SENTINEL-3 SLR YEARLY REPORT - 2020

COPERNICUS PRECISE ORBIT DETERMINATION SERVICE (CPOD)

04/02/2021

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Document ID:	GMV-CPOD-SLR-0005
DIL Code:	TD-17
Internal Code:	GMV 20521/21 V2/21
Version:	1.1
Date:	04/02/2021
ESA contract number:	4000132155/20/I-BG

DOCUMENT STATUS SHEET

Version	Date	Pages	Changes
1.0	01/02/2021	32	First version
1.1	04/02/2021	34	To include SLR citation in section 1.2 and 1.5.2 To clarify that no eccentricities have been applied to the station´s coordinates. To update Figure 3-7, Figure 3-8 and Table 3-4 in section 3.2, to correct the estimated biases, as they were divided by 2 incorrectly. To update Figure 3-12 and Figure 3-13 in section 3.3, to correct the estimated biases, as they were divided by 2 incorrectly.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

1.1. PURPOSE

This document has been prepared in the frame of the project *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 year 2020.

1.2. SCOPE

This document is a deliverable by GMV to acknowledge the work of the **International Laser Ranging Service (ILRS) [RD.2]** community in supporting 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	JPL	Jet Propulsion Laboratory
CLS	Collecte Localisation Satellites	LEO	Low Earth Orbit
CNES	Centre National d'Études Spatiales	LRR	Laser Retro-reflector
CPF	Consolidated Prediction Format	NAPEOS	NAvigation Package for Earth Orbiting Satellites
CPOD	Copernicus POD	OLCI	Ocean & Land Colour Instrument
DIL	Document Item List	PDGS	Payload Data Ground Segment
DLR	Deutsche Zentrum für Luft- und Raumfahrt	POD	Precise Orbit Determination
DORIS	Doppler Orbytography and Radiopositioning Integrated by Satellite	QWG	Quality Working Group
EGU	European Geosciences Union	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
ESTEC	European Space research and TEchnology Centre	SLR	Satellite Laser Ranging
EUMETSAT	EUropean organisation for the exploitation of METeorological SATellites	SLSTR	Sea and Land Surface Temperature Radiometer
FTP	File Transfer Protocol	SRAL	SAR Radar Altimeter
GFZ	Geo Forschungs Zentrum	STC	Short Time Critical
GNSS	Global Navigation Satellite System	STD	Standard Deviation
GPS	Global Positioning System	TUD	Technische Universiteit Delft
IGS	International GNSS Service	TUM	Technische Universität München
ILRS	International Laser Ranging Service	USA	United States of America
ITRF	International Terrestrial Reference Frame		

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

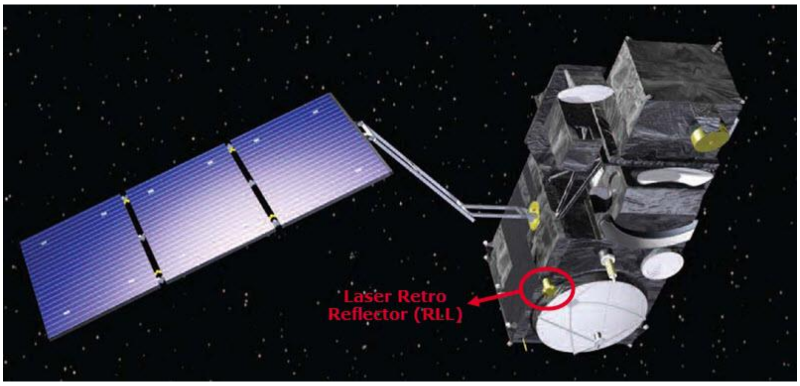
Ref.	Title	Code	Version	Date
[RD.1]	Analysis of elements for Sentinel-3 SLR tracking	GMV-GMESPOD-TN-0028	1.2	10/05/2018
[RD.2]	Pearlman, M.R., Degnan, J.J., and Bosworth, J.M., "The International Laser Ranging Service", Advances in Space Research, Vol. 30, No. 2, pp. 135-143, July 2002, DOI:10.1016/S0273-1177(02)00277-6.	N/A	N/A	Jul 2002

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, with WETL station currently on hold, pending for a formal approval from ESA as of a recent change in the laser configuration. 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 6-1 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.

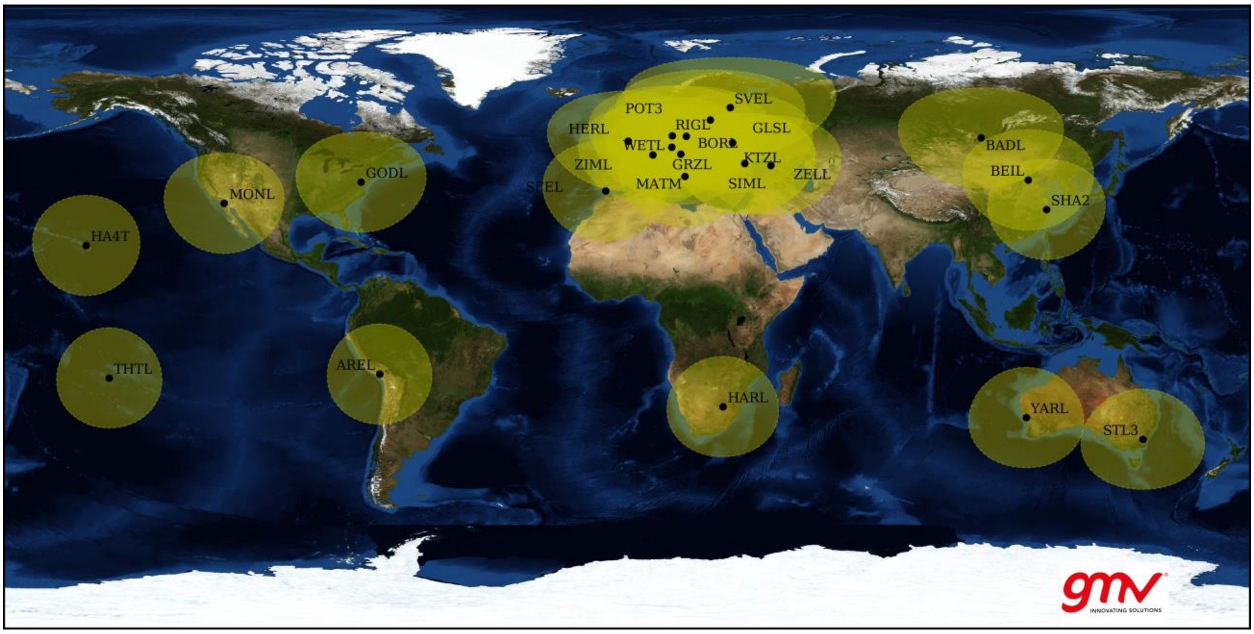


Figure 2-2: Geographical location of the set of the SLR Stations that are allowed to track the Sentinel-3 satellites

The 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 11th and 12th 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.

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	
...								
11	Sentinel-3B	sentinel3b	1803901	8011	ESA/EUMETSAT	814.5	98.65	Restricted tracking; authorization required
12	Sentinel-3A	sentinel3a	1601101	8010	ESA/EUMETSAT	814.5	98.65	Restricted tracking; authorization required
...								
19	Sentinel-6A/Jason-CSA	sentinel6a	2008601	4380	NASA, ESA, EUMETSAT, NOAA, CNES	1339.4-1355.9	66.042	
20	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

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 2020 in particular.

Figure 2-4 and Figure 2-5 show the temporal evolution on the **total number of satellite passes per GPS week** for the Sentinel-3A and Sentinel-3B. This temporal evolution is shown for the entire missions in Figure 2-4, whereas Figure 2-5 only pays attention on the year 2020.

As seen in the figures, the number of Sentinel-3 passes has remained quite constant (**between 50 and 150 passes**) during 2020. The number of passes have improved compared to the previous year.

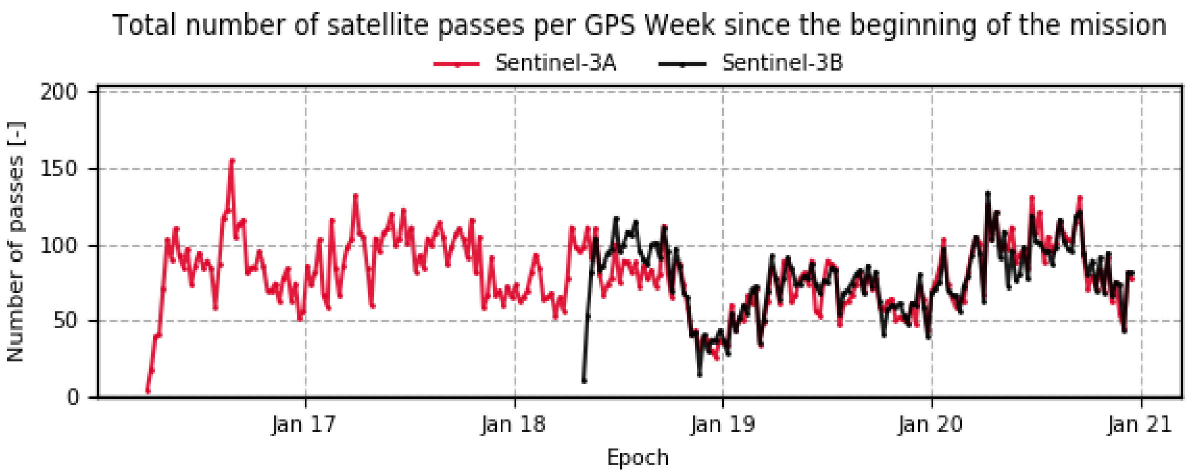


Figure 2-4: Total number of satellite passes per GPS week since the beginning of the satellite mission (Sentinel-3A and Sentinel-3B)

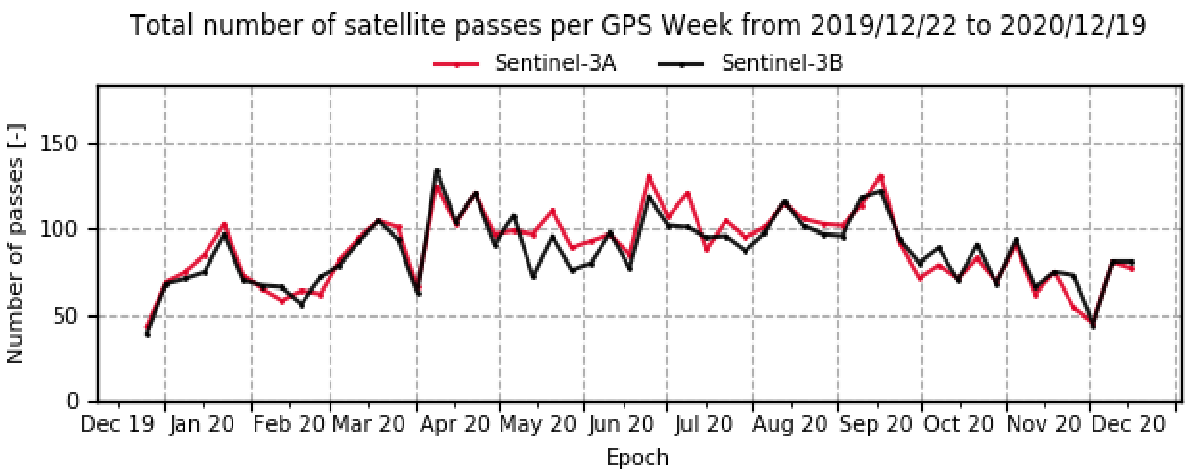


Figure 2-5: Total number of satellite passes per GPS week in 2020 (Sentinel-3A and Sentinel-3B)

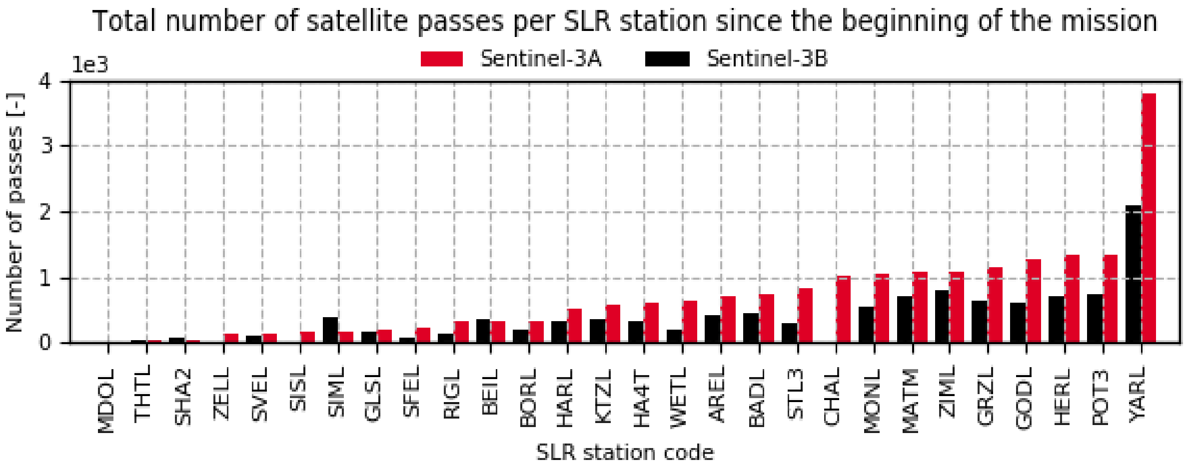


Figure 2-6: Total number of satellite passes per SLR station since the beginning of the satellite mission (Sentinel-3A and Sentinel-3B)

