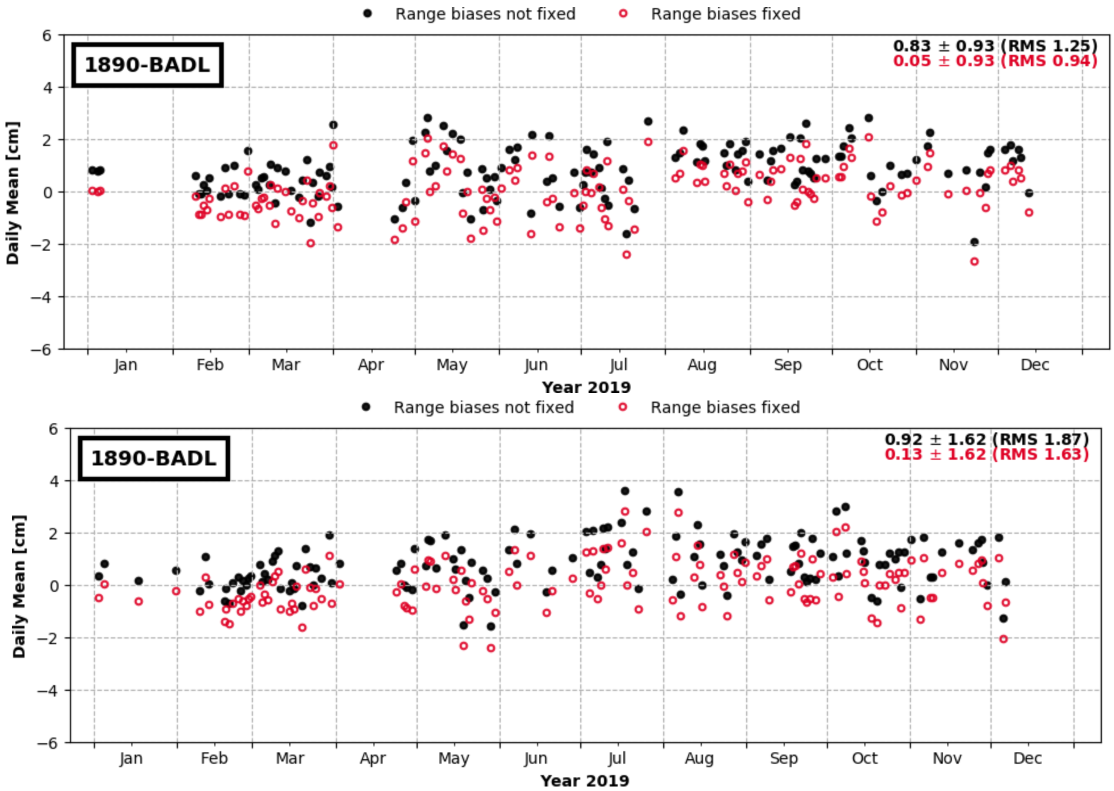
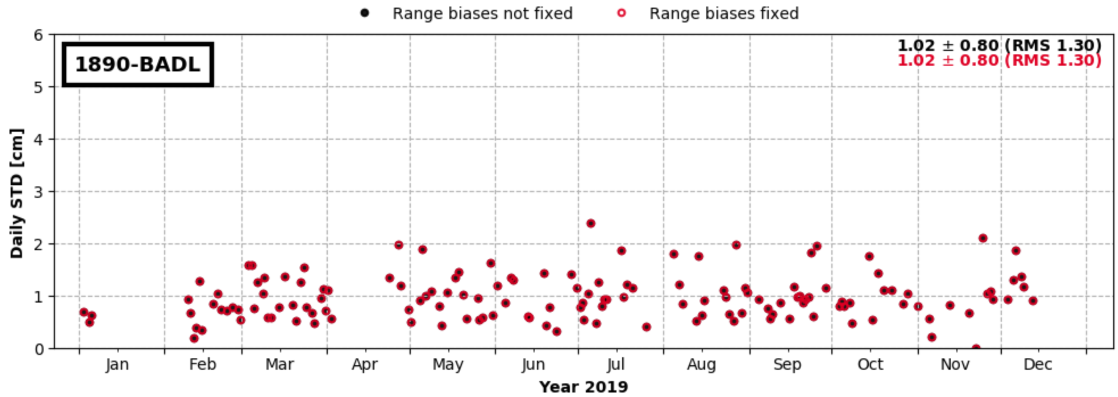


Figure 4-28: Daily mean of the SLR observation residuals [1-range; cm] of the SLR station 1890 (BADL) in 2019 (above Sentinel-3A, and below Sentinel-3B)



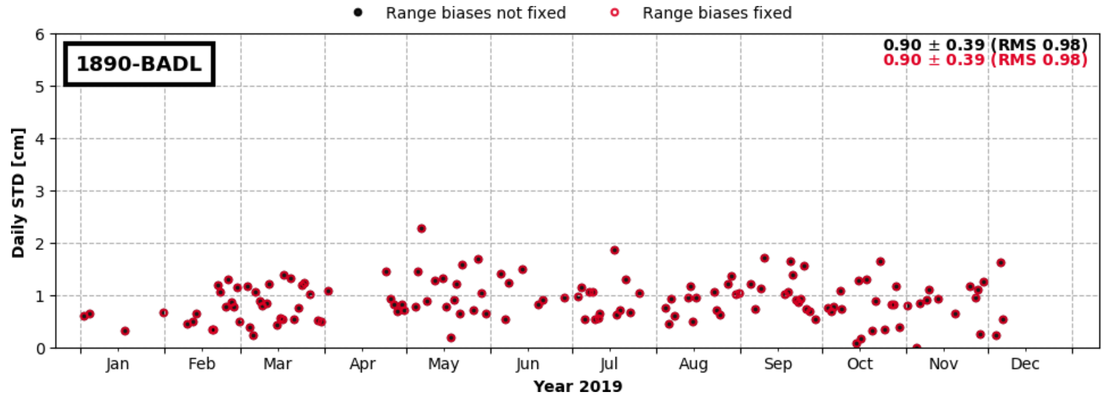


Figure 4-29: Daily STD of the SLR observation residuals [1-range; cm] of the SLR station 1890 (BADL) in 2019 (above Sentinel-3A, and below Sentinel-3B)

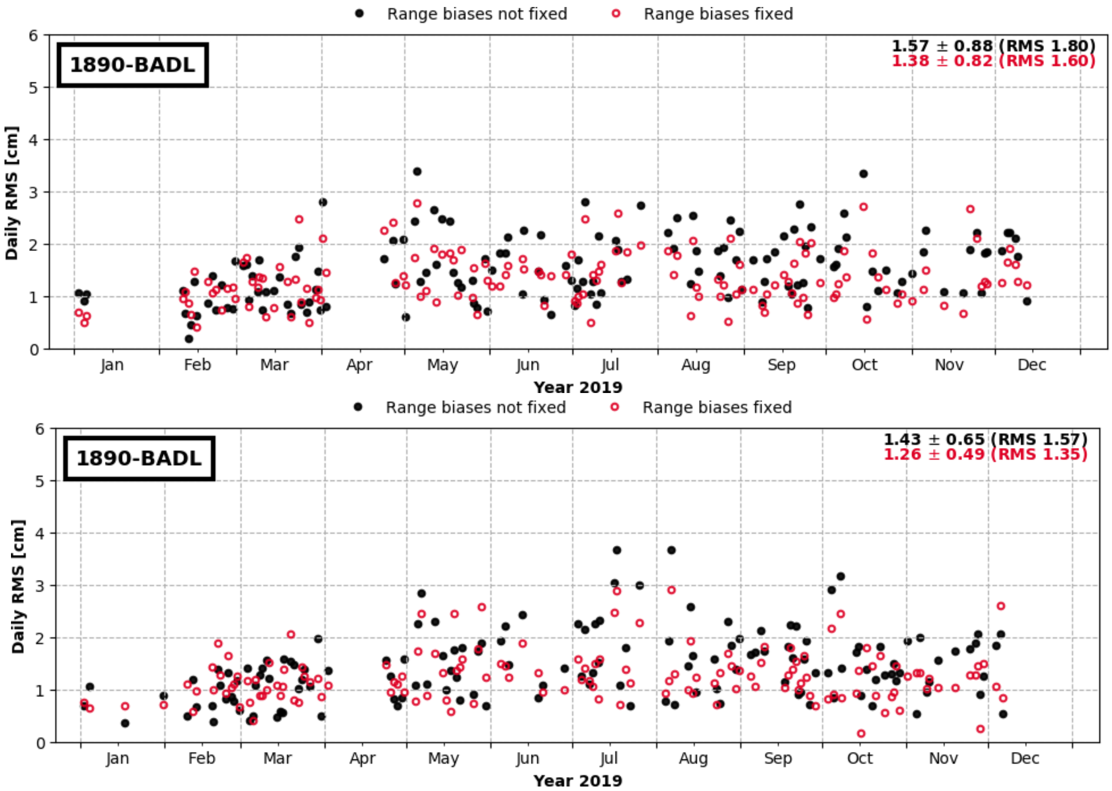


Figure 4-30: Daily RMS of the SLR observation residuals [1-range; cm] of the SLR station 1890 (BADL) in 2019 (above Sentinel-3A, and below Sentinel-3B)

4.6. SLR STATION 1893 (KTZL)

The SLR station Katsively (1893 - KTZL) has been active more than a quarter of the time period evaluated. In this case, the figures of Table 4-6 show a little more tracking on the Sentinel-3A satellite than on the Sentinel-3B satellite. However, the differences are not high. As seen from the table below, the KTZL station has provided a mean value of 10-11 SLR observations per satellite pass, which is an average value regarding the figures of all SLR stations. In addition, it has been detected a very few outliers, which have been filtered-out from the SLR statistics.

Table 4-6: Summary of the processing statistics of the SLR station 1893 (KTZL)

		Sentinel-3A	Sentinel-3B	Jason3
Number of satellite passes (*.npt* files)	All mission	411	187	647
	"Year 2019" (20340-20866)	128	108	184
Days processed(*)	Total	366	366	-
Active days	Total	107	92	-
	% (w.r.t. the total days processed)	29.23 %	25.14 %	-
Number of satellite passes processed	Total	128	107	-
	% (w.r.t. the *.npt* files)	100.00 %	99.07 %	-
Number of observations processed	Total	1327	1172	-
Number of observations per satellite pass	Mean	10.37	10.95	-
Number of observations filtered out	Total	12	11	-
	% (w.r.t. the total obs. processed)	0.90 %	0.94 %	-

(*) The total number of days processed does not coincide with the total number of days evaluated in "year 2019" (i.e., 371 days) since the combined orbit solution has not been generated on a few days as a result of either long manoeuvres or large gaps of data or other issues.

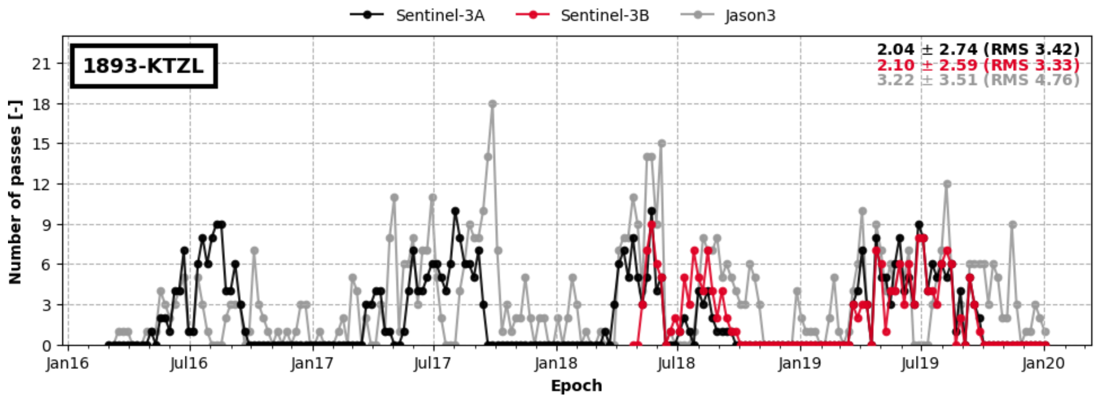


Figure 4-31: Total number of satellite passes per GPS week of the SLR station 1893 (KTZL) since the beginning of the satellite mission (Sentinel-3A, Sentinel-3B and Jason-3)

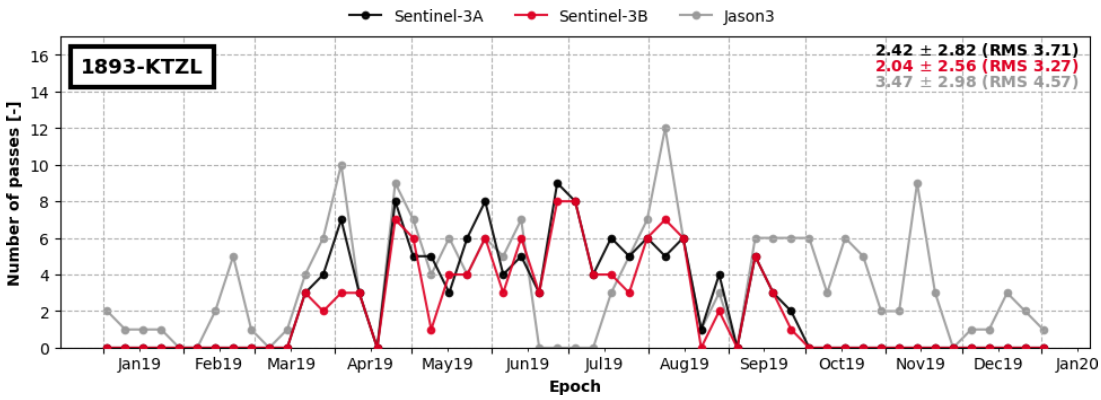


Figure 4-32: Total number of satellite passes per GPS week of the SLR station 1893 (KTZL) in 2019 (Sentinel-3A, Sentinel-3B and Jason-3)

As seen in Figure 4-31 and Figure 4-32, the KTZL station shows a seasonal pattern, which has been constant over the years. The Sentinel-3 satellites have been equally tracked throughout the entire missions, and reporting similar values to those obtained by the Jason-3 satellite. However, it must be pointed out that Jason-3 satellite receives tracking at the end of the years from the KTZL station, whereas the Sentinel-3 satellite do not.

The SLR observations from KTZL station have been concentrated from March to September showing a daily constant number throughout these months. In this case, the statistics of the figures below reveal some underperformance after having fixed the range biases, which might be a consequence of a station misconfiguration when obtaining the outcome of the SLR residuals. On the other hand, this underperformance might also be related to the dispersion observable on the SLR observations. Several SLR observations present an unexpected behaviour, which might negatively have impacted the estimation of the range bias for the KTZL station.

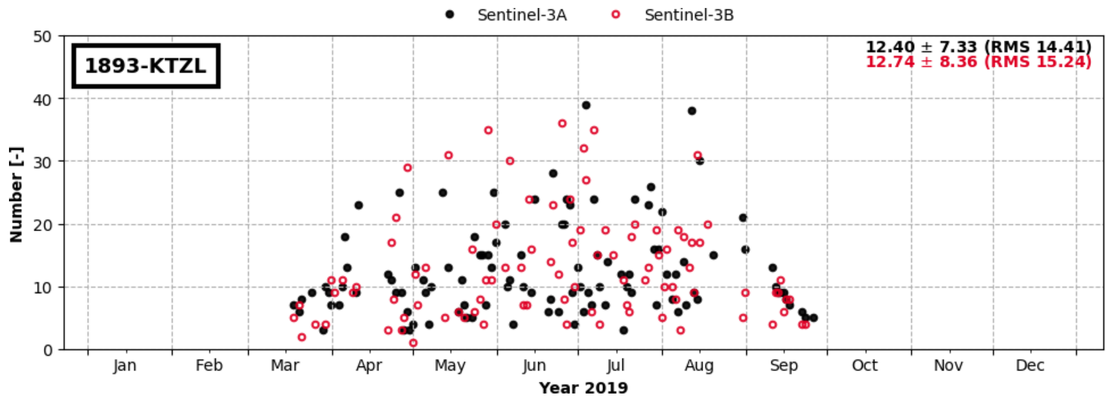


Figure 4-33: Daily total number of the accepted SLR observations of the SLR station 1893 (KTZL) in 2019 (Sentinel-3A and Sentinel-3B)

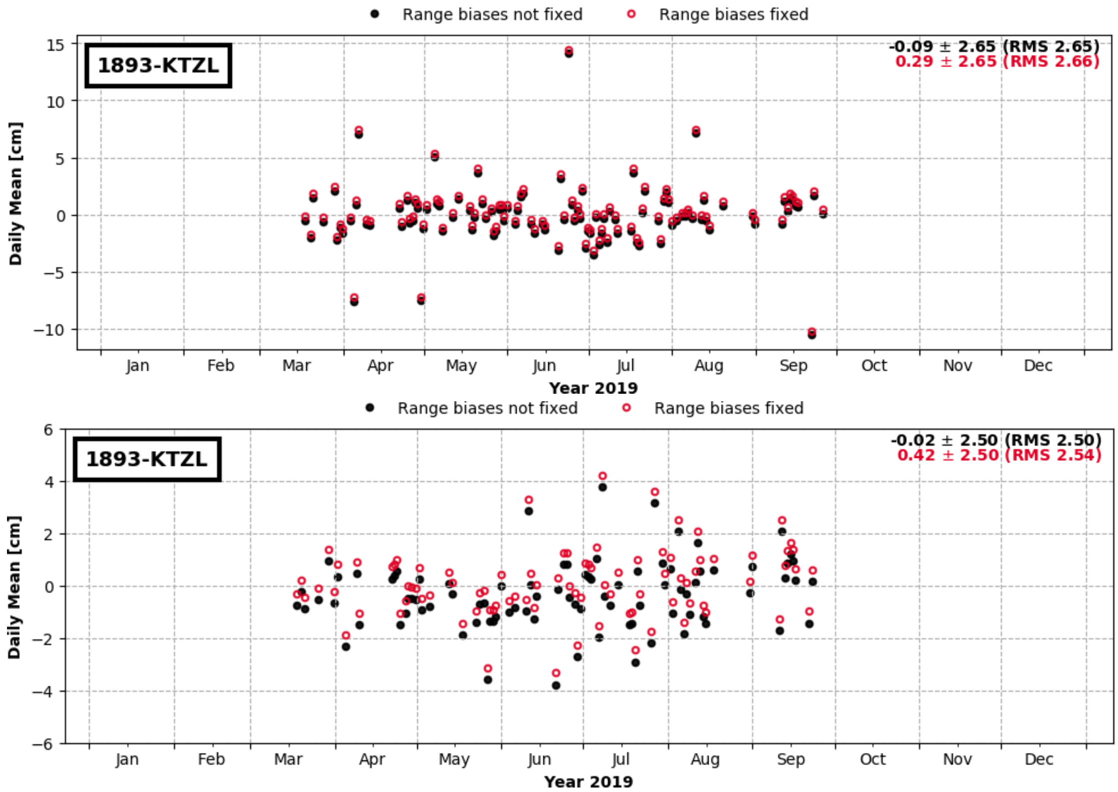


Figure 4-34: Daily mean of the SLR observation residuals [1-range; cm] of the SLR station 1893 (KTZL) in 2019 (above Sentinel-3A, and below Sentinel-3B)

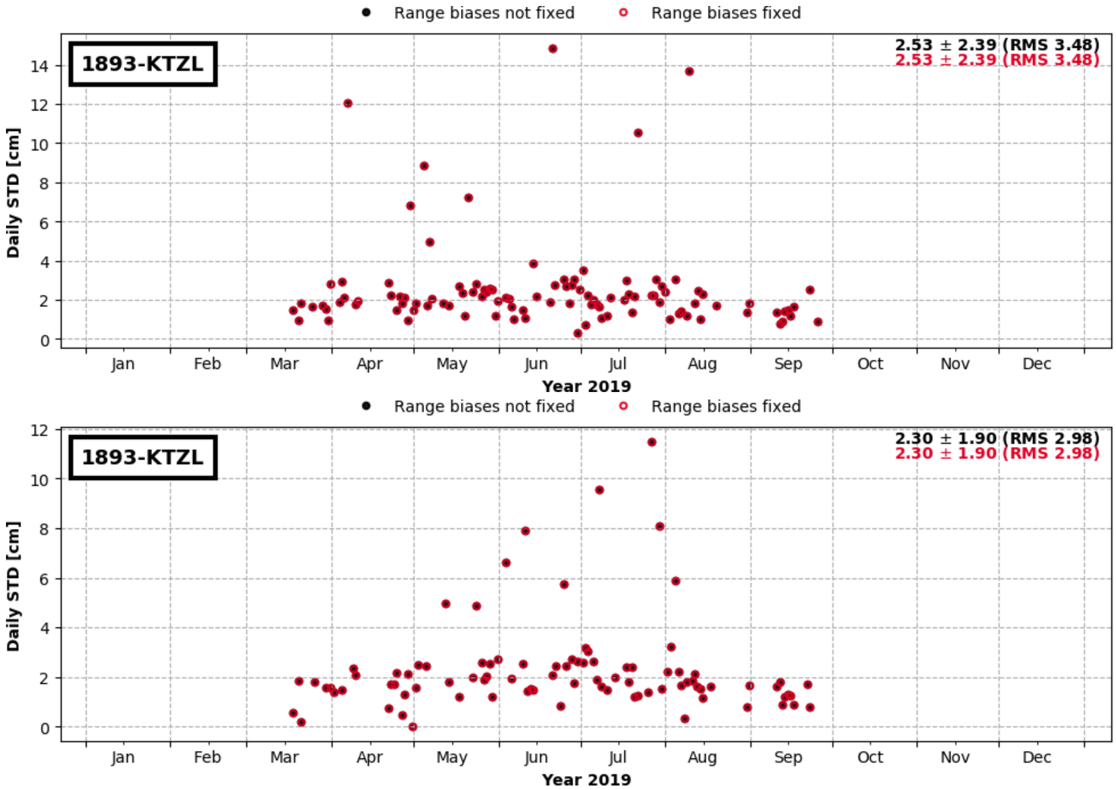


Figure 4-35: Daily STD of the SLR observation residuals [1-range; cm] of the SLR station 1893 (KTZL) in 2019 (above Sentinel-3A, and below Sentinel-3B)

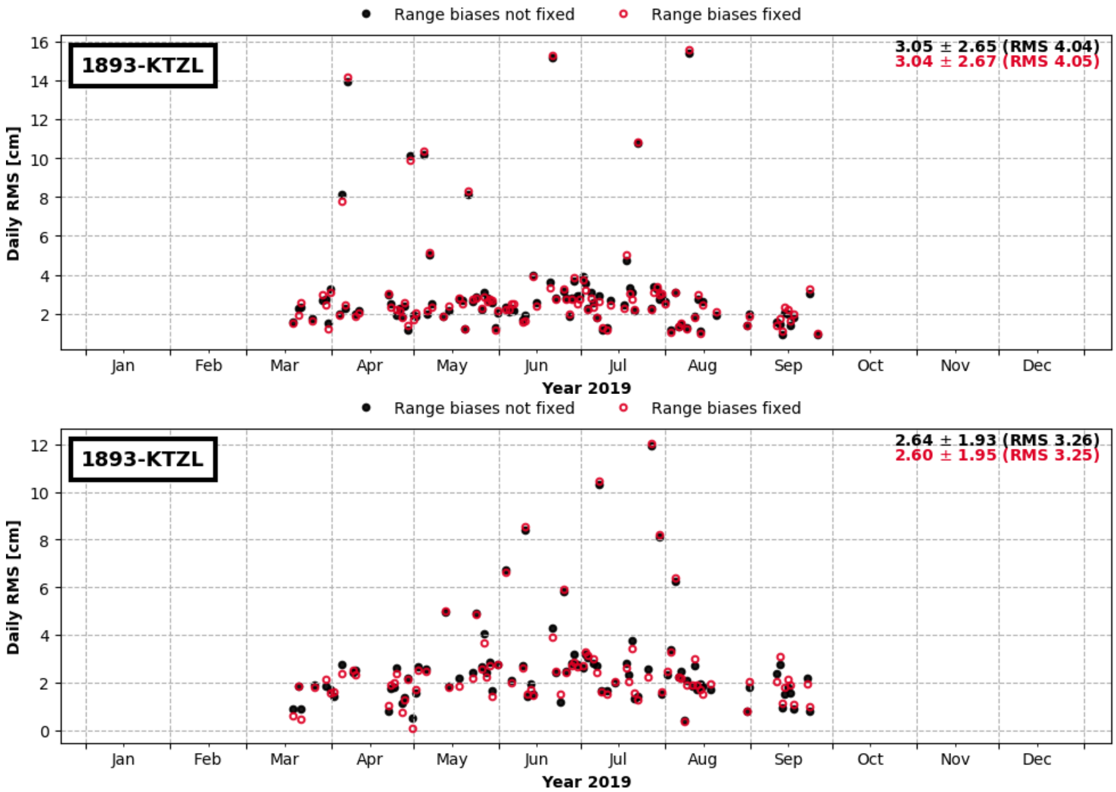


Figure 4-36: Daily RMS of the SLR observation residuals [1-range; cm] of the SLR station 1893 (KTZL) in 2019 (above Sentinel-3A, and below Sentinel-3B)

4.7. SLR STATION 7090 (YARL)

The SLR station Yarragadee (7090 - YARL) has been active almost all the time period evaluated. It is clearly the SLR station providing the most number of satellite passes, and therefore, giving the largest quantity of SLR observations with great distance to the rest of the SLR stations. From Table 4-7, it can be seen that YARL station brings a high number of SLR observations per satellite pass (i.e., a mean value of 17-18 SLR observations), in line with the figures of the SLR stations most tracking the Sentinel-3 satellites.

A particular issue of the YARL station must be highlighted, which is related to the number of satellite passes processed reported in Table 4-7. As seen from the table, this figure is quite far from the "ideal" 100 %, which will show equality between the processed figures and the figures directly obtained from the *npt* files. This fact is related to the way of how the satellite passes have been calculated on both cases. On the *npt* files case, each entry of the YARL station (considering an entry a set of SLR observations included below the same header in the *npt* file) is calculated as a satellite pass. On the other hand, when processing the SLR residuals, it is considered a satellite pass when the last observation of a set of observations and the fist one of the following set are more than 30 minutes distant. During the time period evaluated, there have been some times where YARL station seems to have lost the tracking connection with the Sentinel-3 satellite for a brief time period, which has led to the generation of two entries in the *npt* files for the same satellite pass. This issue explains the differences appeared on the figures shown in Table 4-7, and has mainly affected the YARL station.

Table 4-7: Summary of the processing statistics of the SLR station 7090 (YARL)

		Sentinel-3A	Sentinel-3B	Jason3
Number of satellite passes (*.npt* files)	All mission	4251	2282	6191
	"Year 2019" (20340-20866)	1046	993	1547
Days processed(*)	Total	366	366	-
Active days	Total	341	337	-
	% (w.r.t. the total days processed)	93.17 %	92.08 %	-
Number of satellite passes processed	Total	869	848	-
	% (w.r.t. the *.npt* files)	83.08 %	85.40 %	-
Number of observations processed	Total	15299	14729	-
Number of observations per satellite pass	Mean	17.61	17.37	-
Number of observations filtered out	Total	0	0	-
	% (w.r.t. the total obs. processed)	0.00 %	0.00 %	-

(*) The total number of days processed does not coincide with the total number of days evaluated in "year 2019" (i.e., 371 days) since the combined orbit solution has not been generated on a few days as a result of either long manoeuvres or large gaps of data or other issues.

Figure 4-37 and Figure 4-38 show a constant tracking of the YARL station to the Sentinel-3 satellites during the entire mission of the satellites. In addition, the YARL station has obtained a mean value of ~20 satellite passes per week during 2019 for both Sentinel-3 satellites. This value grows up to ~30 satellite passes for the Jason-3 satellite.

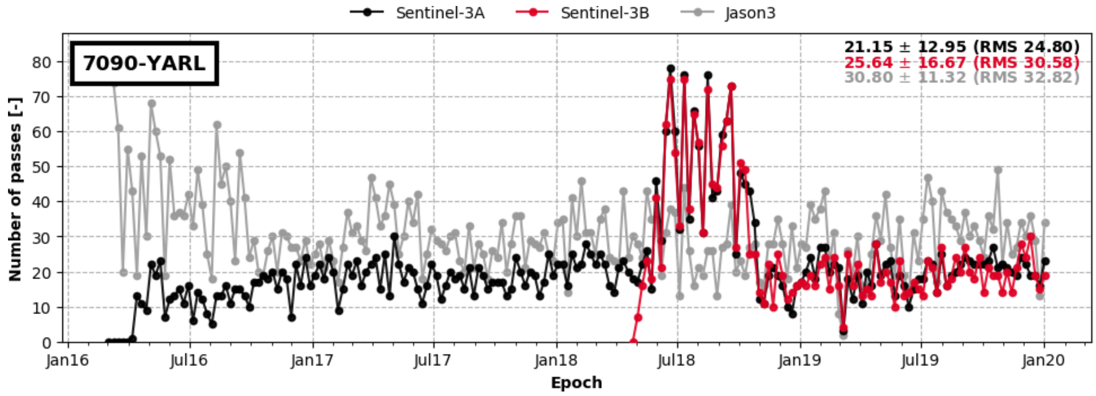


Figure 4-37: Total number of satellite passes per GPS week of the SLR station 7090 (YARL) since the beginning of the satellite mission (Sentinel-3A, Sentinel-3B and Jason-3)

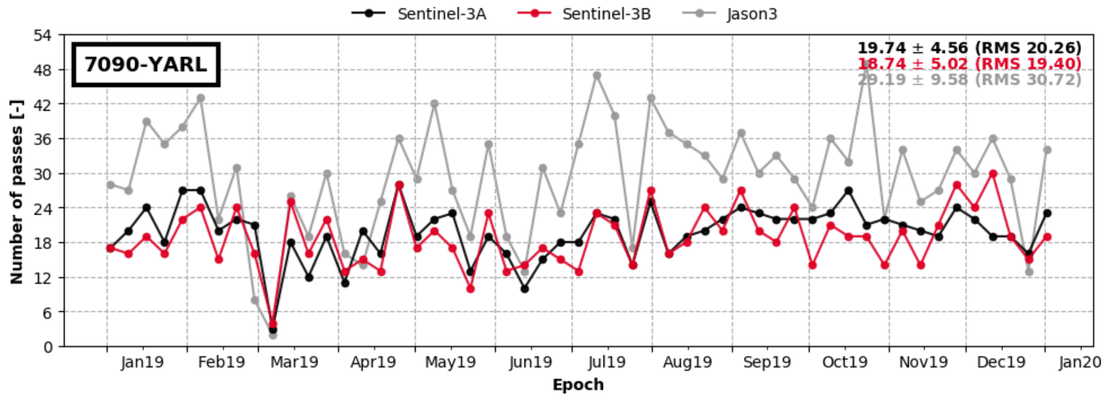


Figure 4-38: Total number of satellite passes per GPS week of the SLR station 7090 (YARL) in 2019 (Sentinel-3A, Sentinel-3B and Jason-3)

The figures previously shown allow the YARL station to give a mean value of near 45 SLR observations per day, which is the highest mean value of all SLR stations.

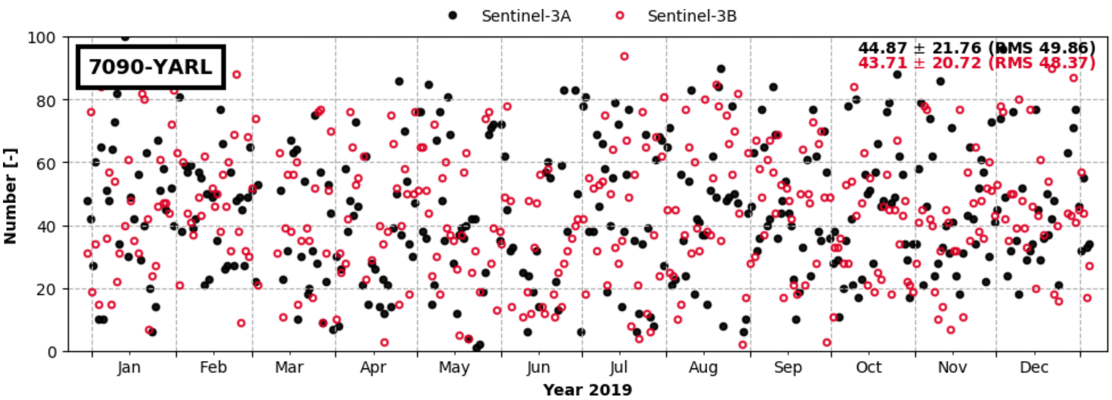


Figure 4-39: Daily total number of the accepted SLR observations of the SLR station 7090 (YARL) in 2019 (Sentinel-3A and Sentinel-3B)

The analysis of the SLR residuals of the following figures reveals constancy and reliability on the SLR observations of the YARL station. Not only the mean value is near 0 but also the standard deviation and root mean square values are tight. The fact of having fixed a range bias for the station has also significantly benefited the statistical outcome on the SLR residuals.

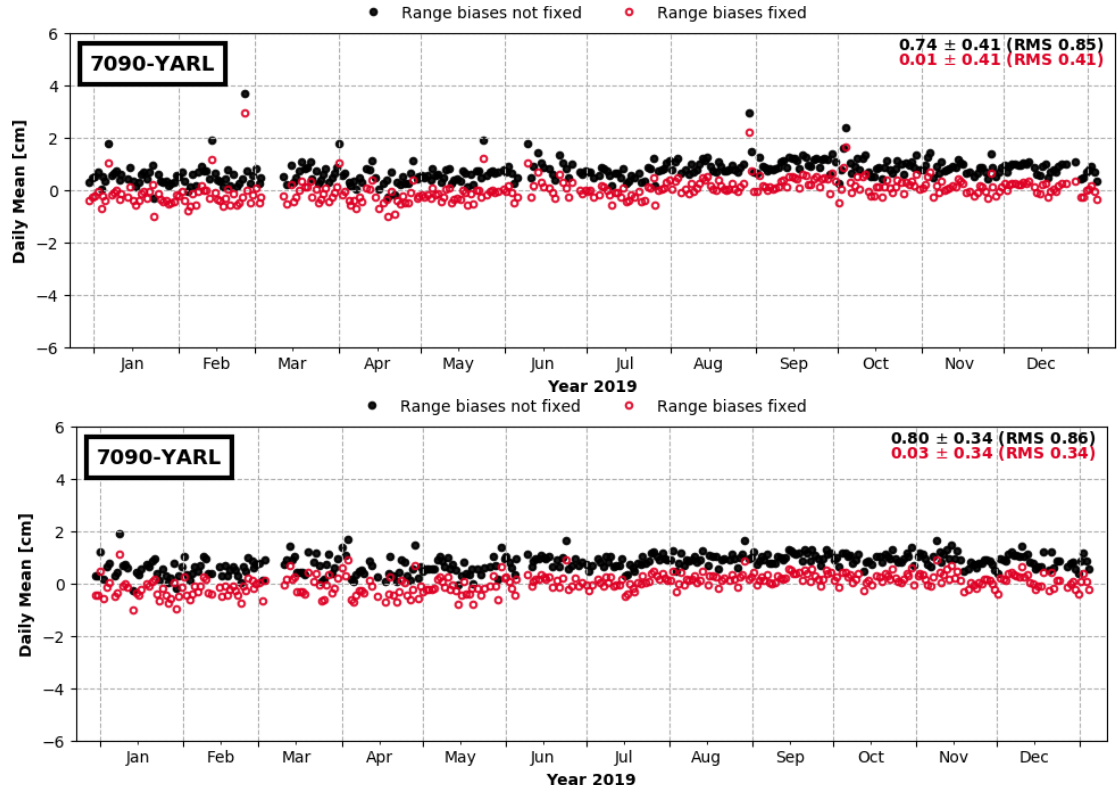


Figure 4-40: Daily mean of the SLR observation residuals [1-range; cm] of the SLR station 7090 (YARL) in 2019 (above Sentinel-3A, and below Sentinel-3B)

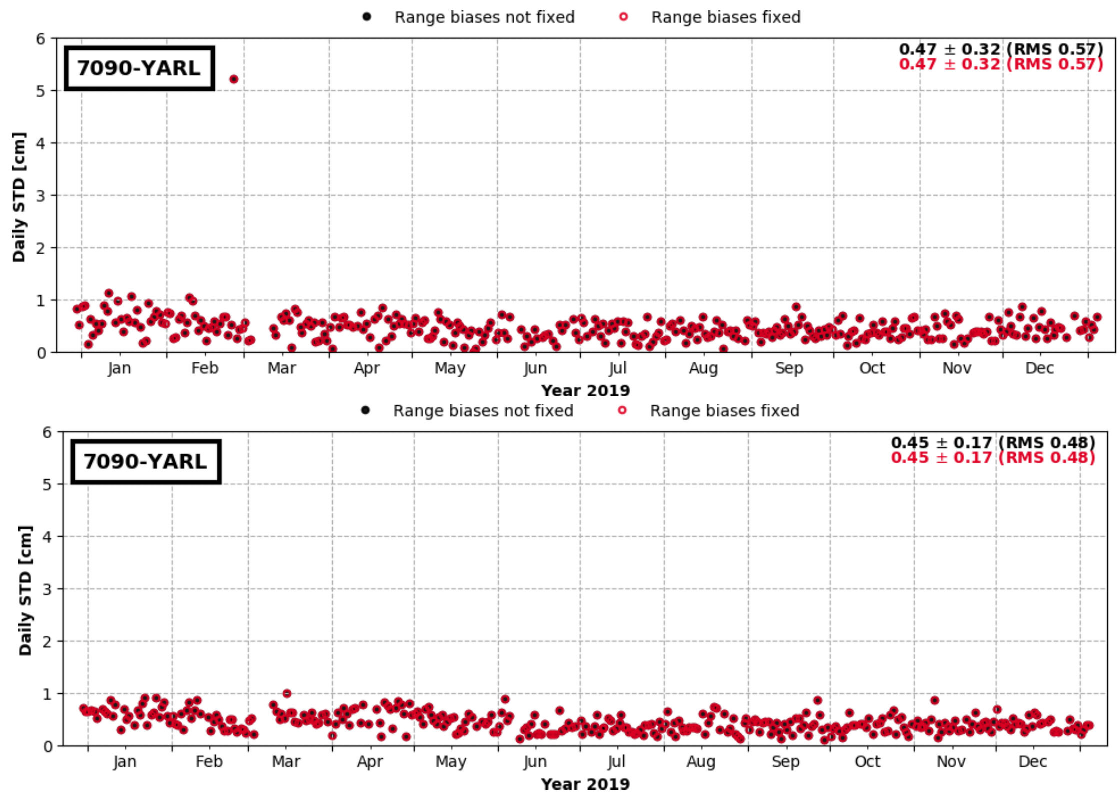


Figure 4-41: Daily STD of the SLR observation residuals [1-range; cm] of the SLR station 7090 (YARL) in 2019 (above Sentinel-3A, and below Sentinel-3B)

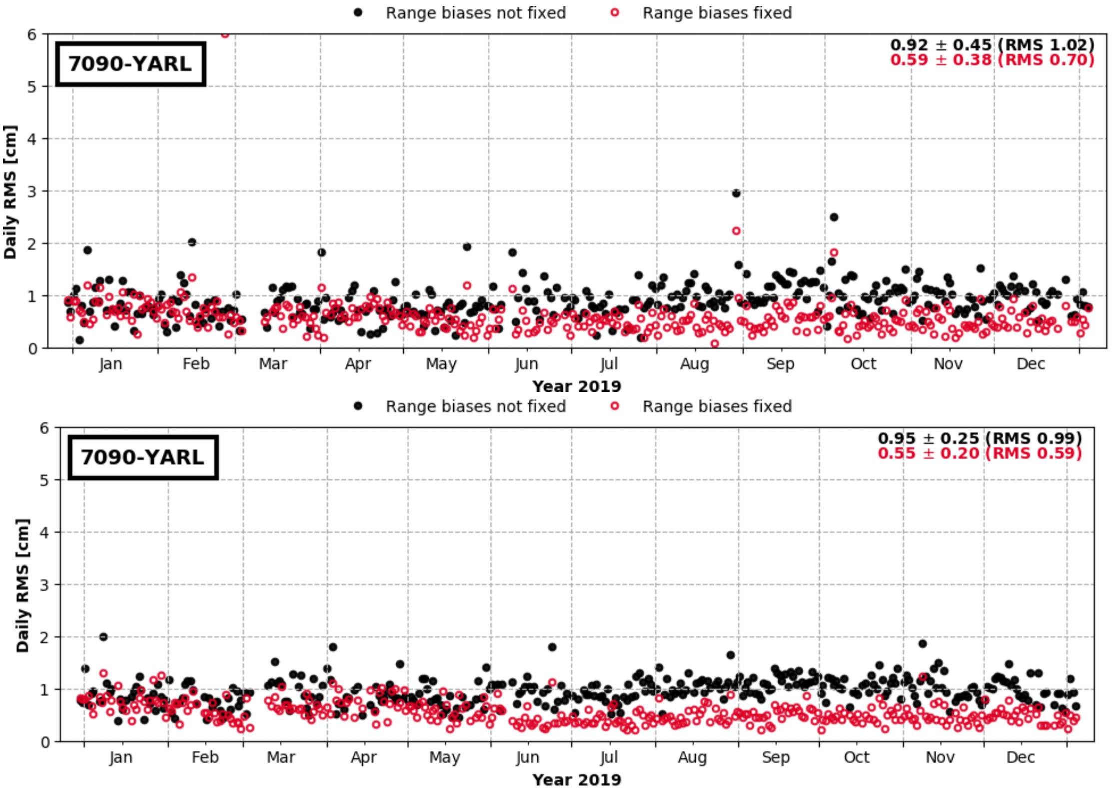


Figure 4-42: Daily RMS of the SLR observation residuals [1-range; cm] of the SLR station 7090 (YARL) in 2019 (above Sentinel-3A, and below Sentinel-3B)

4.8. SLR STATION 7105 (GODL)

The SLR station Greenbelt (7105 - GODL) has been active more than a third of the time period analysed. The GODL station has reported similar outcome for both Sentinel-3 satellites delivering a high number of SLR observations per satellite pass (i.e., a mean value of ~17 SLR observations).

