COPERNICUS POD REGULAR SERVICE REVIEW MAY - AUG 2023

3RD GENERATION OF THE COPERNICUS PRECISE ORBIT DETERMINATION SERVICE (CPOD)

Prepared by: X
CPOD Team
Project Engineer

Approved by: X
J. Aguilar
Quality Manager

Authorised by: X
C. Fernández
Project Manager

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1.0	2023/10/06	123	First version

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1. INTRODUCTION

1.1. PURPOSE

This document describes the results of the Copernicus POD (CPOD) Regular Service Review (RSR) #29 covering the period between May and August 2023 (both included), in the frame of the Copernicus POD Service. It applies to the satellites Sentinel-1A, -2A, -2B, -3A, -3B and -6A, which are all in their Routine Operational Phase (ROP).

1.2. SCOPE

This document is a deliverable by GMV in the frame of the Copernicus POD Service.

This document has been prepared by GMV with contributions from **AIUB**, **CLS**, **CNES**, **DLR**, **ESOC**, **EUMETSAT**, **GFZ**, **GSFC**, **JPL**, **TU Delft**, **TU Graz**, and **TUM** (inputs to prepare Section 3).

1.3. 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
AGRA	Service of the atmospheric contribution to geopotential	LRR	Laser Retro-reflector
AIUB	Astronomical Institute University of Bern	MACP	Manoeuvre Acceleration Profile
ANX	Ascending Node	MLI	Multi Layered Insulation
ARP	Antenna Reference Point	MSI	Multi-Spectral Instrument
BRDC	Broadcast ephemeris file	NAPEOS	NAvigation Package for Earth Orbiting Satellites
CLS	Collecte Localisation Satellites	NASA	National Aeronautics and Space Agency
CNES	Centre National d'Études Spatiales	NAVATT	NAVigation and ATTitude information
CODE	Center for Orbit Determination in Europe	NAVSOL	Navigation Solution
CPF	Consolidated Prediction Format	NCR	Non-Conformance Report
CPOD	Copernicus POD	NOAA	National Oceanic and Atmospheric Administration
DCB	Differential Code Biases	NRT	Near Real Time
DIL	Document Item List	NTC	Non Time Critical
DLR	Deutsche Zentrum für Luft- und Raumfahrt	ODA	On-Line Data Access
DOP	Dilution of Precision	OFLPOD	Offline POD
DORIS	Doppler Orbytography and Radiopositioning Integrated by Satellite	OLCI	Ocean & Land Colour Instrument
DORNAV	Doris Navigation	OPOD	Offline POD
DOY	Day of Year	OSV	Orbit State Vector
DPM	Data Processing Model	JPL	Jet Propulsion Laboratory
ECMWF	European Center for Medium-range Weather Forecasts	PAC	Processing Archiving Centre
EDDS	External Data Distribution System	PCO	Phase Centre Offset
EGP	External GPS Provider	PDAP	Payload Data and Acquisition Processing
EIGEN	European Improved Gravity model of the Earth by New techniques	PDGS	Payload Data Ground Segment
EOF	Earth Observation File	PDI	Product Data Item
EOP	Earth Orientation Parameters	PDMC	Payload Data Management Centre