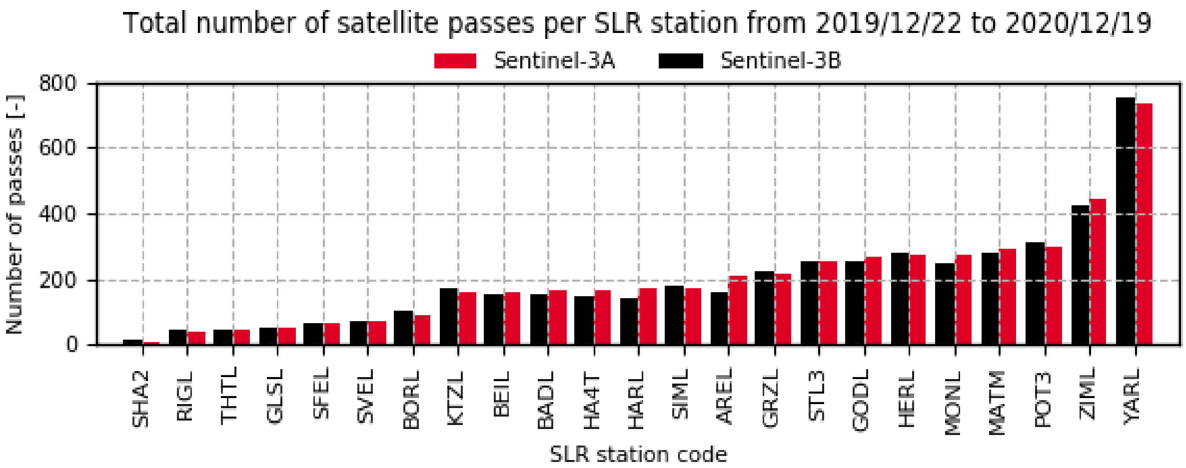


Figure 2-7: Total number of satellite passes per SLR station in 2020 (Sentinel-3A and Sentinel-3B)

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 and Sentinel-3B, and they are shown for the entire mission of the three satellites (Figure 2-6), and solely for the year 2020 (Figure 2-7).

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. The centres contributing to the combined solution are: AIUB, CNES, CPOD, DLR, ESOC, EUM, GFZ, CLS, JPL, TUD and TUM.

Table 3-1 lists all the Sentinel-3 orbit solutions that will be used in the present analysis. These orbit solutions are based on very similar GNSS processing strategies, although using different processing schemes, models and software:

- The CNES orbit solution includes DORIS observations along with the GPS data.
- The CPOF is a new orbit solution generated by the CPOD Service, with have a different parametrization (more reduce-dynamic) compared to the current operational solution. This parametrization will substitute the current one.
- The combined orbit solution (labelled as COMB) is then obtained from a combination of all orbit solutions of the centres mentioned above. 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.

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.

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
Centre National d'Études Spatiales (CNES)	CNES
Copernicus Precise Orbit Determination (CPOD) Service	CPOF
Combined, using orbits from: AIUB, CNES, CPOD, DLR, ESOC, EUM, GFZ, CLS, JPL, TUD and TUM	COMB

Figure 3-1 and Figure 3-3 show the orbital comparisons (3D RMS) between the CNES and CPOF orbit solutions 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 1.5 cm in mean). Note that the jump on the CPOF solution around June 2020 is because of a change in the parametrization. It can be concluded that all orbit solutions are of good quality.

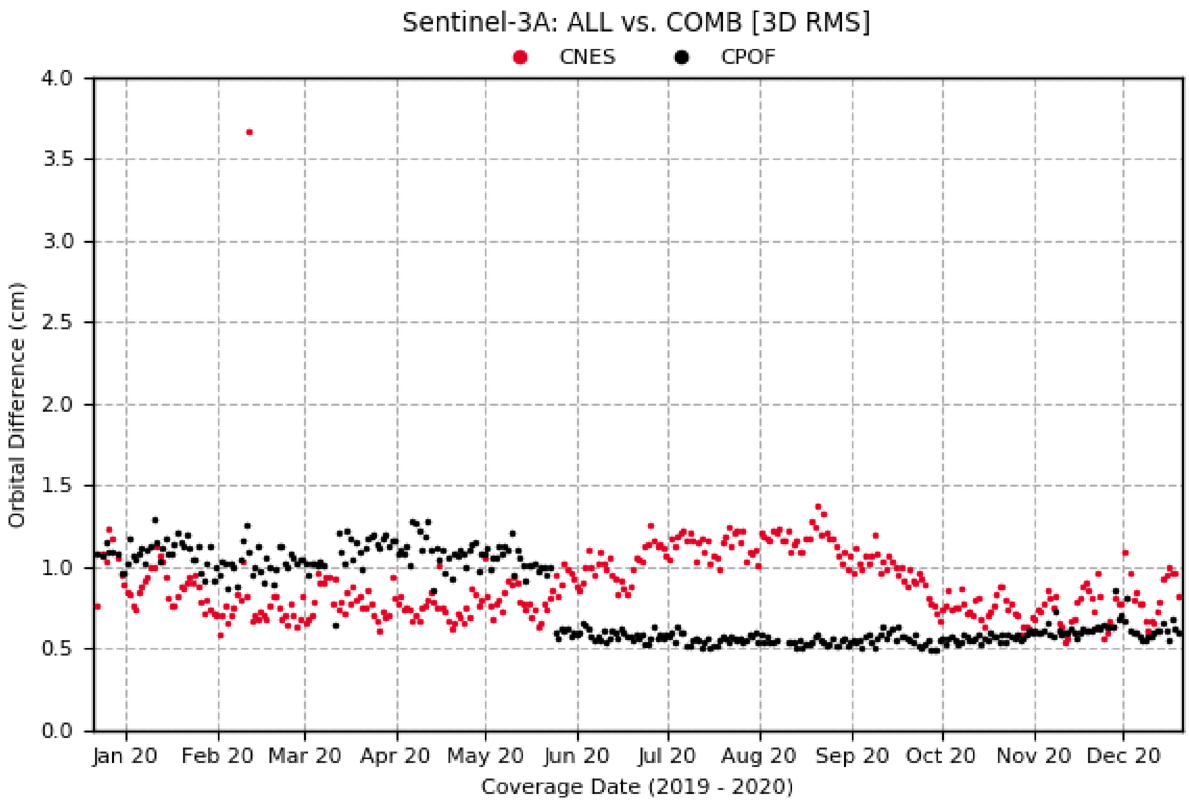


Figure 3-1: Orbital comparisons [3D RMS; cm] between each Sentinel-3A orbit solution and the Sentinel-3A combined orbit solution

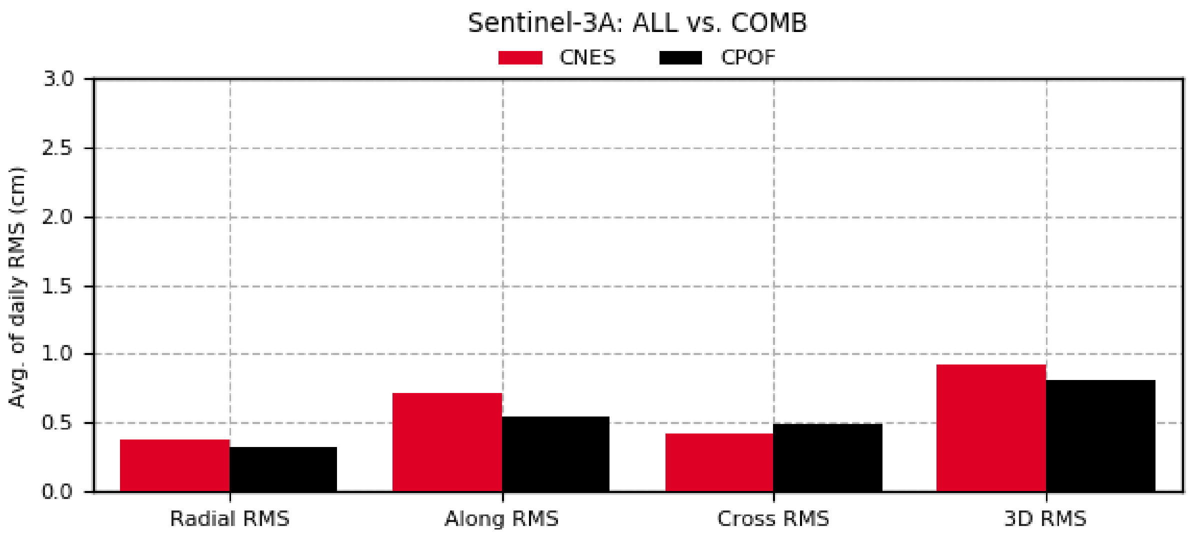


Figure 3-2: Mean and STD of the orbital comparisons [3D RMS; cm] between each Sentinel-3A orbit solution and the Sentinel-3A combined orbit solution

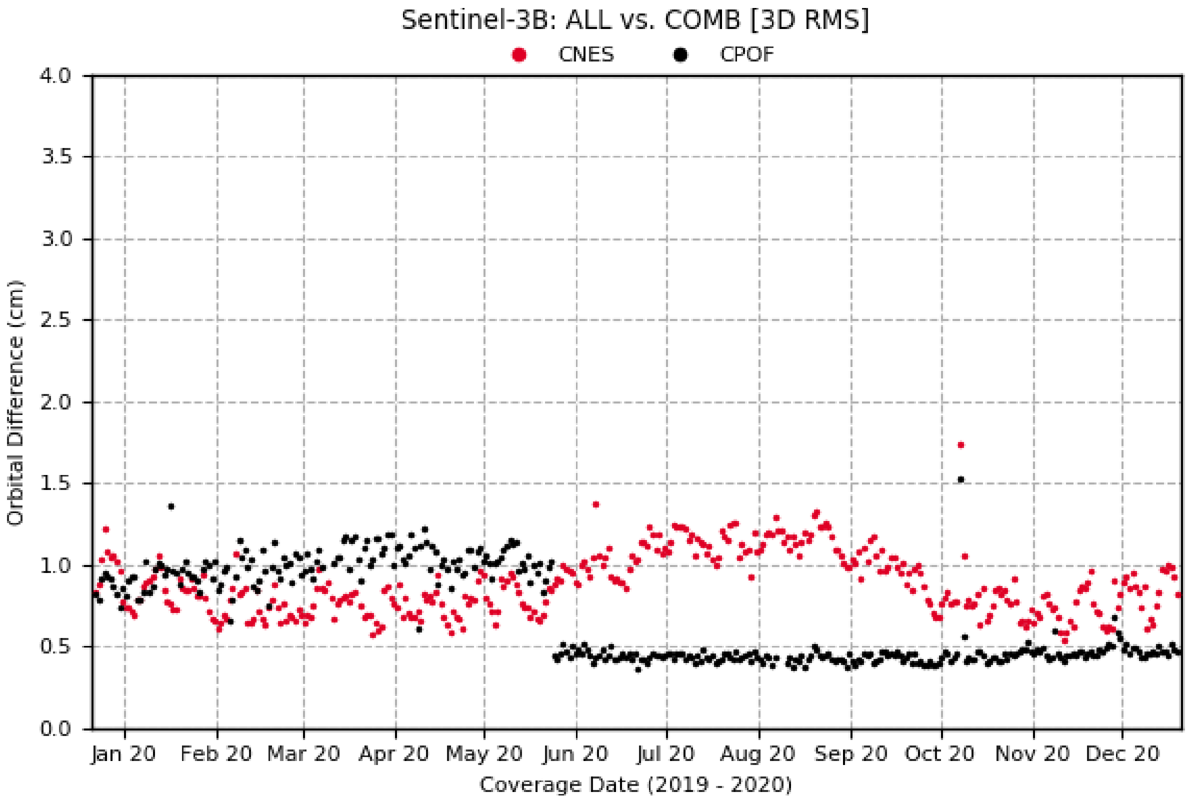


Figure 3-3: Orbital comparisons [3D RMS; cm] between each Sentinel-3B orbit solution and the Sentinel-3B combined orbit solution