Table 4-8: Summary of the processing statistics of the SLR station 7105 (GODL)

		Sentinel-3A	Sentinel-3B	Jason3
Number of satellite passes (*.npt* files)	All mission	1046	398	1617
	"Year 2019" (20340-20866)	231	211	392
Days processed(*)	Total	366	366	-
Active days	Total	124	124	-
	% (w.r.t. the total days processed)	33.88 %	33.88 %	-
Number of satellite passes processed	Total	229	208	-
	% (w.r.t. the *.npt* files)	99.13 %	98.58 %	-
Number of observations processed	Total	3786	3667	-
Number of observations per satellite pass	Mean	16.53	17.63	-
Number of observations filtered out	Total	0	0	-
	% (w.r.t. the total obs. processed)	0.00 %	0.00 %	-

(*) The total number of days processed does not coincide with the total number of days evaluated in "year 2019" (i.e., 371 days) since the combined orbit solution has not been generated on a few days as a result of either long manoeuvres or large gaps of data or other issues.

After a time period where the GODL station lost connectivity with the Sentinel-3 satellites (i.e., from the end of year 2018 to the beginning of year 2019), the station has resumed the tracking. It is currently tracking Sentinel-3 and Jason-3 satellites with similar figures as seen in Figure 4-43 and Figure 4-44.

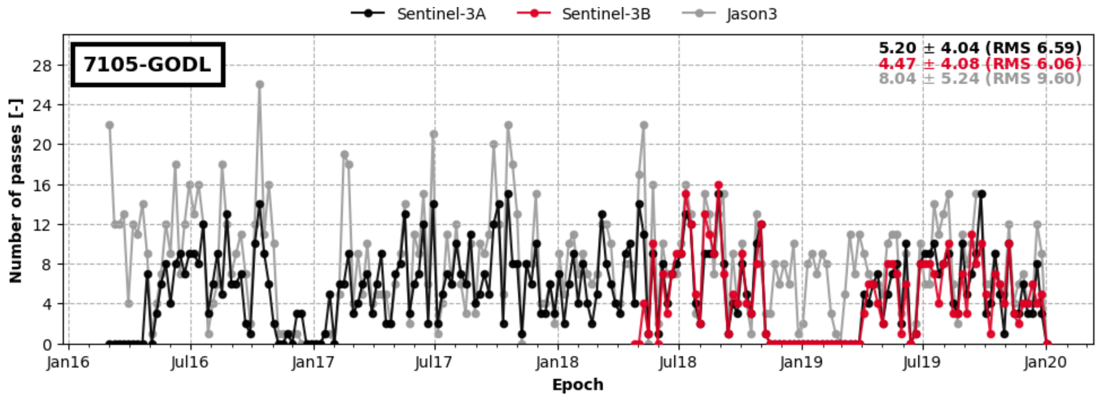


Figure 4-43: Total number of satellite passes per GPS week of the SLR station 7105 (GODL) since the beginning of the satellite mission (Sentinel-3A, Sentinel-3B and Jason-3)

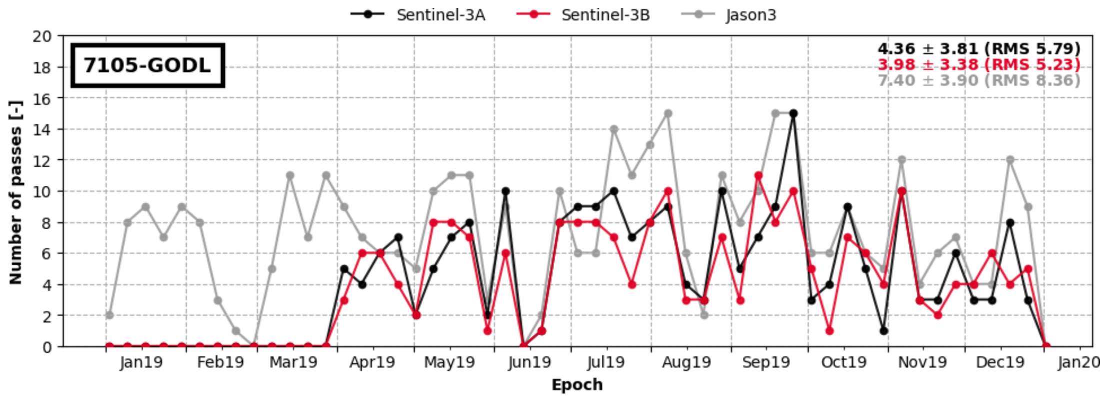


Figure 4-44: Total number of satellite passes per GPS week of the SLR station 7105 (GODL) in 2019 (Sentinel-3A, Sentinel-3B and Jason-3)

The GODL station is providing a great number of SLR observations per day, which leads the station to be one of the SLR stations giving the most quantity of SLR observations per day (see Figure 4-45).

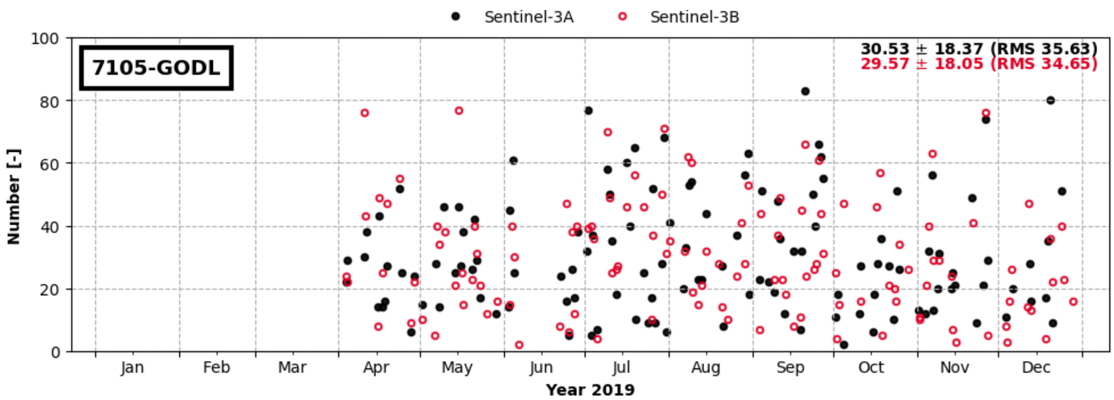


Figure 4-45: Daily total number of the accepted SLR observations of the SLR station 7105 (GODL) in 2019 (Sentinel-3A and Sentinel-3B)

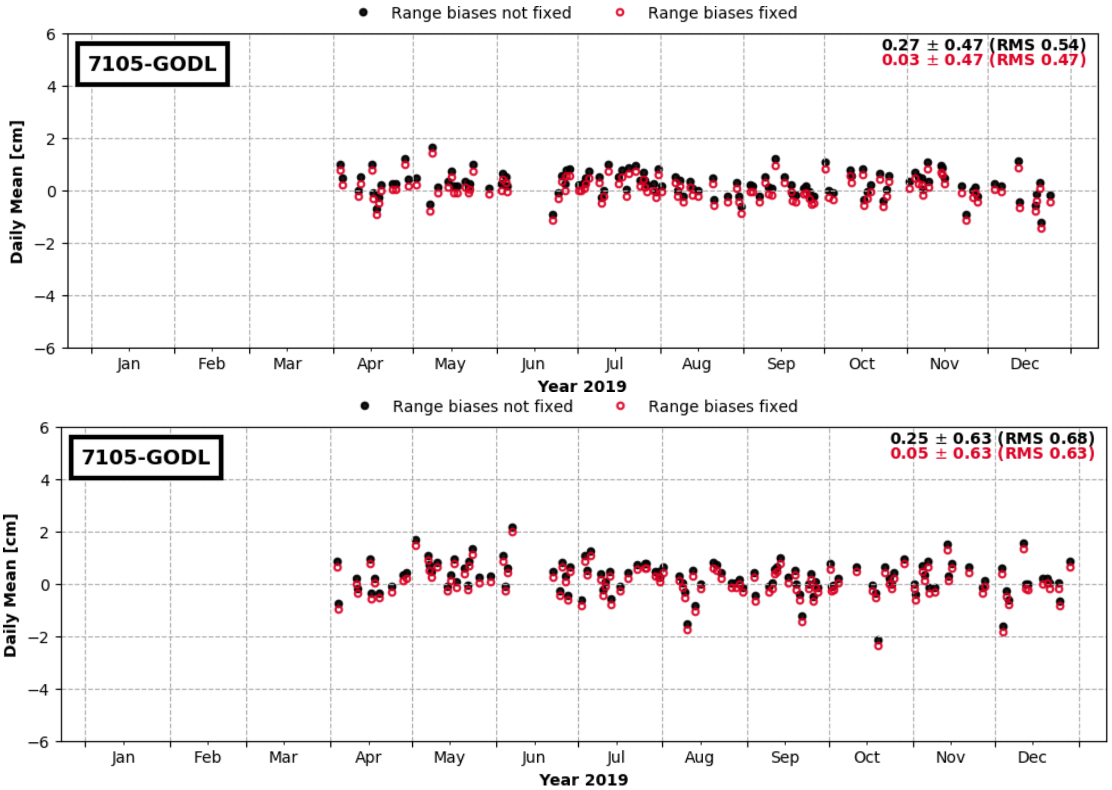


Figure 4-46: Daily mean of the SLR observation residuals [1-range; cm] of the SLR station 7105 (GODL) in 2019 (above Sentinel-3A, and below Sentinel-3B)

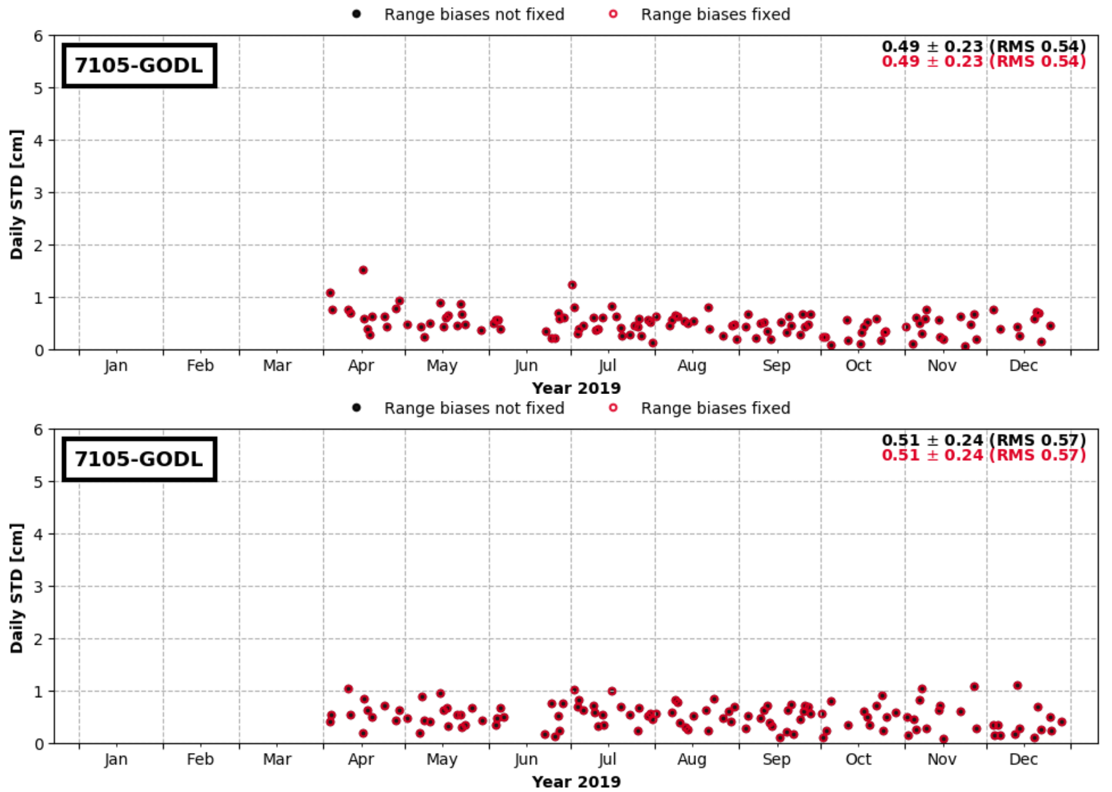


Figure 4-47: Daily STD of the SLR observation residuals [1-range; cm] of the SLR station 7105 (GODL) in 2019 (above Sentinel-3A, and below Sentinel-3B)

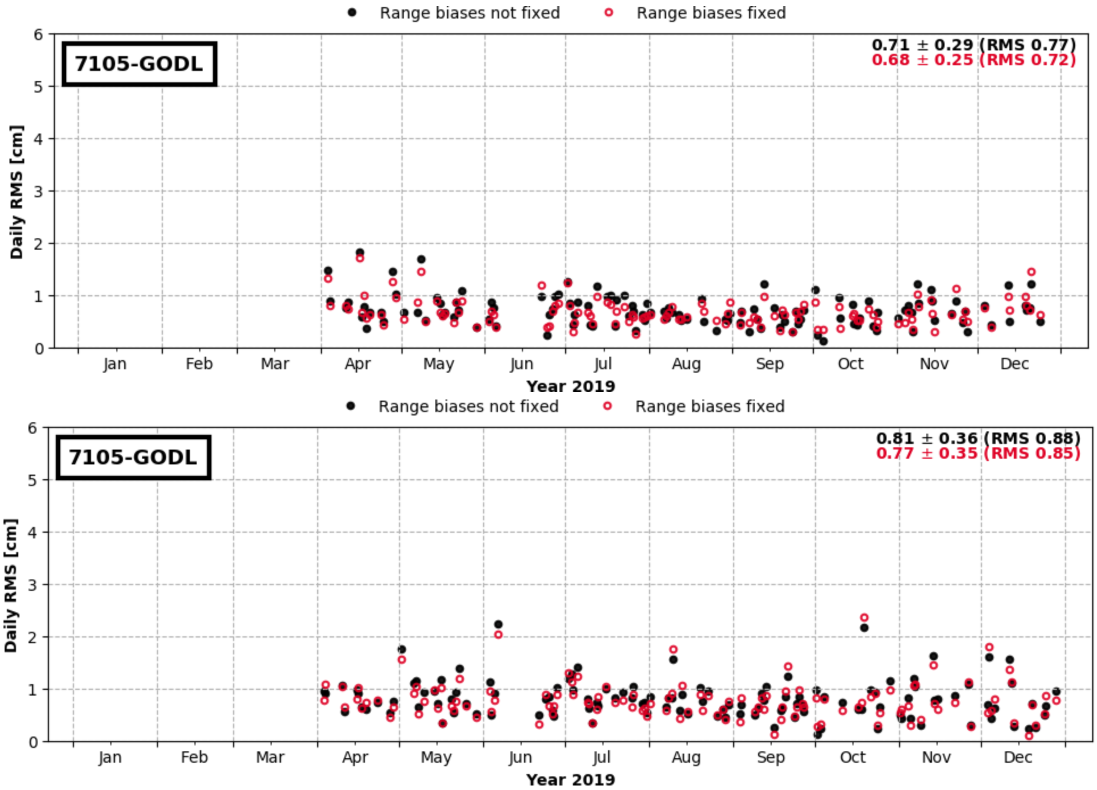


Figure 4-48: Daily RMS of the SLR observation residuals [1-range; cm] of the SLR station 7105 (GODL) in 2019 (above Sentinel-3A, and below Sentinel-3B)

As the case of the YARL station, the SLR residuals of GODL station show mean values tending to 0, and they obtain reduced standard deviation and root mean squares values. These SLR residuals also reveal better figures when the station range bias is fixed.

4.9. SLR STATION 7110 (MONL)

Table 4-9: Summary of the processing statistics of the SLR station 7110 (MONL)

		Sentinel-3A	Sentinel-3B	Jason3
Number of satellite passes (*.npt* files)	All mission	1059	554	1622
	"Year 2019" (20340-20866)	166	161	260
Days processed(*)	Total	366	366	-
Active days	Total	117	114	-
	% (w.r.t. the total days processed)	31.97 %	31.15 %	-
Number of satellite passes processed	Total	164	151	-
	% (w.r.t. the *.npt* files)	98.80 %	93.79 %	-
Number of observations processed	Total	2958	2771	-
Number of observations per satellite pass	Mean	18.04	18.35	-
Number of observations filtered out	Total	0	0	-
	% (w.r.t. the total obs. processed)	0.00 %	0.00 %	-

(*) The total number of days processed does not coincide with the total number of days evaluated in "year 2019" (i.e., 371 days) since the combined orbit solution has not been generated on a few days as a result of either long manoeuvres or large gaps of data or other issues.

The SLR station Monument Peak (7110 – MONL) is another SLR station tracking Sentinel-3 satellites that can be considered as more active. Almost a third of the time period evaluated, the MONL station has been delivering SLR observations from the Sentinel-3 satellites. And, it is not only one of the most active but also one of the SLR stations providing most quantity of SLR observations per satellite pass (with a mean value of ~18 SLR observations).

As the GODL station case, the MONL station also lost connection with the Sentinel-3 satellites from the end of year 2018 to the beginning of year 2019 (see Figure 4-49 and Figure 4-50). Once the tracking was resumed, the MONL station has been providing data of the Sentinel-3 satellites at similar rate of the Jason-3 satellite.

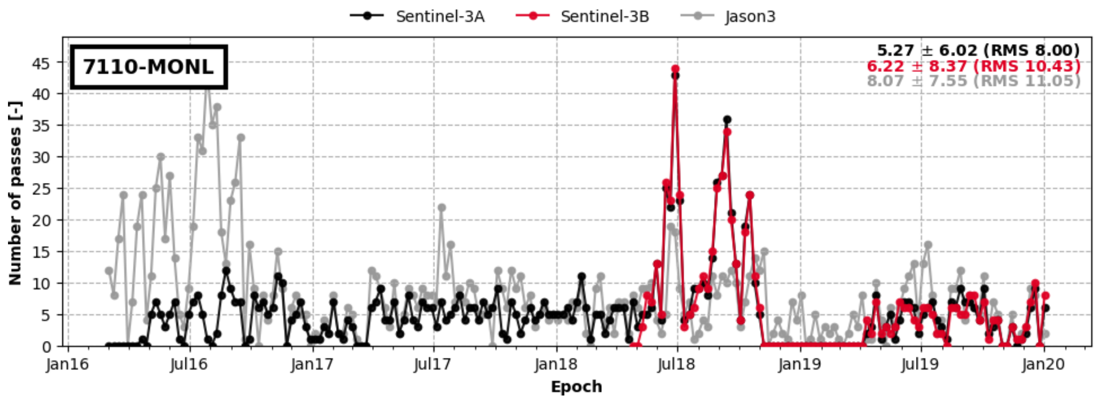


Figure 4-49: Total number of satellite passes per GPS week of the SLR station 7110 (MONL) since the beginning of the satellite mission (Sentinel-3A, Sentinel-3B and Jason-3)

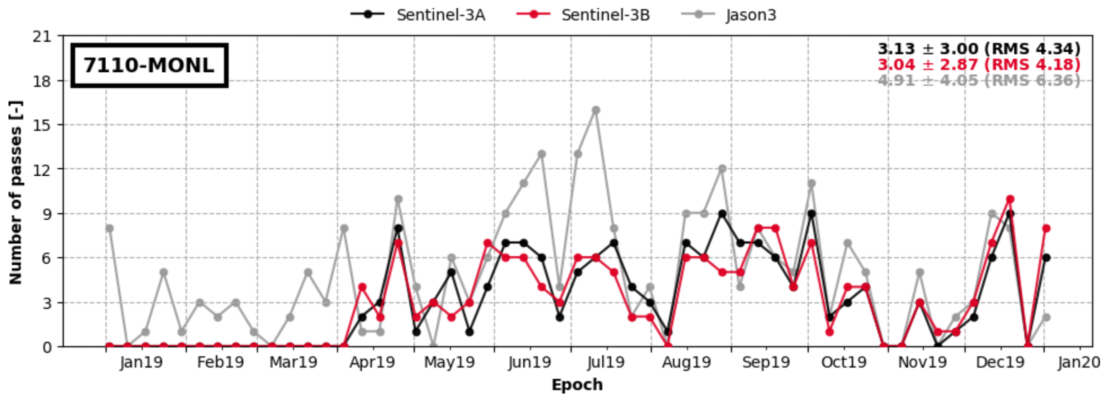


Figure 4-50: Total number of satellite passes per GPS week of the SLR station 7110 (MONL) in 2019 (Sentinel-3A, Sentinel-3B and Jason-3)

From Figure 4-51, it can be seen the large number of SLR observations that the MONL station is delivering on a daily basis. Such figures are quite similar to those obtained from the GODL station.

In addition, the residual statistics from these SLR observations show mean values tending to 0 and standard deviation and root mean square values with reduced figures. The fact of having fixed a range bias for the MONL station has also improved the values acquired on the statistics shown below.

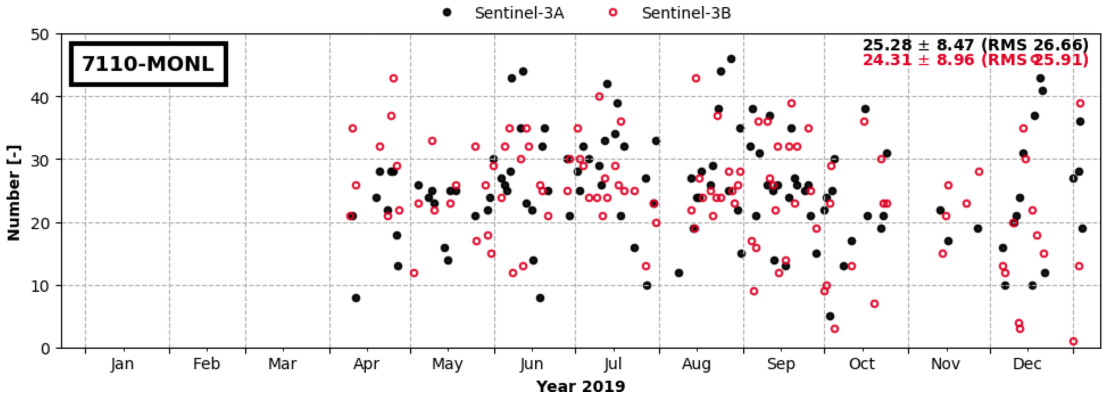


Figure 4-51: Daily total number of the accepted SLR observations of the SLR station 7110 (MONL) in 2019 (Sentinel-3A and Sentinel-3B)

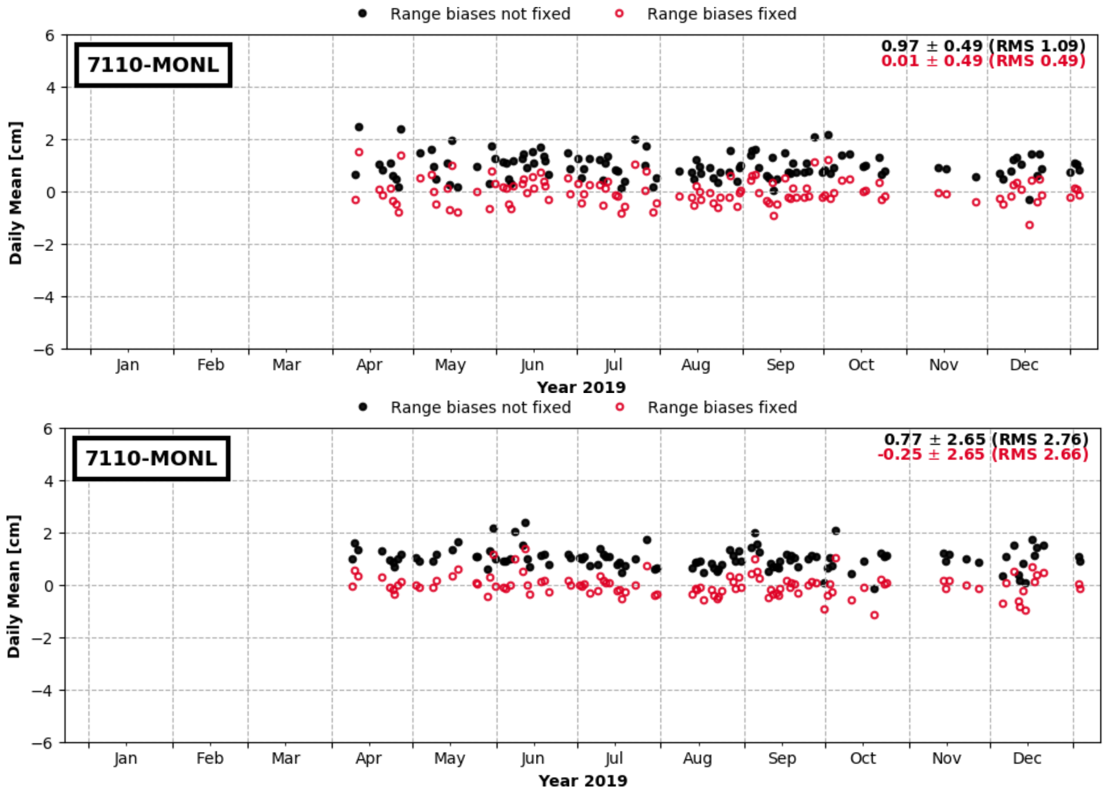
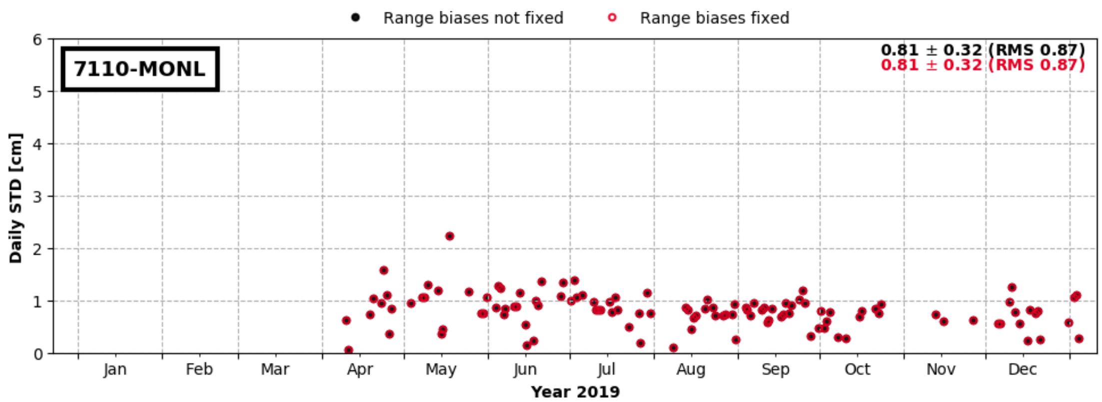


Figure 4-52: Daily mean of the SLR observation residuals [1-range; cm] of the SLR station 7110 (MONL) in 2019 (above Sentinel-3A, and below Sentinel-3B)



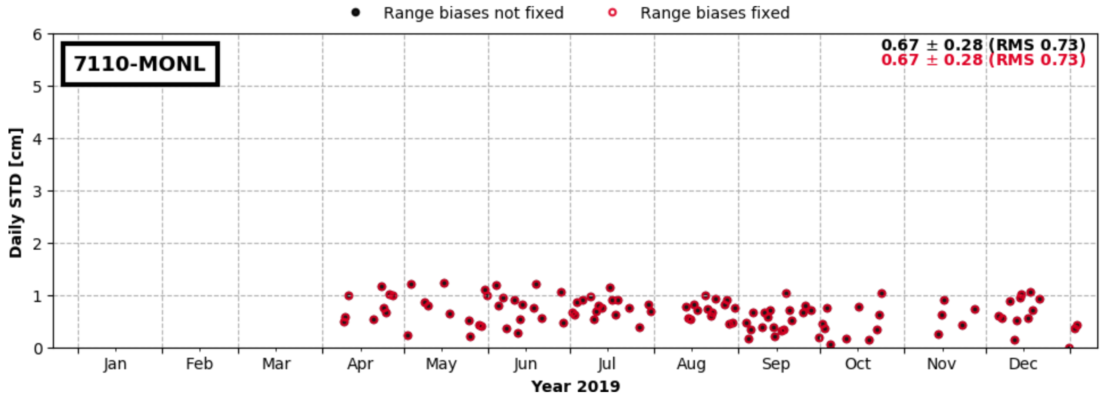


Figure 4-53: Daily STD of the SLR observation residuals [1-range; cm] of the SLR station 7110 (MONL) in 2019 (above Sentinel-3A, and below Sentinel-3B)

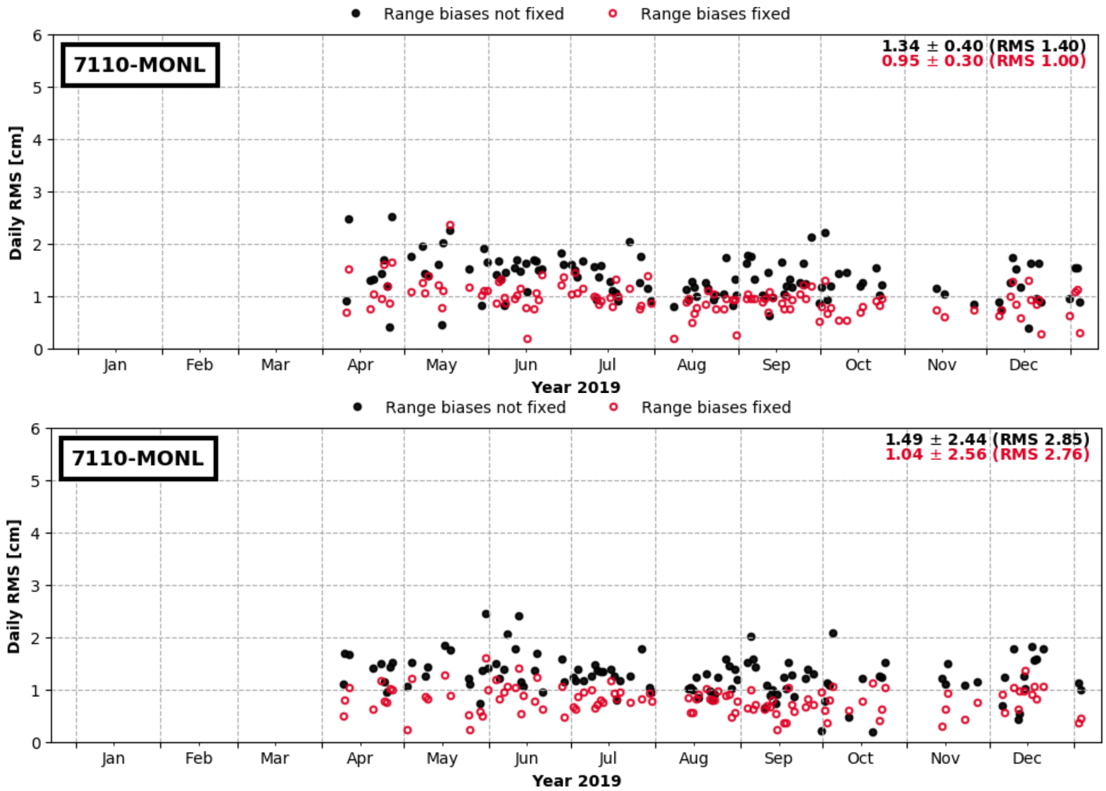


Figure 4-54: Daily RMS of the SLR observation residuals [1-range; cm] of the SLR station 7110 (MONL) in 2019 (above Sentinel-3A, and below Sentinel-3B)

4.10. SLR STATION 7119 (HA4T)

The SLR station Haleakala (7119 – HA4T) has been active almost a quarter of the time period analysed. It is currently one of the SLR stations most tracking the Sentinel-3 satellites providing a mean value of 15-16 SLR observations per satellite pass, which is a medium-high value regarding the figures of the rest of the SLR stations. From Table 4-10, it can be seen that Sentinel-3A and Sentinel-3B satellites have been similarly tracked from HA4T station.

Table 4-10: Summary of the processing statistics of the SLR station 7119 (HA4T)

		Sentinel-3A	Sentinel-3B	Jason3
Number of satellite passes (*.npt* files)	All mission	458	170	713
	"Year 2019" (20340-20866)	106	98	170
Days processed(*)	Total	366	366	-
Active days	Total	91	90	-
	% (w.r.t. the total days processed)	24.86 %	24.59 %	-
Number of satellite passes processed	Total	101	95	-
	% (w.r.t. the *.npt* files)	95.28 %	96.94 %	-
Number of observations processed	Total	1486	1496	-
Number of observations per satellite pass	Mean	14.71	15.75	-
Number of observations filtered out	Total	0	1	-
	% (w.r.t. the total obs. processed)	0.00 %	0.07 %	-

(*) The total number of days processed does not coincide with the total number of days evaluated in "year 2019" (i.e., 371 days) since the combined orbit solution has not been generated on a few days as a result of either long manoeuvres or large gaps of data or other issues.

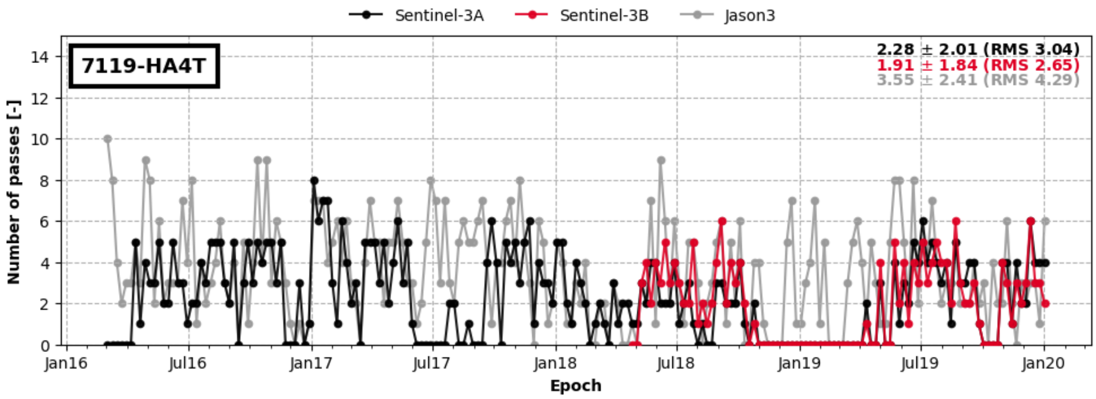


Figure 4-55: Total number of satellite passes per GPS week of the SLR station 7119 (HA4T) since the beginning of the satellite mission (Sentinel-3A, Sentinel-3B and Jason-3)

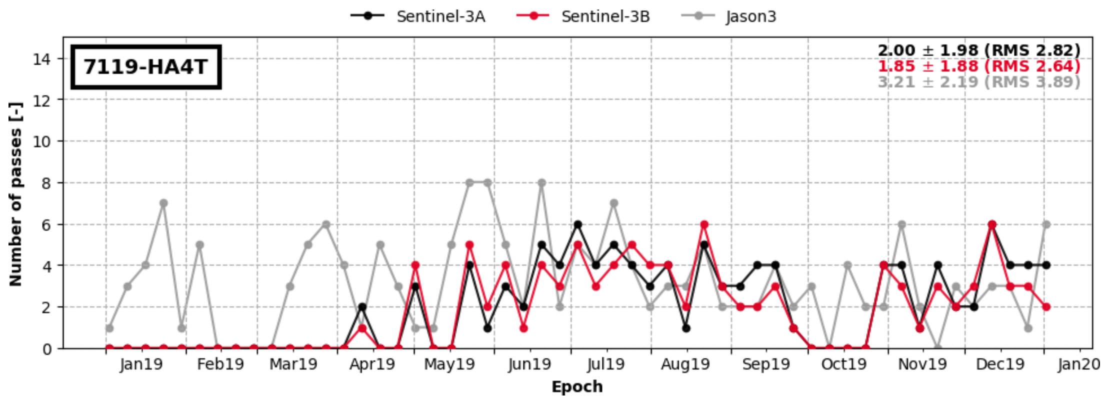


Figure 4-56: Total number of satellite passes per GPS week of the SLR station 7119 (HA4T) in 2019 (Sentinel-3A, Sentinel-3B and Jason-3)

Figure 4-55 and Figure 4-56 also reveal that the HA4T station lost tracking on Sentinel-3 satellites from the end of year 2018 to the beginning of year 2019. However, after this time period the station has resumed the tracking on both satellites bringing similar tracking figures than the ones obtained by the Jason-3 satellite. It must be highlighted that the HA4T station also lost connection to Sentinel-3 satellites on October 2019 but the tracking was also resumed in a short time period.

The number of the SLR observations that the HA4T station is delivering on a daily basis can be considered as an average number if all SLR stations are taken into account.

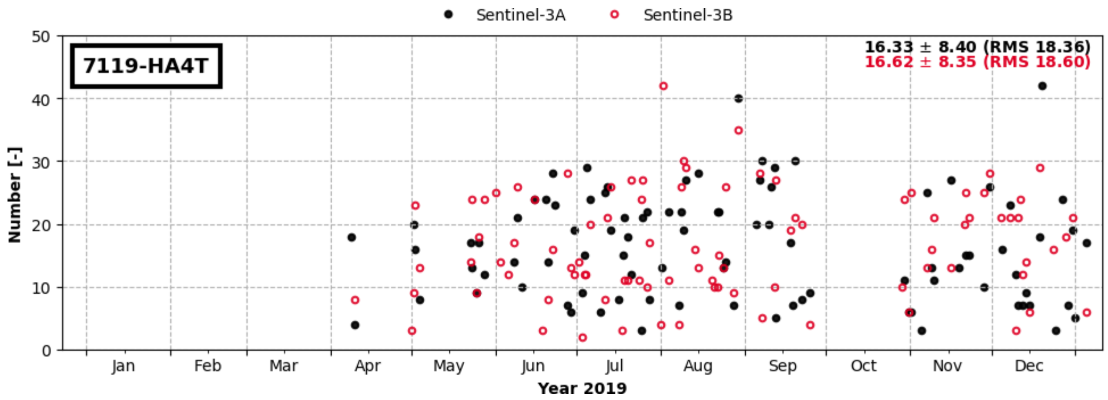


Figure 4-57: Daily total number of the accepted SLR observations of the SLR station 7119 (HA4T) in 2019 (Sentinel-3A and Sentinel-3B)

From the following figures, it can be said that the HA4T station is proving a good quality of SLR observations since the statistics on the SLR residuals show good performance. Such statistics have significantly benefited from having fixed a range bias value for the station.