Acronym	Definition	Acronym	Definition
ERA	Earth Rotation Angle	PDOP	Position DOP
ESA	European Space Agency	PFS	Product Format Specification
ESOC	European Space Operation Centre	PMP	Project Management Plan
EUM	EUMETSAT	PRIP	Production Interface Delivery Point
EUMETSAT	EUropean organisation for the exploitation of METeorological SATellites	POD	Precise Orbit Determination
FES	Finite Element Solution	POE	Precise Orbit Ephemeris
FFS	File Format Specification	PRN	Pseudo-Random Number
FFT	Fast Fourier Transform	PVT	Position, Velocity and Timing
FOS	Flight Operations System	QWG	Quality Working Group
FPA	Focal Plane Assembly	RINEX	Receiver Independent Exchange
FTP	File Transfer Protocol	RMS	Root Mean Square
FTPS	File Transfer Protocol Secure	ROE	Rapid Orbit Ephemerides
GDOP	Geometric DOP	ROP	Routine Operations Phase
GFZ	Geo Forschungs Zentrum	RSGA	Report of Solar-Geophysical Activity
GHOST	GPS High Precision Orbit Determination Software Tools	RSR	POD Regular Service Review
GINS	Géodesie par Intégrations Numériques Simultanées	SAD	Satellite Ancillary Data
GIPSY-OASIS	GNSS-Inferred Positioning System and Orbit Analysis Simulation Software	SALP	Service d'Altimetrie et Localisation Precise
GIPSY-X	GNSS-Inferred Positioning System X	SAR	Synthetic Aperture Radar
GMES	Global Monitoring for Environment and Security	SLA	Service Level Agreement
GNSS	Global Navigation Satellite System	SLR	Satellite Laser Ranging
GOCO	Gravity Observation Combination	SoL	Sentinel Online
GPS	Global Positioning System	SPR	Software Problem Report
GRGS	Groupe de Recherche de Géodésie Spatiale	SRAL	SAR Radar Altimeter
GSFC	Goddard Space Flight Center	STC	Short Time Critical
HKTM	House Keeping Telemetry	STD	Standard Deviation
ICD	Interface Control Document	STM	Surface Topography Mission
IERS	International Earth Rotation Service	SWIR	Short Wave InfraRed
IGS	International GNSS Service	TBD	To Be Decided
ILRS	International Laser Ranging Service	TDOP	Time DOP
INT	Integration Room	TUD	Technische Universiteit Delft
IPF	Instrument Processing Facility	TUM	Technische Universität München
ITRF	International Terrestrial Reference Frame	UTC	Coordinated Universal Time
KPI	Key Performance Indicator		

1.4. APPLICABLE AND REFERENCE DOCUMENTS

1.4.1. 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]	Sentinels POD Service File Format Specification	GMV-CPOD-FFS-0001	3.0	2023/07/21
[AD.2]	Sentinel-1 PDGS to Copernicus POD Service ICD	GMV-CPOD-ICD-0009	2.1	2022/11/04
[AD.3]	Copernicus POD Service to Sentinel-1 PDGS ICD	GMV-CPOD-ICD-0008	2.1	2022/11/04
[AD.4]	External Auxiliary Data Providers to Copernicus POD Service ICD	GMV-CPOD-ICD-0002	2.0	2021/06/02
[AD.5]	Sentinel-2 PDGS and Copernicus POD Service ICD	GMV-CPOD-ICD-0010	2.1	2022/11/04
[AD.6]	Sentinel-3 PDGS to Copernicus POD Service ICD	GMV-CPOD-ICD-0012	2.1	2022/11/04
[AD.7]	Copernicus POD Service to Sentinel-3 PDGS ICD	GMV-CPOD-ICD-0011	2.1	2022/11/04
[AD.8]	EUMETSAT and Copernicus POD Service ICD for Sentinel-6A	GMV-CPOD-ICD-0007	1.3	2022/05/20

1.4.2. 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]	Sentinel-1 properties for GPS POD	GMV-GMESPOD-TN-0025	1.4	2019/09/16
[RD.2]	Sentinel-2 properties for GPS POD	GMV-GMESPOD-TN-0026	1.4	2019/09/16
[RD.3]	Sentinel-3 properties for GPS POD	GMV-GMESPOD-TN-0027	2.0	2022/03/10
[RD.4]	Sentinel-6 POD Context	JC-TN-ESA-SY-0420	2.2	2023/05/03

2. OVERVIEW OF THE COPERNICUS POD SERVICE OPERATIONS

The Copernicus POD (CPOD) Service is currently operating six satellites in their Routine Operational Phase (ROP). Table 2-1 shows the launch date of each satellite.