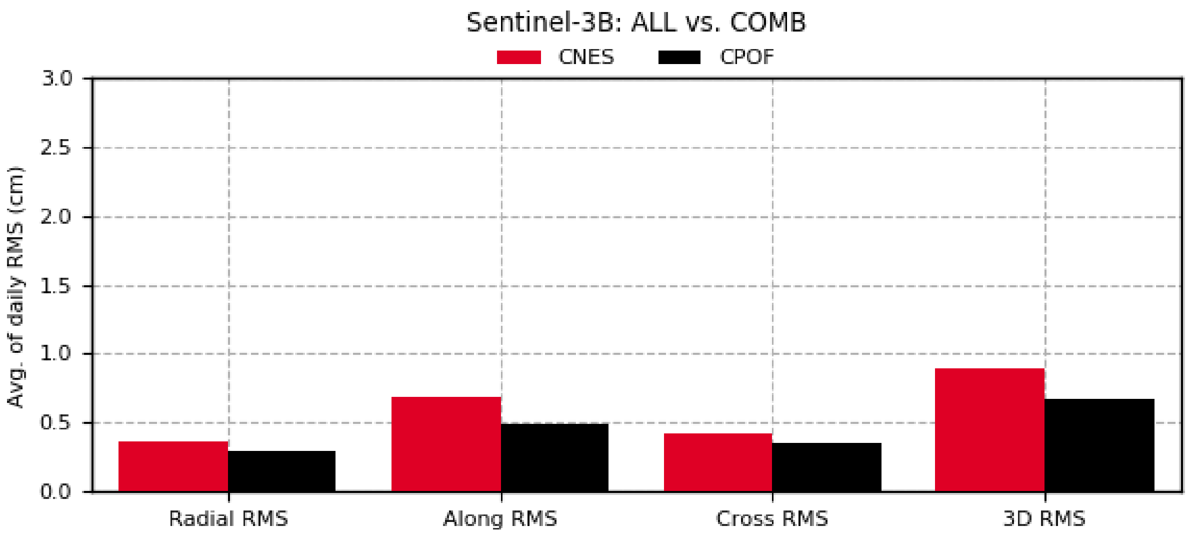


Figure 3-4: Mean and STD of the orbital comparisons [3D RMS; cm] between each Sentinel-3B orbit solution and the Sentinel-3B combined orbit solution

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 2020

Orbit solution	Sentinel-3A [cm]							
	Radial RMS		Along-track RMS		Cross-track RMS		3D RMS	
	Mean	STD	Mean	STD	Mean	STD	Mean	STD
CNES	0.38	0.10	0.72	0.48	0.42	0.17	0.93	0.49
CPOF	0.32	0.07	0.54	0.54	0.49	0.11	0.81	0.52

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 2020

Orbit solution	Sentinel-3B [cm]							
	Radial RMS		Along-track RMS		Cross-track RMS		3D RMS	
	Mean	STD	Mean	STD	Mean	STD	Mean	STD
CNES	0.37	0.10	0.69	0.18	0.42	0.19	0.89	0.26
CPOF	0.29	0.08	0.49	0.27	0.35	0.12	0.68	0.28

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.

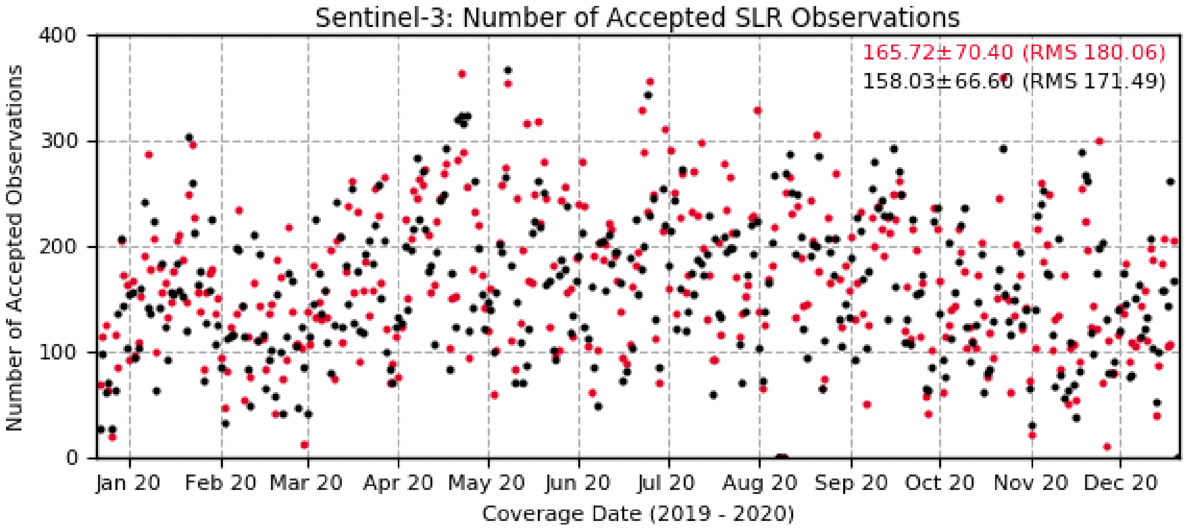


Figure 3-5: Daily total number of the accepted SLR observations of all SLR stations tracking Sentinel-3A and Sentinel-3B satellites in 2020

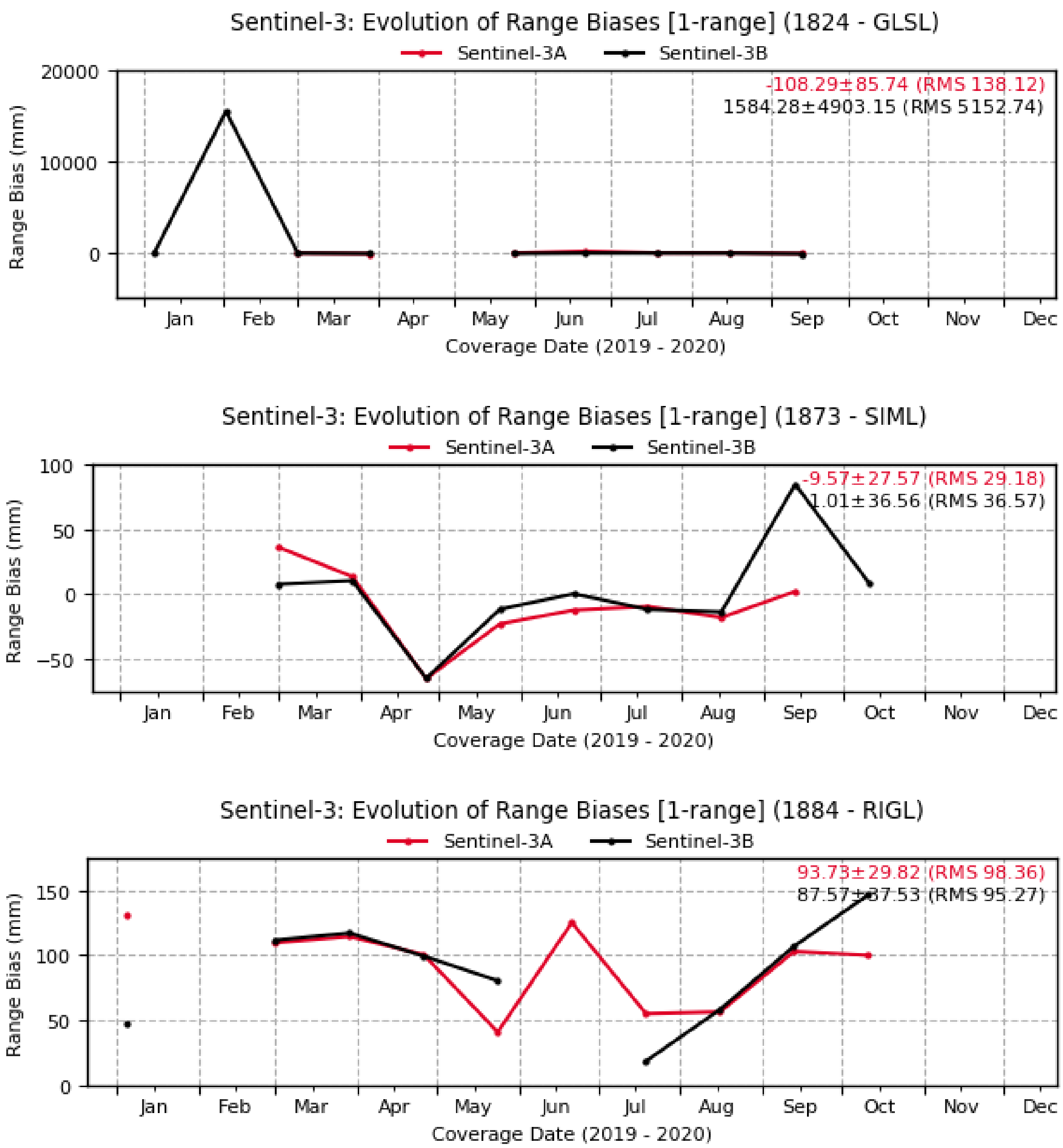
As seen from the previous figure, the SLR stations have generated a considerable amount of SLR observations, with an average value of over 150 SLR observations per day for both Sentinel-3 satellites.

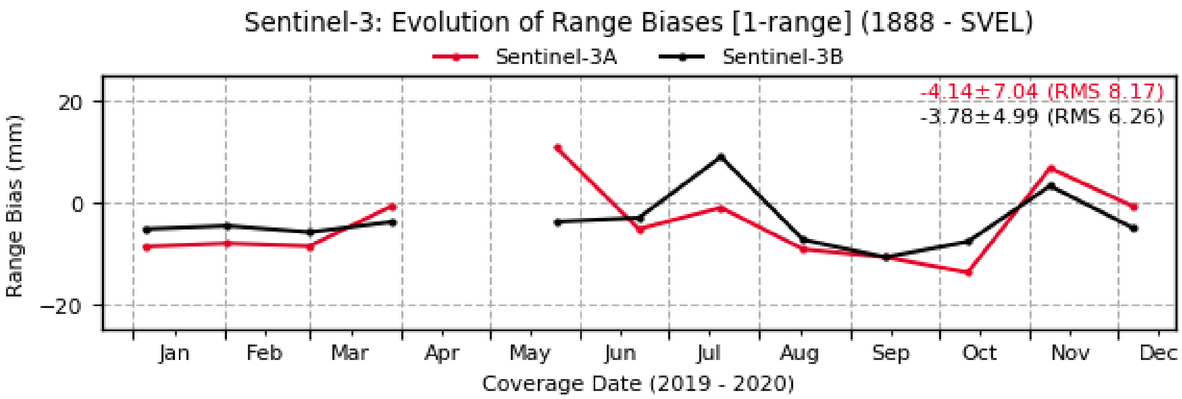
Prior to the calculation of the SLR residuals, it has been deemed worth to estimate a range bias for each SLR station in order to improve the statistical outcome on the residuals.