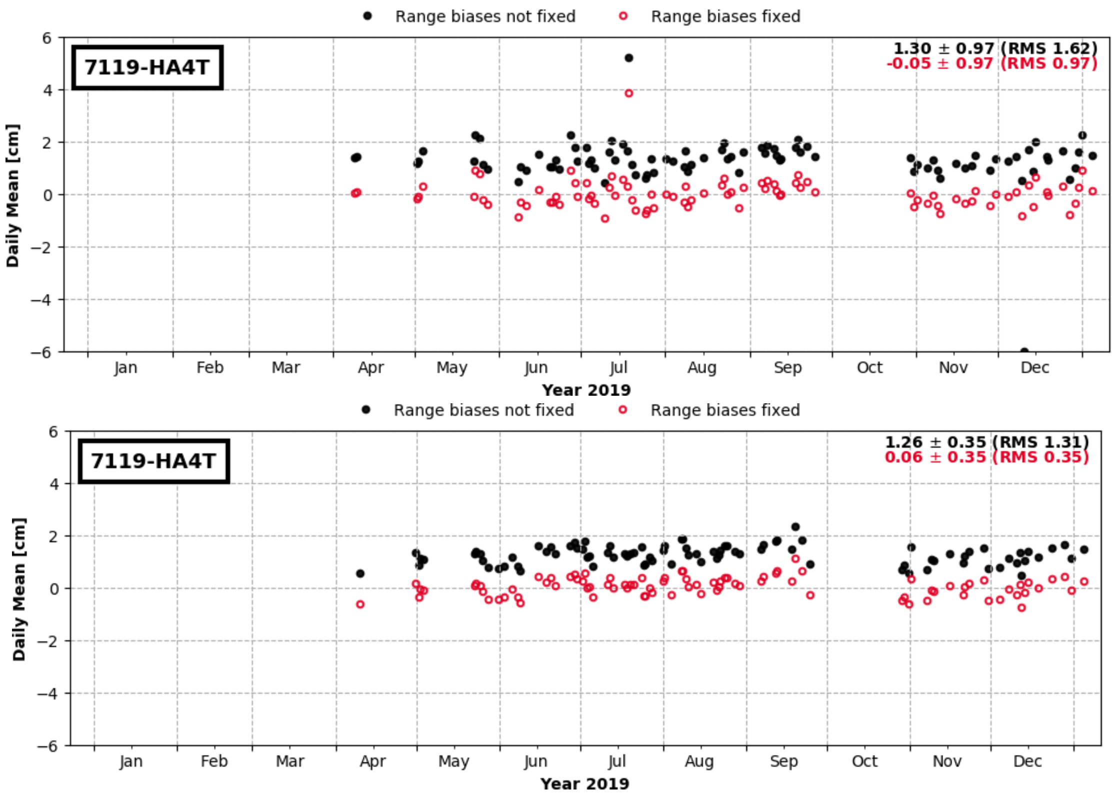


Figure 4-58: Daily mean of the SLR observation residuals [1-range; cm] of the SLR station 7119 (HA4T) in 2019 (above Sentinel-3A, and below Sentinel-3B)

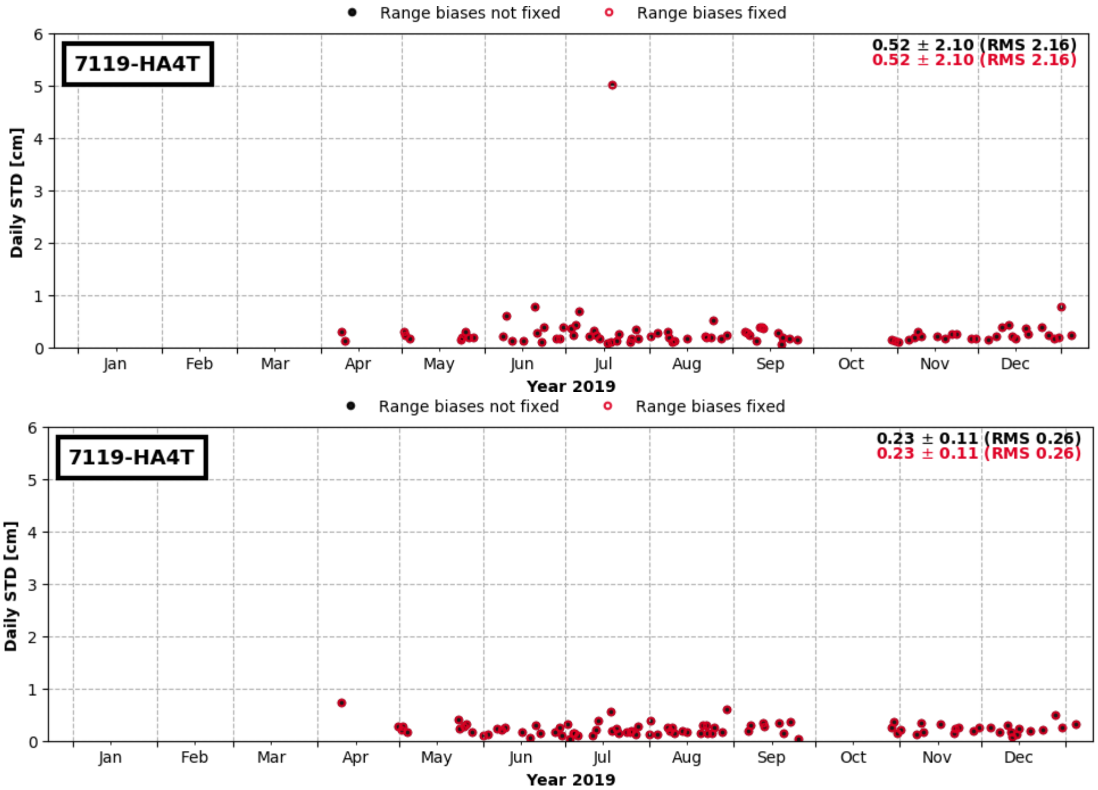


Figure 4-59: Daily STD of the SLR observation residuals [1-range; cm] of the SLR station 7119 (HA4T) in 2019 (above Sentinel-3A, and below Sentinel-3B)

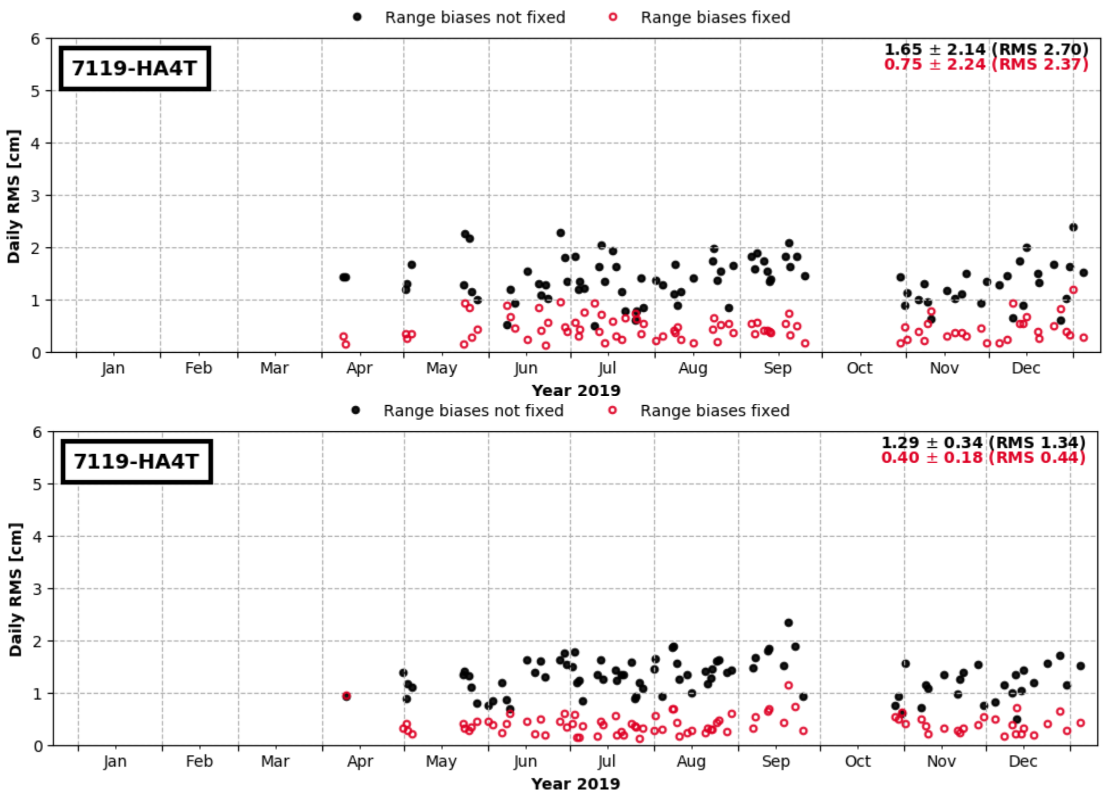


Figure 4-60: Daily RMS of the SLR observation residuals [1-range; cm] of the SLR station 7119 (HA4T) in 2019 (above Sentinel-3A, and below Sentinel-3B)

4.11. SLR STATION 7249 (BEIL)

The SLR station Beijing (7249 - BEIL) has been active during almost a quarter of the time period evaluated. The BEIL station has similarly tracked both Sentinel-3 satellites providing a mean value of ~6 SLR observations per satellite pass, which value can be considered low compared to the rest of SLR stations with similar activity. From Table 4-11, it must be highlighted the large percentage number on the SLR observations filtered-out, which might show a station misconfiguration when processing the data of the BEIL station.

Table 4-11: Summary of the processing statistics of the SLR station 7249 (BEIL)

		Sentinel-3A	Sentinel-3B	Jason3
Number of satellite passes (*.npt* files)	All mission	165	200	501
	"Year 2019" (20340-20866)	108	107	121
Days processed(*)	Total	366	366	-
Active days	Total	88	85	-
	% (w.r.t. the total days processed)	24.04 %	23.22 %	-
Number of satellite passes processed	Total	105	107	-
	% (w.r.t. the *.npt* files)	97.22 %	100.00 %	-
Number of observations processed	Total	586	599	-
Number of observations per satellite pass	Mean	5.58	5.60	-
Number of observations filtered out	Total	15	11	-
	% (w.r.t. the total obs. processed)	2.56 %	1.84 %	-

(*) The total number of days processed does not coincide with the total number of days evaluated in "year 2019" (i.e., 371 days) since the combined orbit solution has not been generated on a few days as a result of either long manoeuvres or large gaps of data or other issues.

The BEIL station has showed an irregular tracking during the entire missions of the satellites, especially on the Sentinel-3A satellite (see Figure 4-61 and Figure 4-62). Fortunately, the station has lately resumed the tracking on both Sentinel-3 satellites, and it is currently bringing a mean value of 2 satellite passes per week. Such value is similar to the one obtained by the Jason-3 satellite.

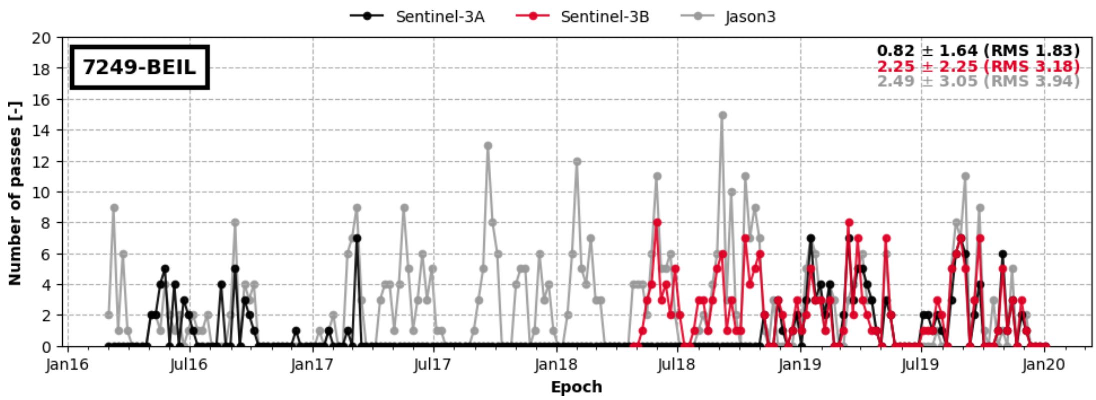


Figure 4-61: Total number of satellite passes per GPS week of the SLR station 7249 (BEIL) since the beginning of the satellite mission (Sentinel-3A, Sentinel-3B and Jason-3)

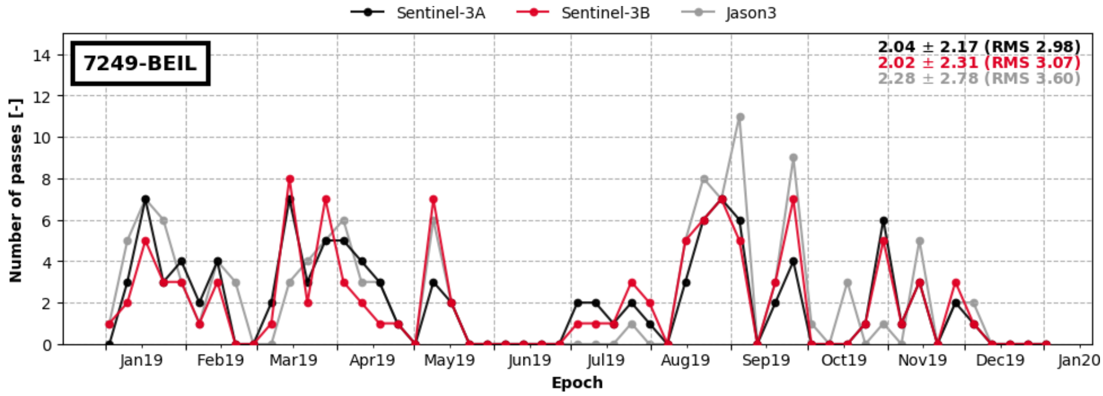


Figure 4-62: Total number of satellite passes per GPS week of the SLR station 7249 (BEIL) in 2019 (Sentinel-3A, Sentinel-3B and Jason-3)

From Figure 4-63, it can be said that BEIL station shows a constant pattern on the daily number of the SLR observations provided when active. However, it must be highlighted that there are still many time periods where the station seems to have lost the tracking on both Sentinel-3 satellites.

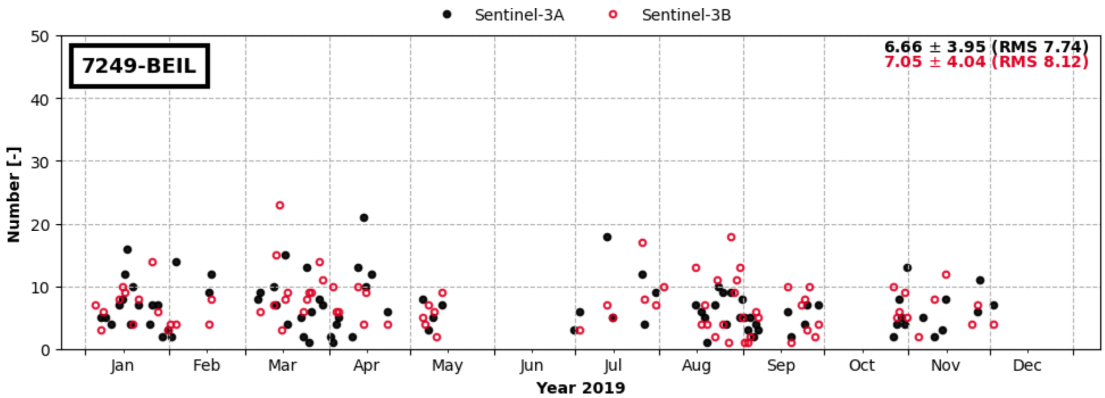
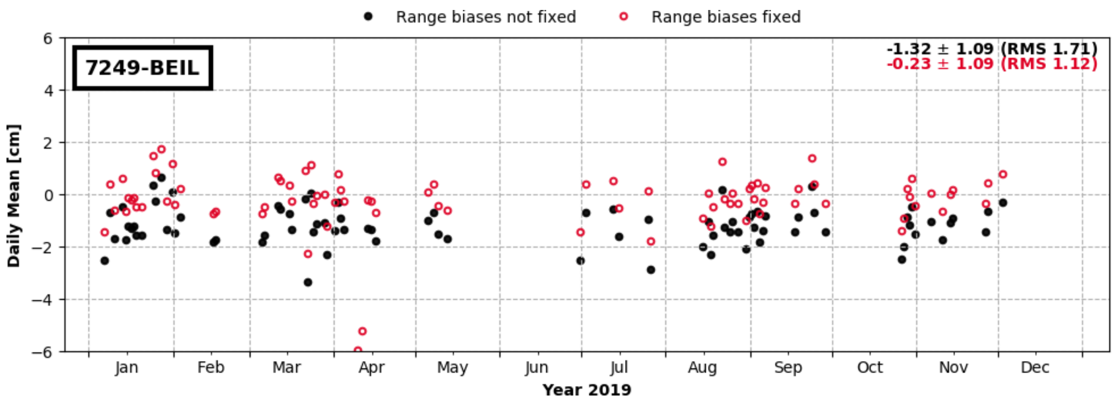


Figure 4-63: Daily total number of the accepted SLR observations of the SLR station 7249 (BEIL) in 2019 (Sentinel-3A and Sentinel-3B)

In general, the statistics on the SLR residuals show good performance of the SLR observations delivered by the BEIL station although a few SLR observations harm the final mean values obtained. The use of a fixed range bias on the station has also benefited the calculation of the SLR residuals.



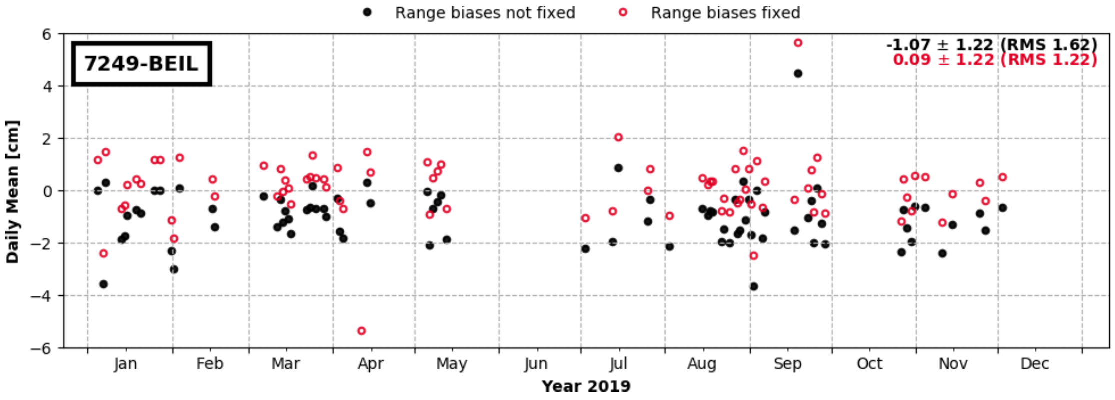


Figure 4-64: Daily mean of the SLR observation residuals [1-range; cm] of the SLR station 7249 (BEIL) in 2019 (above Sentinel-3A, and below Sentinel-3B)

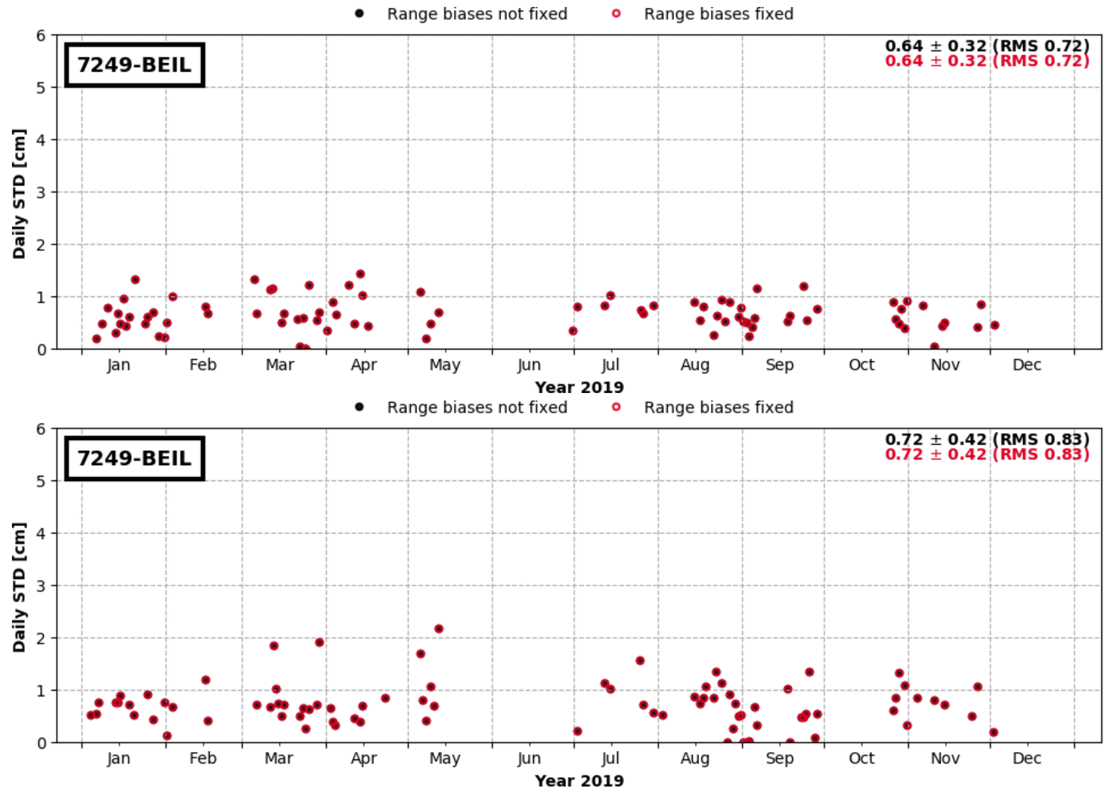
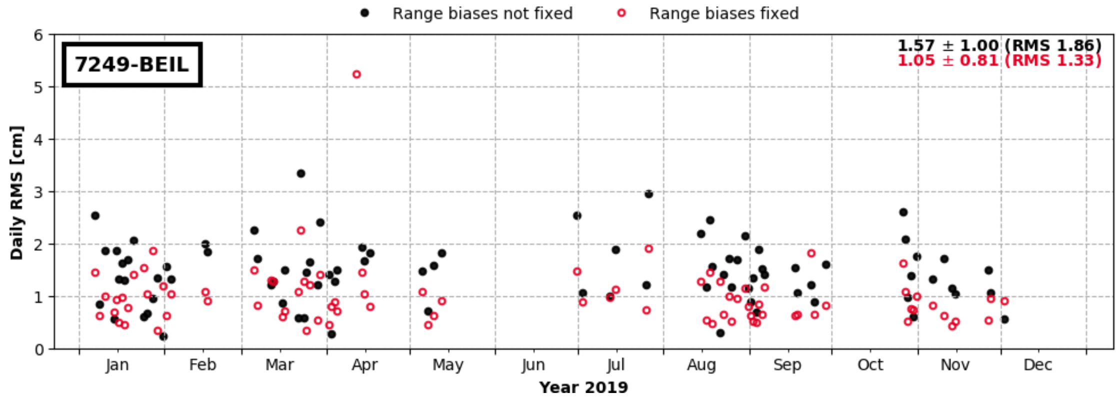


Figure 4-65: Daily STD of the SLR observation residuals [1-range; cm] of the SLR station 7249 (BEIL) in 2019 (above Sentinel-3A, and below Sentinel-3B)



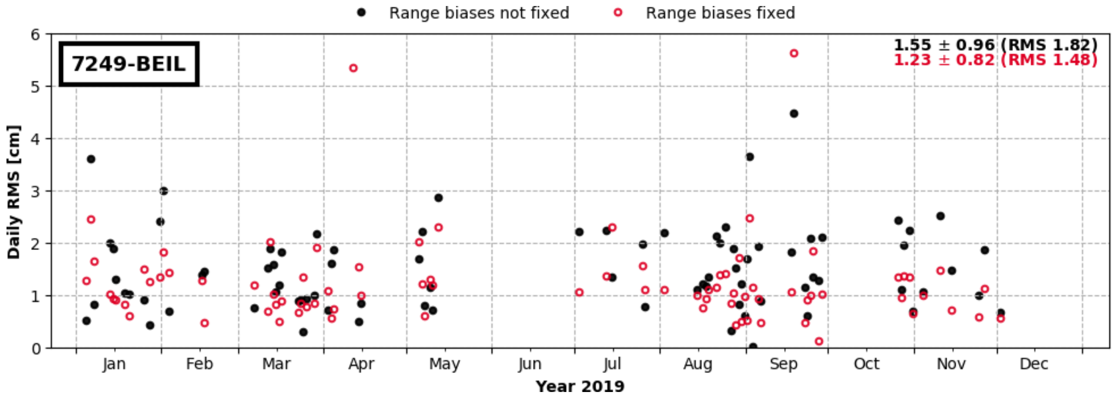


Figure 4-66: Daily RMS of the SLR observation residuals [1-range; cm] of the SLR station 7249 (BEIL) in 2019 (above Sentinel-3A, and below Sentinel-3B)

4.12. SLR STATION 7403 (AREL)

The SLR station Arequipa (7403 - AREL) has been active almost a third of the time period analysed, and therefore, it is one of the SLR stations most tracking the Sentinel-3 satellites. Table 4-12 does not show any discrepancy between the figures obtained between Sentinel-3A and Sentinel-3B satellites. From the table, it must be highlighted that the AREL station is bringing a mean value of ~10 SLR observations per satellite pass, which is a figure a little below the outcome provided by other SLR stations with similar activity.

Table 4-12: Summary of the processing statistics of the SLR station 7403 (AREL)

		Sentinel-3A	Sentinel-3B	Jason3
Number of satellite passes (*.npt* files)	All mission	531	255	685
	"Year 2019" (20340-20866)	159	157	173
Days processed(*)	Total	366	366	-
Active days	Total	113	117	-
	% (w.r.t. the total days processed)	30.87 %	31.97 %	-
Number of satellite passes processed	Total	152	152	-
	% (w.r.t. the *.npt* files)	95.60 %	96.82 %	-
Number of observations processed	Total	1557	1568	-
Number of observations per satellite pass	Mean	10.24	10.32	-
Number of observations filtered out	Total	3	6	-
	% (w.r.t. the total obs. processed)	0.19 %	0.38 %	-

(*) The total number of days processed does not coincide with the total number of days evaluated in "year 2019" (i.e., 371 days) since the combined orbit solution has not been generated on a few days as a result of either long manoeuvres or large gaps of data or other issues.

The tracking pattern of the AREL station (southern hemisphere) reveals a common pattern over the years: high performance during their winter time and low performance during their summer time. As seen in Figure 4-67 and Figure 4-68, the AREL station also lost connection on the Sentinel-3 satellites from the end of year 2018 and the beginning of year 2019. After this time period, the station achieved the highest number of satellite passes. On the other hand, it must be highlighted that the three satellites report similar tracking figures from the AREL station.

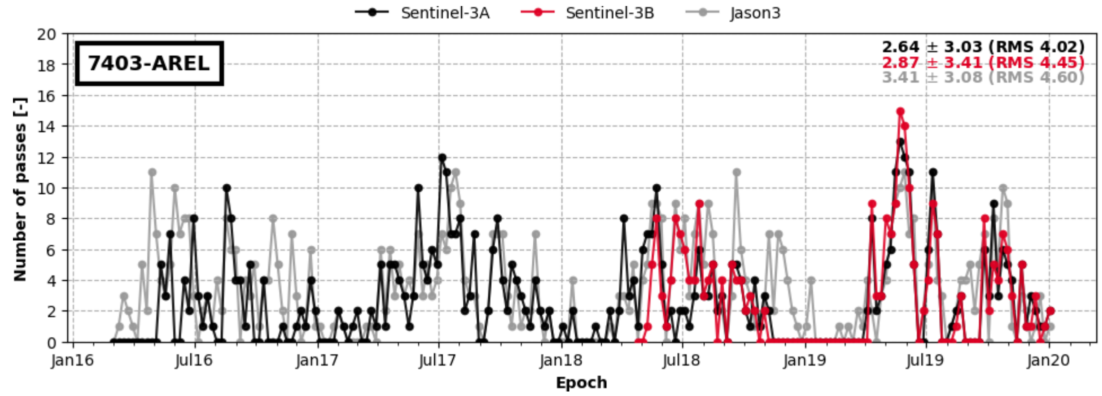


Figure 4-67: Total number of satellite passes per GPS week of the SLR station 7403 (AREL) since the beginning of the satellite mission (Sentinel-3A, Sentinel-3B and Jason-3)

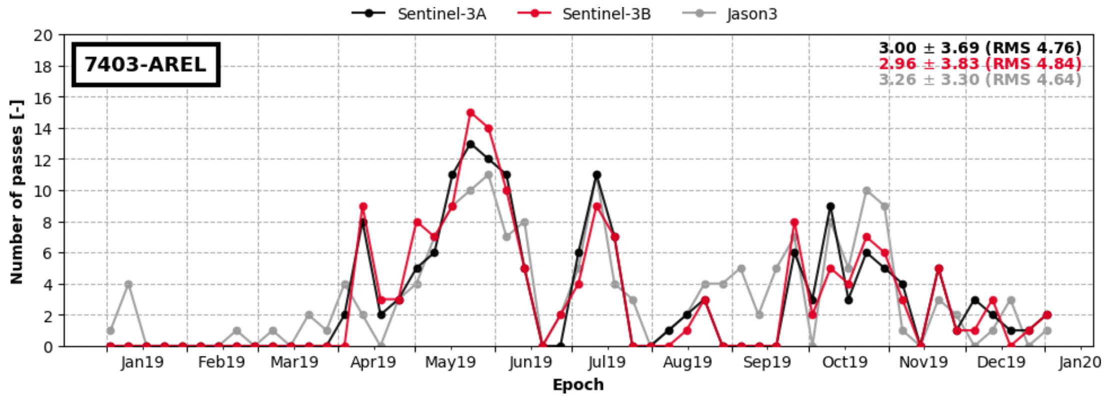


Figure 4-68: Total number of satellite passes per GPS week of the SLR station 7403 (AREL) in 2019 (Sentinel-3A, Sentinel-3B and Jason-3)

The temporal analysis on the number of the SLR observations provided by the AREL station shows an irregular pattern combining time periods with a high concentration of SLR observations and time periods more dispersive. Despite this fact, the AREL station is bringing a mean value of 13-14 SLR observations per day when active.

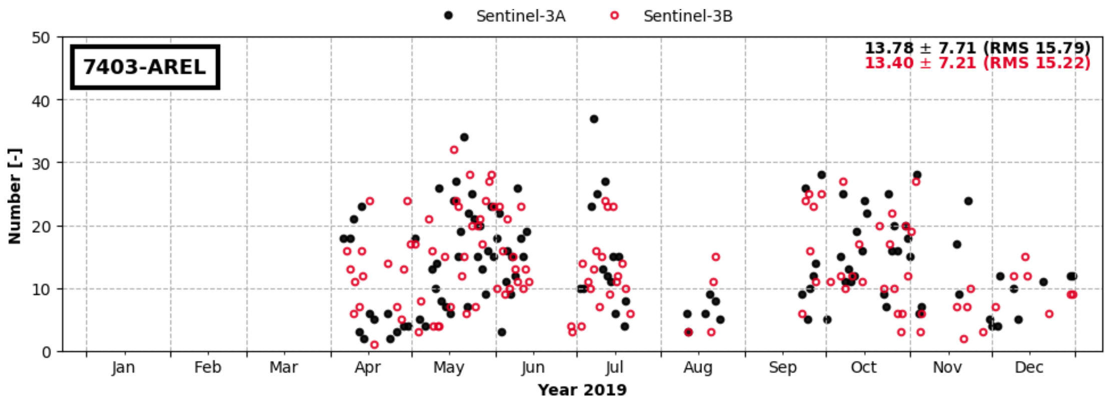


Figure 4-69: Daily total number of the accepted SLR observations of the SLR station 7403 (AREL) in 2019 (Sentinel-3A and Sentinel-3B)

From the figures below, it can be said that the SLR observations provided by the AREL station show good performance in general. However a more constant behaviour on the SLR observations might benefit the final outcome obtained. Note the positive-negative behaviour on the mean values.

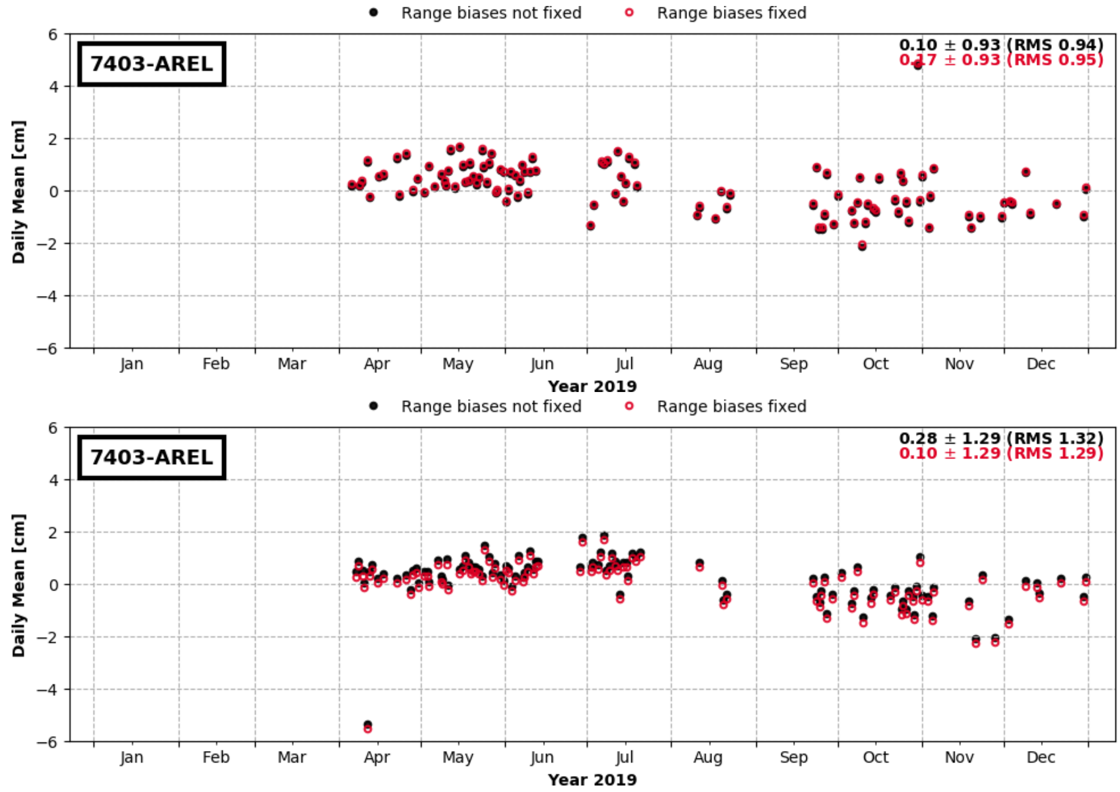


Figure 4-70: Daily mean of the SLR observation residuals [1-range; cm] of the SLR station 7403 (AREL) in 2019 (above Sentinel-3A, and below Sentinel-3B)

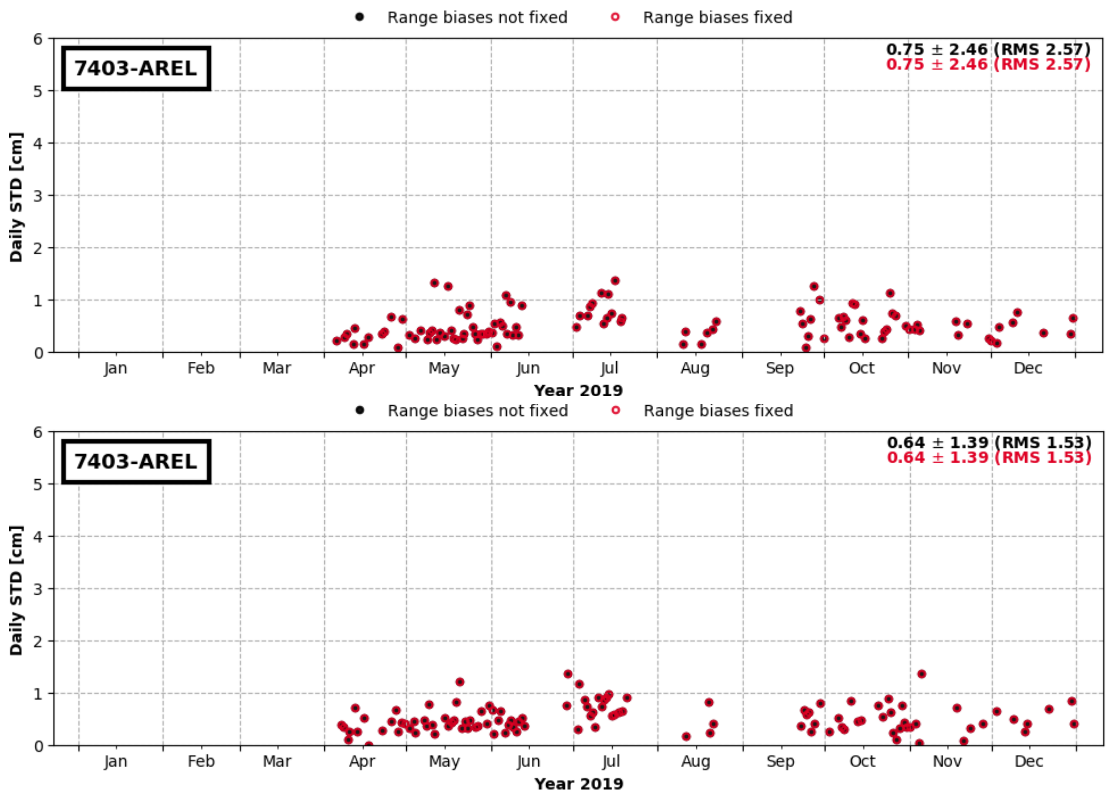


Figure 4-71: Daily STD of the SLR observation residuals [1-range; cm] of the SLR station 7403 (AREL) in 2019 (above Sentinel-3A, and below Sentinel-3B)

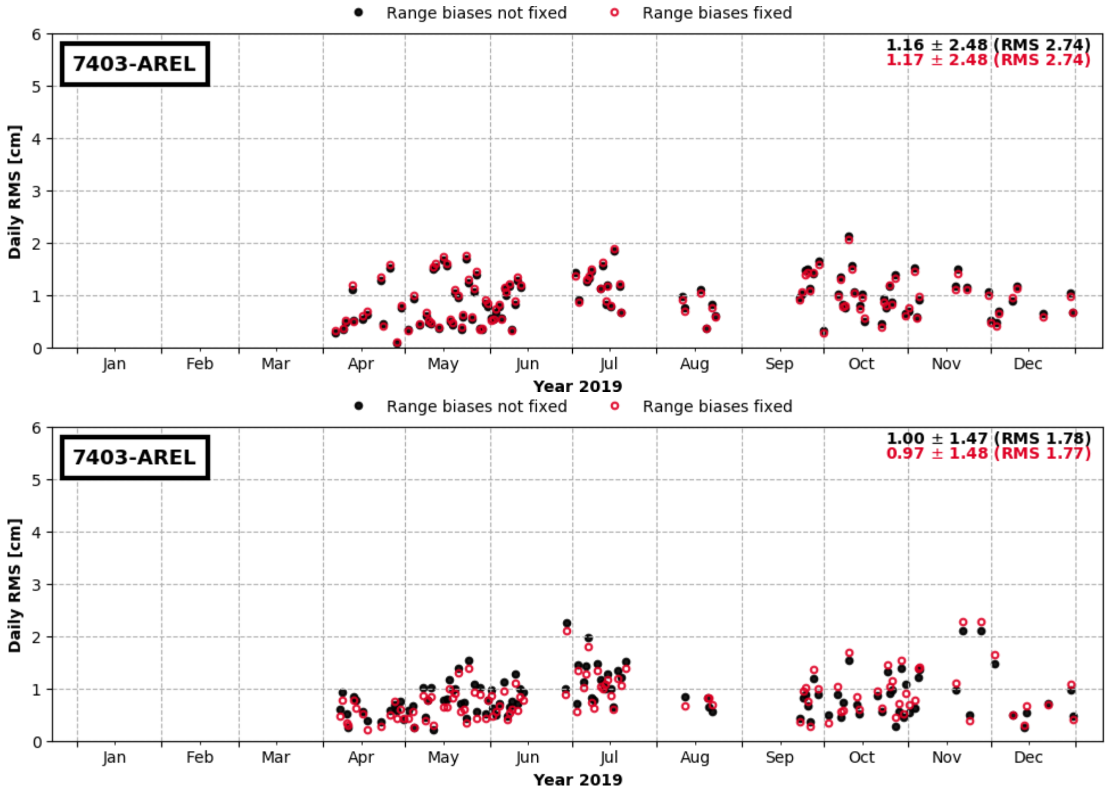


Figure 4-72: Daily RMS of the SLR observation residuals [1-range; cm] of the SLR station 7403 (AREL) in 2019 (above Sentinel-3A, and below Sentinel-3B)

4.13. SLR STATION 7501 (HARL)

Table 4-13: Summary of the processing statistics of the SLR station 7501 (HARL)

		Sentinel-3A	Sentinel-3B	Jason3
Number of satellite passes (*.npt* files)	All mission	396	223	876
	"Year 2019" (20340-20866)	114	109	246
Days processed(*)	Total	366	366	-
Active days	Total	92	88	-
	% (w.r.t. the total days processed)	25.14 %	24.04 %	-
Number of satellite passes processed	Total	106	99	-
	% (w.r.t. the *.npt* files)	92.98 %	90.83 %	-
Number of observations processed	Total	1504	1473	-
Number of observations per satellite pass	Mean	14.19	14.88	-
Number of observations filtered out	Total	0	0	-
	% (w.r.t. the total obs. processed)	0.00 %	0.00 %	-

(*) The total number of days processed does not coincide with the total number of days evaluated in "year 2019" (i.e., 371 days) since the combined orbit solution has not been generated on a few days as a result of either long manoeuvres or large gaps of data or other issues.