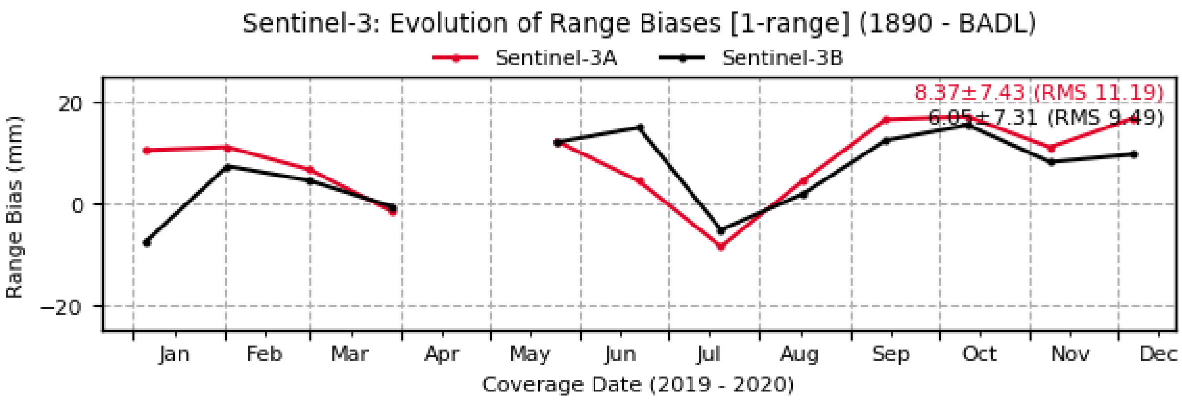
3.2. ESTIMATION OF THE RANGE BIASES FOR ALL SLR STATIONS

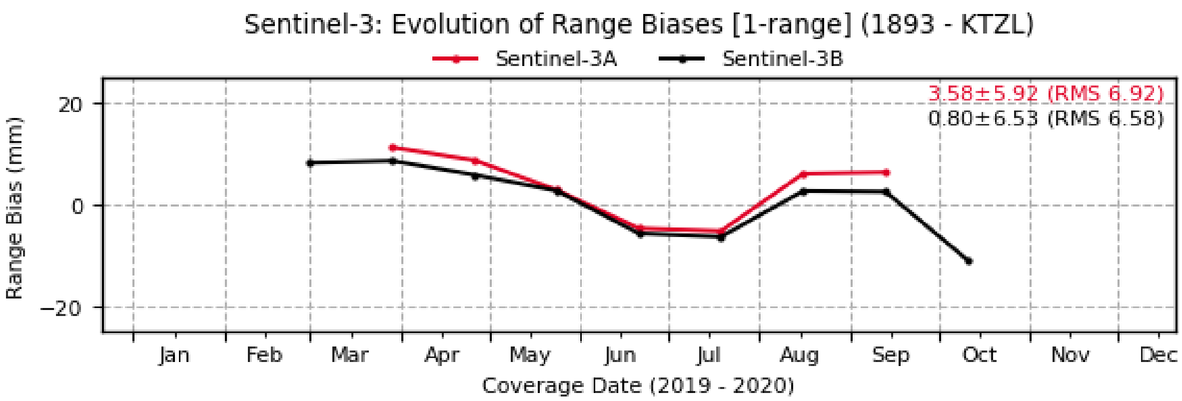
A range bias per station is estimated by fixing the Sentinel-3 combined orbit solution and estimating the range bias of the SLR observations over 4 GPS weeks. Note that no eccentricities have been applied to the coordinates of the stations (station´s coordinates can be found in section 6).

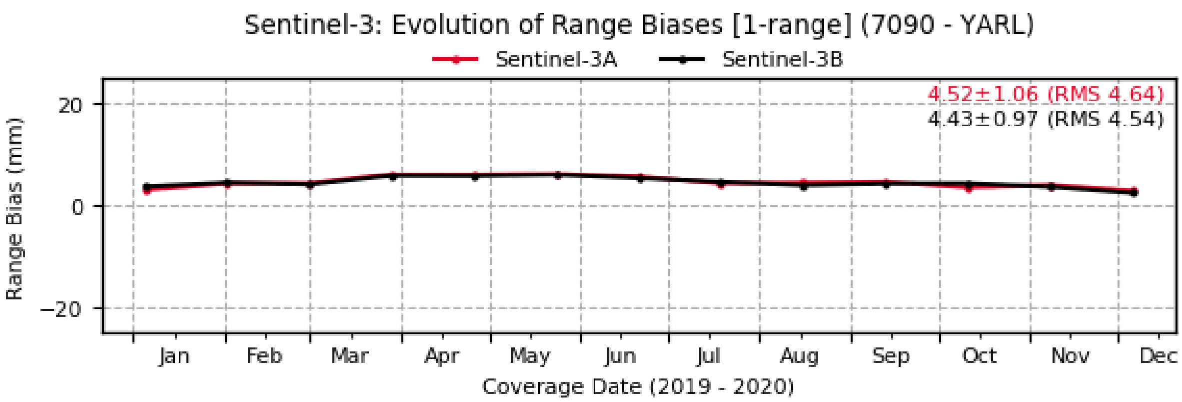
The following figure includes the plots of the temporal evolution of these estimated range biases for each SLR station assessed and discerning between Sentinel-3A and Sentinel-3B. From the plots of the figure, it can be seen that the vast majority of the SLR stations presents a quite constant evolution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

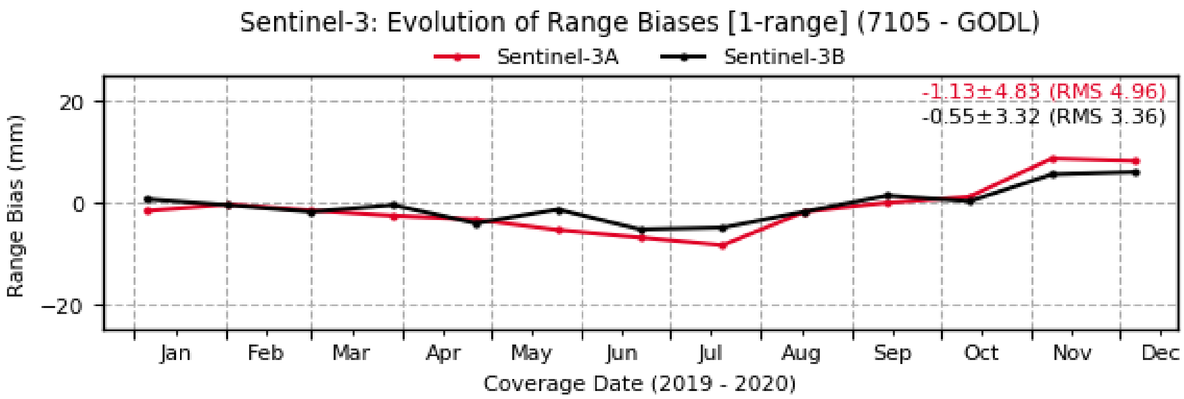


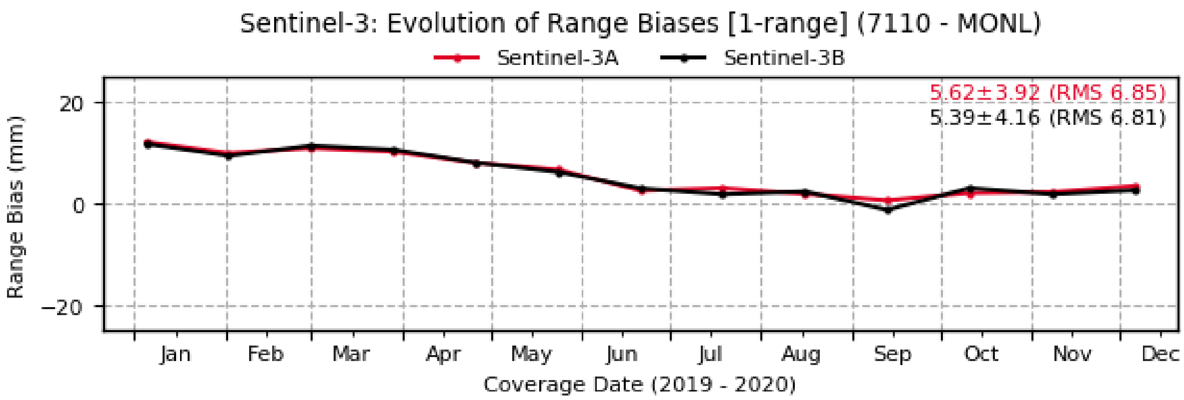

Sentinel-3: Evolution of Range Biases [1-range] (1888 - SVEL)
Sentinel-3A
Sentinel-3B
-4.14±7.04 (RMS 8.17)
-3.78±4.99 (RMS 6.26)
Range Bias (mm)
Coverage Date (2019 - 2020)

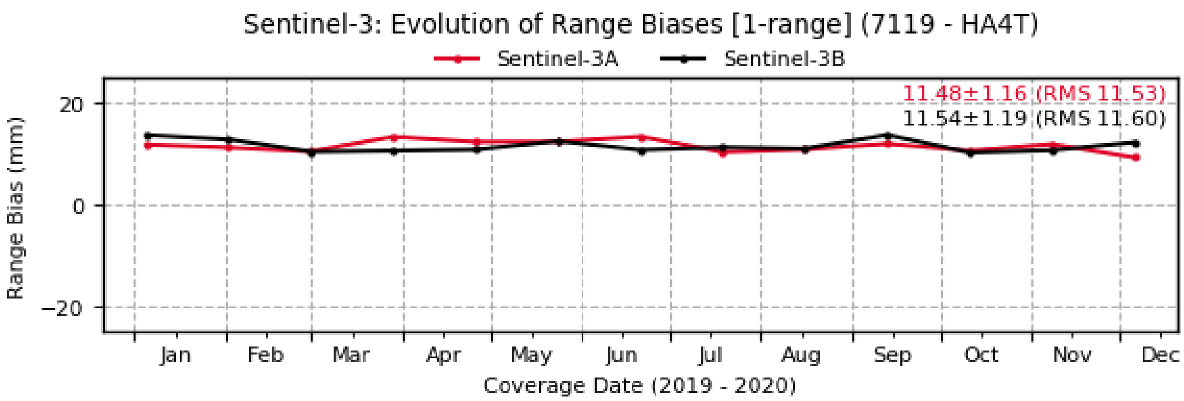

Sentinel-3: Evolution of Range Biases [1-range] (1890 - BADL)
Sentinel-3A
Sentinel-3B
8.37±7.43 (RMS 11.19)
6.05±7.31 (RMS 9.49)
Range Bias (mm)
Coverage Date (2019 - 2020)

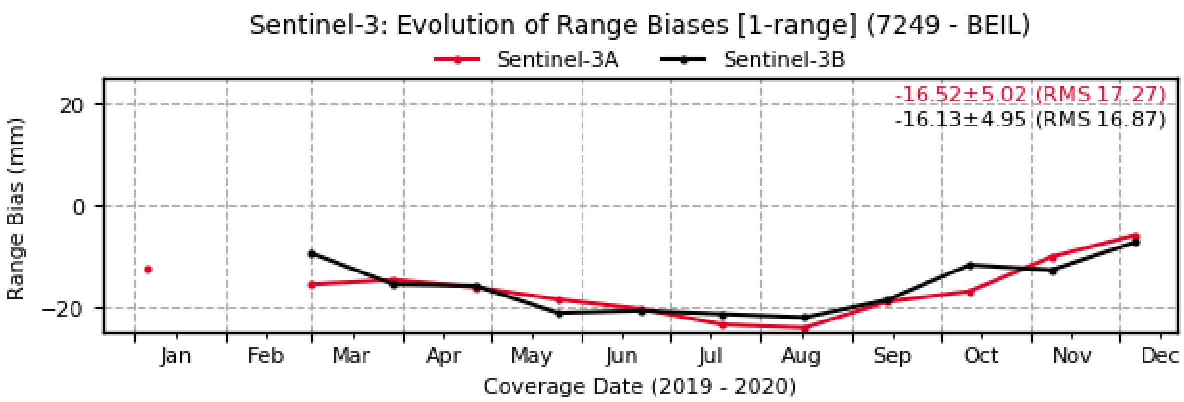

Sentinel-3: Evolution of Range Biases [1-range] (1893 - KTZL)
Sentinel-3A
Sentinel-3B
3.58±5.92 (RMS 6.92)
0.80±6.53 (RMS 6.58)
Range Bias (mm)
Coverage Date (2019 - 2020)

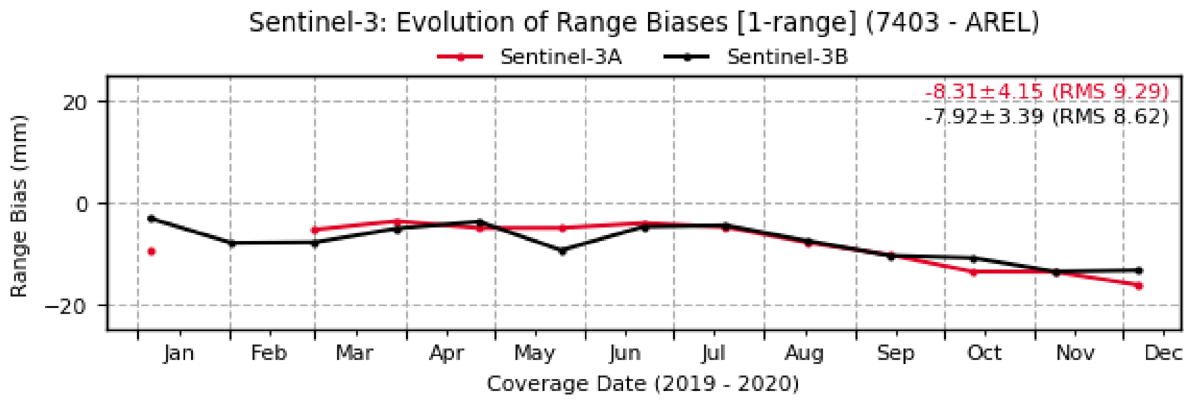

Sentinel-3: Evolution of Range Biases [1-range] (7090 - YARL)
Sentinel-3A
Sentinel-3B
4.52±1.06 (RMS 4.64)
4.43±0.97 (RMS 4.54)
Range Bias (mm)
Coverage Date (2019 - 2020)

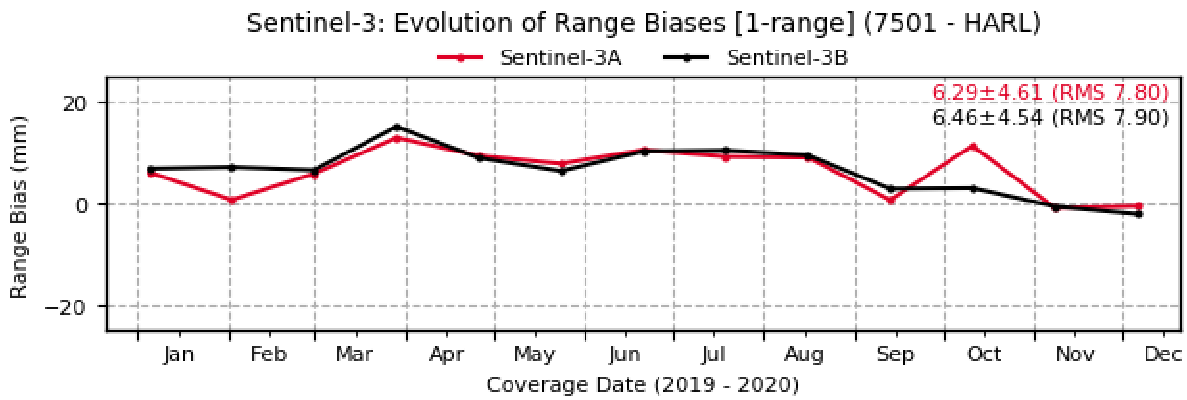

Sentinel-3: Evolution of Range Biases [1-range] (7105 - GODL)
Sentinel-3A
Sentinel-3B
-1.13±4.83 (RMS 4.96)
-0.55±3.32 (RMS 3.36)
Range Bias (mm)
20
0
−20
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Coverage Date (2019 - 2020)

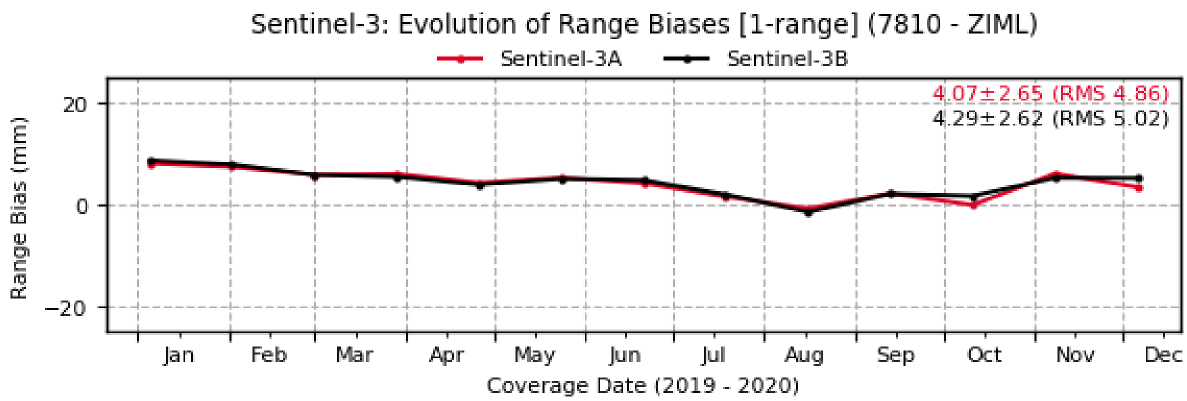

Sentinel-3: Evolution of Range Biases [1-range] (7110 - MONL)
Sentinel-3A
Sentinel-3B
5.62±3.92 (RMS 6.85)
5.39±4.16 (RMS 6.81)
Range Bias (mm)
20
0
−20
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Coverage Date (2019 - 2020)

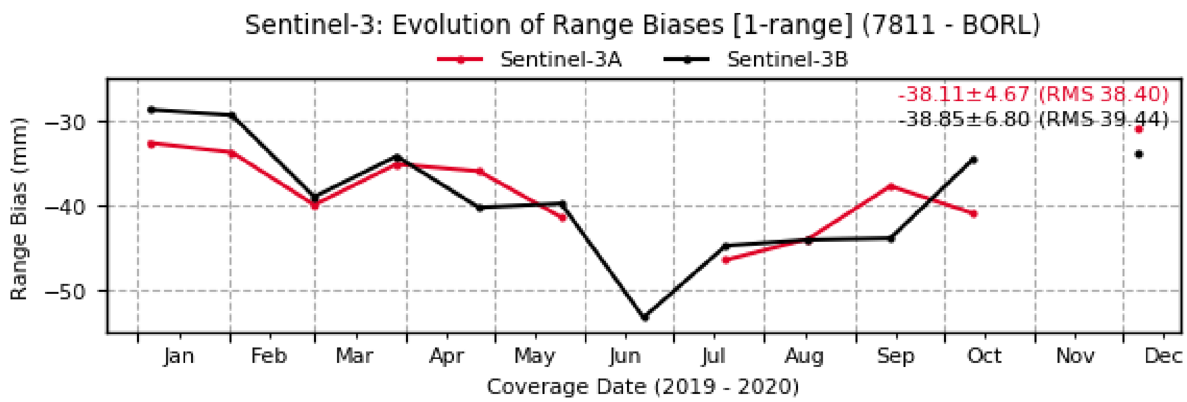

Sentinel-3: Evolution of Range Biases [1-range] (7119 - HA4T)
Sentinel-3A
Sentinel-3B
11.48±1.16 (RMS 11.53)
11.54±1.19 (RMS 11.60)
Range Bias (mm)
20
0
−20
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Coverage Date (2019 - 2020)

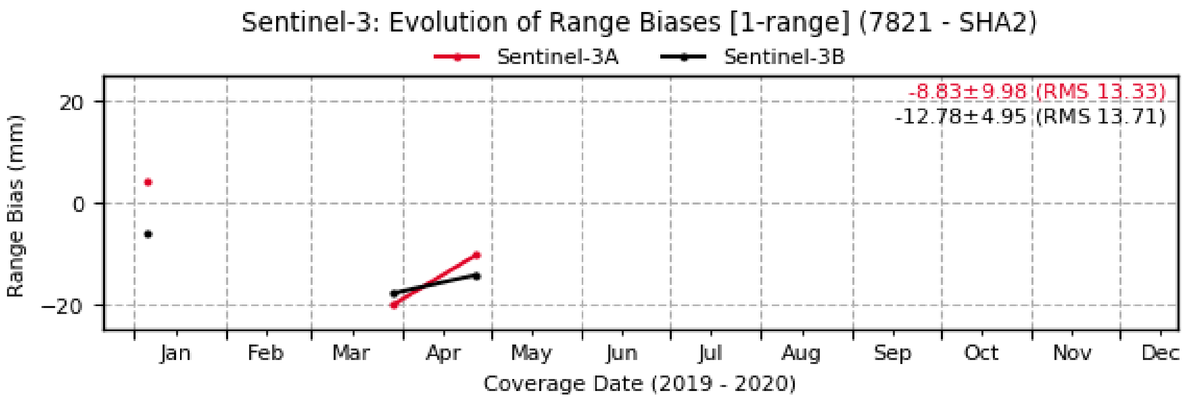

Sentinel-3: Evolution of Range Biases [1-range] (7249 - BEIL)
Sentinel-3A
Sentinel-3B
-16.52±5.02 (RMS 17.27)
-16.13±4.95 (RMS 16.87)
Range Bias (mm)
20
0
−20
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Coverage Date (2019 - 2020)

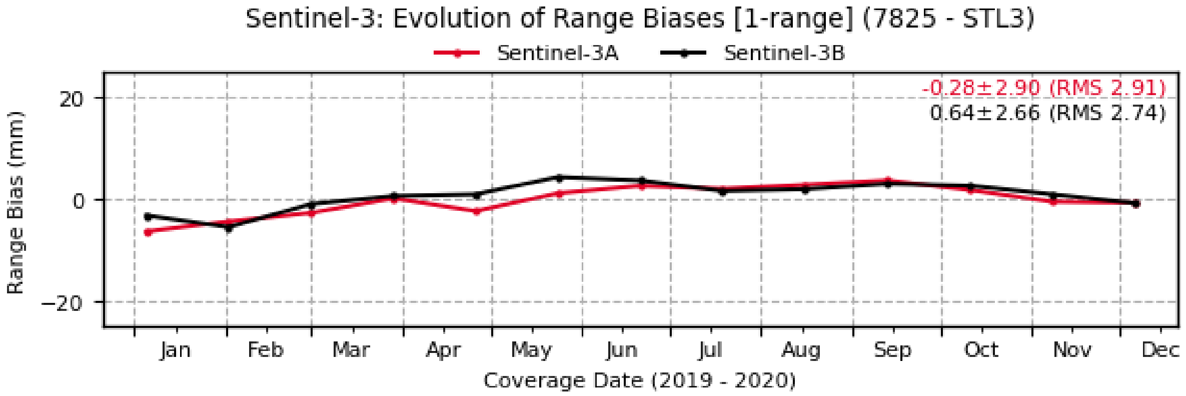

Sentinel-3: Evolution of Range Biases [1-range] (7403 - AREL)
Sentinel-3A
Sentinel-3B
-8.31±4.15 (RMS 9.29)
-7.92±3.39 (RMS 8.62)
Range Bias (mm)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Coverage Date (2019 - 2020)

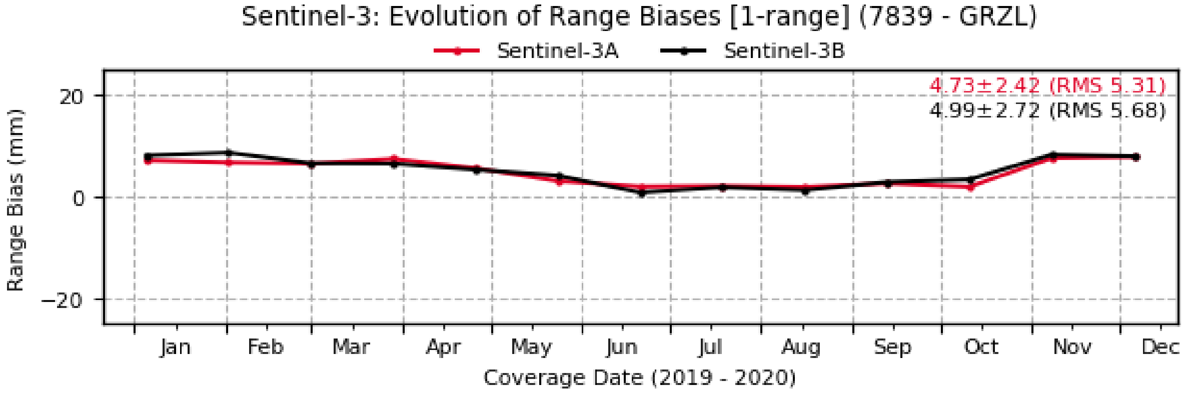

Sentinel-3: Evolution of Range Biases [1-range] (7501 - HARL)
Sentinel-3A
Sentinel-3B
6.29±4.61 (RMS 7.80)
6.46±4.54 (RMS 7.90)
Range Bias (mm)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Coverage Date (2019 - 2020)

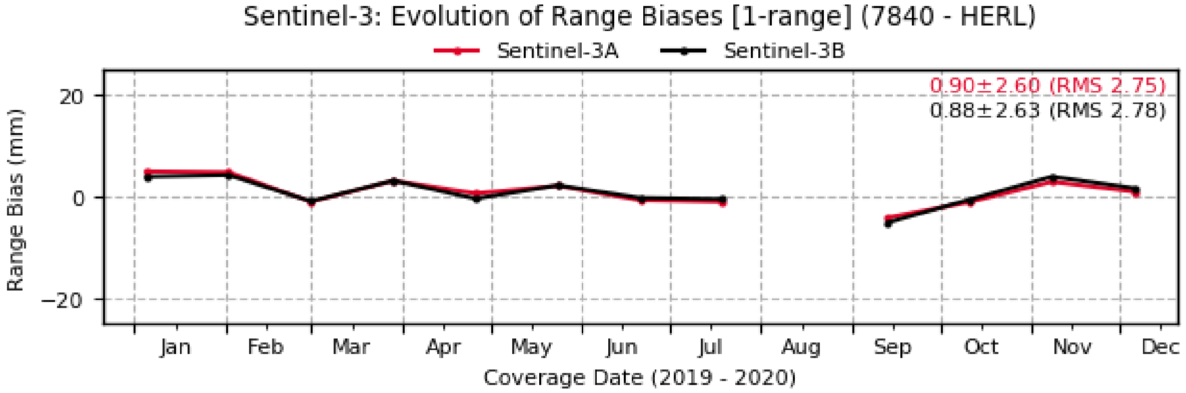

Sentinel-3: Evolution of Range Biases [1-range] (7810 - ZIML)
Sentinel-3A
Sentinel-3B
4.07±2.65 (RMS 4.86)
4.29±2.62 (RMS 5.02)
Range Bias (mm)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Coverage Date (2019 - 2020)