The SLR station Hartebeesthoek (7501 - HARL) has been active during a quarter of the time period evaluated. On this time, the HARL station has delivered a mean value of ~15 SLR observations per satellite pass, which is a high value. From Table 4-13, no significant differences are obtained on the processing statistics of the Sentinel-3 satellites since both satellites have been similarly tracked by the HARL station.

After a time period where the HARL station lost connection to the Sentinel-3 satellites (i.e., from the end of year 2018 to the beginning of year 2019), the station has resumed the tracking with punctual ups and downs. In this case, it must be highlighted that the Jason-3 satellite presents a noticeably difference on the tracking received by the HARL station.

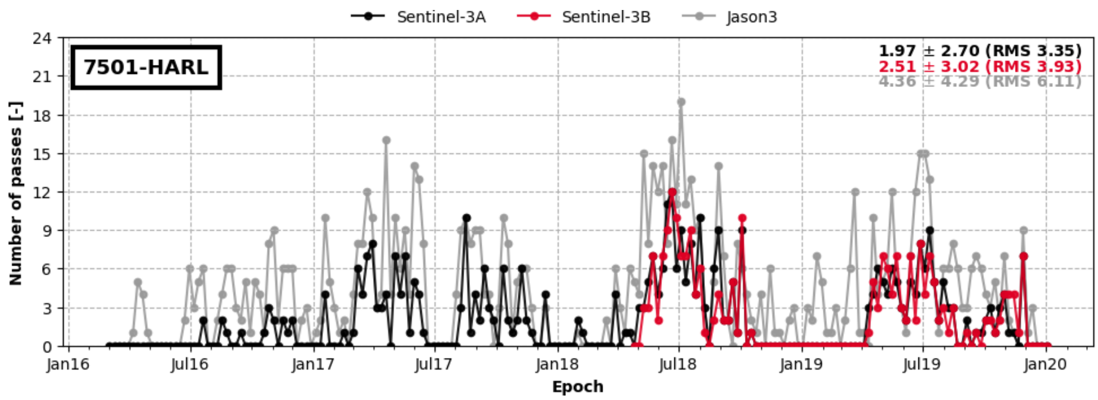


Figure 4-73: Total number of satellite passes per GPS week of the SLR station 7501 (HARL) since the beginning of the satellite mission (Sentinel-3A, Sentinel-3B and Jason-3)

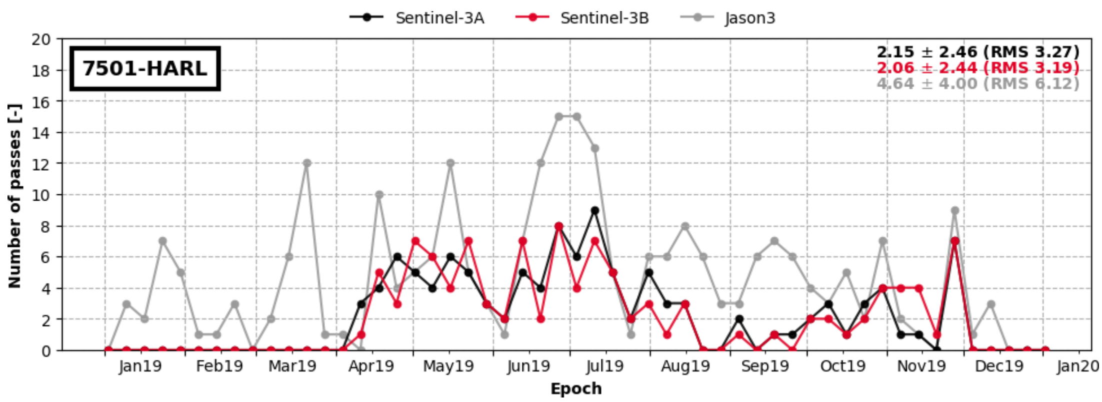


Figure 4-74: Total number of satellite passes per GPS week of the SLR station 7501 (HARL) in 2019 (Sentinel-3A, Sentinel-3B and Jason-3)

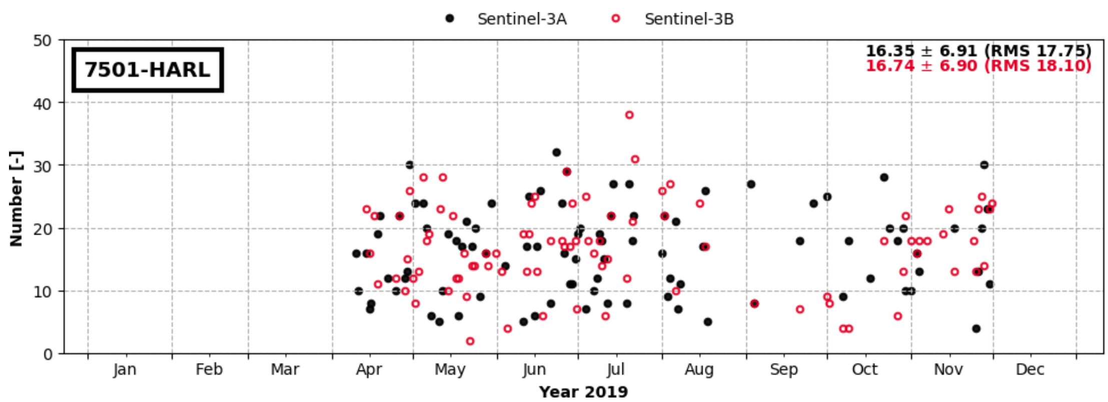


Figure 4-75: Daily total number of the accepted SLR observations of the SLR station 7501 (HARL) in 2019 (Sentinel-3A and Sentinel-3B)

Despite the ups and downs, the HARL station is providing a large number of the SLR observations per day when active, which mean value is up to 16-17 SLR observations (see Figure 4-75).

Such SLR observations present a very good performance according to the statistical outcome shown in the figures below. A mean value tending to 0 and tight standard deviation and root mean squares values are the statistics obtained for the SLR observations of the HARL station. These statistics have also significantly improved after having fixed a range bias on the station.

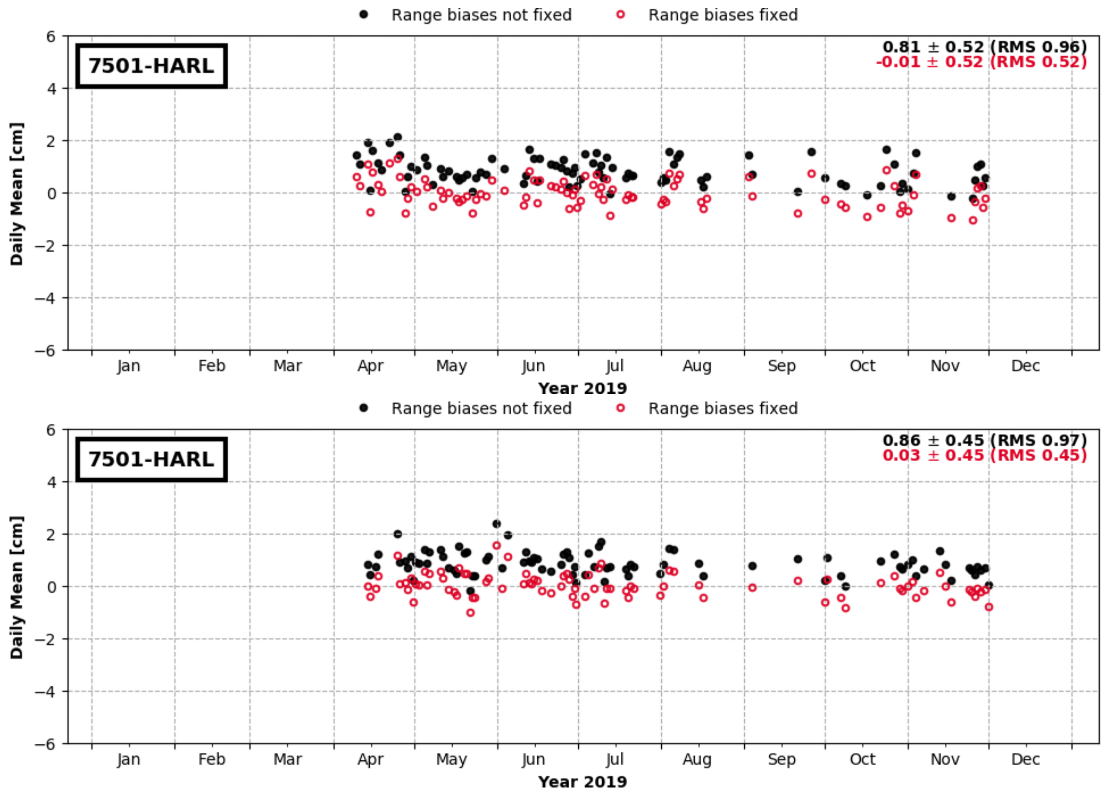
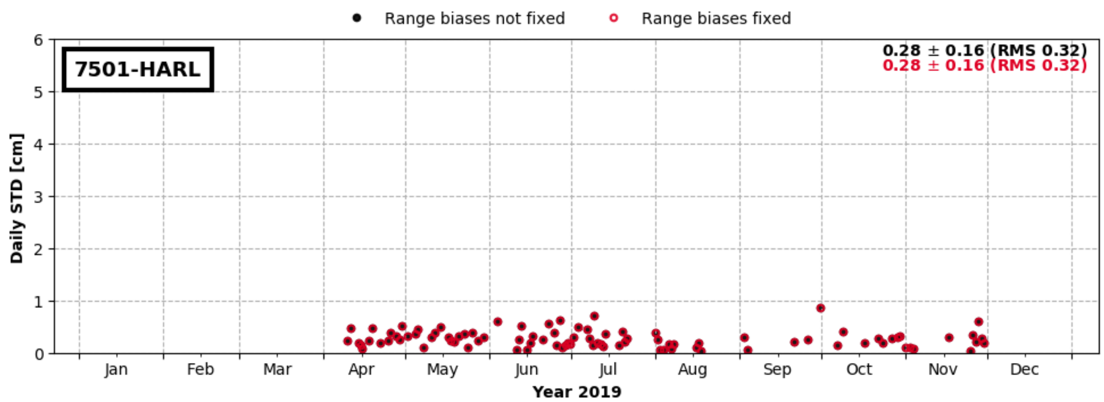


Figure 4-76: Daily mean of the SLR observation residuals [1-range; cm] of the SLR station 7501 (HARL) in 2019 (above Sentinel-3A, and below Sentinel-3B)



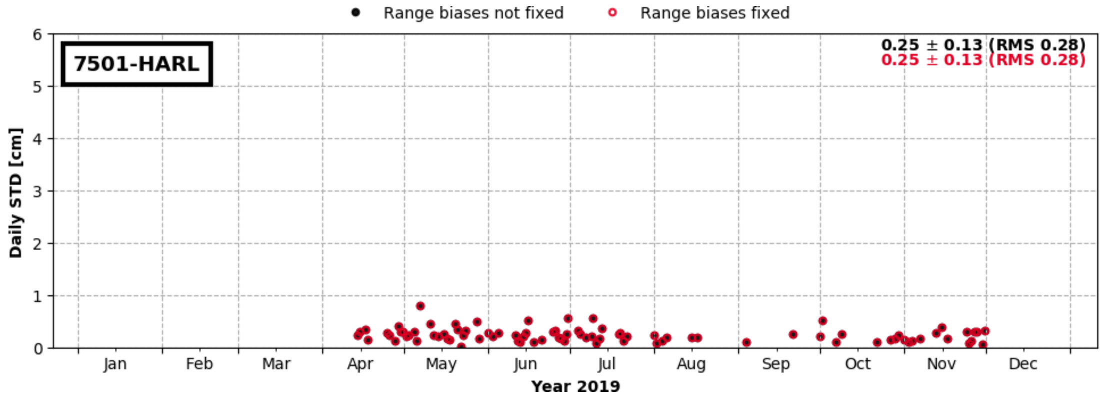


Figure 4-77: Daily STD of the SLR observation residuals [1-range; cm] of the SLR station 7501 (HARL) in 2019 (above Sentinel-3A, and below Sentinel-3B)

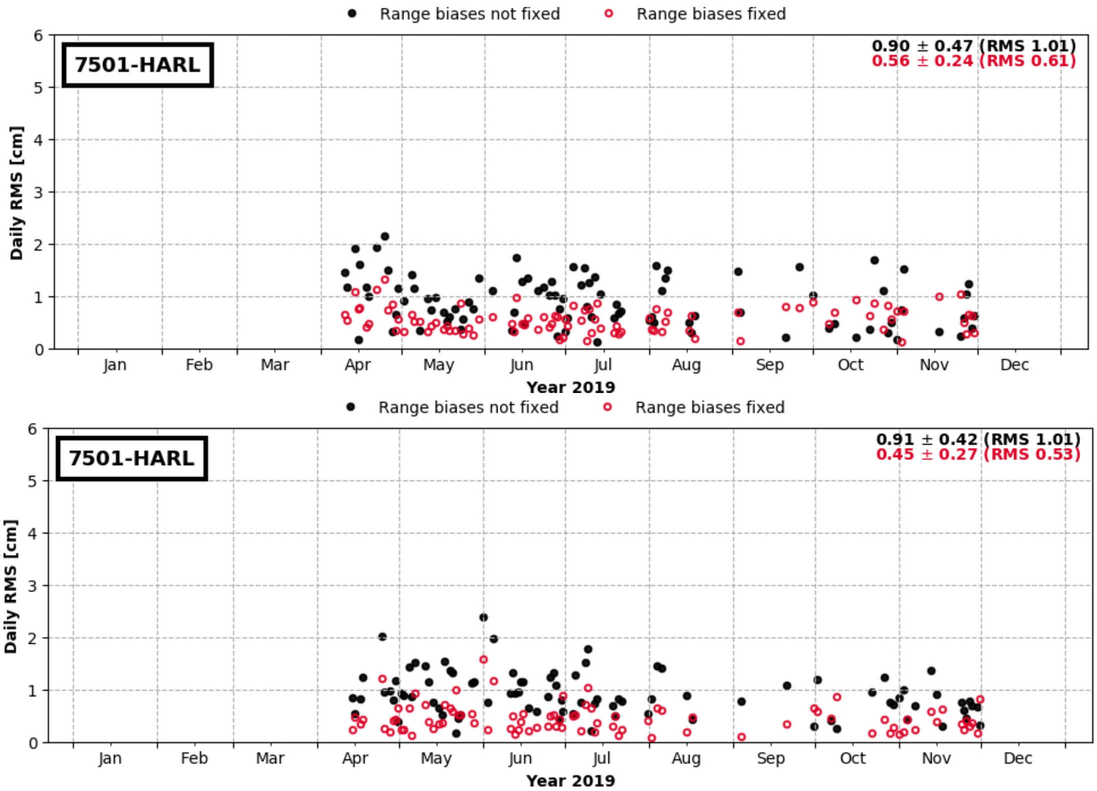


Figure 4-78: Daily RMS of the SLR observation residuals [1-range; cm] of the SLR station 7501 (HARL) in 2019 (above Sentinel-3A, and below Sentinel-3B)

4.14. SLR STATION 7810 (ZIML)

The SLR station Zimmerwald (7810 - ZIML) has been active during a short time period of year 2019, which has mainly been caused by a lack of connection to the FTP server where the CPF predictions of the Sentinel-3 satellites are stored. After this issue was solved at the end of year 2019, the ZIML station resumed the tracking, which is currently retrieving similar figures as past years. Therefore, the processing statistics of the ZIML station have been greatly impacted during 2019. Despite this fact, the ZIML station continues being one of the SLR station providing most quantity of SLR observations per satellite pass (i.e., a mean value of 14-15 SLR observations).

Table 4-14: Summary of the processing statistics of the SLR station 7810 (ZIML)

		Sentinel-3A	Sentinel-3B	Jason3
Number of satellite passes (*.npt* files)	All mission	658	369	2454
	"Year 2019" (20340-20866)	77	84	787
Days processed(*)	Total	366	366	-
Active days	Total	44	46	-
	% (w.r.t. the total days processed)	12.02 %	12.57 %	-
Number of satellite passes processed	Total	77	83	-
	% (w.r.t. the *.npt* files)	100.00 %	98.81 %	-
Number of observations processed	Total	1041	1269	-
Number of observations per satellite pass	Mean	13.52	15.29	-
Number of observations filtered out	Total	0	0	-
	% (w.r.t. the total obs. processed)	0.00 %	0.00 %	-

(*) The total number of days processed does not coincide with the total number of days evaluated in "year 2019" (i.e., 371 days) since the combined orbit solution has not been generated on a few days as a result of either long manoeuvres or large gaps of data or other issues.

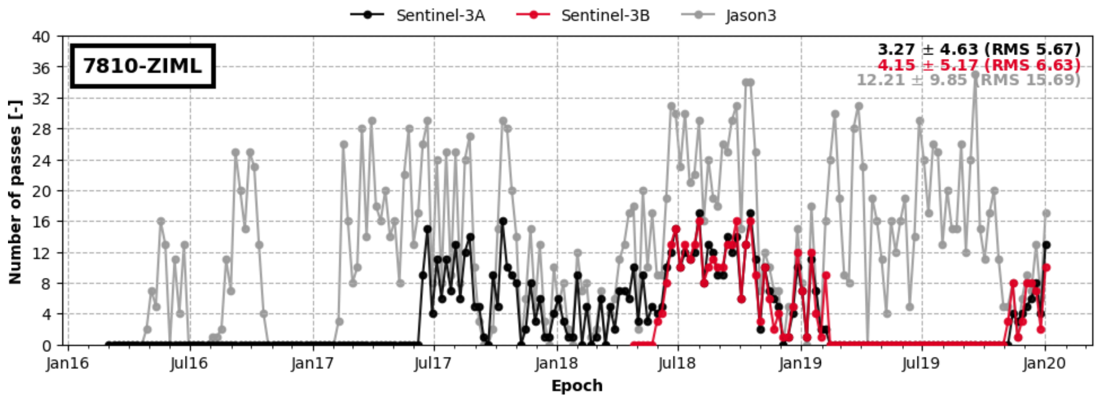


Figure 4-79: Total number of satellite passes per GPS week of the SLR station 7810 (ZIML) since the beginning of the satellite mission (Sentinel-3A, Sentinel-3B and Jason-3)

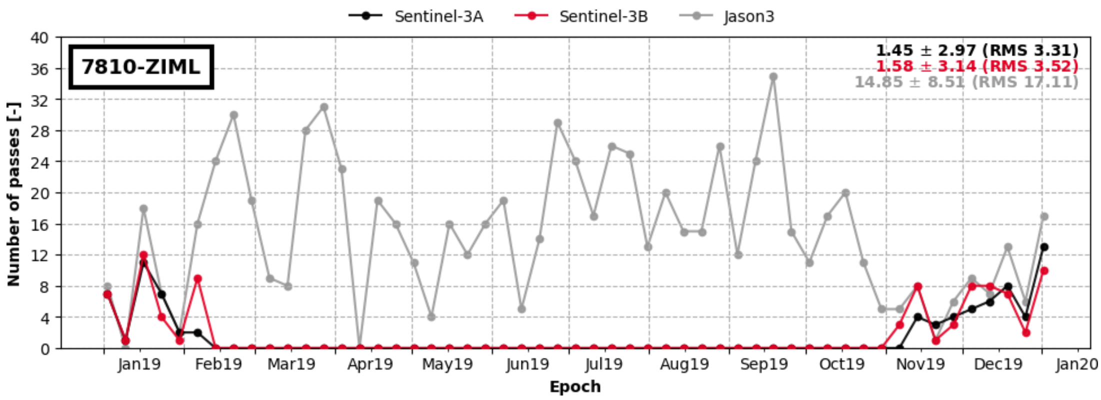


Figure 4-80: Total number of satellite passes per GPS week of the SLR station 7810 (ZIML) in 2019 (Sentinel-3A, Sentinel-3B and Jason-3)

The loss of connection can be clearly seen in Figure 4-79 and Figure 4-80. From the figures above, it can also be highlighted the importance of the ZIML station on the general tracking of the Sentinel-3 satellites as a significant amount of satellite passes have been lost during the lack of connection (see the outcome on the Jason-3 satellite).

The importance of the ZIML station is also shown in the following figures. On the one hand, the ZIML station provides a high number of SLR observations per day as shown in Figure 4-81. On the other hand, the analysis of the SLR residuals reveals a very good performance of the SLR observations delivered by the station. Not only SLR residuals with mean value tending to 0 are obtained but also SLR residuals with reduced standard deviation and root mean squares values. The use of a fixed range bias has also benefited the statistical outcome of the ZIML station.

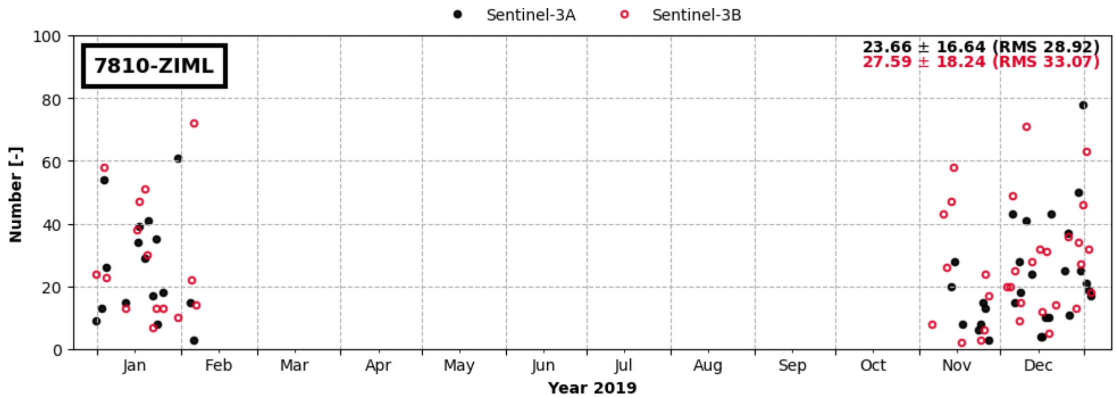


Figure 4-81: Daily total number of the accepted SLR observations of the SLR station 7810 (ZIML) in 2019 (Sentinel-3A and Sentinel-3B)

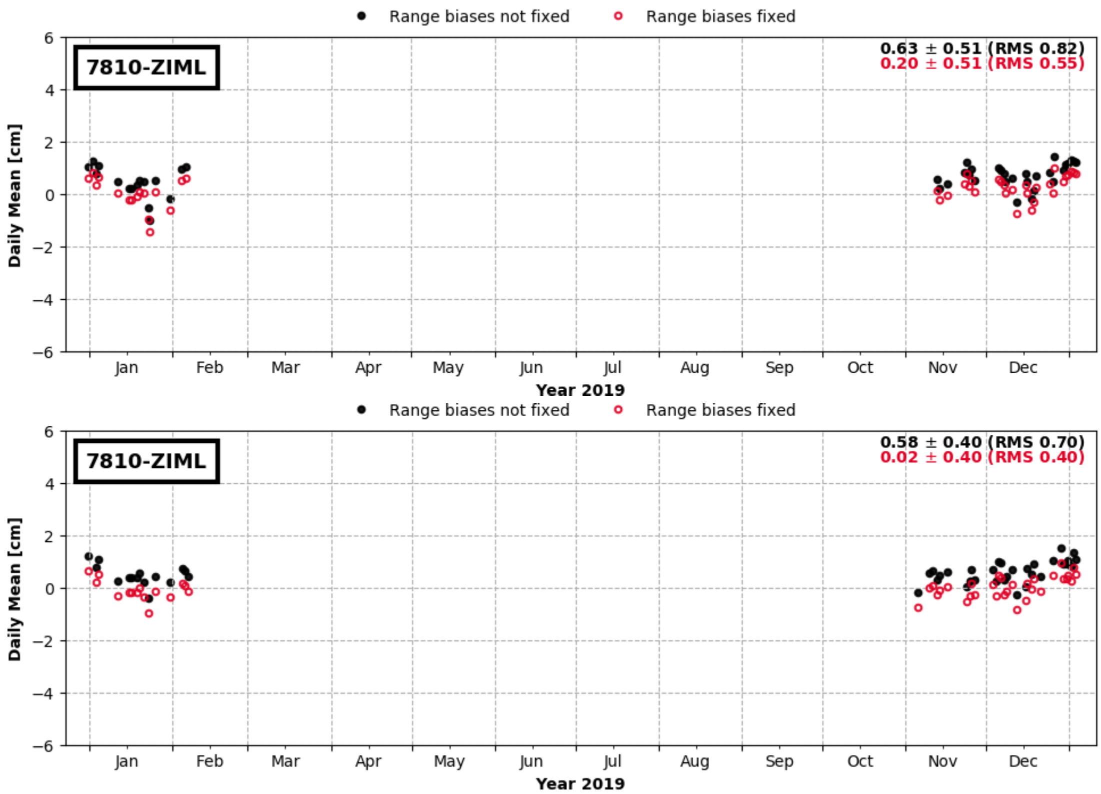


Figure 4-82: Daily mean of the SLR observation residuals [1-range; cm] of the SLR station 7810 (ZIML) in 2019 (above Sentinel-3A, and below Sentinel-3B)

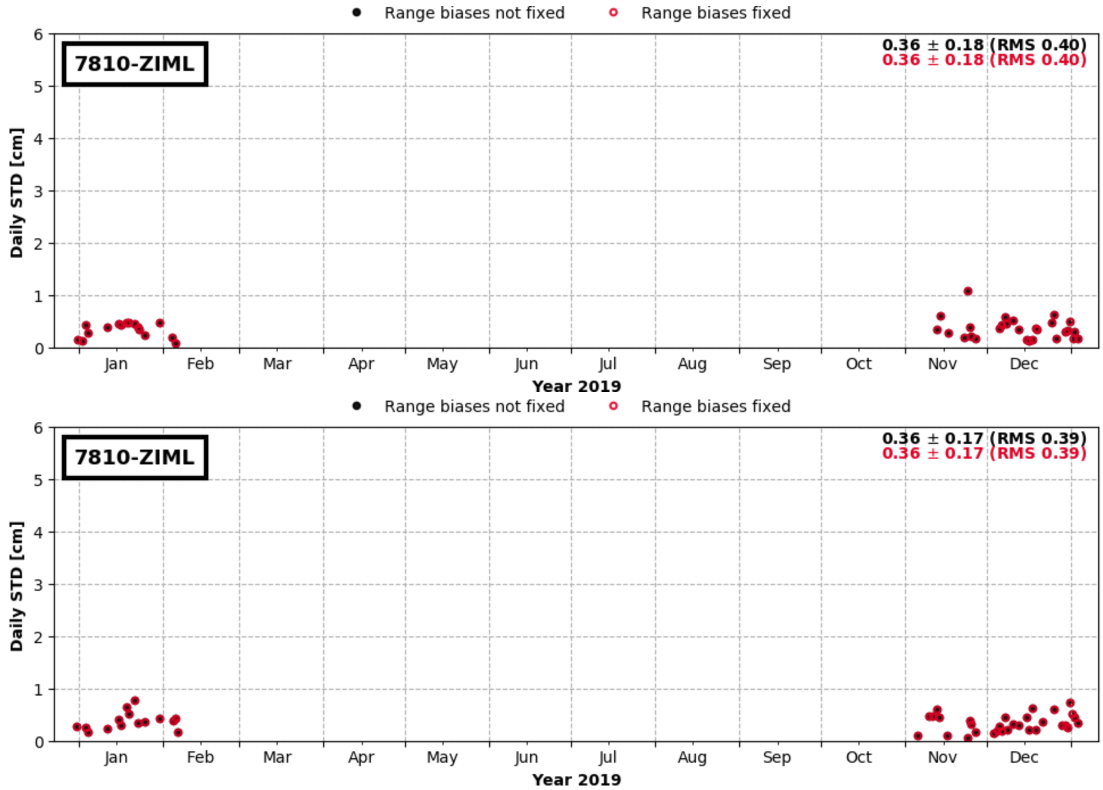


Figure 4-83: Daily STD of the SLR observation residuals [1-range; cm] of the SLR station 7810 (ZIML) in 2019 (above Sentinel-3A, and below Sentinel-3B)

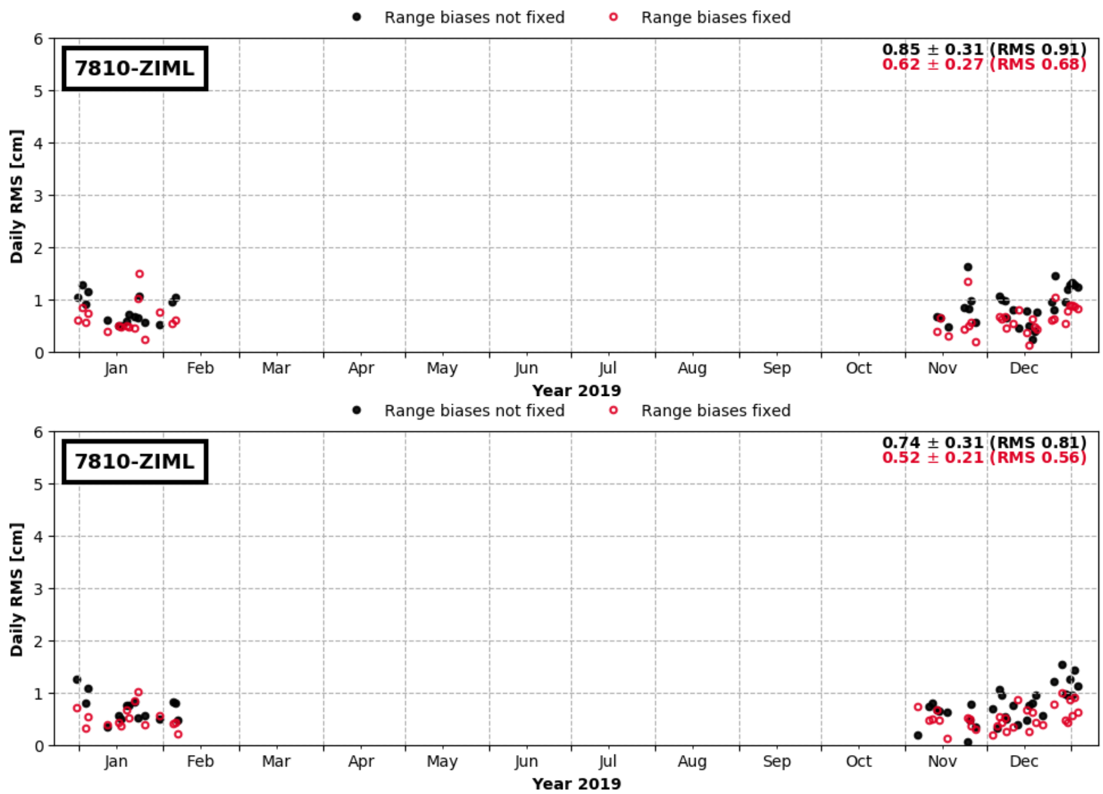


Figure 4-84: Daily RMS of the SLR observation residuals [1-range; cm] of the SLR station 7810 (ZIML) in 2019 (above Sentinel-3A, and below Sentinel-3B)

4.15. SLR STATION 7811 (BORL)

The SLR station Borowiec (7811 - BORL) has been active near 15 % of the time period analysed. For each satellite pass, the BORL station has given a mean value of 15-16 SLR observations, which is a high value considering the figures of all SLR stations. From Table 4-15, it can be pointed out that the BORL station has similarly tracked both Sentinel-3 satellites.

Table 4-15: Summary of the processing statistics of the SLR station 7811 (BORL)

		Sentinel-3A	Sentinel-3B	Jason3
Number of satellite passes (*.npt* files)	All mission	238	100	311
	"Year 2019" (20340-20866)	69	70	88
Days processed(*)	Total	366	366	-
Active days	Total	58	53	-
	% (w.r.t. the total days processed)	15.85 %	14.48 %	-
Number of satellite passes processed	Total	68	69	-
	% (w.r.t. the *.npt* files)	98.55 %	98.57 %	-
Number of observations processed	Total	1046	1104	-
Number of observations per satellite pass	Mean	15.38	16.00	-
Number of observations filtered out	Total	1	0	-
	% (w.r.t. the total obs. processed)	0.10 %	0.00 %	-

(*) The total number of days processed does not coincide with the total number of days evaluated in "year 2019" (i.e., 371 days) since the combined orbit solution has not been generated on a few days as a result of either long manoeuvres or large gaps of data or other issues.

The tracking of the BORL station has followed a similar pattern over time. As seen in Figure 4-85 and Figure 4-86, the number of satellite passes per week has not suffered neither from any significant lack of tracking nor from any inflated number of satellite passes during a specific time period. In general, the BORL station is reporting similar values for all three satellites.

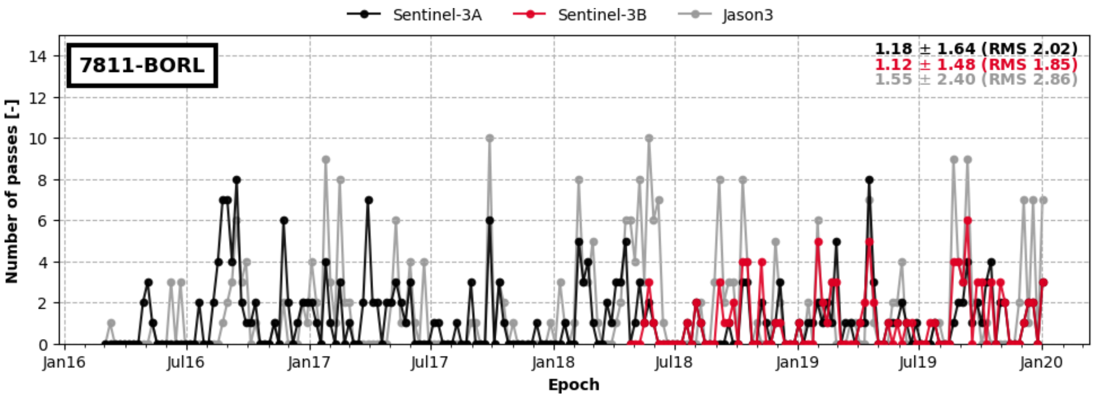


Figure 4-85: Total number of satellite passes per GPS week of the SLR station 7811 (BORL) since the beginning of the satellite mission (Sentinel-3A, Sentinel-3B and Jason-3)

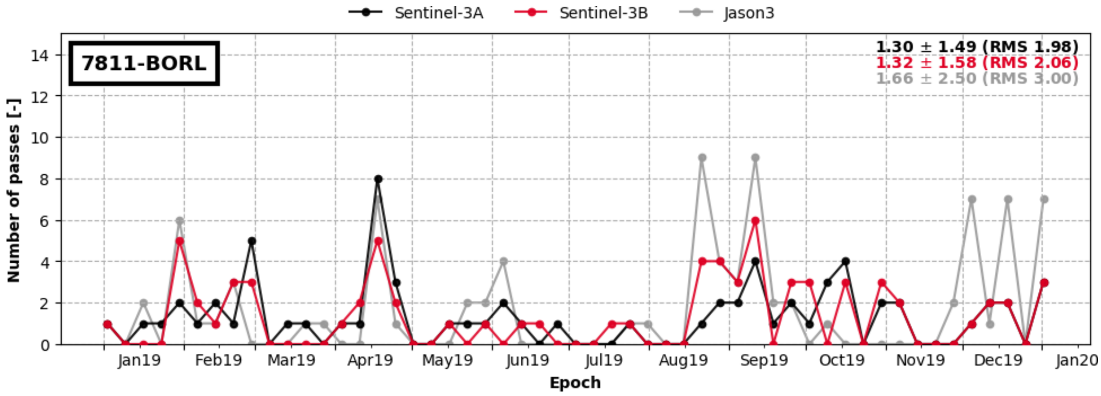


Figure 4-86: Total number of satellite passes per GPS week of the SLR station 7811 (BORL) in 2019 (Sentinel-3A, Sentinel-3B and Jason-3)

Taking into account the number of the SLR observations, the BORL station is delivering a mean value of ~20 SLR observations on a daily basis when it is active. This value is a little over the mean value provided by all SLR stations.

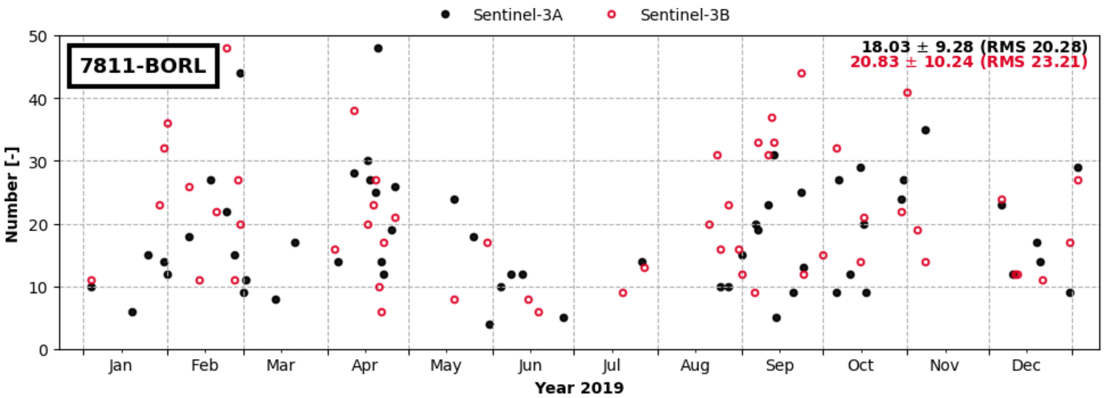
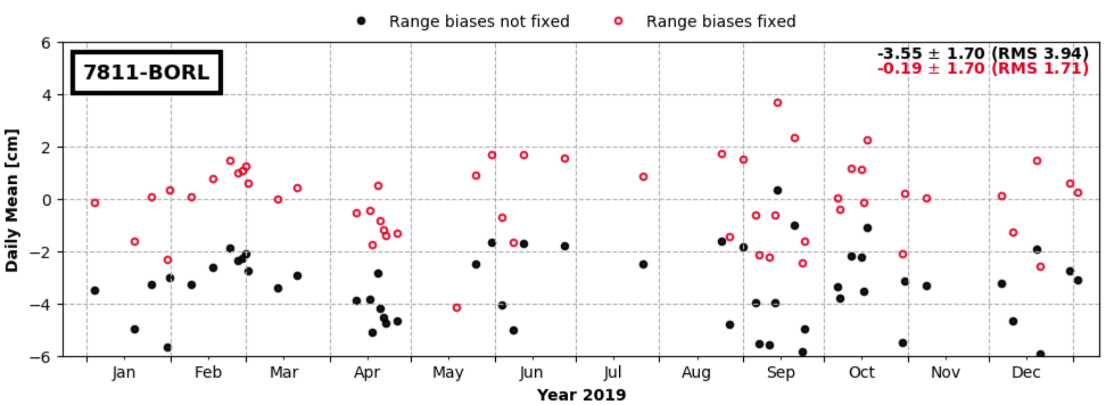


Figure 4-87: Daily total number of the accepted SLR observations of the SLR station 7811 (BORL) in 2019 (Sentinel-3A and Sentinel-3B)

From the analysis of the SLR residuals, two issues can be highlighted: (a) the statistical improvement of the SLR residuals is huge after having applied the station range bias, and (b) the performance of the SLR observation is quite dispersive. All the statistics presented below show standard deviation values above the ones obtained by the SLR stations with best performance.



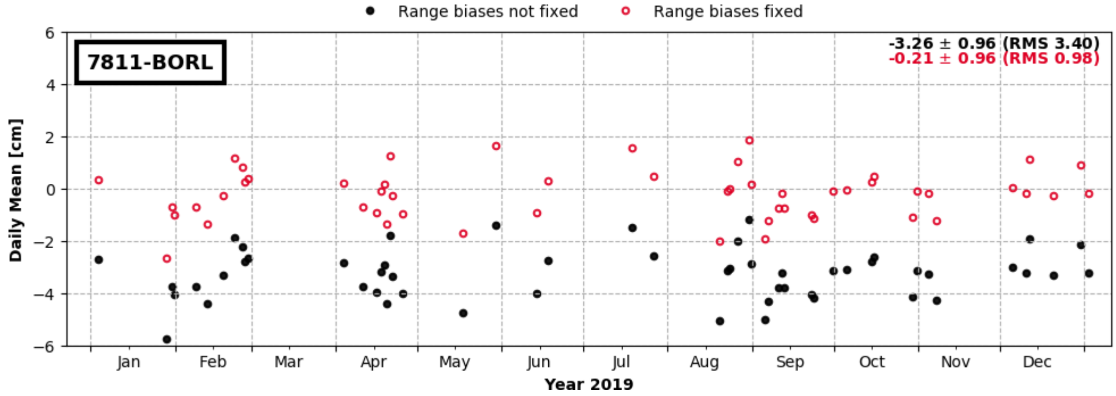


Figure 4-88: Daily mean of the SLR observation residuals [1-range; cm] of the SLR station 7811 (BORL) in 2019 (above Sentinel-3A, and below Sentinel-3B)

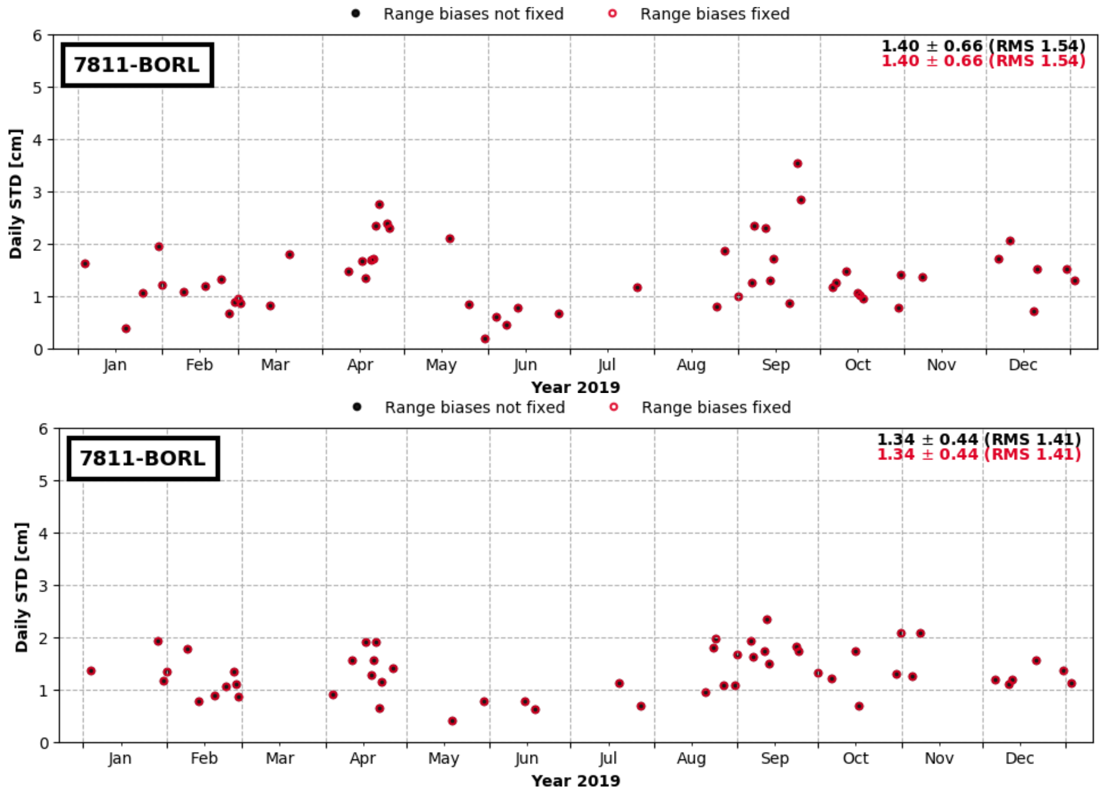
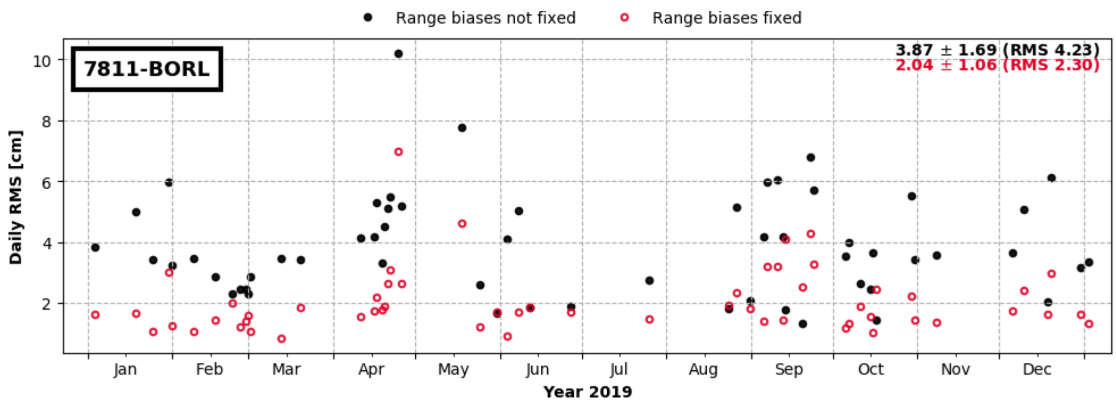


Figure 4-89: Daily STD of the SLR observation residuals [1-range; cm] of the SLR station 7811 (BORL) in 2019 (above Sentinel-3A, and below Sentinel-3B)



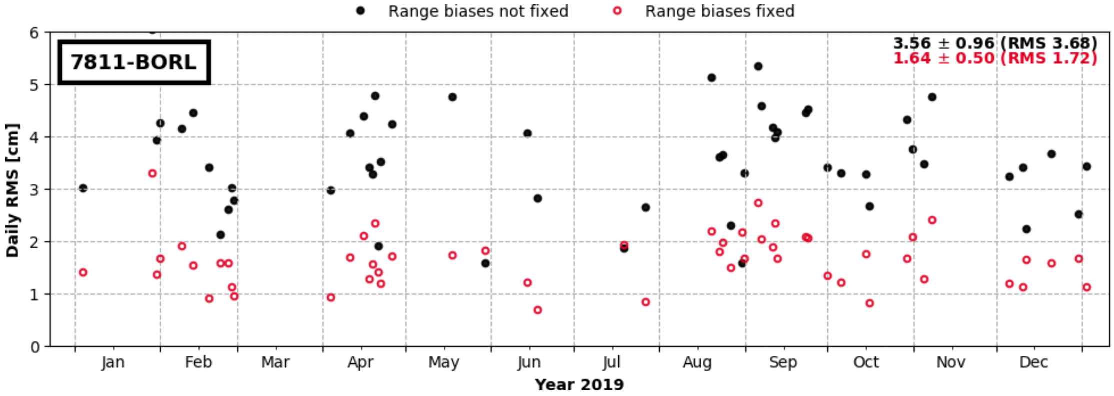


Figure 4-90: Daily RMS of the SLR observation residuals [1-range; cm] of the SLR station 7811 (BORL) in 2019 (above Sentinel-3A, and below Sentinel-3B)

4.16. SLR STATION 7821 (SHA2)

The SLR station Shanghai (7821 – SHA2) has been active during a very short time interval of the time period evaluated. The SHA2 station had an issue with the connection to the FTP server where the Sentinel-3 CPF predictions are stored. Once solved, the station resumed the tracking of the Sentinel-3 satellites. However, very few conclusions can be drawn from the data delivered by the SHA2 station in 2019. One of them is that the SHA2 station has more tracked Sentinel-3B satellite than Sentinel-3A satellite. And, another conclusion is that the station provided a mean value of 7-8 SLR observations per satellite pass, which can be considered as an average value.

Table 4-16: Summary of the processing statistics of the SLR station 7821 (SHA2)

		Sentinel-3A	Sentinel-3B	Jason3
Number of satellite passes (*.npt* files)	All mission	45	67	531
	"Year 2019" (20340-20866)	9	21	147
Days processed(*)	Total	366	366	-
Active days	Total	8	14	-
	% (w.r.t. the total days processed)	2.19 %	3.83 %	-
Number of satellite passes processed	Total	8	21	-
	% (w.r.t. the *.npt* files)	88.89 %	100.00 %	-
Number of observations processed	Total	56	167	-
Number of observations per satellite pass	Mean	7.00	7.95	-
Number of observations filtered out	Total	0	0	-
	% (w.r.t. the total obs. processed)	0.00 %	0.00 %	-

(*) The total number of days processed does not coincide with the total number of days evaluated in "year 2019" (i.e., 371 days) since the combined orbit solution has not been generated on a few days as a result of either long manoeuvres or large gaps of data or other issues.

If the entire missions are analysed, it can be said that the SHA2 station has barely tracked the Sentinel-3 satellites. There are only a few times where the SHA2 station has provided Sentinel-3 SLR observations on a continuous way. On the other hand, the Jason-3 satellite has been noticeably tracked by the SHA2 station during the entire mission. Therefore, there could be margin for improvement for Sentinel-3 satellites in order to achieve better figures from the SHA2 station.

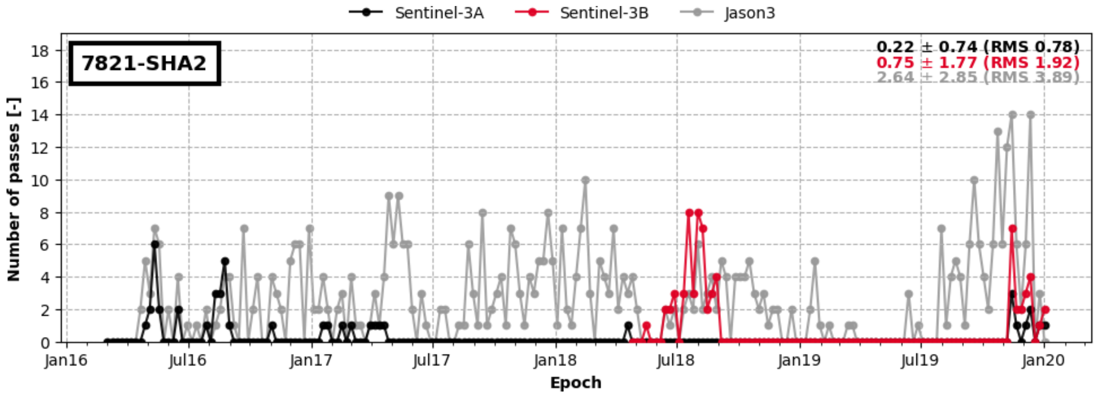


Figure 4-91: Total number of satellite passes per GPS week of the SLR station 7821 (SHA2) since the beginning of the satellite mission (Sentinel-3A, Sentinel-3B and Jason-3)

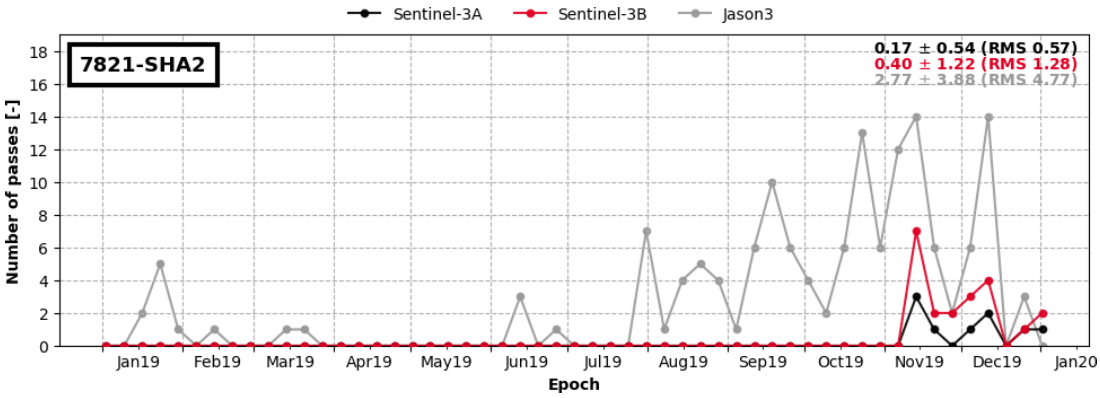


Figure 4-92: Total number of satellite passes per GPS week of the SLR station 7821 (SHA2) in 2019 (Sentinel-3A, Sentinel-3B and Jason-3)

The fact of having more SLR observations from Sentinel-3B satellite has allowed the SHA2 station to achieve better outcome on this satellite. In addition, the SLR observations of the Sentinel-3B satellite have been less dispersive (see figures below), which has also benefited the final outcome. Finally, it must also be highlighted that the use of a fixed range bias has only improved the results of the Sentinel-3B satellite.

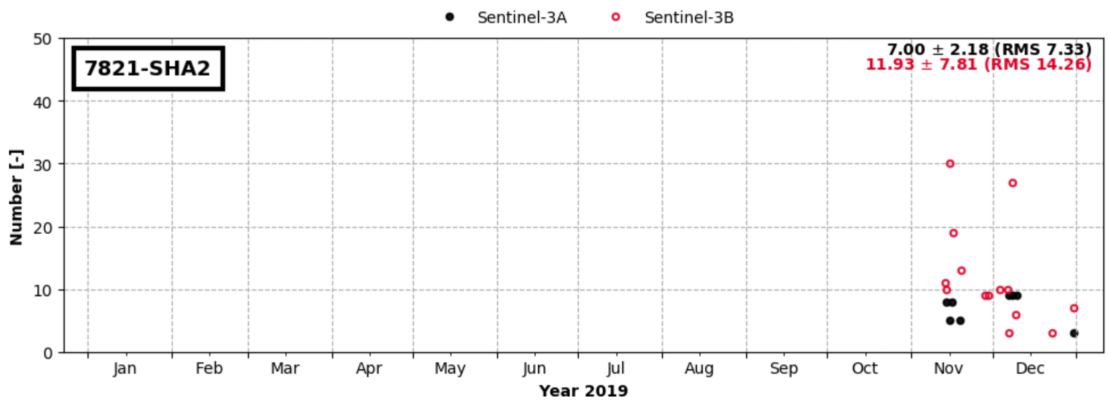


Figure 4-93: Daily total number of the accepted SLR observations of the SLR station 7821 (SHA2) in 2019 (Sentinel-3A and Sentinel-3B)

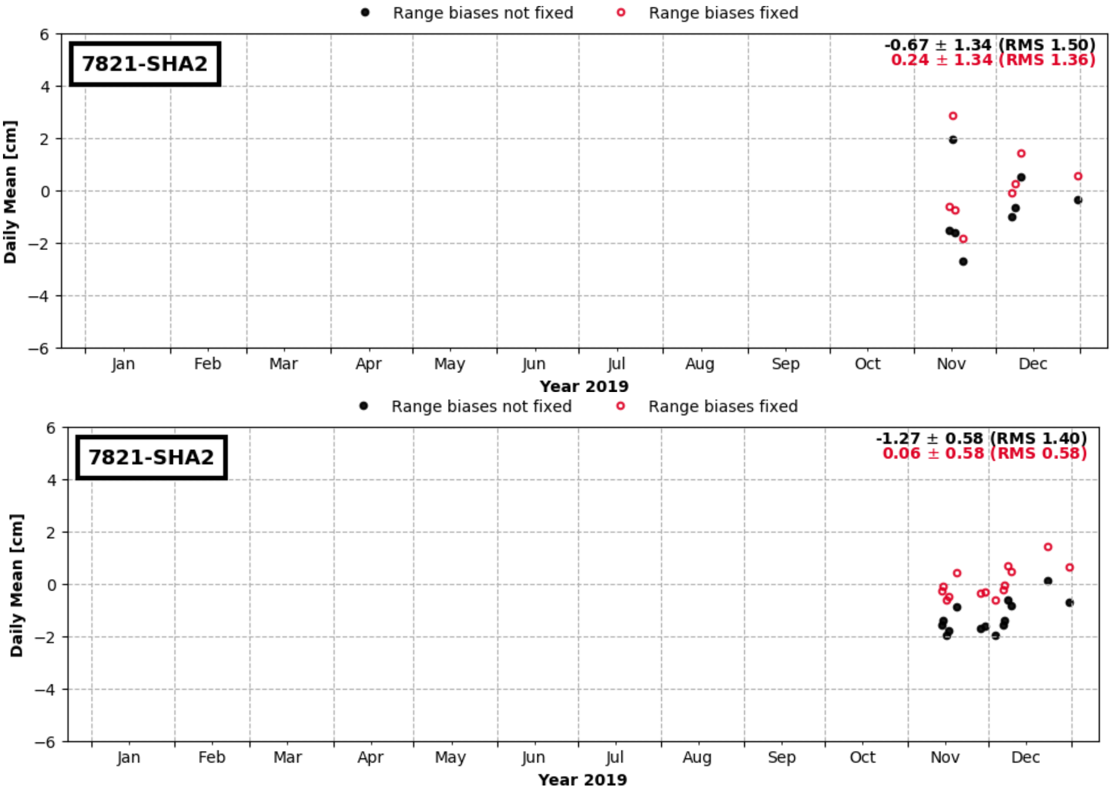


Figure 4-94: Daily mean of the SLR observation residuals [1-range; cm] of the SLR station 7821 (SHA2) in 2019 (above Sentinel-3A, and below Sentinel-3B)

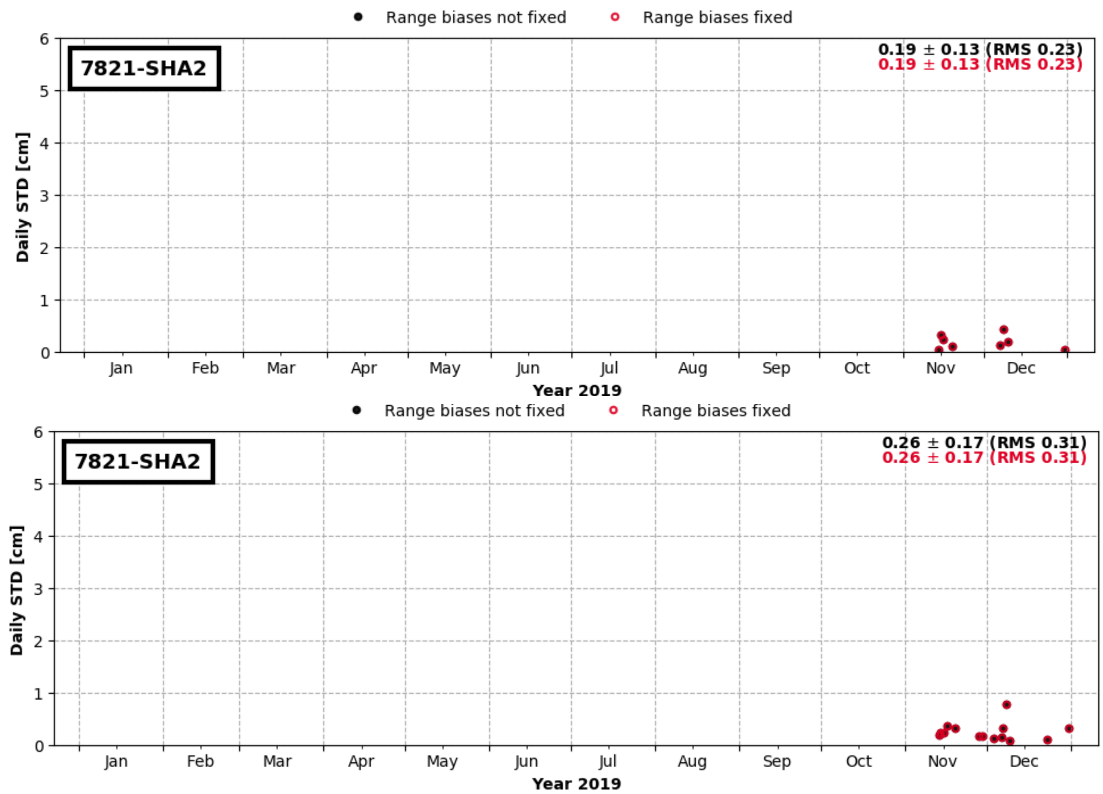


Figure 4-95: Daily STD of the SLR observation residuals [1-range; cm] of the SLR station 7821 (SHA2) in 2019 (above Sentinel-3A, and below Sentinel-3B)

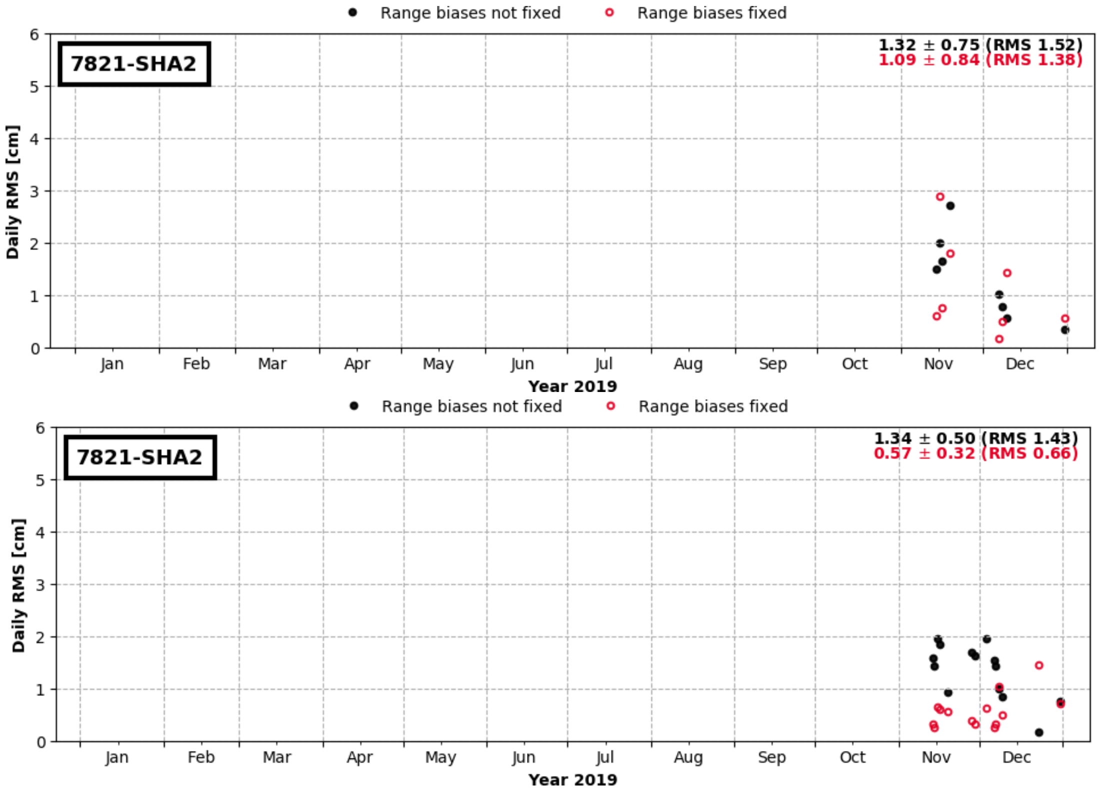


Figure 4-96: Daily RMS of the SLR observation residuals [1-range; cm] of the SLR station 7821 (SHA2) in 2019 (above Sentinel-3A, and below Sentinel-3B)

4.17. SLR STATION 7825 (STL3)

Table 4-17: Summary of the processing statistics of the SLR station 7825 (STL3)

		Sentinel-3A	Sentinel-3B	Jason3
Number of satellite passes (*.npt* files)	All mission	562	33	2173
	"Year 2019" (20340-20866)	5	8	554
Days processed(*)	Total	366	366	-
Active days	Total	4	6	-
	% (w.r.t. the total days processed)	1.09 %	1.64 %	-
Number of satellite passes processed	Total	5	8	-
	% (w.r.t. the *.npt* files)	100.00 %	100.00 %	-
Number of observations processed	Total	42	52	-
Number of observations per satellite pass	Mean	8.40	6.50	-
Number of observations filtered out	Total	0	0	-
	% (w.r.t. the total obs. processed)	0.00 %	0.00 %	-

(*) The total number of days processed does not coincide with the total number of days evaluated in "year 2019" (i.e., 371 days) since the combined orbit solution has not been generated on a few days as a result of either long manoeuvres or large gaps of data or other issues.

The SLR station Mt. Stromlo (7825 – STL3) has resumed the tracking of Sentinel-3 satellites after a long period of inactivity. A change on the laser configuration of the STL3 station prevented the tracking of Sentinel-3 satellites since mid-2018. However, the last energy tests carried out by the station allow the STL3 station to resume the tracking of both satellites from the end of year 2019.

As very little data has been gathered from the time period evaluated, there are no comments to be done about the performance of the STL3 station. The next document will contain more information about the current tracking of the Sentinel-3 satellites from the station.

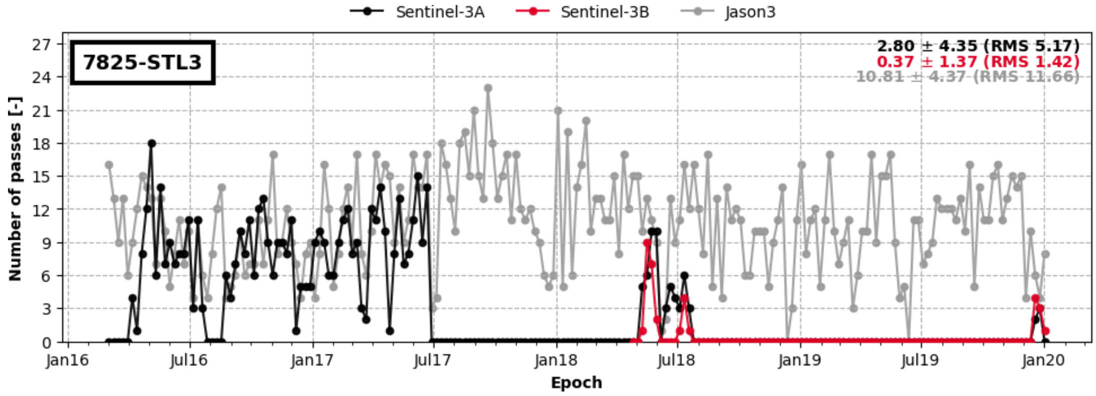


Figure 4-97: Total number of satellite passes per GPS week of the SLR station 7825 (STL3) since the beginning of the satellite mission (Sentinel-3A, Sentinel-3B and Jason-3)

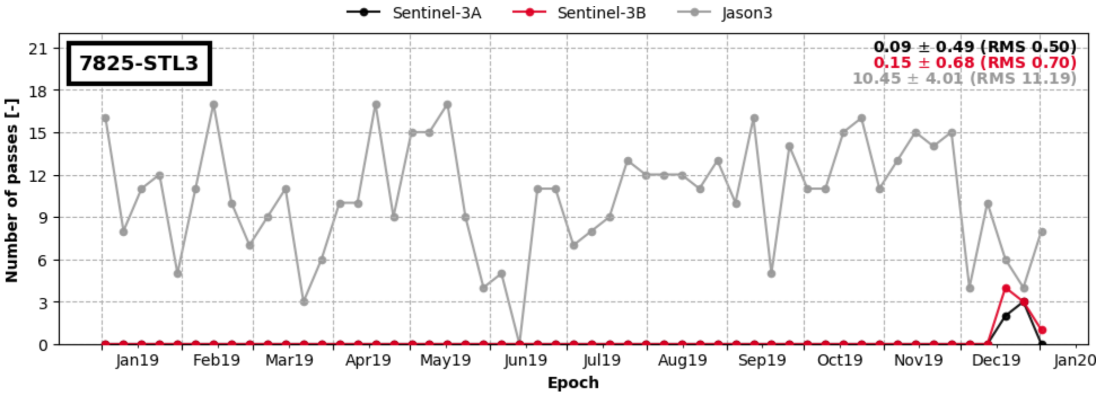


Figure 4-98: Total number of satellite passes per GPS week of the SLR station 7825 (STL3) in 2019 (Sentinel-3A, Sentinel-3B and Jason-3)

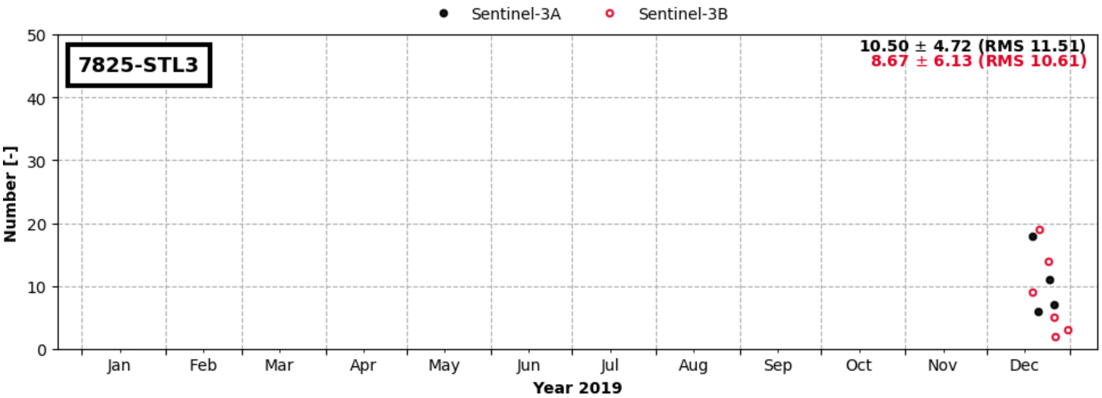


Figure 4-99: Daily total number of the accepted SLR observations of the SLR station 7825 (STL3) in 2019 (Sentinel-3A and Sentinel-3B)

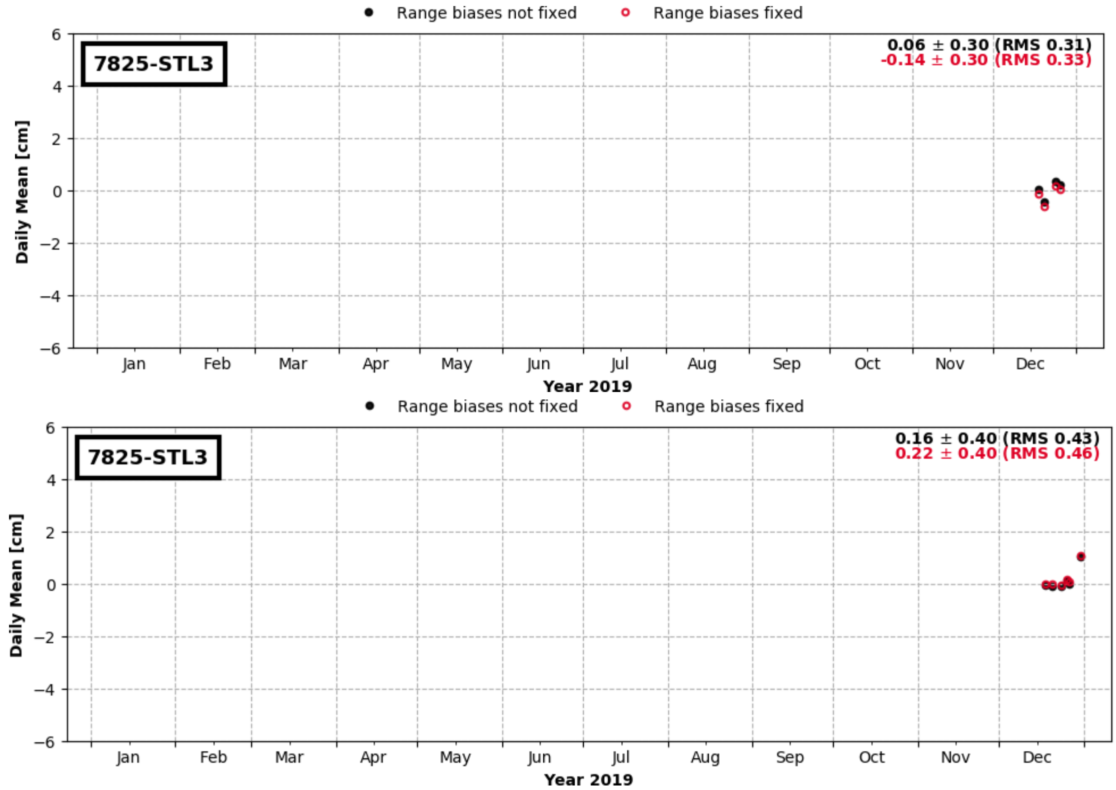


Figure 4-100: Daily mean of the SLR observation residuals [1-range; cm] of the SLR station 7825 (STL3) in 2019 (above Sentinel-3A, and below Sentinel-3B)

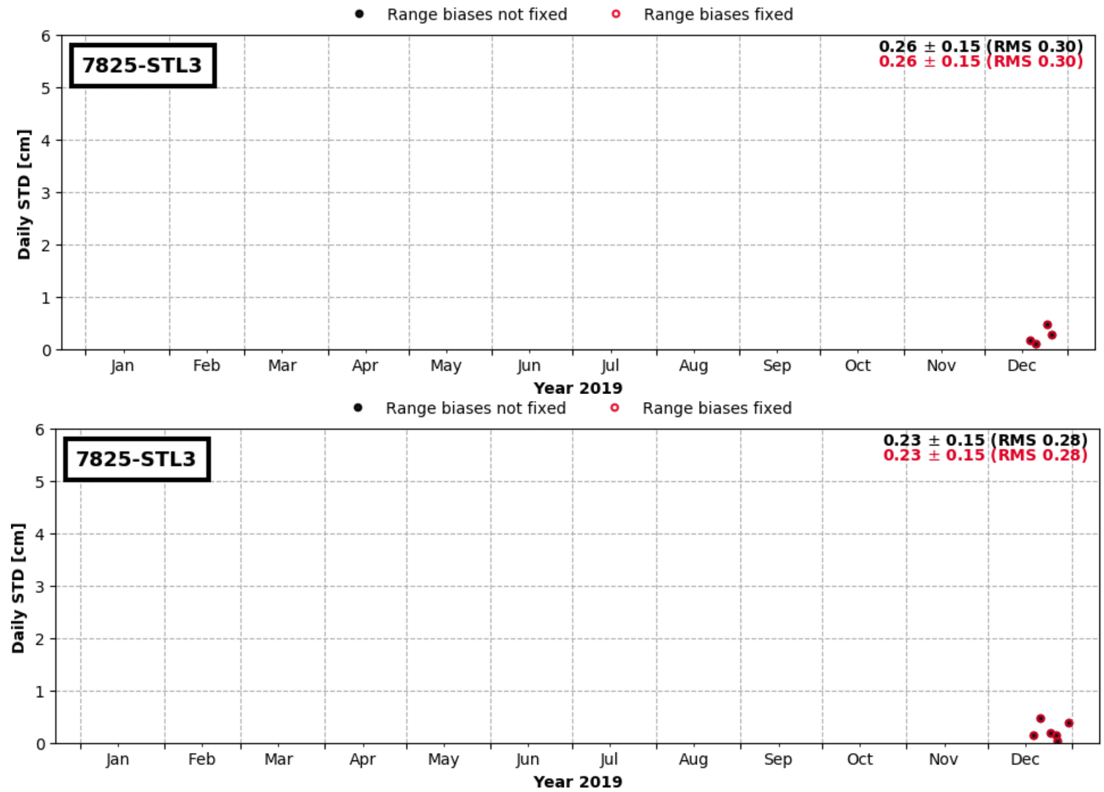


Figure 4-101: Daily STD of the SLR observation residuals [1-range; cm] of the SLR station 7825 (STL3) in 2019 (above Sentinel-3A, and below Sentinel-3B)

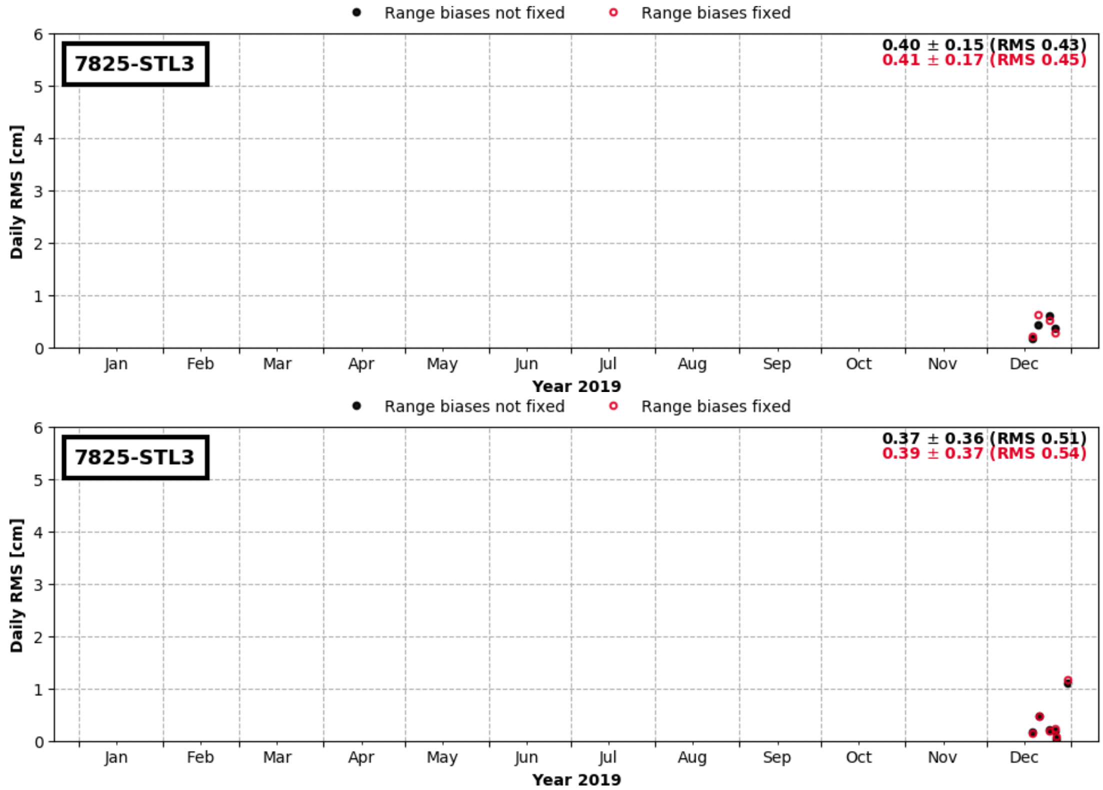


Figure 4-102: Daily RMS of the SLR observation residuals [1-range; cm] of the SLR station 7825 (STL3) in 2019 (above Sentinel-3A, and below Sentinel-3B)

4.18. SLR STATION 7839 (GRZL)

Table 4-18: Summary of the processing statistics of the SLR station 7839 (GRZL)

		Sentinel-3A	Sentinel-3B	Jason3
Number of satellite passes (*.npt* files)	All mission	930	412	1390
	"Year 2019" (20340-20866)	214	235	305
Days processed(*)	Total	366	366	-
Active days	Total	131	136	-
	% (w.r.t. the total days processed)	35.79 %	37.16 %	-
Number of satellite passes processed	Total	210	231	-
	% (w.r.t. the *.npt* files)	98.13 %	98.30 %	-
Number of observations processed	Total	4132	4737	-
Number of observations per satellite pass	Mean	19.68	20.51	-
Number of observations filtered out	Total	17	0	-
	% (w.r.t. the total obs. processed)	0.41 %	0.00 %	-

(*) The total number of days processed does not coincide with the total number of days evaluated in "year 2019" (i.e., 371 days) since the combined orbit solution has not been generated on a few days as a result of either long manoeuvres or large gaps of data or other issues.