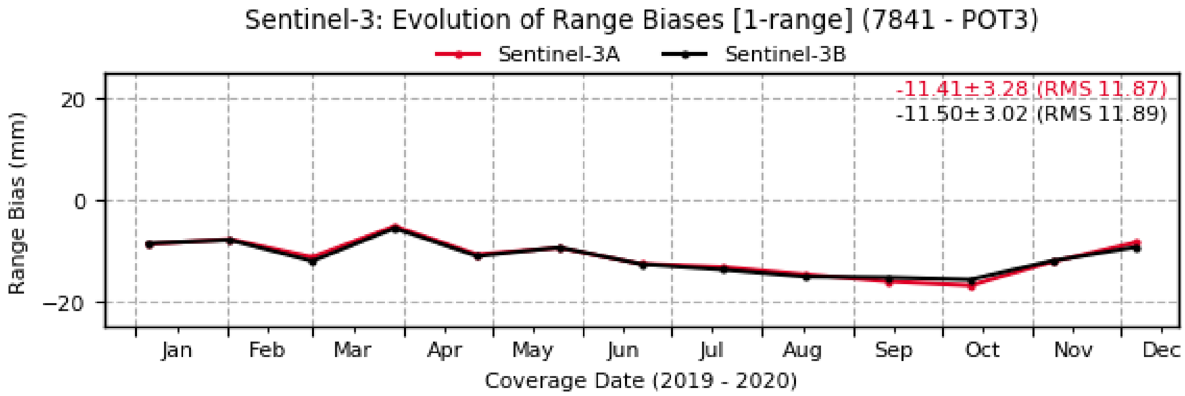

Sentinel-3: Evolution of Range Biases [1-range] (7811 - BORL)
Sentinel-3A
Sentinel-3B
-38.11±4.67 (RMS 38.40)
-38.85±6.80 (RMS 39.44)
Range Bias (mm)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Coverage Date (2019 - 2020)


Sentinel-3: Evolution of Range Biases [1-range] (7821 - SHA2)
Sentinel-3A
Sentinel-3B
-8.83±9.98 (RMS 13.33)
-12.78±4.95 (RMS 13.71)
Range Bias (mm)
Coverage Date (2019 - 2020)


Sentinel-3: Evolution of Range Biases [1-range] (7825 - STL3)
Sentinel-3A
Sentinel-3B
-0.28±2.90 (RMS 2.91)
0.64±2.66 (RMS 2.74)
Range Bias (mm)
Coverage Date (2019 - 2020)


Sentinel-3: Evolution of Range Biases [1-range] (7839 - GRZL)
Sentinel-3A
Sentinel-3B
4.73±2.42 (RMS 5.31)
4.99±2.72 (RMS 5.68)
Range Bias (mm)
Coverage Date (2019 - 2020)


Sentinel-3: Evolution of Range Biases [1-range] (7840 - HERL)
Sentinel-3A
Sentinel-3B
0.90±2.60 (RMS 2.75)
0.88±2.63 (RMS 2.78)
Range Bias (mm)
Coverage Date (2019 - 2020)



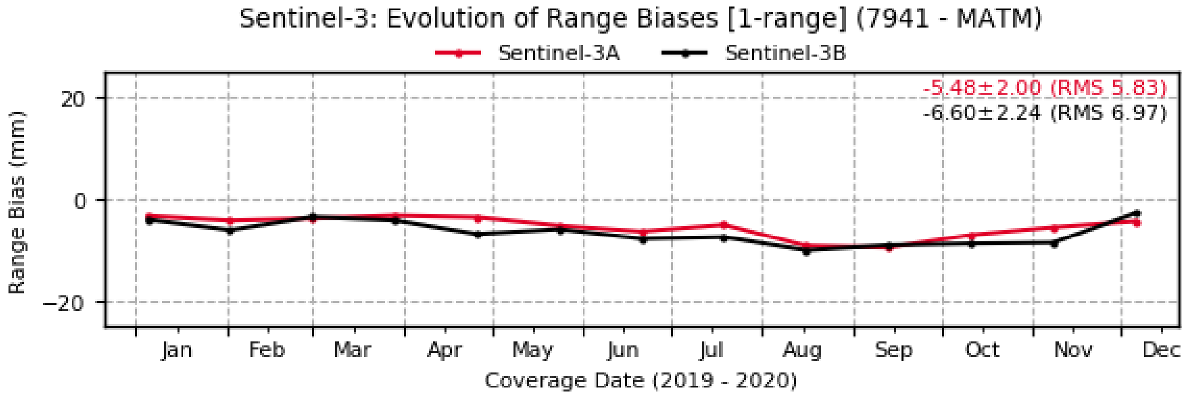
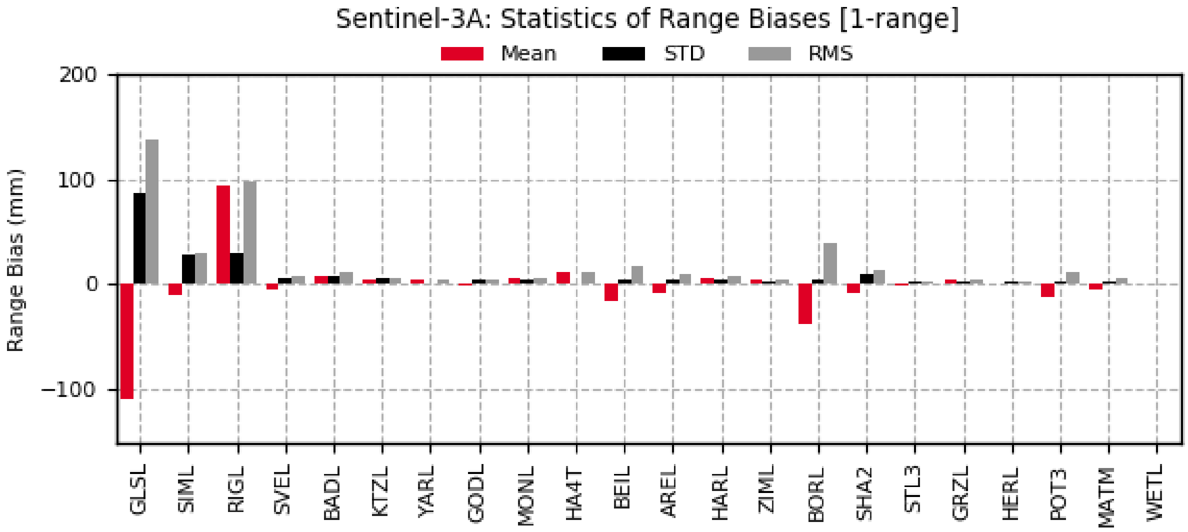


Figure 3-6: Evolution of the range biases [1-range; mm] calculated for each SLR station tracking Sentinel-3A and Sentinel-3B satellites in 2020

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.



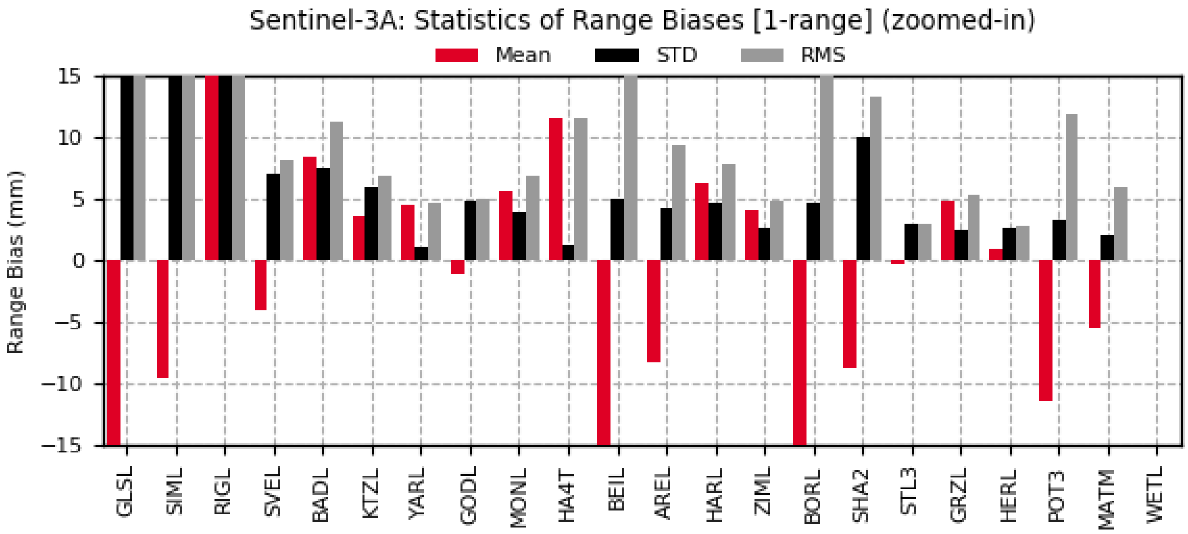
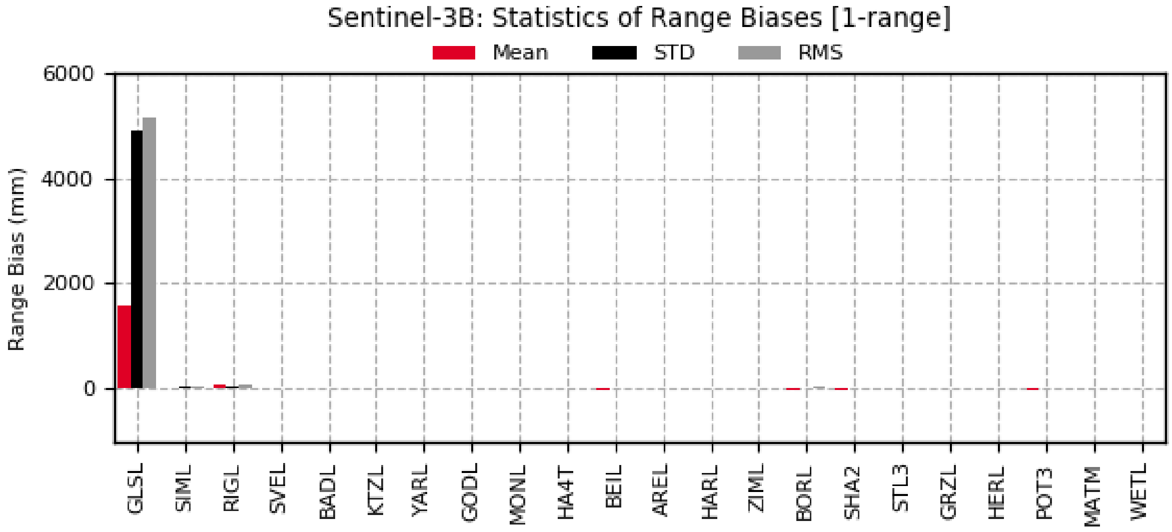


Figure 3-7: Mean, STD and RMS of the Sentinel-3A range biases [1-range; mm] of each SLR station (the figure below is a zoomed-in of the figure above)