The SLR station Graz (7839 - GRZL) has been active more than a third of the time period analysed. The GRZL station is consequently one of the SLR stations that is most tracking the Sentinel-3 satellites, and it is also one of the SLR stations providing most quantity of SLR observations per satellite pass (i.e., a mean value of ~20 SLR observations). From Table 4-18, it can be seen that the GRZL station presents a little better figures on the tracking of the Sentinel-3B satellite than the Sentinel-3A satellite.

Figure 4-103 and Figure 4-104 show a similar pattern on the tracking of all three satellites, which has been maintained over the years. On September 2019, there was a loss of connection between the GRZL station and the Sentinel-3 satellites, but the tracking was rapidly recovered. Despite this fact, the tracking figures are quite similar amongst the three satellites.

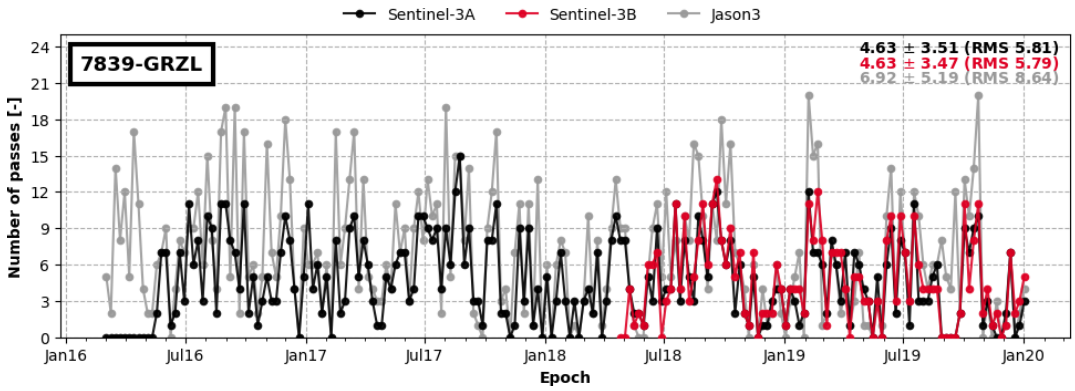


Figure 4-103: Total number of satellite passes per GPS week of the SLR station 7839 (GRZL) since the beginning of the satellite mission (Sentinel-3A, Sentinel-3B and Jason-3)

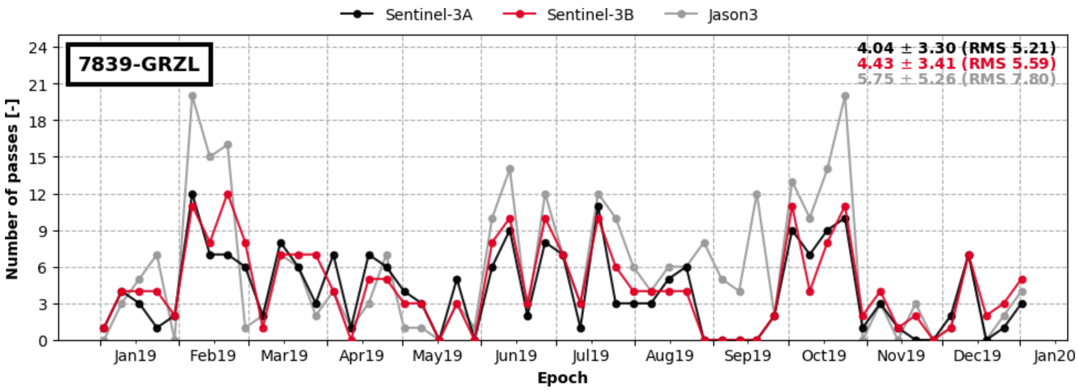


Figure 4-104: Total number of satellite passes per GPS week of the SLR station 7839 (GRZL) in 2019 (Sentinel-3A, Sentinel-3B and Jason-3)

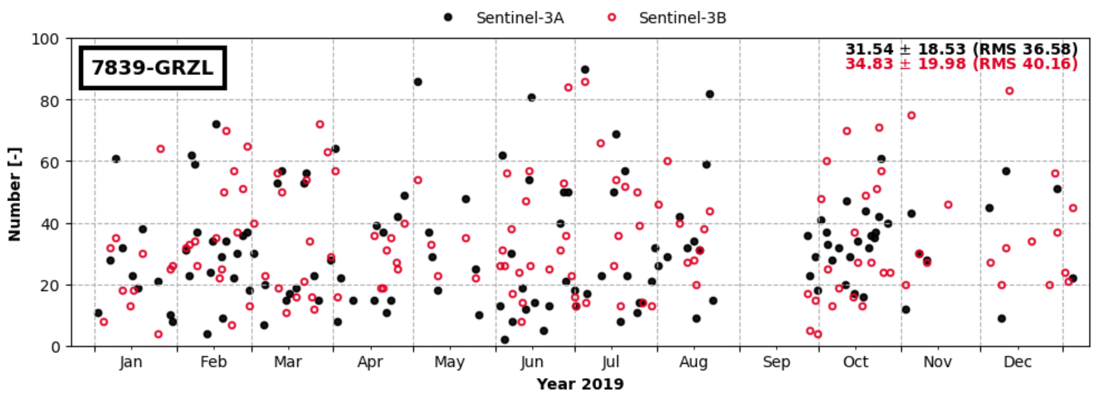


Figure 4-105: Daily total number of the accepted SLR observations of the SLR station 7839 (GRZL) in 2019 (Sentinel-3A and Sentinel-3B)

The SLR observations provided by the GRZL station are abundant (see Figure 4-105) with a mean value of 30-35 SLR observations per day. Such SLR observations present very good performance as shown in the figures below. On the one hand, the mean value of the obtained SLR residuals tend to 0 and, on the other hand, the standard deviation and root mean square values are very little. In addition, this statistical outcome has significantly been benefited after having fixed the range bias of the GRZL station.

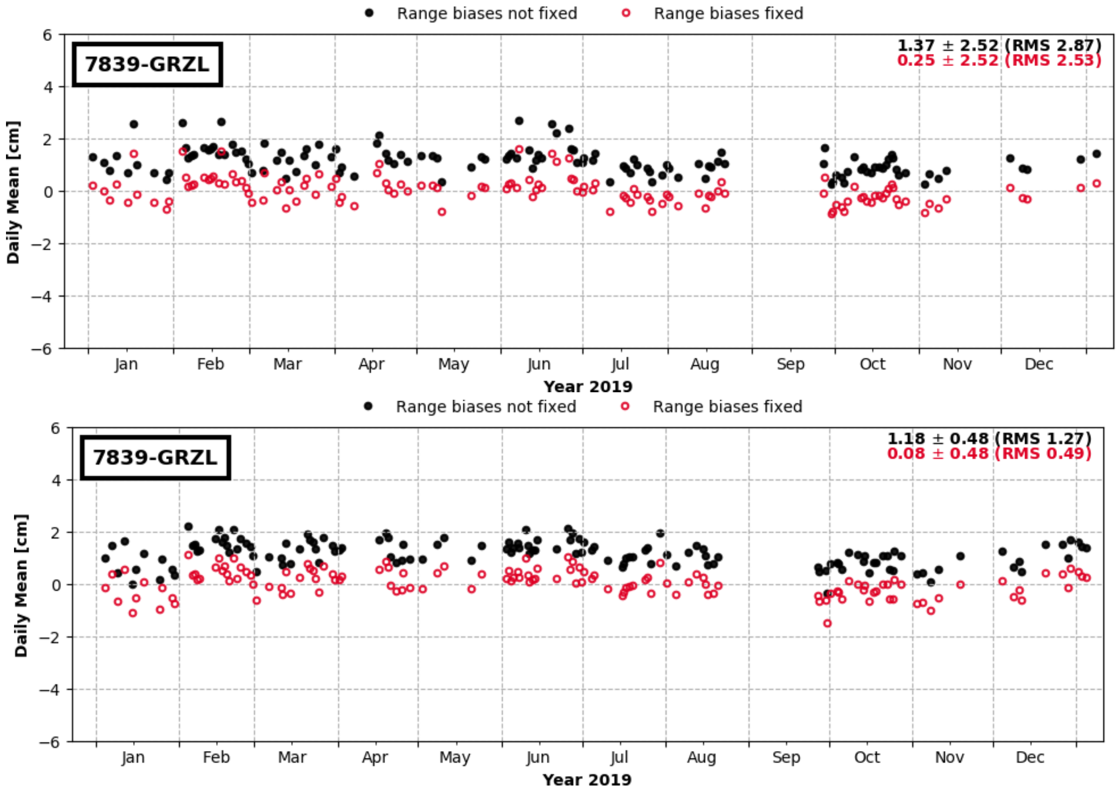
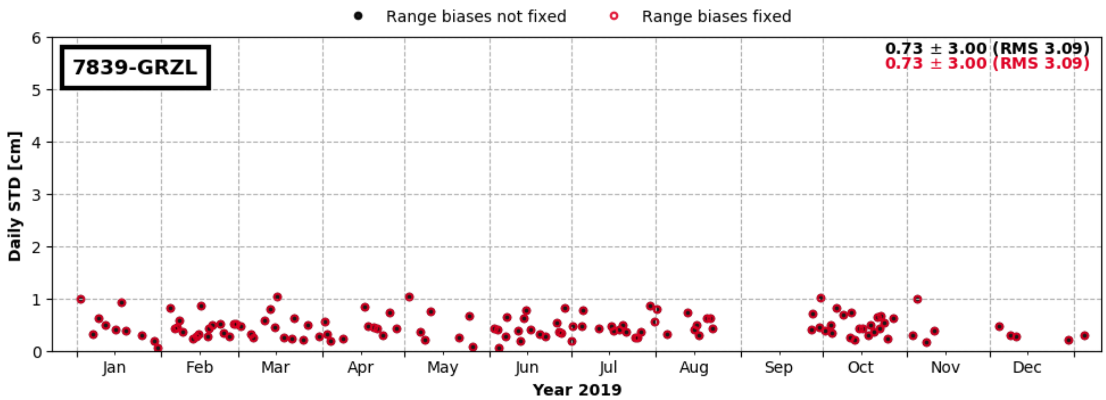


Figure 4-106: Daily mean of the SLR observation residuals [1-range; cm] of the SLR station 7839 (GRZL) in 2019 (above Sentinel-3A, and below Sentinel-3B)



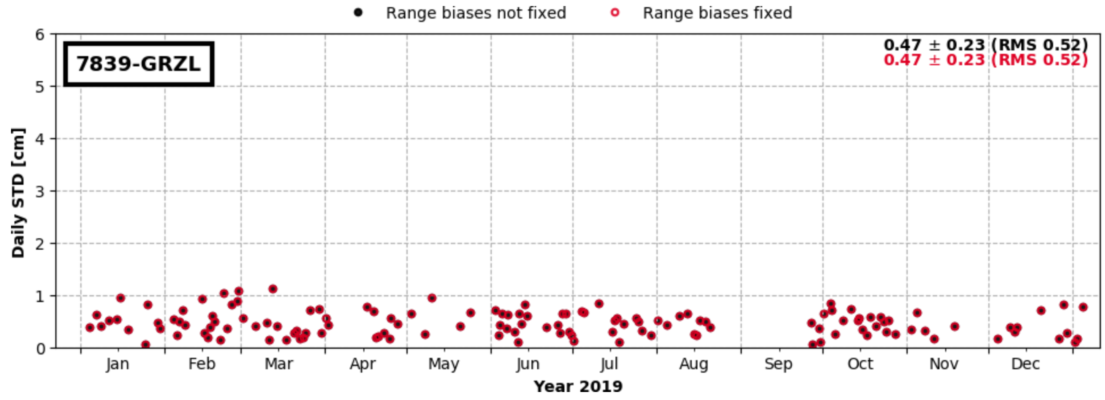


Figure 4-107: Daily STD of the SLR observation residuals [1-range; cm] of the SLR station 7839 (GRZL) in 2019 (above Sentinel-3A, and below Sentinel-3B)

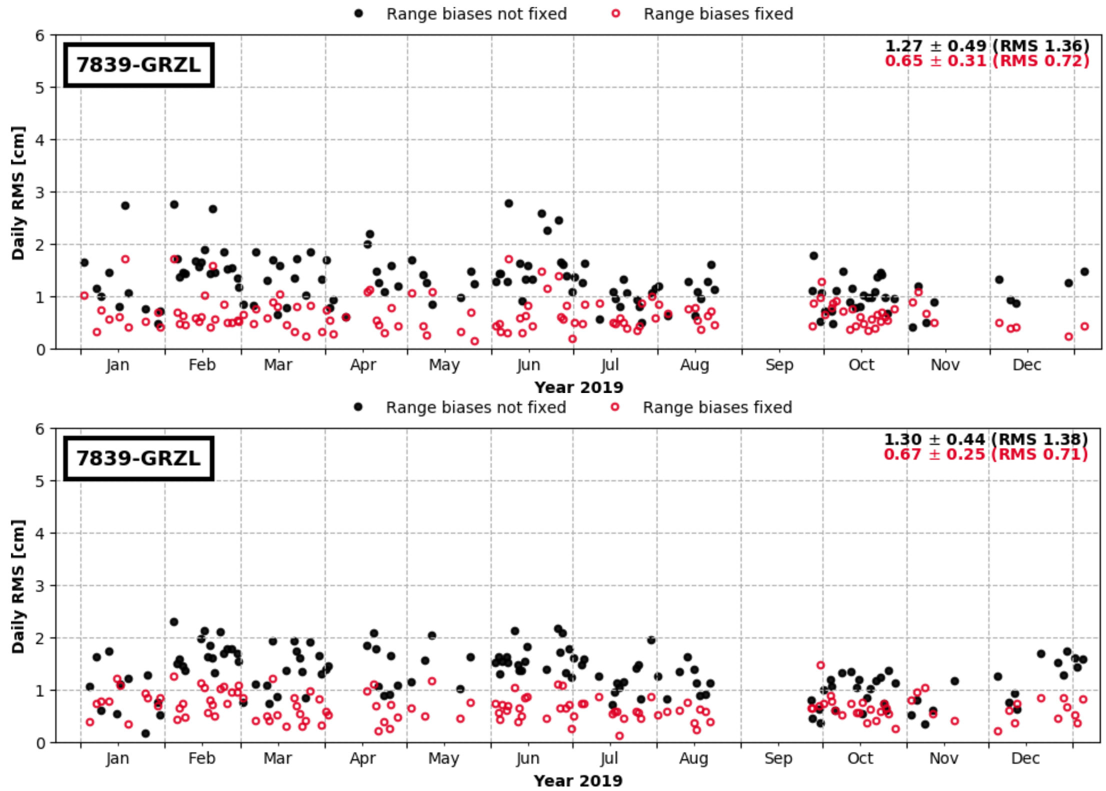


Figure 4-108: Daily RMS of the SLR observation residuals [1-range; cm] of the SLR station 7839 (GRZL) in 2019 (above Sentinel-3A, and below Sentinel-3B)

4.19. SLR STATION 7840 (HERL)

The SLR station Herstmonceaux (7840 - HERL) has been active more than the third of the time period evaluated. Therefore, the HERL station is also one of the SLR stations most tracking the Sentinel-3 satellites. From Table 4-19, it can be seen that there have been no significant differences on the tracking of both satellites from the HERL station, which has been providing a mean value of ~15 SLR observations per satellite pass.

Table 4-19: Summary of the processing statistics of the SLR station 7840 (HERL)

		Sentinel-3A	Sentinel-3B	Jason3
Number of satellite passes (*.npt* files)	All mission	1067	442	1917
	"Year 2019" (20340-20866)	230	235	497
Days processed(*)	Total	366	366	-
Active days	Total	134	137	-
	% (w.r.t. the total days processed)	36.61 %	37.43 %	-
Number of satellite passes processed	Total	227	233	-
	% (w.r.t. the *.npt* files)	98.70 %	99.15 %	-
Number of observations processed	Total	3378	3396	-
Number of observations per satellite pass	Mean	14.88	14.58	-
Number of observations filtered out	Total	0	0	-
	% (w.r.t. the total obs. processed)	0.00 %	0.00 %	-

(*) The total number of days processed does not coincide with the total number of days evaluated in "year 2019" (i.e., 371 days) since the combined orbit solution has not been generated on a few days as a result of either long manoeuvres or large gaps of data or other issues.

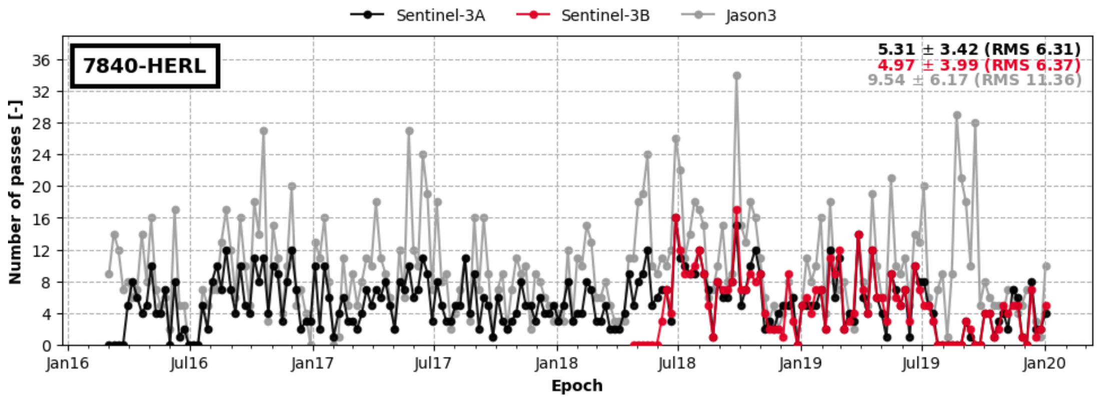


Figure 4-109: Total number of satellite passes per GPS week of the SLR station 7840 (HERL) since the beginning of the satellite mission (Sentinel-3A, Sentinel-3B and Jason-3)

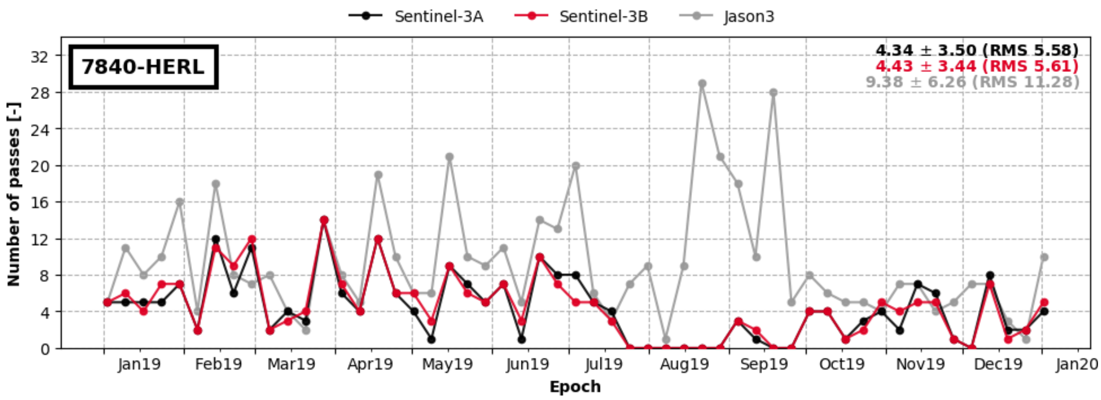


Figure 4-110: Total number of satellite passes per GPS week of the SLR station 7840 (HERL) in 2019 (Sentinel-3A, Sentinel-3B and Jason-3)

In Figure 4-109 and Figure 4-110, it can be seen that during very few times the HERL station has lost the tracking of the Sentinel-3 satellites. The last interval of time with a lack of connection between the station and the satellites coincides with a tracking peak of the Jason-3 satellite. Had it not been for this loss of connectivity, the tracking of the three satellites would have been very similar for all of them during 2019.

The HERL station delivered a large number of SLR observations per day with a mean value up to ~25 SLR observations when the station was active (see Figure 4-111).

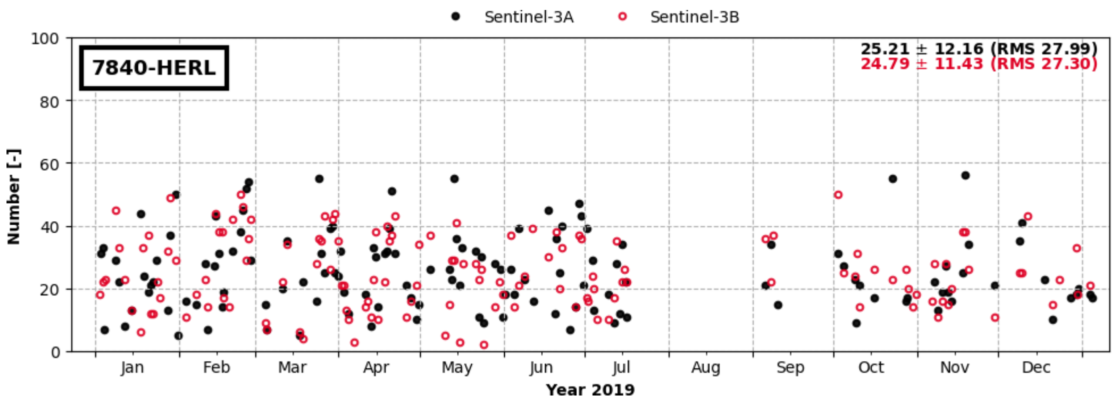


Figure 4-111: Daily total number of the accepted SLR observations of the SLR station 7840 (HERL) in 2019 (Sentinel-3A and Sentinel-3B)

From the analysis of the residuals, it can be said that the HERL station provides SLR observations with very good performance. The SLR residuals show a mean value tending to 0, and standard deviation and root mean square values below 1 cm for both satellites. This statistical outcome has been improved after having fixed a range bias to the station.

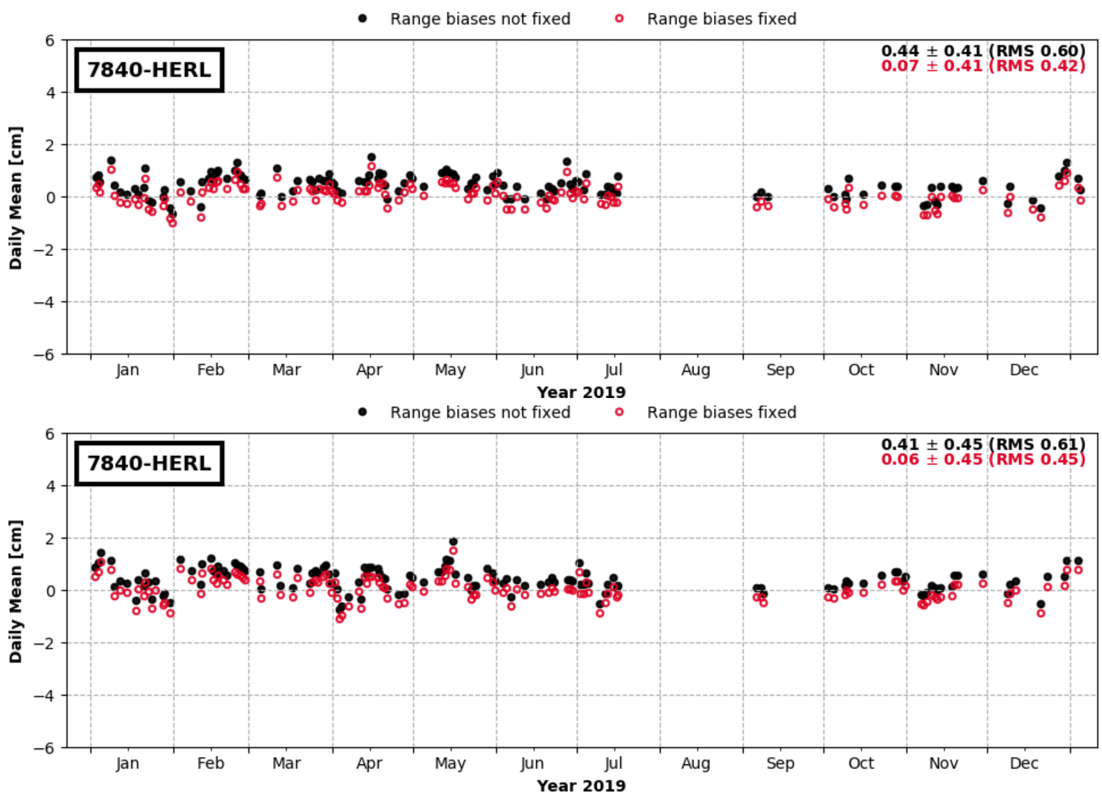


Figure 4-112: Daily mean of the SLR observation residuals [1-range; cm] of the SLR station 7840 (HERL) in 2019 (above Sentinel-3A, and below Sentinel-3B)

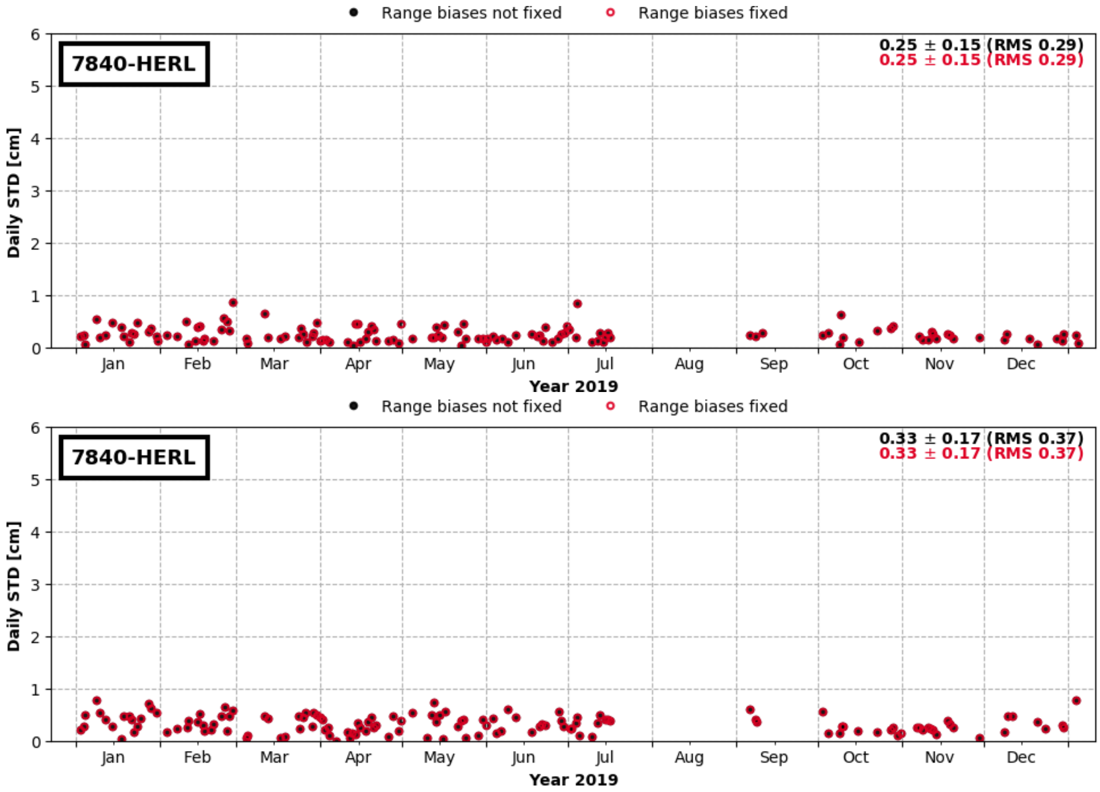


Figure 4-113: Daily STD of the SLR observation residuals [1-range; cm] of the SLR station 7840 (HERL) in 2019 (above Sentinel-3A, and below Sentinel-3B)

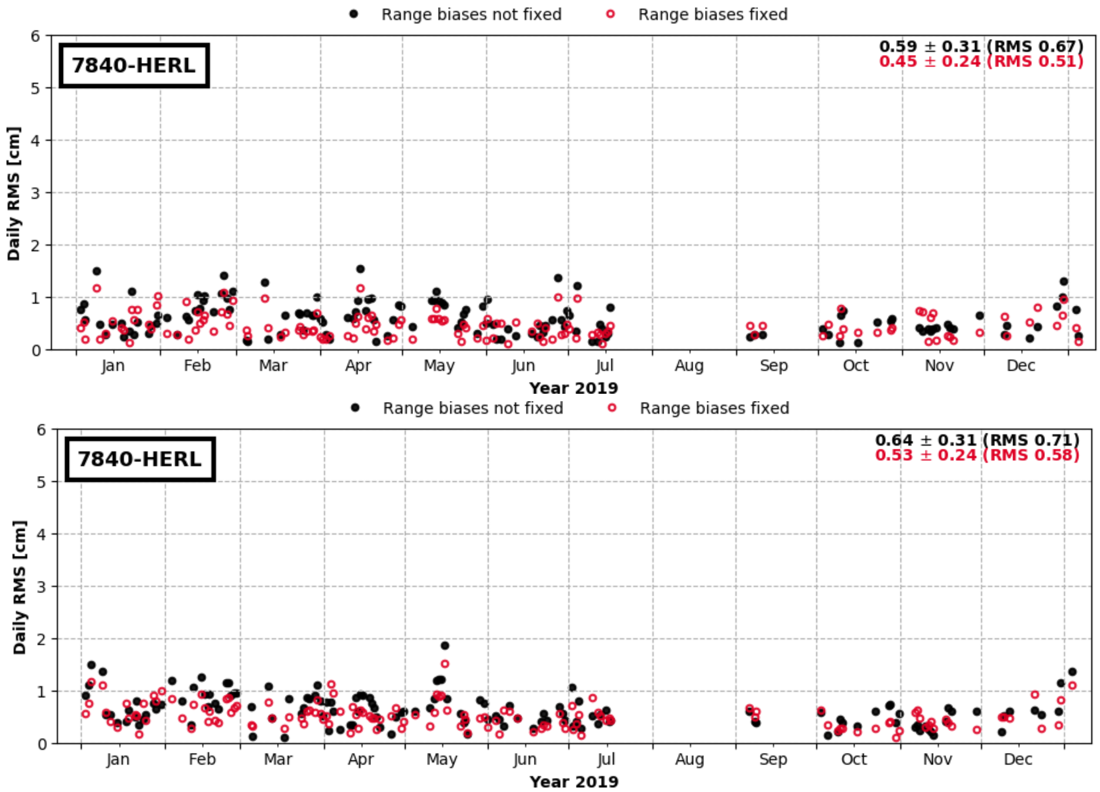


Figure 4-114: Daily RMS of the SLR observation residuals [1-range; cm] of the SLR station 7840 (HERL) in 2019 (above Sentinel-3A, and below Sentinel-3B)

4.20. SLR STATION 7841 (POT3)

The SLR station Potsdam3 (7841 – POT3) has been active more than the 40 % of the time period evaluated. The POT3 station is then one of the SLR stations most tracking the Sentinel-3 satellites. However, despite this fact, the POT3 station is not one of the stations providing the most quantity of SLR observations per satellite pass. From Table 4-20, it can be seen that there are almost no processing differences between both Sentinel-3 satellites.

Table 4-20: Summary of the processing statistics of the SLR station 7841 (POT3)

		Sentinel-3A	Sentinel-3B	Jason3
Number of satellite passes (*.npt* files)	All mission	1042	418	1440
	"Year 2019" (20340-20866)	231	217	247
Days processed(*)	Total	366	366	-
Active days	Total	157	153	-
	% (w.r.t. the total days processed)	42.90 %	41.80 %	-
Number of satellite passes processed	Total	228	216	-
	% (w.r.t. the *.npt* files)	98.70 %	99.54 %	-
Number of observations processed	Total	3061	2991	-
Number of observations per satellite pass	Mean	13.43	13.85	-
Number of observations filtered out	Total	0	0	-
	% (w.r.t. the total obs. processed)	0.00 %	0.00 %	-

(*) The total number of days processed does not coincide with the total number of days evaluated in "year 2019" (i.e., 371 days) since the combined orbit solution has not been generated on a few days as a result of either long manoeuvres or large gaps of data or other issues.

The Sentinel-3 satellites have been routinely tracked from the POT3 station during their entire missions. There are very few times where the station seems to have lost connectivity with the satellites, but the activity has been resumed in a short time. On 2019, the POT3 station has reported similar tracking values for all three satellites (see Figure 4-116).

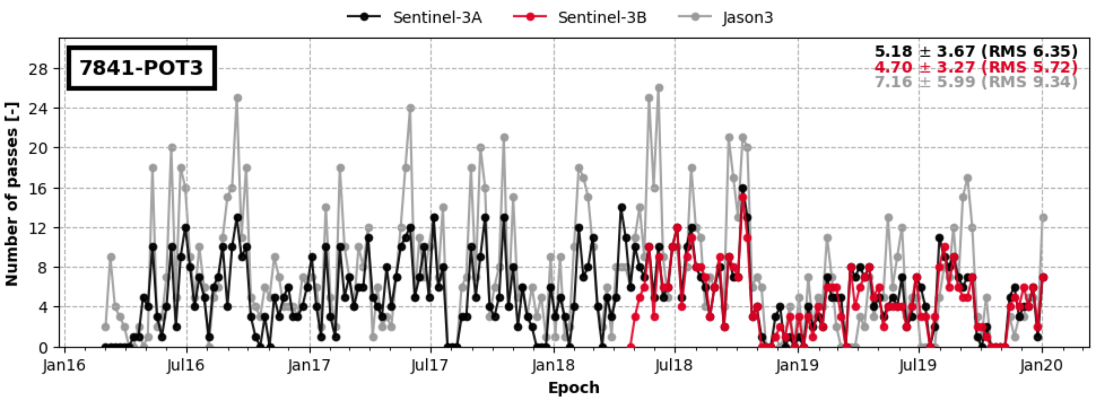


Figure 4-115: Total number of satellite passes per GPS week of the SLR station 7841 (POT3) since the beginning of the satellite mission (Sentinel-3A, Sentinel-3B and Jason-3)

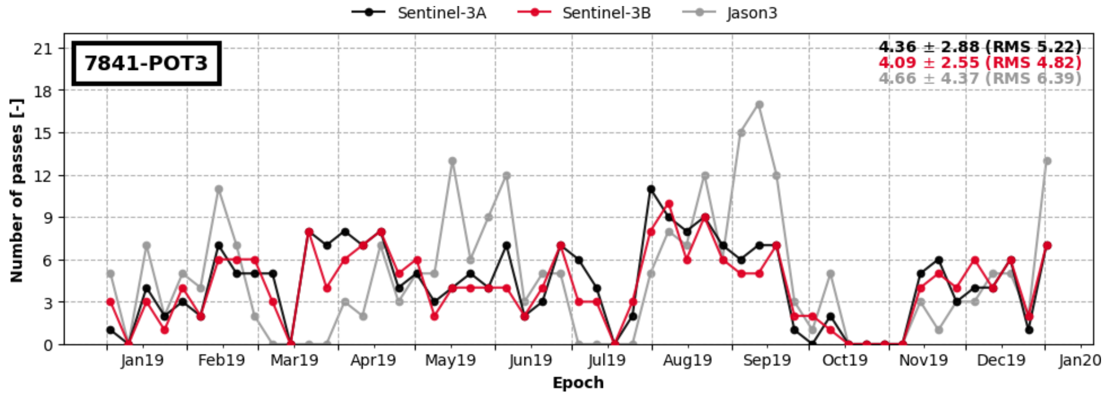


Figure 4-116: Total number of satellite passes per GPS week of the SLR station 7841 (POT3) in 2019 (Sentinel-3A, Sentinel-3B and Jason-3)

Except for some short interval of times of inactivity during 2019, the POT3 station has been providing a mean value of ~20 SLR observations on a daily basis as shown in Figure 4-117.

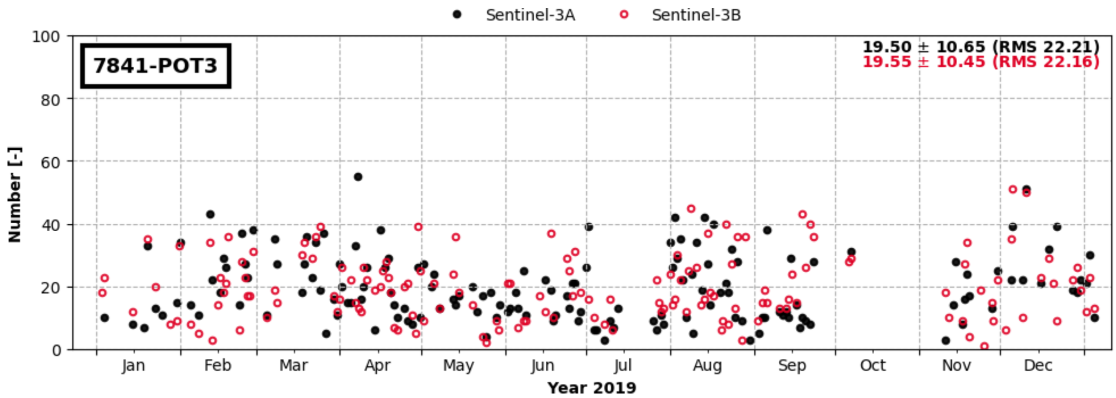
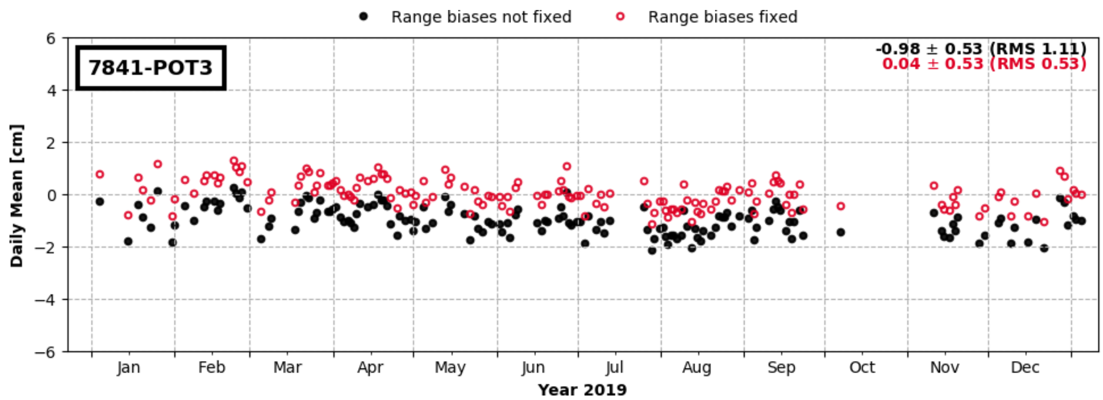


Figure 4-117: Daily total number of the accepted SLR observations of the SLR station 7841 (POT3) in 2019 (Sentinel-3A and Sentinel-3B)

The SLR residuals present mean values tending to 0, and also obtain very tight standard deviation and root mean square values. These facts reveal the good performance on the SLR observations being delivered by the POT3 station. It must be highlighted that the use of a fixed range bias to the station has remarkably benefited the statistical outcome.