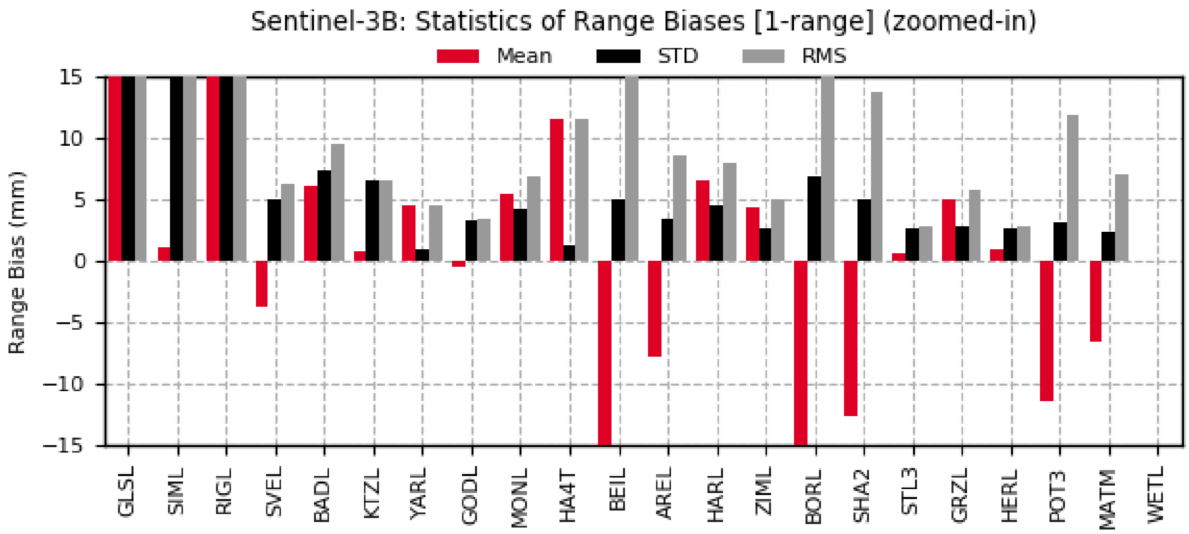


Figure 3-8: Mean, STD and RMS of the Sentinel-3B range biases [1-range; mm] of each SLR station (the figure below is a zoomed-in of the figure above)

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 2020 used to calculate the SLR residuals

SLR station		Mean value [mm]	
Monument	Code	Sentinel-3A	Sentinel-3B
1824	GLSL	-108.29	1584.28
1873	SIML	-9.57	1.01
1884	RIGL	93.73	87.57
1888	SVEL	-4.14	-3.78
1890	BADL	8.37	6.05
1893	KTZL	3.58	0.80
7090	YARL	4.52	4.43
7105	GODL	-1.13	-0.55
7110	MONL	5.62	5.39
7119	HA4T	11.48	11.54
7249	BEIL	-16.52	-16.13
7403	AREL	-8.31	-7.92
7501	HARL	6.29	6.46
7810	ZIML	4.07	4.29
7811	BORL	-38.11	-38.85
7821	SHA2	-8.83	-12.78
7825	STL3	-0.28	0.64
7839	GRZL	4.73	4.99
7840	HERL	0.90	0.88
7841	POT3	-11.41	-11.50
7941	MATM	-5.48	-6.60
8834	WETL	-	-

3.3. SLR RESIDUALS PER ORBIT SOLUTION

This subsection shows the SLR residuals obtained by the CNES, CPOF and COMB orbit solution, before and after applying the range biases estimated above.

Note that 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.

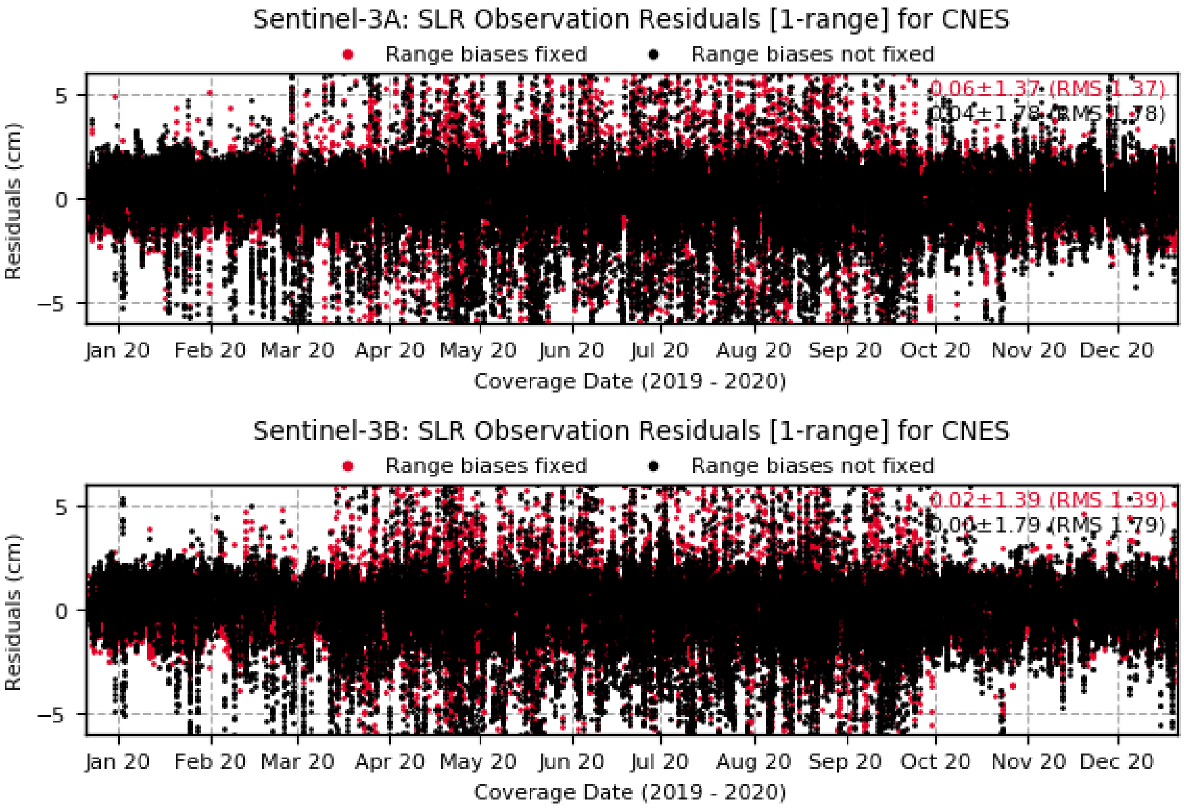


Figure 3-9: SLR observation residuals [1-range; cm] obtained for CNES orbit solution in 2020 (above Sentinel-3A, and below Sentinel-3B)

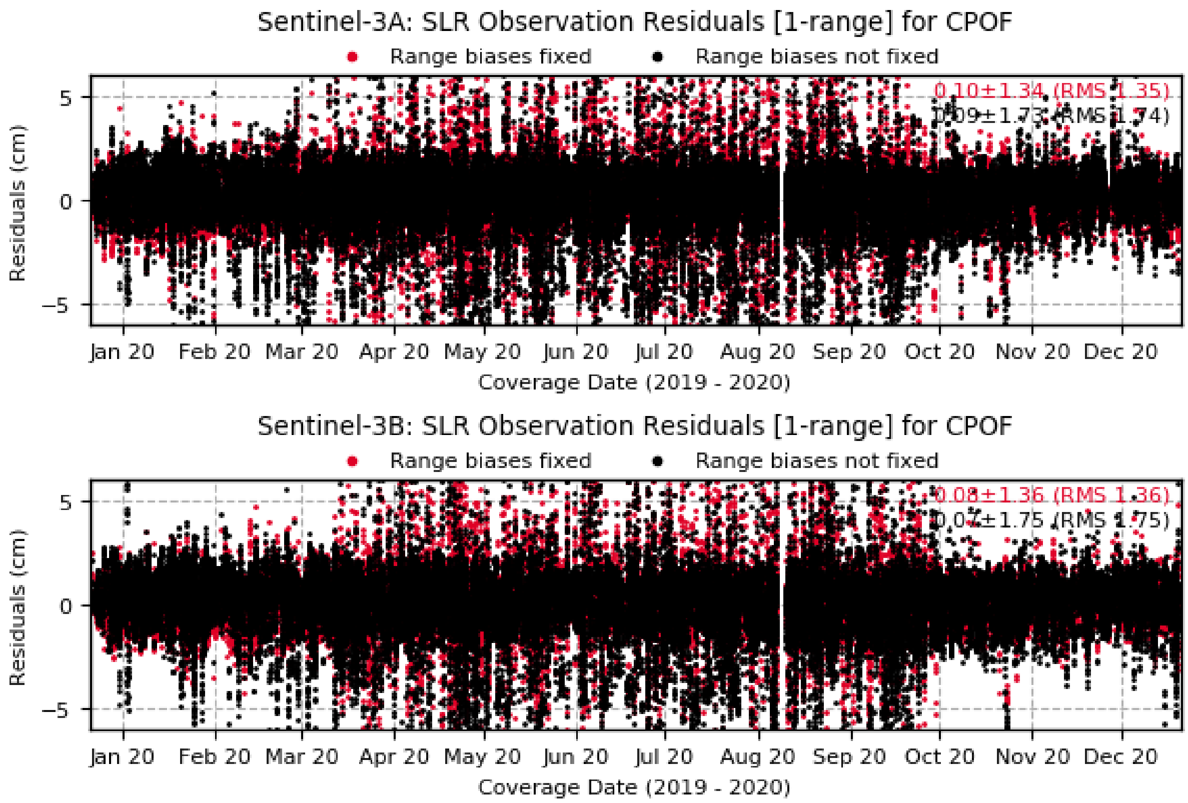


Figure 3-10: SLR observation residuals [1-range; cm] obtained for CPOF orbit solution in 2020 (above Sentinel-3A, and below Sentinel-3B)

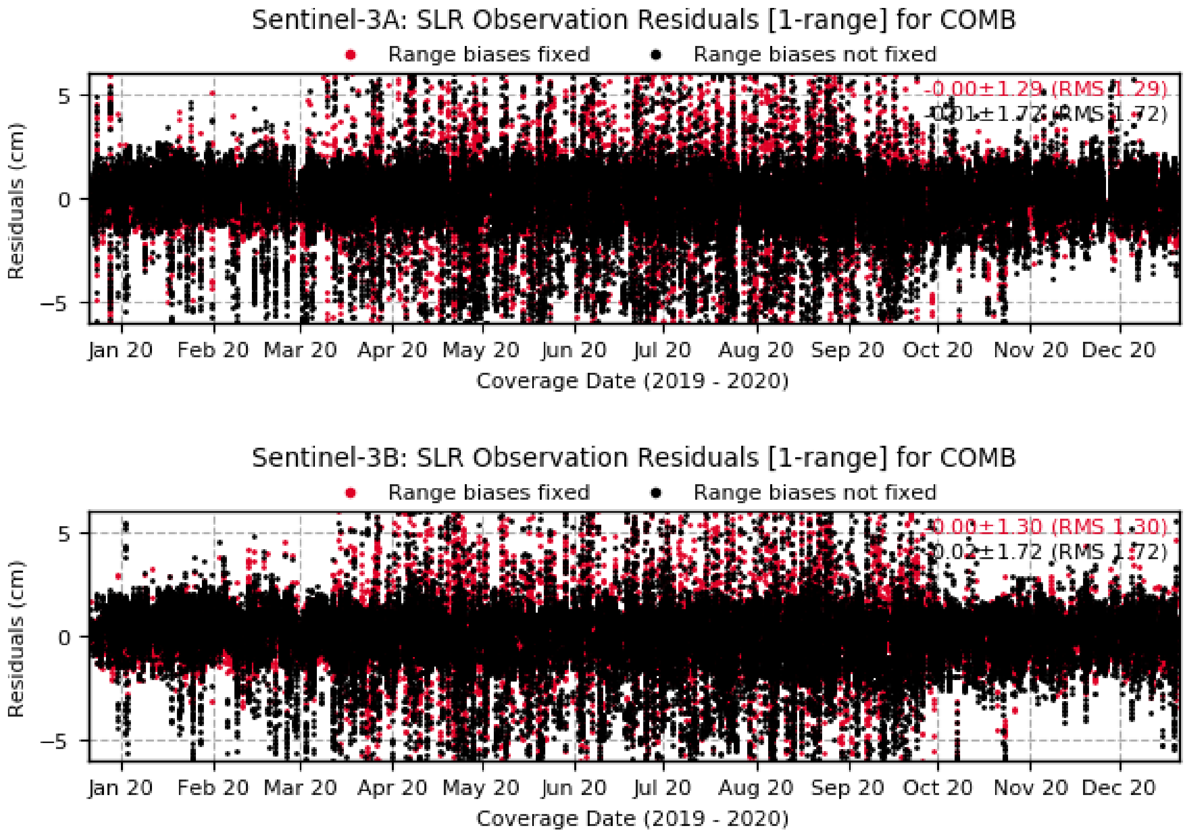


Figure 3-11: SLR observation residuals [1-range; cm] obtained for COMB orbit solution in 2020 (above Sentinel-3A, and below Sentinel-3B)

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 1 and 1.5 cm for all orbit solutions.

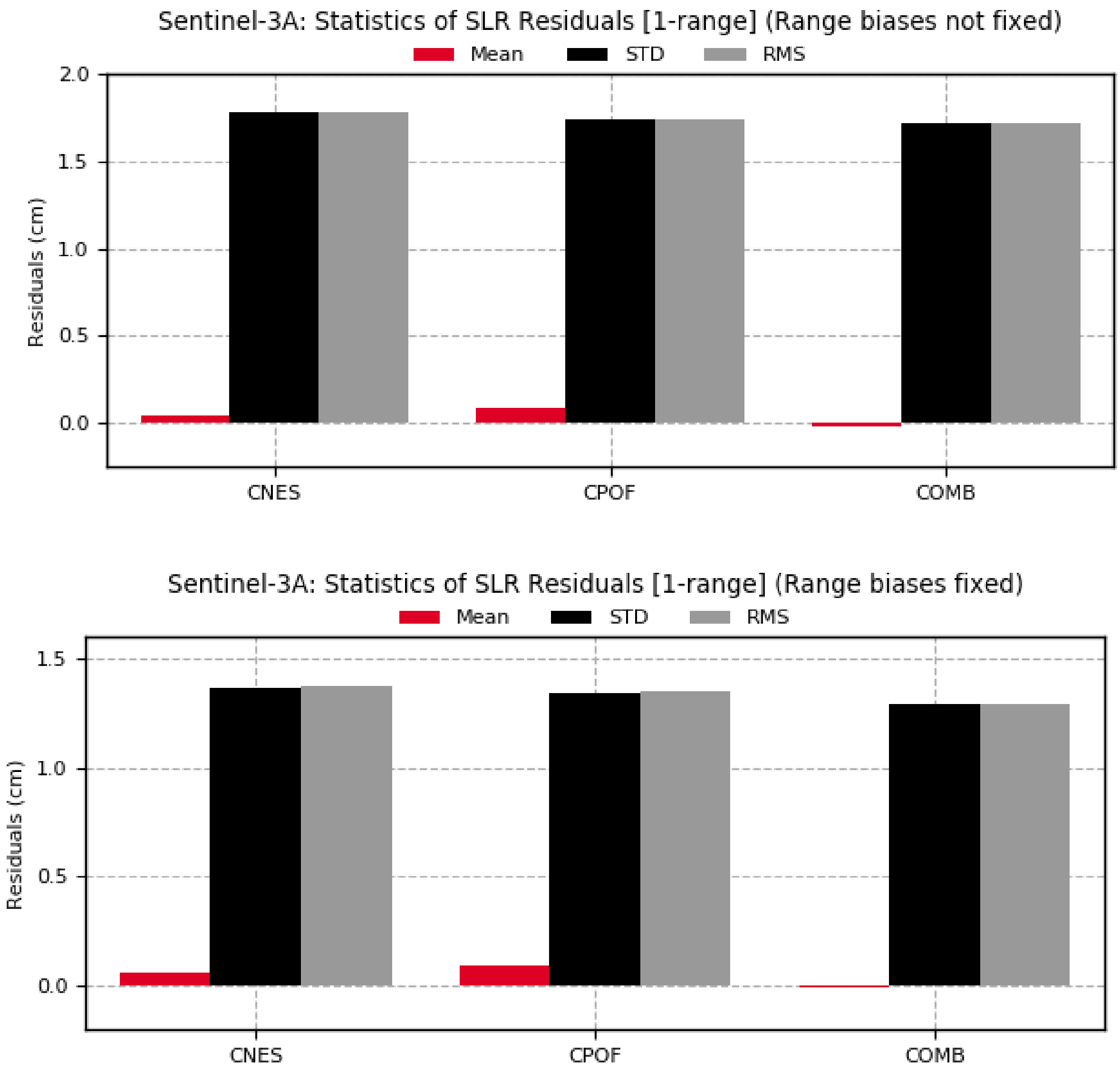
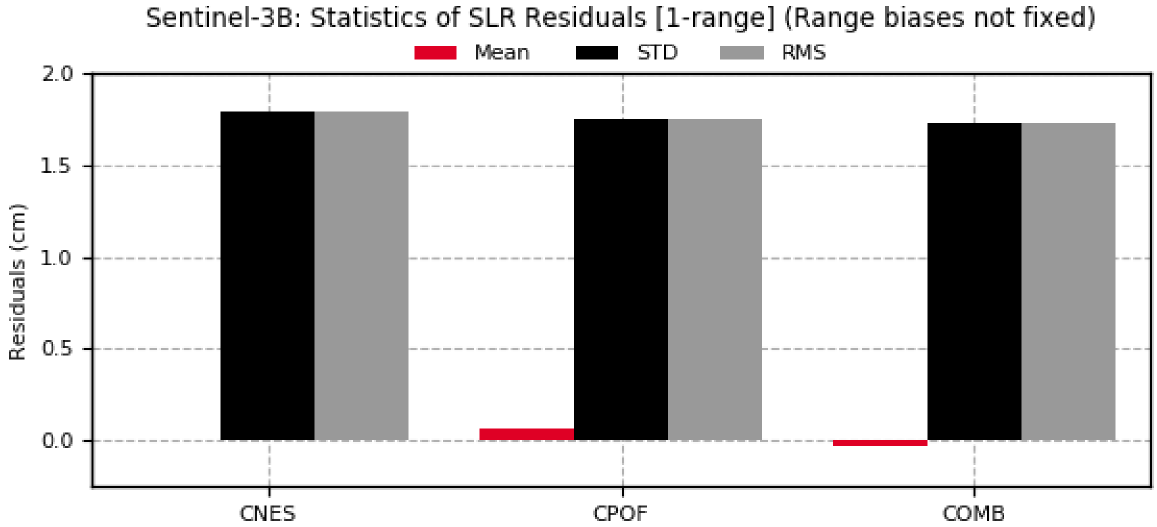


Figure 3-12: Mean, STD and RMS of the Sentinel-3A SLR observation residuals [1-range; cm] from all orbit solutions in 2020 (above the range biases have not been fixed, below the range biases have been fixed)



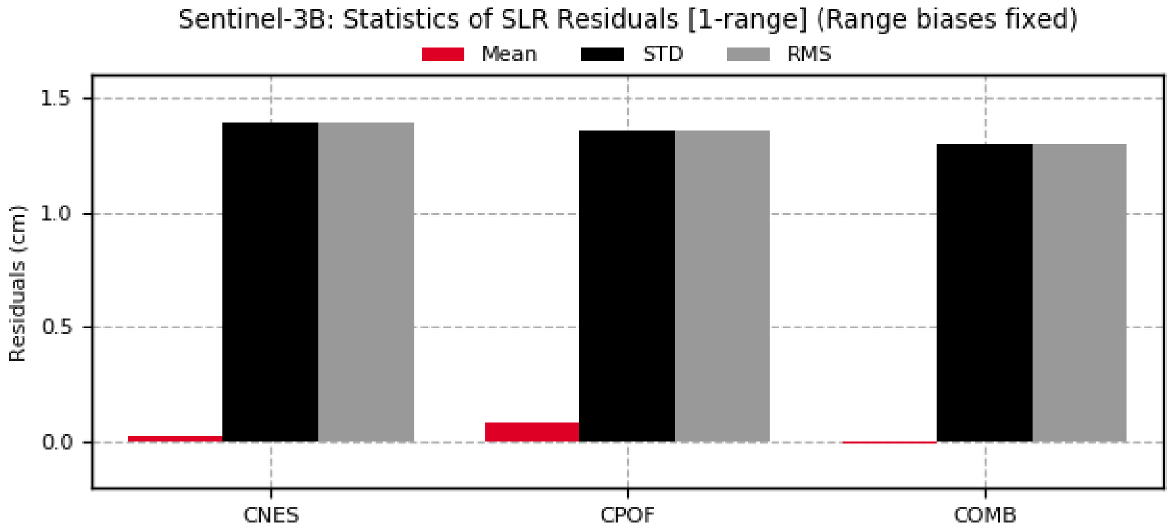


Figure 3-13: Mean, STD and RMS of the Sentinel-3B SLR observation residuals [1-range; cm] from all orbit solutions in 2020 (above the range biases have not been fixed, below the range biases have been fixed)

Finally, all the statistics of the subsection 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 2020

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
CNES	0.04	0.06	1.78	1.37	1.78	1.37	0.0	0.02	1.79	1.39	1.79	1.39
CPOF	0.09	0.1	1.73	1.34	1.74	1.35	0.07	0.08	1.75	1.36	1.75	1.36
COMB	-0.01	-0.0	1.72	1.29	1.72	1.29	-0.02	-0.0	1.72	1.3	1.72	1.3

4. 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 2020, the number of generated CPF predictions was 366 for each of the Sentinel-3 satellites, which coincides with the total number of the expected files.

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 2020 is summarised in Table 4-1.

Table 4-1: Manoeuvre days on the Sentinel-3 satellites during 2020

Sentinel-3A	Sentinel-3B
2020/03/11	2020/02/05
2020/06/17	2020/04/08
2020/09/02	2020/05/27
2020/12/02	2020/07/29
2020/12/16	2020/10/07
	2020/12/16

Figure 4-1 shows the quality of the CPF predicted files delivered by the CPOD Service, as compared against 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 4-2.

Figure 4-1 shows a significant improvement around May 2020, caused by a change in the parametrization to generate the CPF file.

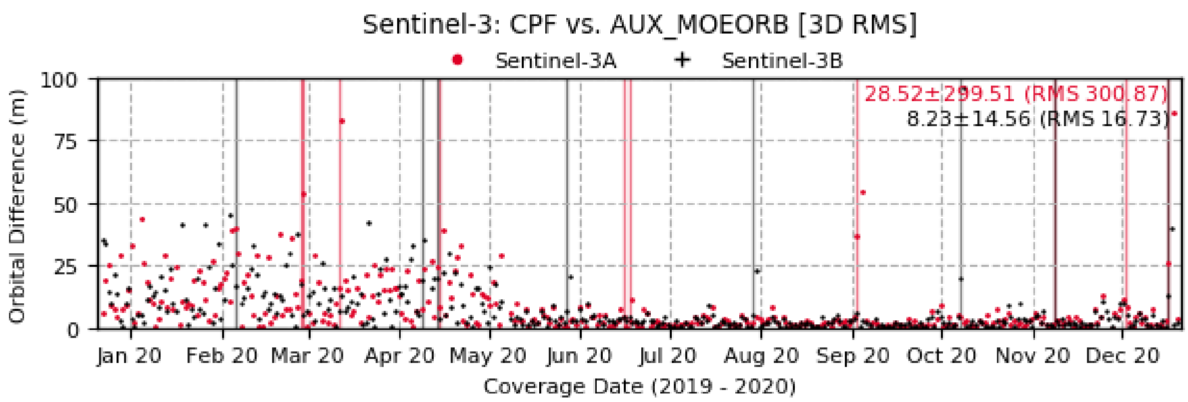


Figure 4-1: Orbital comparisons [3D RMS; m] between the Sentinel-3 CPF predictions and the Sentinel-3 CPOD STC products during 2020

Table 4-2: 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 2020

	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	0.34	2.44	2.46	27.24	287.5	288.8	6.45	84.09	84.34	28.52	299.5	300.9
Sentinel-3B	0.12	0.18	0.21	8.21	14.55	16.70	0.20	0.82	0.85	8.23	14.56	16.73

From the data above, it can be said that the accuracy of the CPF files is below 10 m in mean (3D RMS) for S-3B, with S-3A presenting such high value due to an outlier caused by a cancelled manoeuvre, the update of which was delivered late. The along-track is less accurate than the other components, as it is highly correlated with uncertainties on the drag modelling.

Finally, Table 4-3 gathers the percentage of the CPF files that have achieved a certain accuracy criterion, which complements the results previously shown.

Table 4-3: Percentiles of the orbital comparisons [3D RMS] between the Sentinel-3 CPF predictions and the Sentinel-3 CPOD STC products during 2020

Product Accuracy		
Threshold	Percentage of Fulfilment	
	Sentinel-3A	Sentinel-3B
< 1 m	14.05 %	17.68 %
< 5 m	59.23 %	60.77 %
< 10 m	75.48 %	75.97 %
< 50 m	97.80 %	98.90 %
< 100 m	98.90 %	99.17 %
< 200 m	99.45 %	100.00 %
< 400 m	99.45 %	100.00 %

5. CONCLUSIONS

This document gathers the 2020 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.
- The tracking of WETL station is currently on-hold. This station has stopped tracking both Sentinel-3 satellites as some parameters on the configuration of the laser have changed, particularly, this station is currently tracking in the Infra-red. The CPOD Service is waiting a formal response from ESA remarking whether it is allowed or not to track Sentinel-3 satellites at this wavelength.
- The total number of satellite passes during 2020 has shown values between 50 and 150 passes for both Sentinel-3 satellites, which have improved the metrics of year 2019. The YARL station continues being the SLR station providing the highest quantity of satellite passes and SLR observations.
- 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 1.5 cm in mean), which improves the reliability of the CPOD products.
- A monthly range 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.
- CPF files generated by CPOD Service have accuracies below 10 m in mean (3D RMS) on 2020.

6. 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 6-1: 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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