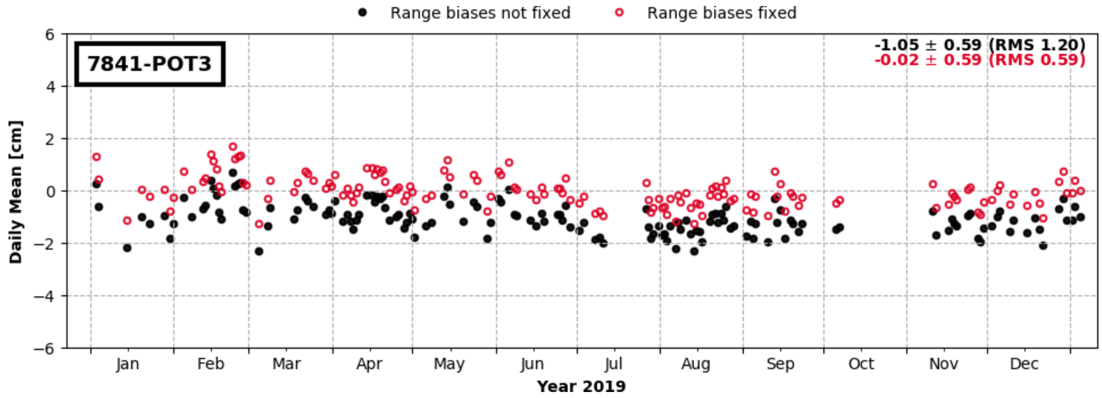


Figure 4-118: Daily mean of the SLR observation residuals [1-range; cm] of the SLR station 7841 (POT3) in 2019 (above Sentinel-3A, and below Sentinel-3B)

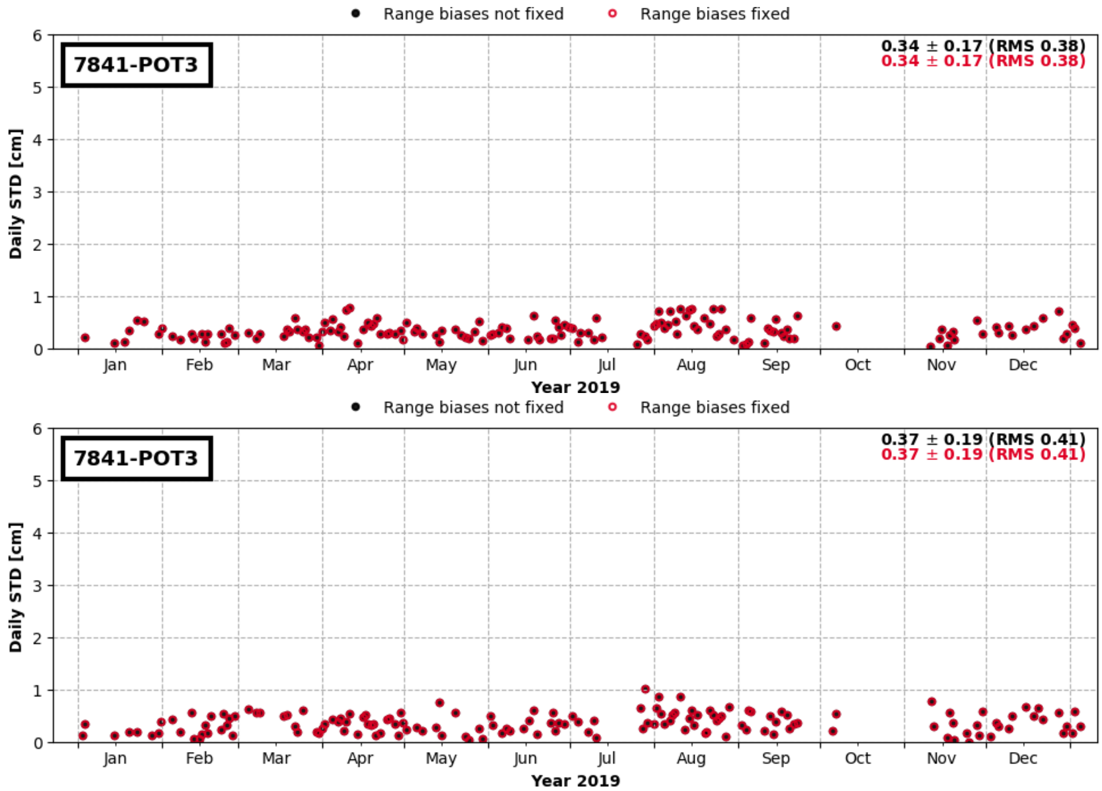
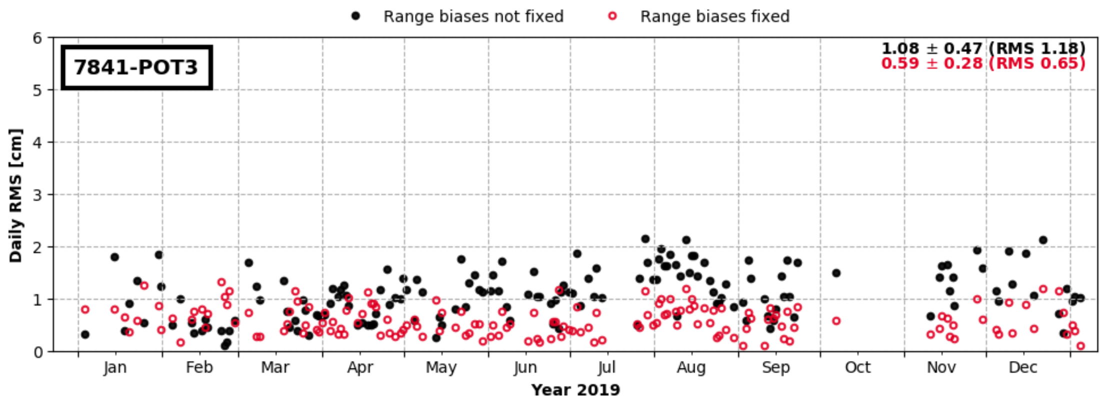


Figure 4-119: Daily STD of the SLR observation residuals [1-range; cm] of the SLR station 7841 (POT3) in 2019 (above Sentinel-3A, and below Sentinel-3B)



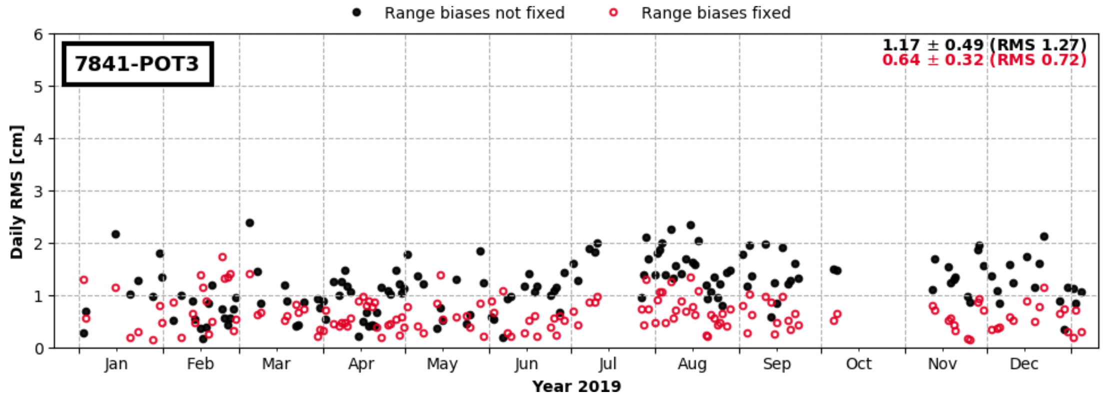


Figure 4-120: Daily RMS of the SLR observation residuals [1-range; cm] of the SLR station 7841 (POT3) in 2019 (above Sentinel-3A, and below Sentinel-3B)

4.21. SLR STATION 7941 (MATM)

The SLR station Matera (MLRO) (7941 - MATM) has been active more than the 40 % of the time period analysed. Similarly to the POT3 station, the MATM station is one of the SLR stations most tracking the Sentinel-3 satellites, but such tracking does not lead the station to provide a huge number on the provision of SLR observations. This is due to the fact that the MATM station gives a reduced number of SLR observations per satellite pass (i.e., a mean value of ~9 SLR observations). From Table 4-21, it can be seen that there are no major differences to be highlighted regarding the tracking of both satellites.

Table 4-21: Summary of the processing statistics of the SLR station 7941 (MATM)

		Sentinel-3A	Sentinel-3B	Jason3
Number of satellite passes (*.npt* files)	All mission	804	427	1692
	"Year 2019" (20340-20866)	230	245	425
Days processed(*)	Total	366	366	-
Active days	Total	160	163	-
	% (w.r.t. the total days processed)	43.72 %	44.54 %	-
Number of satellite passes processed	Total	227	243	-
	% (w.r.t. the *.npt* files)	98.70 %	99.18 %	-
Number of observations processed	Total	2072	2062	-
Number of observations per satellite pass	Mean	9.13	8.49	-
Number of observations filtered out	Total	1	0	-
	% (w.r.t. the total obs. processed)	0.05 %	0.00 %	-

(*) The total number of days processed does not coincide with the total number of days evaluated in "year 2019" (i.e., 371 days) since the combined orbit solution has not been generated on a few days as a result of either long manoeuvres or large gaps of data or other issues.

The MATM station has been tracking the Sentinel-3 satellites since the beginning of their missions (see Figure 4-121 and Figure 4-122). There are only a few interval of times where the station seems to have lost the connection to the satellites, but this lack of activity has resumed soon. During 2019, the MATM station has notably more tracked the Jason-3 satellite, which figures are doubling the ones achieved by the Sentinel-3 satellites.

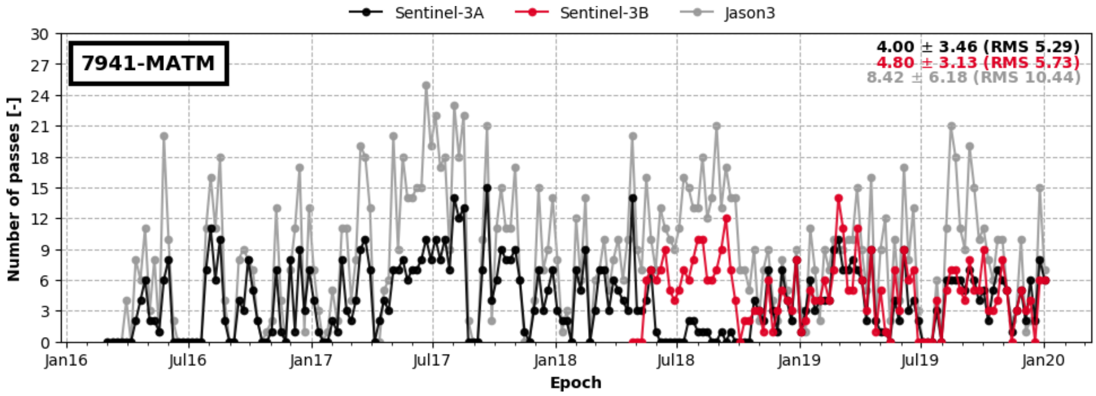


Figure 4-121: Total number of satellite passes per GPS week of the SLR station 7941 (MATM) since the beginning of the satellite mission (Sentinel-3A, Sentinel-3B and Jason-3)

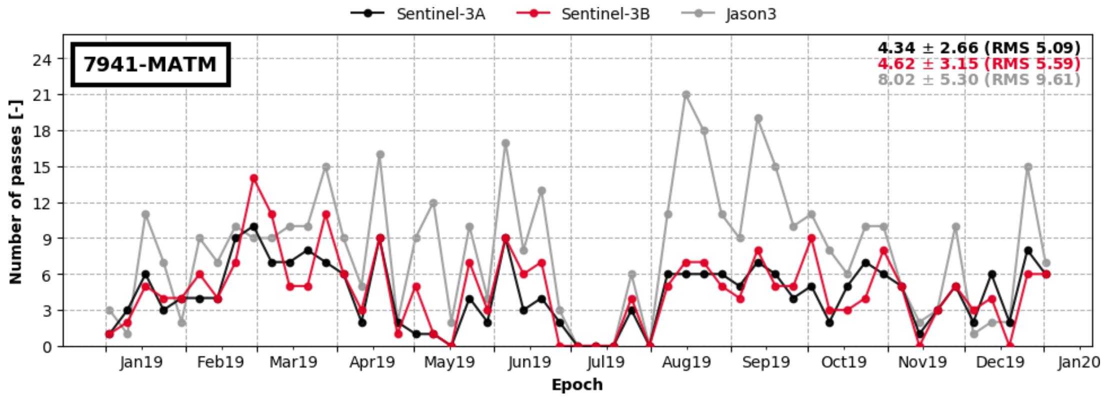


Figure 4-122: Total number of satellite passes per GPS week of the SLR station 7941 (MATM) in 2019 (Sentinel-3A, Sentinel-3B and Jason-3)

Regarding the SLR observations, the MATM station has been providing a mean value of ~13 SLR observations per day when active, which is an average value regarding the outcome of all SLR stations (see Figure 4-123).

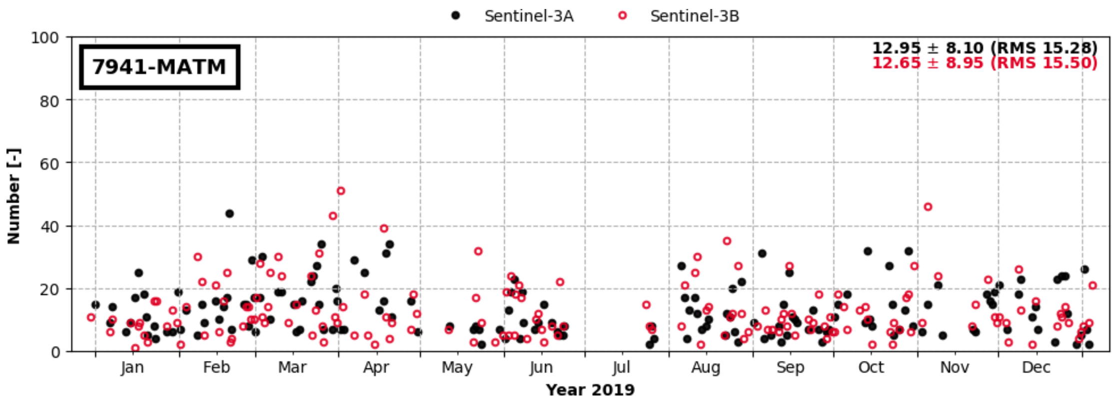


Figure 4-123: Daily total number of the accepted SLR observations of the SLR station 7941 (MATM) in 2019 (Sentinel-3A and Sentinel-3B)

From the analysis of the SLR residuals, it can be said that the SLR observations provided by the MATM station present very good performance. In addition, the final statistical outcome has been benefited from the use of a fixed range bias to the station.

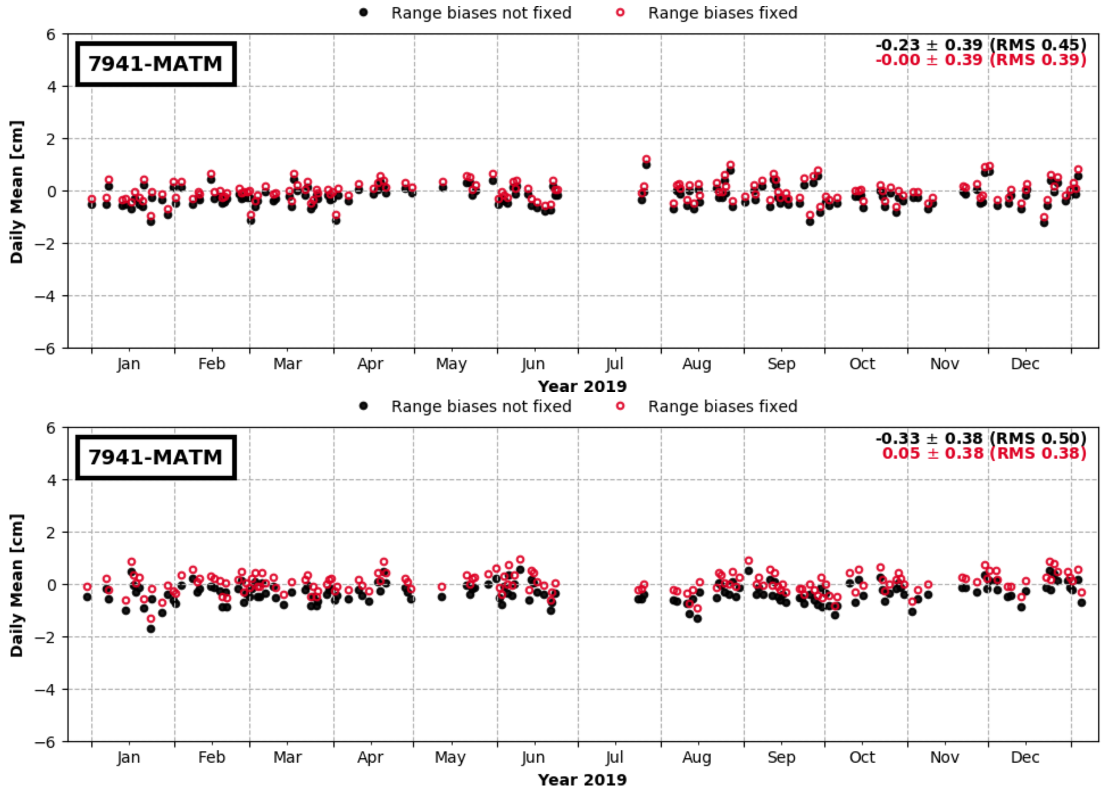


Figure 4-124: Daily mean of the SLR observation residuals [1-range; cm] of the SLR station 7941 (MATM) in 2019 (above Sentinel-3A, and below Sentinel-3B)

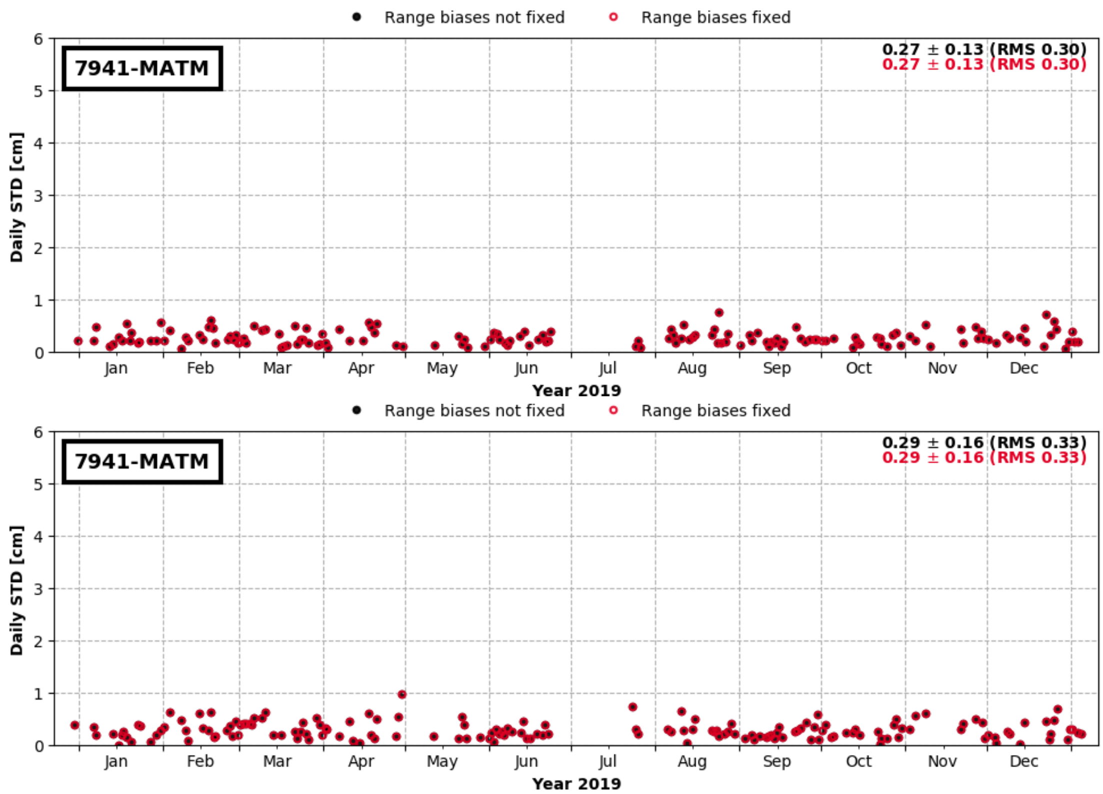


Figure 4-125: Daily STD of the SLR observation residuals [1-range; cm] of the SLR station 7941 (MATM) in 2019 (above Sentinel-3A, and below Sentinel-3B)

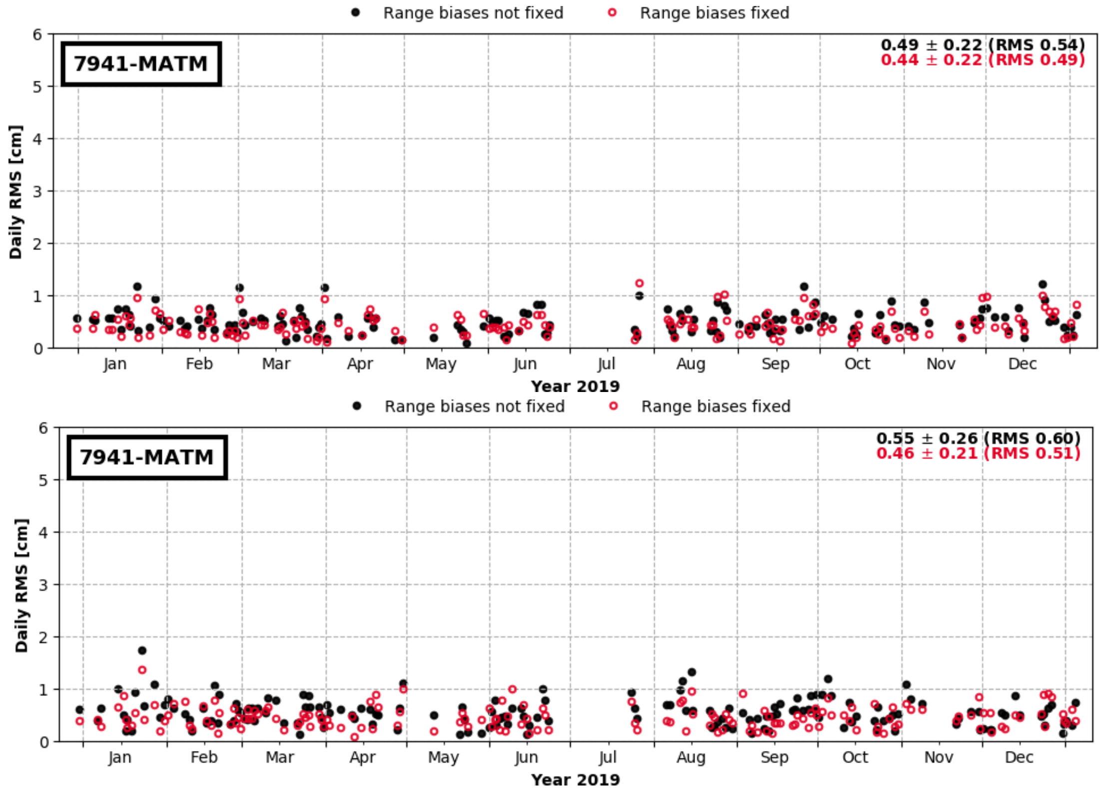


Figure 4-126: Daily RMS of the SLR observation residuals [1-range; cm] of the SLR station 7941 (MATM) in 2019 (above Sentinel-3A, and below Sentinel-3B)

4.22. SLR STATION 8834 (WETL)

Table 4-22: Summary of the processing statistics of the SLR station 8834 (WETL)

		Sentinel-3A	Sentinel-3B	Jason3
Number of satellite passes (*.npt* files)	All mission	630	197	1804
	"Year 2019" (20340-20866)	116	93	536
Days processed(*)	Total	366	366	-
Active days	Total	70	64	-
	% (w.r.t. the total days processed)	19.13 %	17.49 %	-
Number of satellite passes processed	Total	116	89	-
	% (w.r.t. the *.npt* files)	100.00 %	95.70 %	-
Number of observations processed	Total	1135	966	-
Number of observations per satellite pass	Mean	9.13	8.49	-
Number of observations filtered out	Total	0	0	-
	% (w.r.t. the total obs. processed)	0.00 %	0.00 %	-

(*) The total number of days processed does not coincide with the total number of days evaluated in "year 2019" (i.e., 371 days) since the combined orbit solution has not been generated on a few days as a result of either long manoeuvres or large gaps of data or other issues.

The SLR station Wettzell (8834 - WETL) has been active below the 20 % of the time period evaluated. This is an unusual result from the WETL station, which has mainly been caused due to a preventing stop on the tracking of the Sentinel-3 satellites. During mid-June 2019, the WETL station changed the laser configuration of their system. At that time, it was not clear that the station could track Sentinel-3 satellites in the infra-red, and what were the power limitations under that wavelength. Therefore, as a precautionary measure, the station stopped the tracking of the Sentinel-3 satellites until an official answer was given. The CPOD Service moved this issue to ESA, which is currently addressing this fact.

As seen from the figures below, the WETL station has routinely been tracking the Sentinel-3 satellites since the beginning of their missions. However, the statistics of most of the year 2019 have been affected by the impact of the precautionary measure.

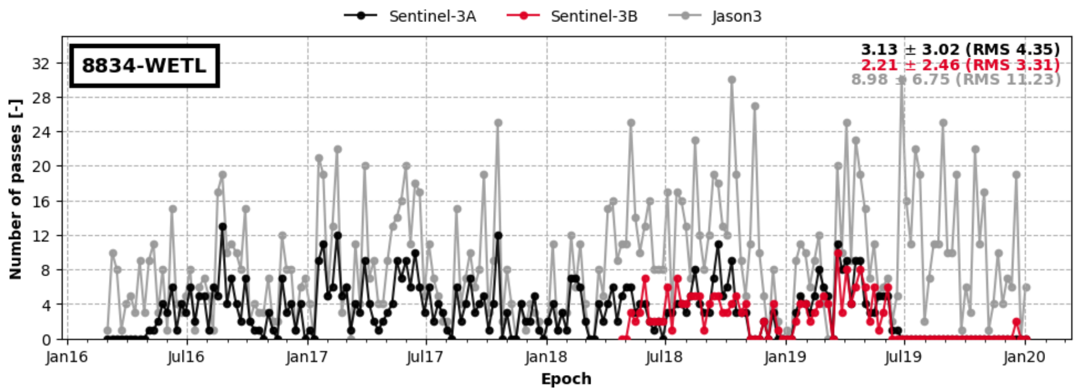


Figure 4-127: Total number of satellite passes per GPS week of the SLR station 8834 (WETL) since the beginning of the satellite mission (Sentinel-3A, Sentinel-3B and Jason-3)

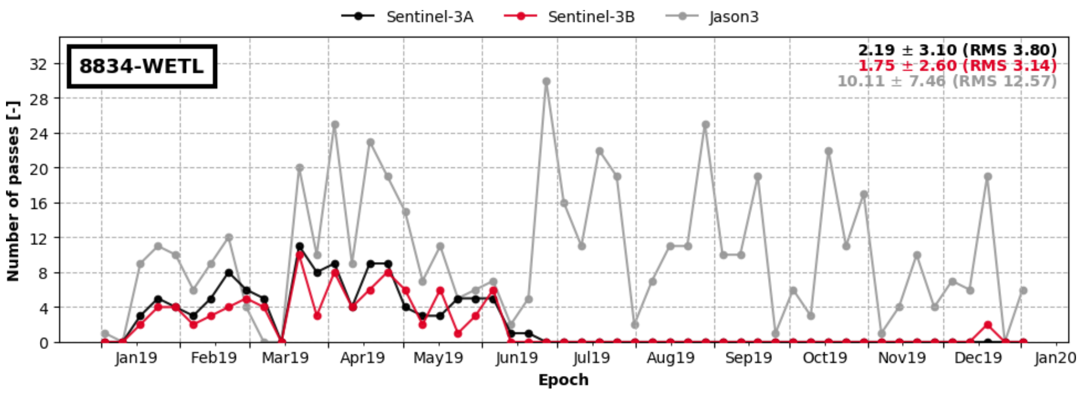


Figure 4-128: Total number of satellite passes per GPS week of the SLR station 8834 (WETL) in 2019 (Sentinel-3A, Sentinel-3B and Jason-3)

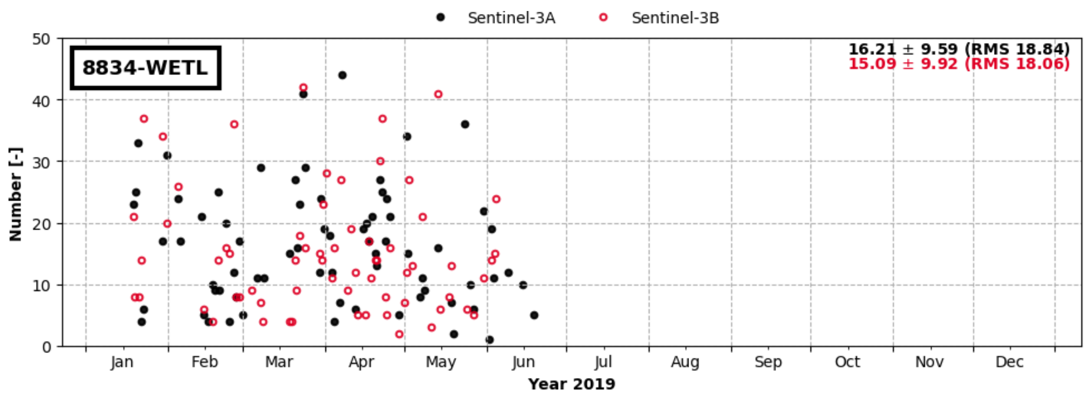


Figure 4-129: Daily total number of the accepted SLR observations of the SLR station 8834 (WETL) in 2019 (Sentinel-3A and Sentinel-3B)

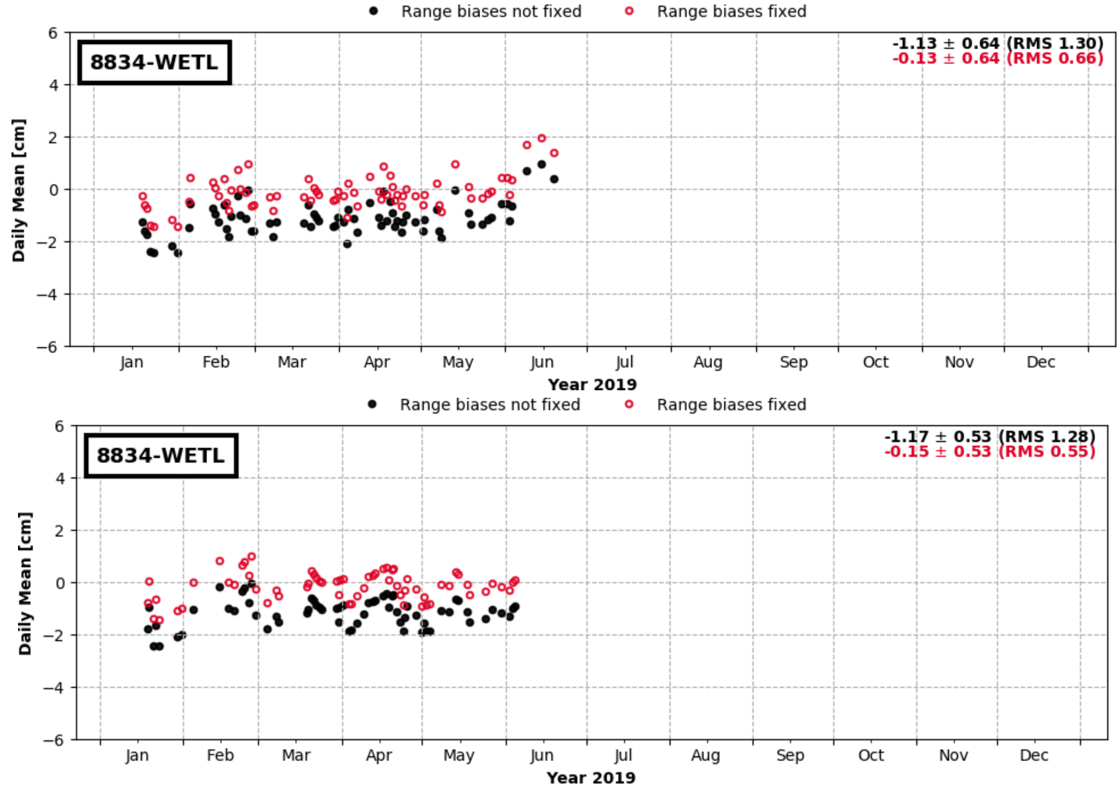


Figure 4-130: Daily mean of the SLR observation residuals [1-range; cm] of the SLR station 8834 (WETL) in 2019 (above Sentinel-3A, and below Sentinel-3B)

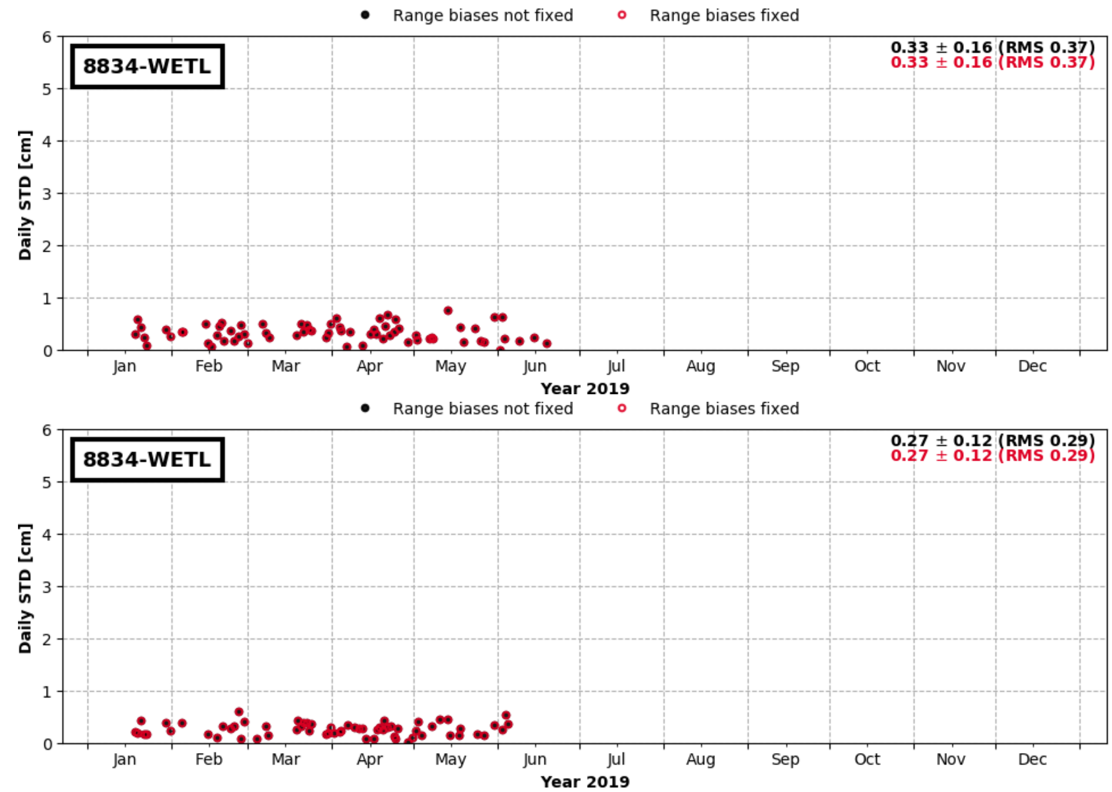


Figure 4-131: Daily STD of the SLR observation residuals [1-range; cm] of the SLR station 8834 (WETL) in 2019 (above Sentinel-3A, and below Sentinel-3B)

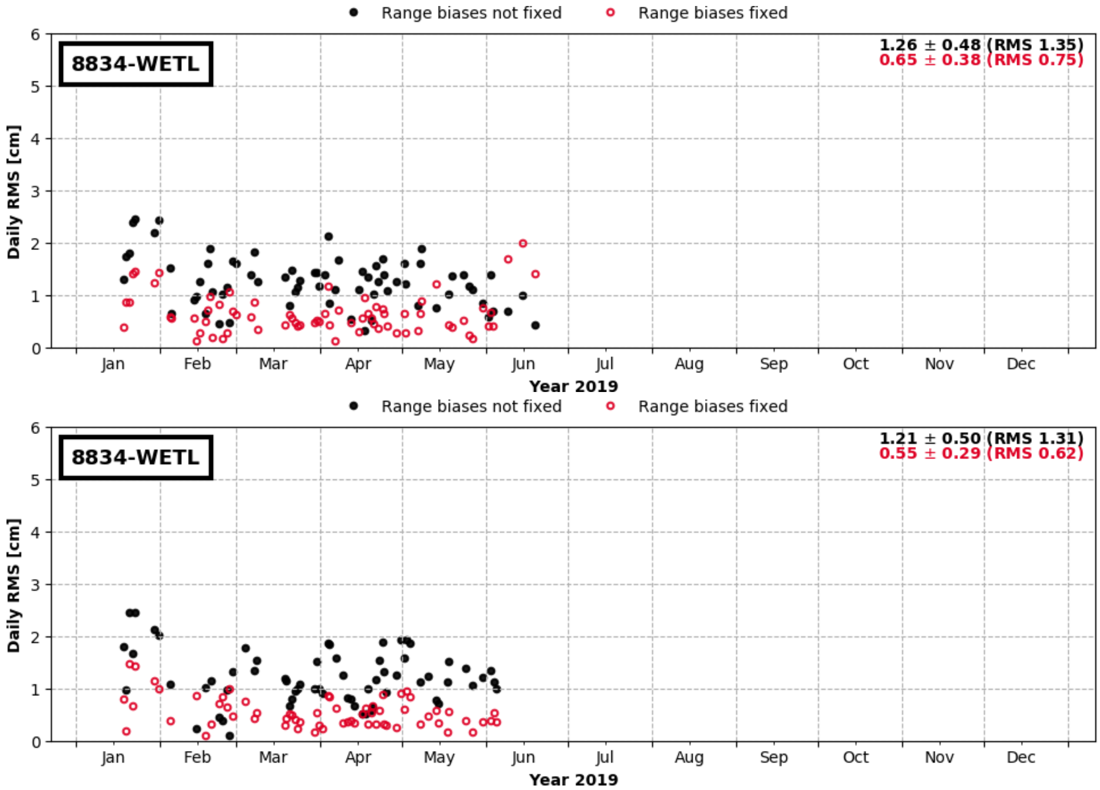


Figure 4-132: Daily RMS of the SLR observation residuals [1-range; cm] of the SLR station 8834 (WETL) in 2019 (above Sentinel-3A, and below Sentinel-3B)

For the interval of time where the SLR observations were delivered, it can be said that the WETL station provided SLR observations of very good performance. Not only the SLR residuals tend to 0 but also the standard deviation and root mean square values present reduced values. In addition, this statistical outcome has significantly been benefited after having fixed a range bias to the station.

4.23. SUMMARY OF THE PROCESSING STATISTICS

This sub section is intended to gather the individual statistics of each SLR station shown throughout the previous sub sections and put them into the same plot. Thus, statistics of the same kind can easily be compared through the following figures.

Firstly, Figure 4-133 summarises the percentage of days that any SLR station tracking the Sentinel-3 satellites during 2019 has been active. Remember that by saying active means a SLR station providing at least one SLR observation on one day. As seen from the figure, the statistics are led by the YARL station with a huge difference to the rest of SLR stations. Leaving the YARL station aside, there is a group of 13 SLR stations that has tracked the Sentinel-3 satellites between 20-50 % on 2019. This number of stations could have grown up to 15 SLR stations if ZIML and WETL stations had had a nominal behaviour during 2019.

Secondly, Figure 4-134 shows the total number of SLR observations processed on each SLR station. Again, the YARL station is leading the statistics, and also with a great difference with respect the other SLR stations. Leaving the YARL station aside, there are 7 SLR stations providing a large number of SLR observations. There are two more stations (i.e., ZIML and probably WETL) that could have joined this group of SLR stations if their activity had been nominal during 2019. If these results are compared to the ones of the previous figure, it can be noticed that some SLR stations highlighted for their activity present lower figures on the total number of SLR observations. This fact can be explained with the outcome of the following figure.

Thirdly, Figure 4-135 plots the mean number of SLR observations per satellite pass of each SLR station. A total of 12 SLR stations are providing more than 12 SLR observations per satellite pass. SLR stations such as RIGL and BORL, which show low activity, are now taking part of this group, whereas SLR stations such as BADL and BEIL, which show good figures on activity, are not within this group.

Fourthly, Figure 4-136 presents the mean number of the total number of SLR observations given for each day by each SLR station. From the outcomes of this and the previous figures, it can be identified which SLR stations are tracking the Sentinel-3 satellites more than once a day when active. SLR stations such as YARL, GODL, ZIML, GRZL, or even MATM fulfil such behaviour frequently.

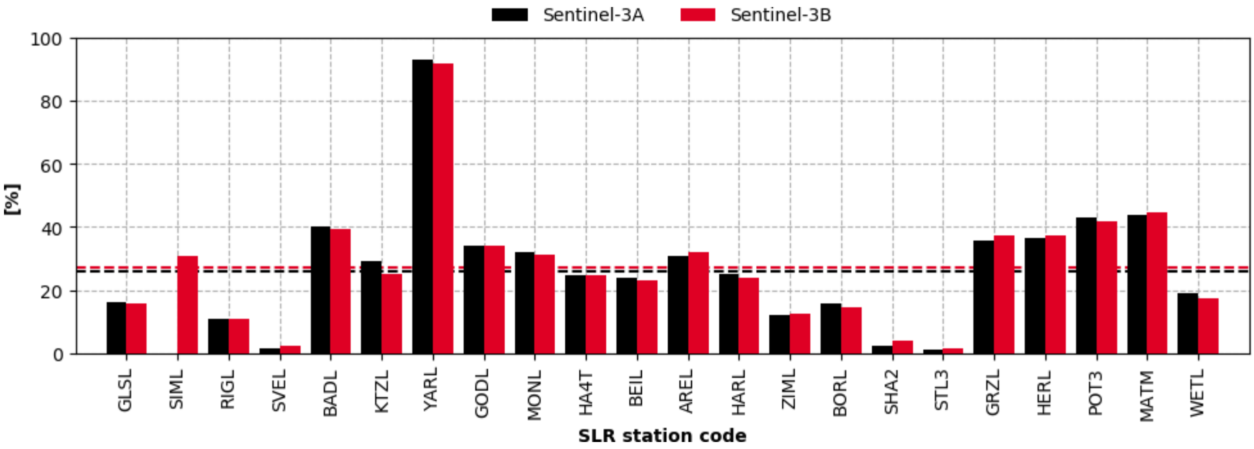


Figure 4-133: Percentage of the active days of each SLR station with respect to the total number of days processed in "year 2019" (i.e., 366 days) for Sentinel-3A and Sentinel-3B (the horizontal lines address the mean value for all SLR stations)

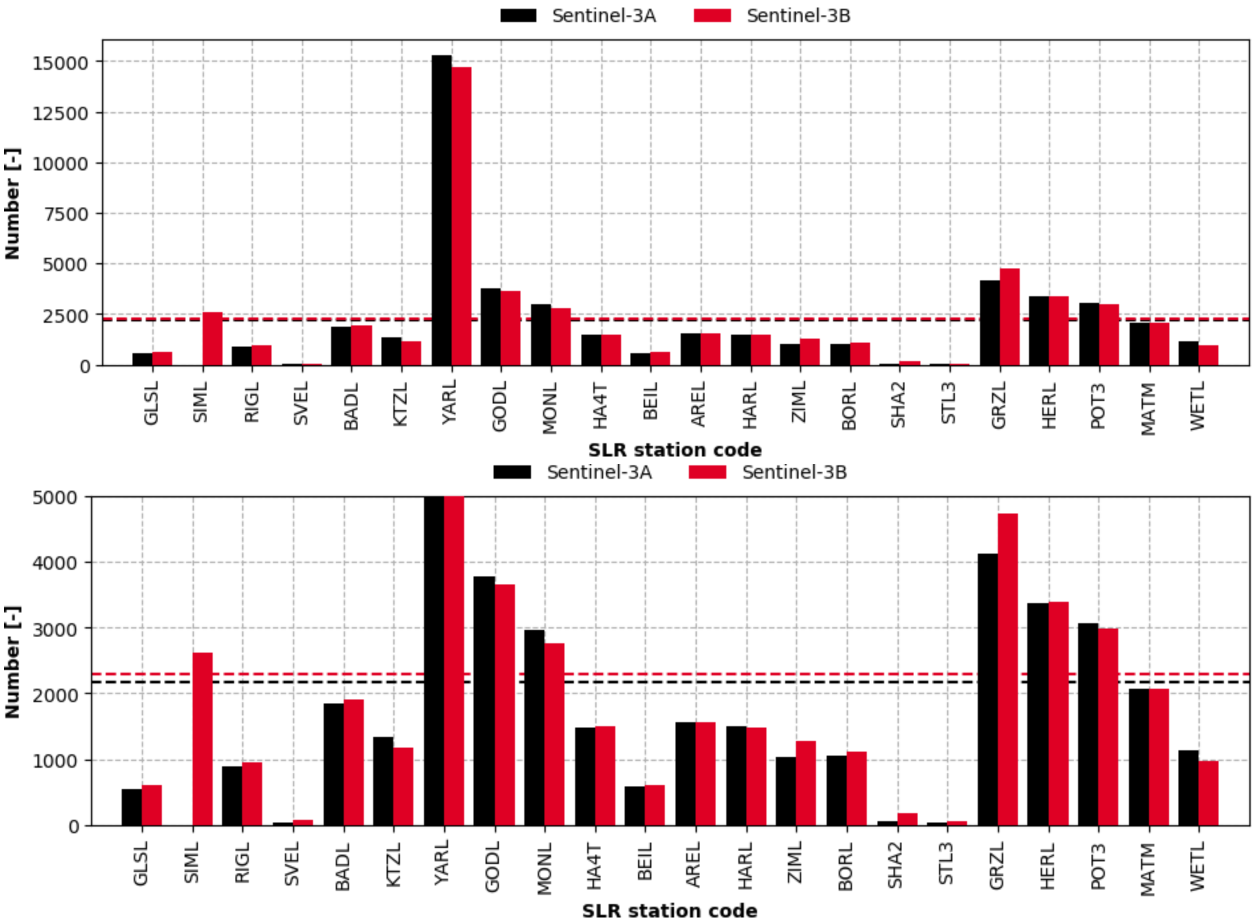


Figure 4-134: Total number of the SLR observations processed for Sentinel-3A and Sentinel-3B in 2019 (the figure below is a zoomed-in of the figure above) (the horizontal lines address the mean value for all SLR stations)

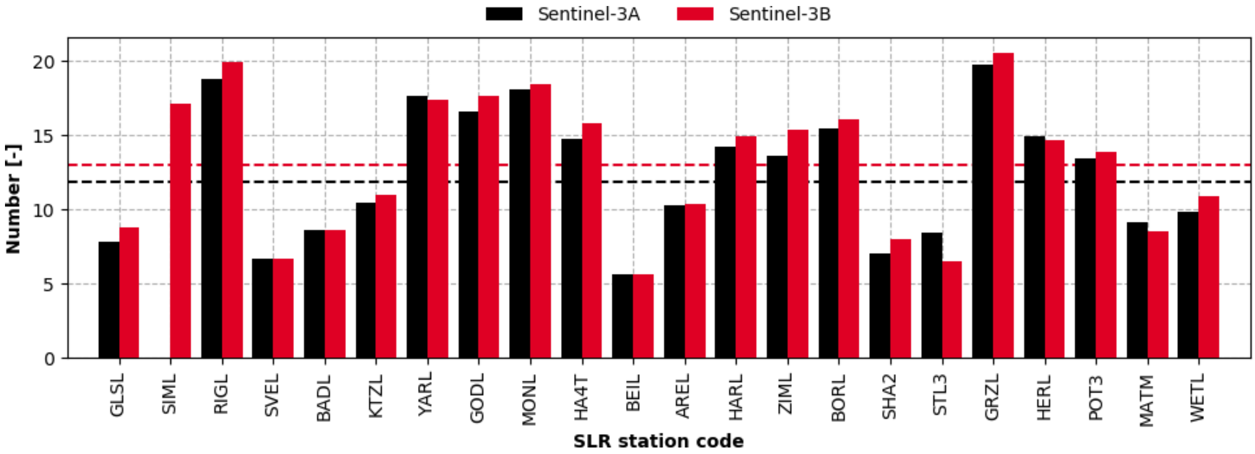


Figure 4-135: Mean number of the SLR observations per satellite pass of each SLR station for Sentinel-3A and Sentinel-3B in 2019 (the horizontal lines address the mean value for all SLR stations)

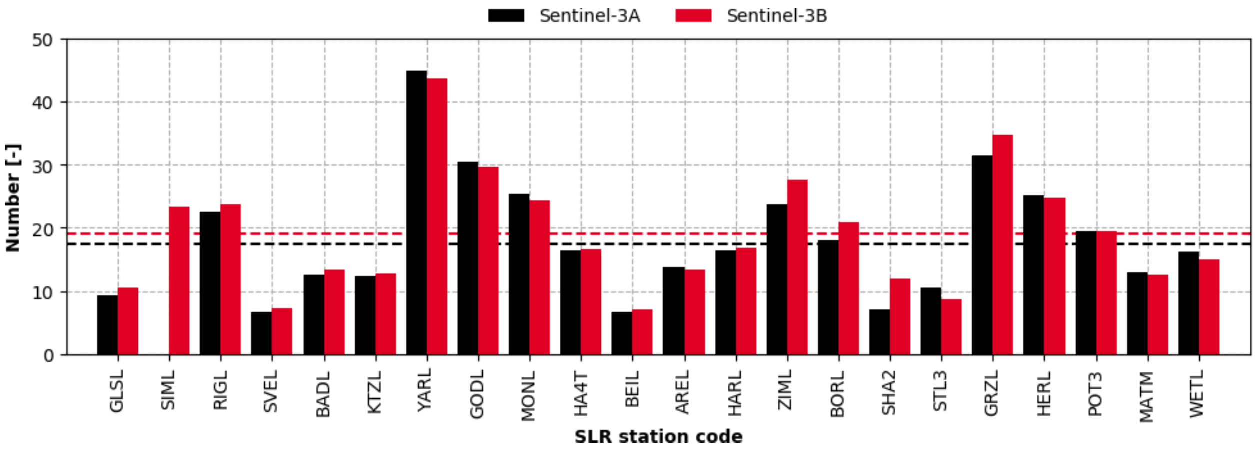


Figure 4-136: Mean number of the daily total number of the accepted SLR observations of each SLR station for Sentinel-3A and Sentinel-3B in 2019 (the horizontal lines address the mean value for all SLR stations)

Fifthly, the following figures show the mean, standard deviation and root mean square values of the statistics obtained from all SLR residuals calculated of each SLR station. These figures plot the statistics for the cases where (a) the range biases have not been fixed and (b) the range biases have been fixed. The analysis of the figures mostly reveals the significant improvement that the statistical outcome has obtained after the range biases have been applied to the stations. The SLR residuals are almost 0 or tend to this number in the vast majority of the cases, and the standard deviation and root mean squares values reduce their figures once the range biases are fixed. Table 4-23 gathers all statistical figures subtracted from the SLR residuals. Keep in mind that a few outliers have been filtered-out on some SLR stations in order not to harm the final statistical outcome.

On the other hand, this statistical outcome also highlights a few stations, whose results are excessively high. Some misconfiguration when calculating the SLR residuals or some underperformance on the SLR observations provided by these SLR stations could be the explanation for such big figures.

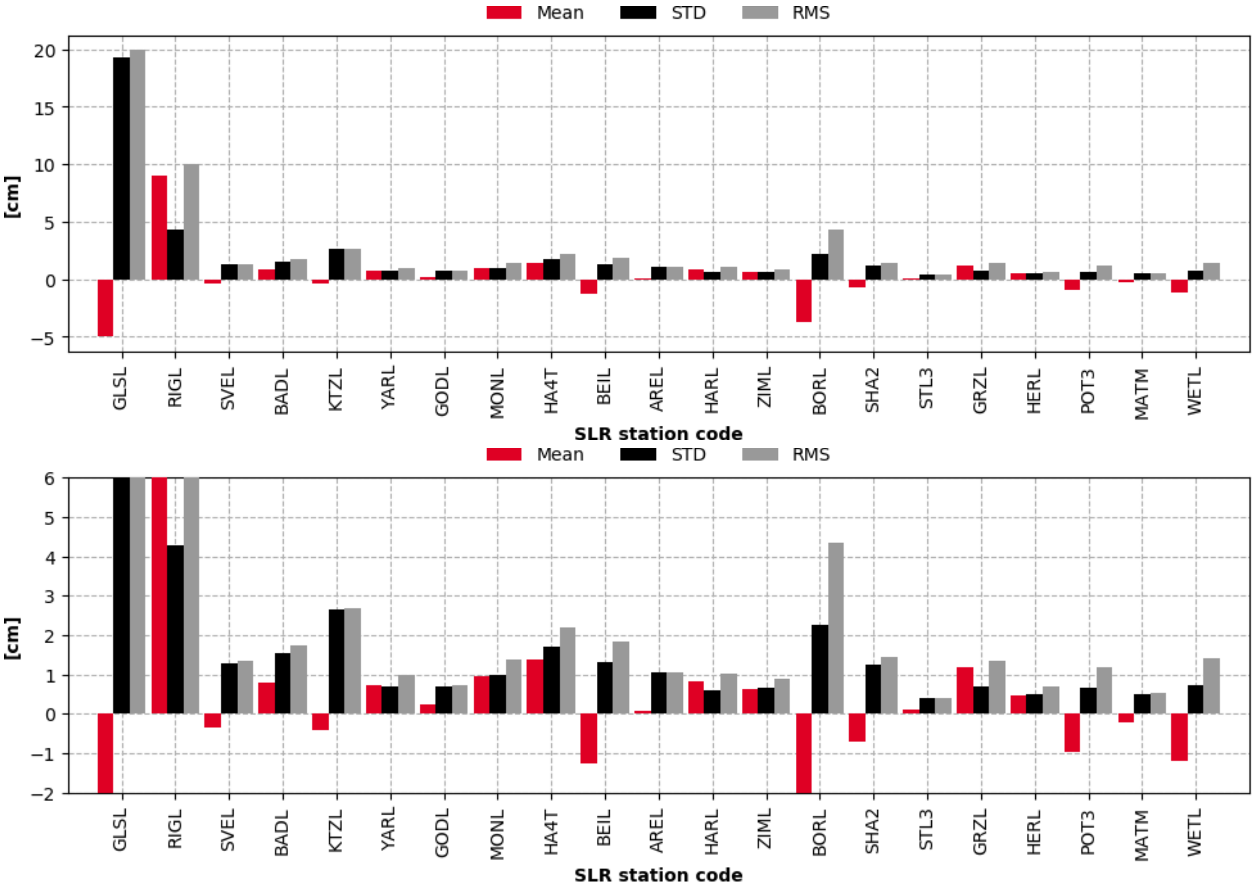
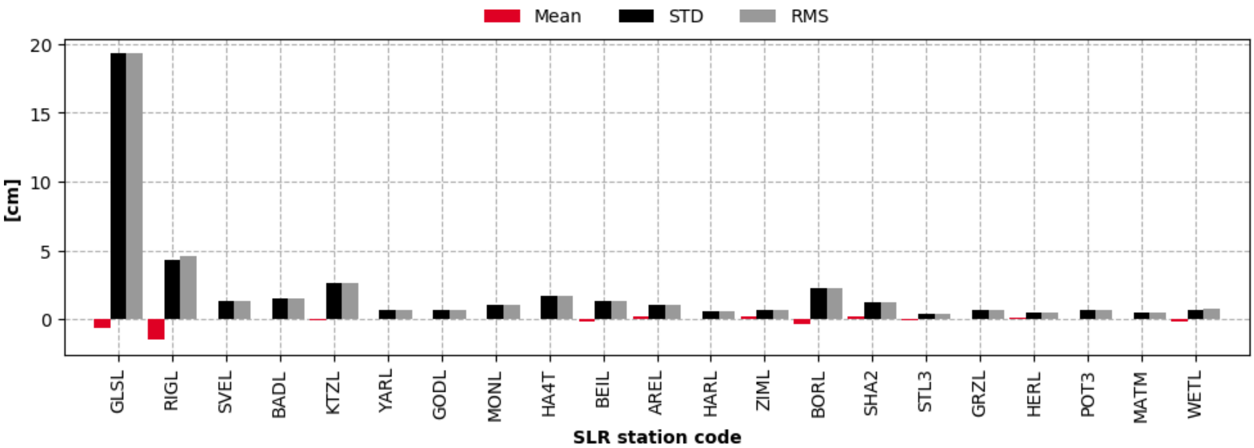


Figure 4-137: Mean, STD and RMS of the Sentinel-3A SLR observation residuals [1-range; cm] per each SLR station in 2019 (the range biases have not been fixed) (the figure below is a zoomed-in of the figure above)



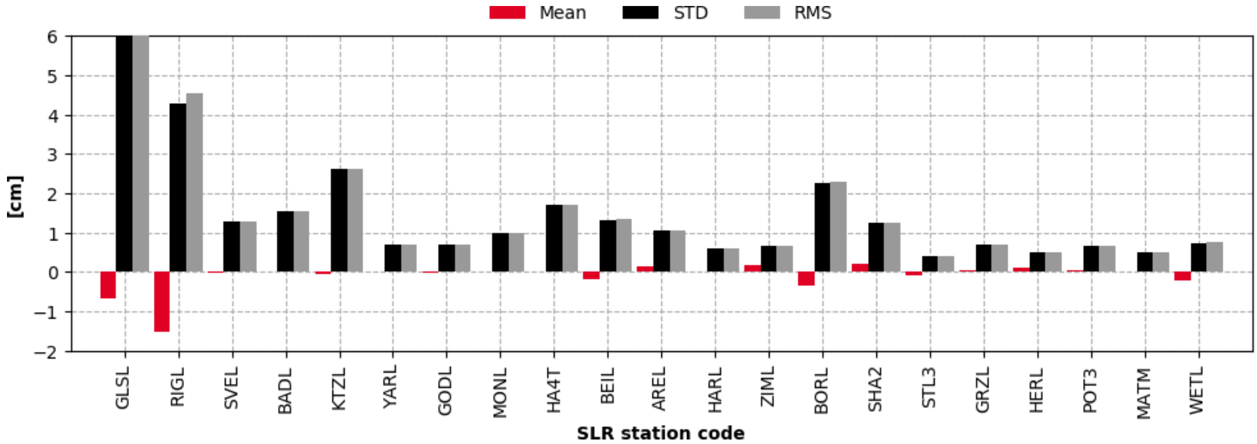


Figure 4-138: Mean, STD and RMS of the Sentinel-3A SLR observation residuals [1-range; cm] per each SLR station in 2019 (the range biases have been fixed) (the figure below is a zoomed-in of the figure above)

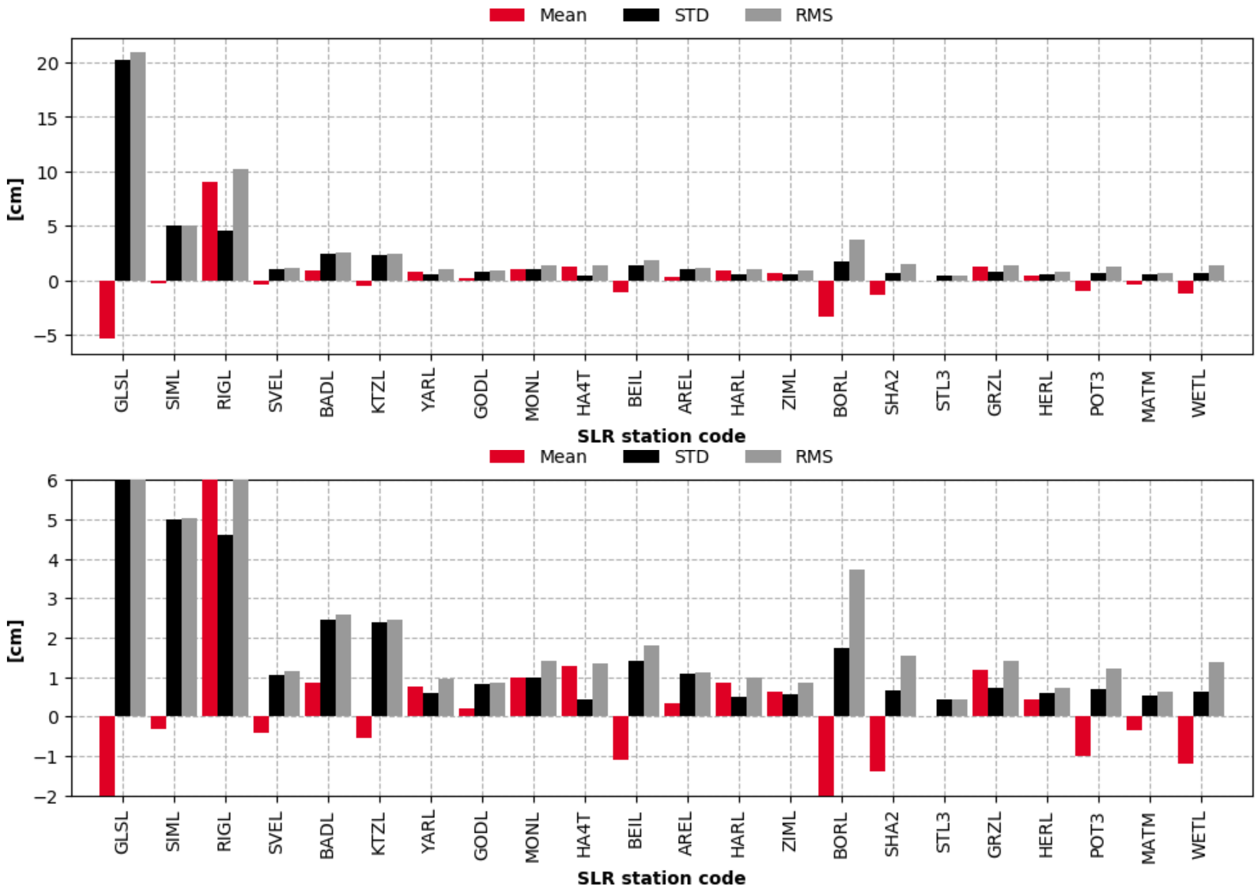
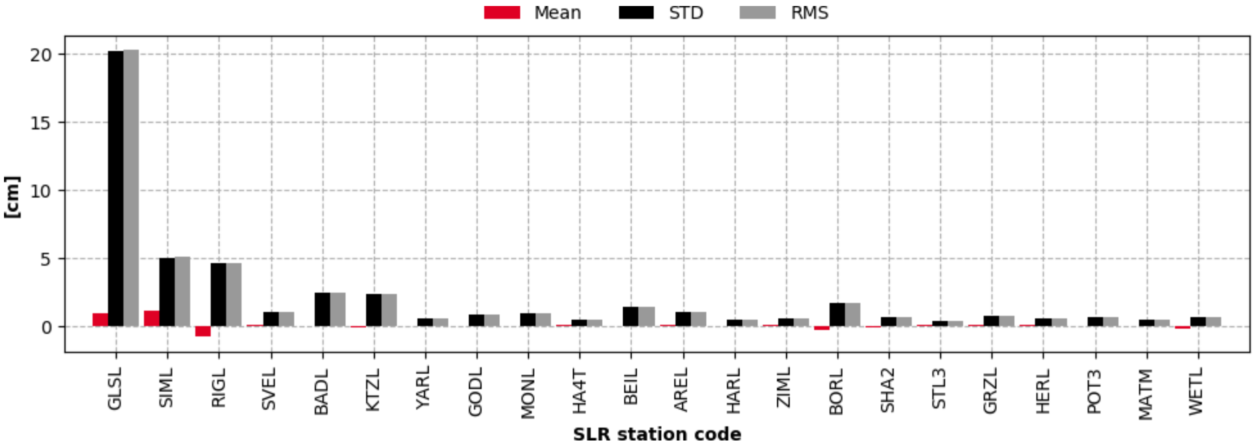


Figure 4-139: Mean, STD and RMS of the Sentinel-3B SLR observation residuals [1-range; cm] per each SLR station in 2019 (the range biases have not been fixed) (the figure below is a zoomed-in of the figure above)



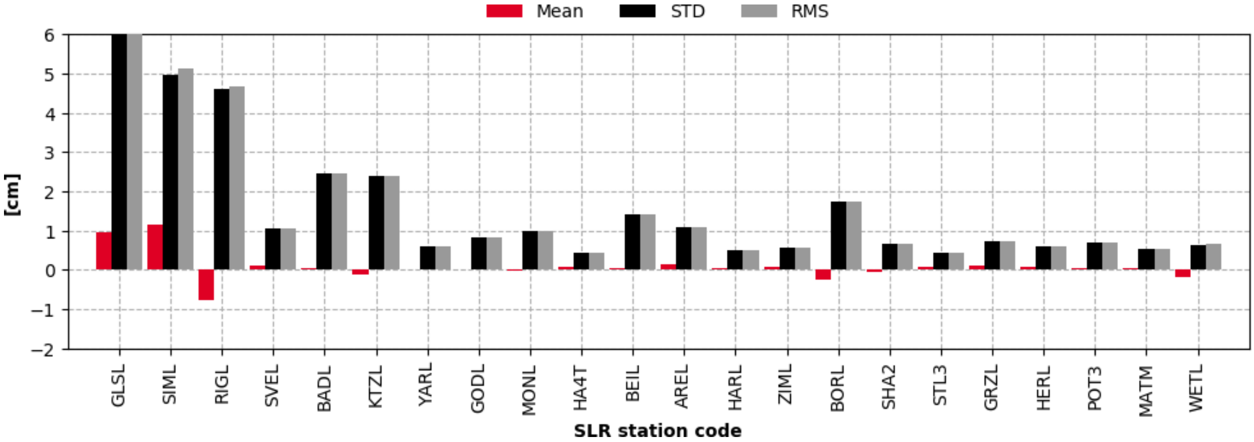


Figure 4-140: Mean, STD and RMS of the Sentinel-3B SLR observation residuals [1-range; cm] per each SLR station in 2019 (the range biases have been fixed) (the figure below is a zoomed-in of the figure above)

Table 4-23: Summary of the mean, STD and RMS of the Sentinel-3A and Sentinel-3B SLR observation residuals [1-range; cm] obtained per each SLR station in 2019

SLR station		Sentinel-3A [1-range; cm]						Sentinel-3B [1-range; cm]					
Mon.	Code	Mean		STD		RMS		Mean		STD		RMS	
		Range biases not fixed	Range biases fixed	Range biases not fixed	Range biases fixed	Range biases not fixed	Range biases fixed	Range biases not fixed	Range biases fixed	Range biases not fixed	Range biases fixed	Range biases not fixed	Range biases fixed
1824	**GLSL**	-5.01	-0.66	19.30	19.30	19.94	19.31	-5.41	0.96	20.21	20.21	20.92	20.23
1873	**SIML**	-	-	-	-	-	-	-0.32	1.16	5.01	4.98	5.02	5.11
1854	**RIGL**	9.00	-1.52	4.29	4.29	9.97	4.55	9.09	-0.78	4.60	4.60	10.19	4.67
1888	**SVEL**	-0.36	-0.02	1.29	1.29	1.34	1.29	-0.42	0.10	1.06	1.06	1.14	1.07
1890	**BADL**	0.79	0.02	1.53	1.53	1.72	1.53	0.84	0.05	2.44	2.44	2.58	2.44
1893	**KTZL**	-0.41	-0.04	2.65	2.60	2.68	2.60	-0.56	-0.12	2.37	2.37	2.44	2.37
7090	**YARL**	0.72	-0.01	0.69	0.69	1.00	0.69	0.76	0.00	0.59	0.59	0.96	0.59
7105	**GODL**	0.22	-0.01	0.69	0.69	0.73	0.69	0.19	0.00	0.82	0.82	0.84	0.82
7110	**MONL**	0.96	0.00	1.00	1.00	1.39	1.00	0.99	-0.03	0.99	0.99	1.40	0.99
7119	**HA4T**	1.37	0.02	1.70	1.70	2.18	1.70	1.27	0.07	0.44	0.44	1.34	0.44
7249	**BEIL**	-1.28	-0.18	1.32	1.32	1.83	1.33	-1.11	0.05	1.41	1.41	1.80	1.42
7403	**AREL**	0.08	0.15	1.05	1.05	1.06	1.06	0.33	0.15	1.07	1.07	1.12	1.08

SLR station		Sentinel-3A [1-range; cm]						Sentinel-3B [1-range; cm]					
Mon.	Code	Mean		STD		RMS		Mean		STD		RMS	
		Range biases not fixed	Range biases fixed	Range biases not fixed	Range biases fixed	Range biases not fixed	Range biases fixed	Range biases not fixed	Range biases fixed	Range biases not fixed	Range biases fixed	Range biases not fixed	Range biases fixed
7501	**HARL**	0.83	0.01	0.61	0.61	1.03	0.61	0.87	0.04	0.49	0.49	1.00	0.49
7810	**ZIML**	0.62	0.18	0.65	0.65	0.90	0.68	0.64	0.08	0.56	0.56	0.84	0.56
7811	**BORL**	-3.73	-0.36	2.25	2.25	4.35	2.28	-3.31	-0.26	1.72	1.72	3.73	1.74
7821	**SHA2**	-0.72	0.19	1.24	1.24	1.43	1.25	-1.38	-0.05	0.66	0.66	1.53	0.67
7825	**STL3**	0.10	-0.10	0.39	0.39	0.40	0.40	0.01	0.07	0.42	0.42	0.42	0.43
7839	**GRZL**	1.16	0.04	0.70	0.70	1.36	0.70	1.20	0.09	0.72	0.72	1.40	0.73
7840	**HERL**	0.46	0.09	0.50	0.50	0.68	0.51	0.44	0.09	0.58	0.58	0.73	0.59
7841	**POT3**	-0.97	0.05	0.67	0.67	1.18	0.67	-0.99	0.03	0.71	0.71	1.22	0.71
7941	**MATM**	-0.22	0.00	0.49	0.49	0.54	0.49	-0.34	0.04	0.53	0.53	0.63	0.53
8834	**WETL**	-1.21	-0.21	0.71	0.71	1.41	0.74	-1.20	-0.18	0.64	0.64	1.36	0.66

5. CPF PREDICTIONS

To allow the SLR tracking of the Sentinel-3 satellites, the CPOD Service makes available the so-called **Consolidated Prediction Files (CPFs)** to the SLR stations, which contain the orbital prediction of the Sentinel-3 satellites. These files are daily created after the generation of the Sentinel-3 CPOD Short-Time Critical (STC) products, and contain a 7-day prediction with respect to the generation time. On 2019, the number of generated CPF predictions was 365 for each of the Sentinel-3 satellites, which coincides with the total number of the expected files. In addition, the version 2 of the CPF predictions was also made available on 27th March 2019, which has been routinely uploaded to the FTP server since then. Therefore, the SLR stations can use the new version in order to track both satellites if required.

It is important to point out that the CPOD Service informs the ILRS community about possible degraded CPF prediction files as a result of satellite manoeuvres. The CPF files generated on manoeuvre days might be generated with a significant loss of accuracy in the prediction, and this fact might consequently pose a difficulty for the tracking of both satellites. The list of days were Sentinel-3 satellites were manoeuvred in 2019 is summarised in Table 5-1.

Table 5-1: Manoeuvre days on the Sentinel-3 satellites during 2019

Sentinel-3A	Sentinel-3B
2019/02/27	2019/02/13
2019/03/13	2019/06/05
2019/06/13	2019/06/19
2019/08/28	2019/08/28
2019/11/27	2019/10/10 (x2)
2019/12/11	2019/10/16
	2019/12/18

The following figure is intended to show the quality of the CPF predicted files delivered by the CPOD Service. Thus, Figure 5-1 presents the accuracy obtained on the orbital comparison between the Sentinel-3 CPF files and the Sentinel-3 CPOD STC products. It must be considered that the CPF files contain predictions of the satellite orbit, whereas the STC products are determinations of the satellite orbit. As the CPF files are daily delivered, the figure below only takes into account the first predicted orbit to perform the comparisons, and the outcome is only shown for the 3D RMS. The statistical results for each component are summarised in Table 5-2.

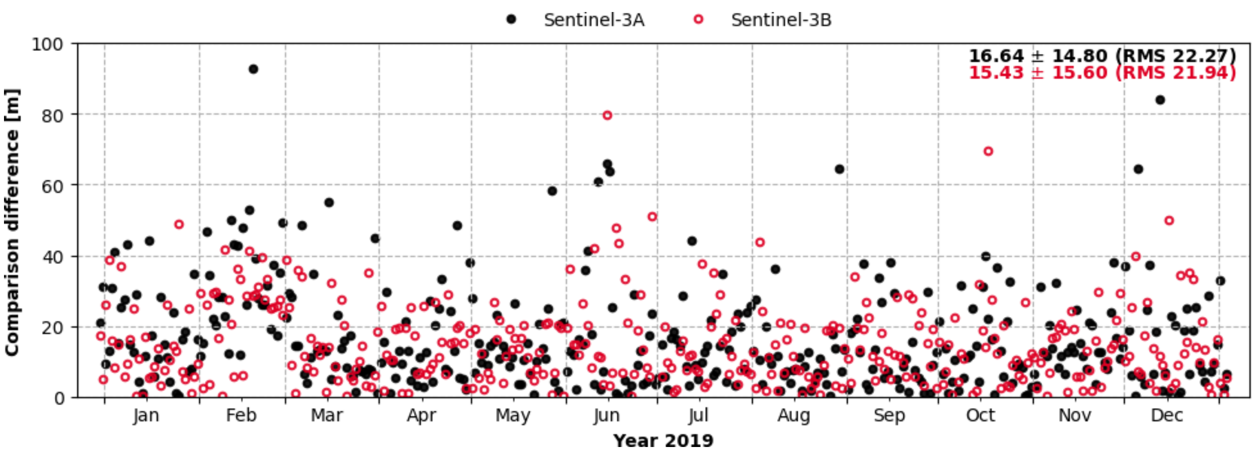


Figure 5-1: Orbital comparisons [3D RMS; m] between the Sentinel-3 CPF predictions and the Sentinel-3 CPOD STC products during 2019

Table 5-2: Summary of the mean, STD and RMS of the orbital comparisons between the Sentinel-3 CPF predictions and the Sentinel-3 CPOD STC products during 2019

	Radial RMS [m]			Along-track RMS [m]			Cross-track RMS [m]			3D RMS [m]		
	Mean	STD	RMS	Mean	STD	RMS	Mean	STD	RMS	Mean	STD	RMS
Sentinel-3A	0.23	0.35	0.42	16.62	14.80	22.26	0.15	0.28	0.31	16.64	14.80	22.27
Sentinel-3B	0.19	0.15	0.24	15.42	15.56	21.90	0.17	0.31	0.35	15.43	15.60	21.94

From the data above, it can be said that the accuracy of the CPF files is below 20 m in mean (3D RMS) for both satellites. If the components are analysed alone, it can be concluded that the error is practically concentrated on the along-track component, which is the most critical direction for the SLR tracking.

Finally, Table 5-3 gathers the percentage of the CPF files that have achieved a certain accuracy criterion, which complements the results previously shown.

Table 5-3: Percentiles of the orbital comparisons [3D RMS] between the Sentinel-3 CPF predictions and the Sentinel-3 CPOD STC products during 2019

Accuracy (3D RMS)	2019	
	Sentinel-3A	Sentinel-3B
< 1 m	3.51 %	4.63 %
< 5 m	19.19 %	18.26 %
< 10 m	40.00 %	40.87 %
< 50 m	97.03 %	98.64 %
< 100 m	99.73 %	99.73 %
< 200 m	100.00 %	99.73 %
< 400 m	100.00 %	100.00 %

6. CONCLUSIONS

This document gathers the 2019 yearly results related to the tracking of the Sentinel-3 satellites from the SLR stations. 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 (CPOD) 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.
- There are two SLR stations that have stopped the tracking of Sentinel-3 satellites during 2019. A change on the laser configuration has led the SISL station to exceed the power limitations to track the Sentinel-3 satellites, and the MDOL station is no longer operational. On the other hand, three SLR stations have resumed the tracking after some time period of inactivity (i.e., ZIML, SFEL and STL3 stations).
- There are four SLR stations which are currently inactive (i.e., WETL, ZELL, GLSL and BADL stations) for different reasons. The CPOD Service have contacted them in order to resume the service.
- The total number of satellite passes during 2019 has shown values between 50 and 100 passes for both Sentinel-3 satellites, which have improved the last trend of year 2018. The YARL station continues being the SLR station providing the highest quantity of satellite passes and SLR observations with great difference to the rest of the SLR stations.
- The observations provided by the ILRS stations are used by the CPOD QWG as an independent means to validate the orbital accuracy of the POD orbits. The comparisons have revealed a good agreement between them (keeping the 3D RMS of the residuals below 2 cm in mean), which improves the reliability of the CPOD products.
- A constant bias has been calculated per each SLR station in order to improve the statistical outcome of the SLR residuals. It has been shown that the use of these range biases benefits the final outcome. However, some discrepancies have been found on a few SLR stations.
- An extended analysis of the SLR residuals obtained per each SLR station by means of the Sentinel-3 COMB orbit solutions has also been performed. Such analysis has shown which SLR stations have best performed the tracking of the Sentinel-3 satellites on 2019, and which SLR stations have presented some underperformance.
- To allow the tracking of the Sentinel-3 satellites, the CPOD Service provides CPF prediction files to the SLR stations on a daily basis. These files contain the orbital prediction of the satellite with accuracies of 15-20 m in mean (3D RMS) on 2019.

7. ANNEX: STATIONS COORDINATE LIST

The following table lists all SLR stations that have tracked any of the two Sentinel-3 satellites at least once during the complete satellite missions. The table includes not only the identification of the SLR stations but also the station coordinates used for the calculation of the statistics throughout the document. These station coordinates are based on the SLRF2014 reference frame, particularly they have been extracted from the SINEX file "ITRF2014-ILRS-TRF.snx" published in the International Terrestrial Reference Frame (ITRF) website.

In addition, the table highlights those SLR stations that are not allowed to track the Sentinel-3 satellites anymore (at the time of writing the document). A change on the laser configuration of the SLR station could be the main reason for this prohibition. Keep in mind that Sentinel-3 satellites are equipped with sensitive instruments (e.g., an OLCI receiver), which can be damaged if high levels of laser energy reach the instrument. Therefore, only those SLR stations fulfilling a certain energy criterion are allowed to track the Sentinel-3 satellites.

Table 7-1: Geographical location and coordinates (SLRF2014) of all SLR stations that have ever tracked Sentinel-3 satellites (in red those not allowed to track the satellites anymore)

Monument	Code	Location Name (Country)	X [m]	Y [m]	Z [m]
1824	GLSL	Golosiiv (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	Zelenchukskaya (Russia)	3451135.973	3060335.220	4391970.306
1890	BADL	Badary (Russia)	-838299.971	3865738.847	4987640.893
1893	KTZL	Katsively (Ukraine)	3785944.345	2550780.789	4439461.397
7080	MDOL	McDonald Observatory, TX (USA)	-1330021.233	-5328401.842	3236480.717
7090	YARL	Yarragadee (Australia)	-2389007.534	5043329.447	-3078524.223
7105	GODL	Greenbelt, MD (USA)	1130719.438	-4831350.580	3994106.573
7110	MONL	Monument Peak, CA (USA)	-2386278.627	-4802353.816	3444881.772
7119	HA4T	Haleakala, Hawaii (USA)	-5466065.553	-2404338.024	2242108.390
7124	THTL	Tahiti (French Polynesia)	-5246407.299	-3077284.309	-1913813.757
7237	CHAL	Changchun (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 (UK)	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

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