Table 2-1: Launch dates of Sentinel-1, -2, -3 and -6 missions

Unit	Sentinel-1	Sentinel-2	Sentinel-3	Sentinel-6
A	2014/04/03	2015/06/23	2016/02/16	2020/11/21
B	–	2017/03/07	2018/04/25	–

During this phase, the main activities of the Copernicus POD Service have been:

- Operation of the Service by monitoring the system.
- Resolution of the anomalies and SPRs detected during the operations.
- Execution of comparisons against external orbital products to check the quality of the CPOD Service products.
- Evolution of the system.
- Preparation of material for conferences and workshops related to POD.

This document describes the activities performed and results obtained in the period from 2023/04/23 until 2023/09/02 both included, with Sentinel-1A, -2A, -2B, -3A, -3B and -6A by the CPOD Service.

This document reports on:

- **Accuracy results** of the **orbital products** when compared against external validation centres in Section 3 with additional information in Annex D.
- **GNSS sensor performance analysis** using GNSS data related to a particular day tracked by every Sentinel in Section 4.
- List of tracking **SLR stations** in Annex A.
- Description of the **POD processing of each QWG solution** in Annex B.
- Description of the **Weights calculation for the generation of the combined orbit solution** in Annex C.
- A summary of the **Product Performance** in Annex E.

3. VALIDATION OF THE CPOD SERVICE ORBIT PRODUCTS

This chapter reports on the orbital accuracy attainable by the CPOD Service with the current system. To perform an external validation of the orbital products, the different external validation centres processed the complete reported period. Not all the centres provide solutions all the time because of the difficulties handling manoeuvres and gaps of data. In any case, the long period provides sufficient information to conclude on the actual accuracy of the orbital products computed by the CPOD Service.

Each external centre used its own POD software tools and configuration. Annex B contains a description of the POD set-up used by each of the processing centres composing the external validation (i.e., AIUB, CLS, CNES, CPOD, DLR, ESOC, EUM, GFZ, GSFC, JPL, TUD, and TUM). Table 3-1 summarises all these centres and the orbit solutions provided by each of them.

Table 3-1: List of the QWG centres and orbit solutions provided by them

Name of centre	Label of centre	Label of the orbit solution/s provided
Astronomical Institute of the University of Bern	AIUB	AIUB AING (non-gravitational)
Collecte Localisation Satellites	CLS	GRG
Centre National d'Études Spatiales	CNES	CNES (operational solution)
Copernicus POD Service	CPOD	CPOD (operational solution) CPOF (solution with new developments)
Deutsche Zentrum für Luft- und Raumfahrt	DLR	DLR
European Space Operation Centre	ESOC	ESOC
European organisation for the exploitation of Meteorological Satellites	EUM	EUMB (Bernese GNSS software)
Deutsches GeoForschungsZentrum	GFZ	GFZ
Goddard Space Flight Center	GSFC	GSFC
Jet Propulsion Laboratory	JPL	JPL
Technische Universiteit Delft	TUD	TUDF
Technische Universität Graz	TUG	TUG
Technische Universität München	TUM	TUM

This chapter presents the comparison between a combined solution and all orbit solutions provided by all centres (included CPOD Service). The combined orbit solution per each satellite has been generated considering all orbital solutions. It has been done with proper weights and following an "IGS-like" approach (see Annex C). The analysis of SLR observations for S-3A, S-3B and S-6A is provided as well. All these statistics will be shown for the period that includes the dates from **2023/04/23** (i.e., 22590 GPS week) to **2023/09/02** (i.e., 22776 GPS week). It important to remind that the orbit comparison of S-3 and S-6 missions include the orbit solutions from CNES, EUM, CLS, GFZ, GSFC (only S-6) and JPL centres, which are not included in S-1 and S-2 missions. The GRGG orbit solution is based on DORIS data only and the CNES orbit solution also includes GNSS+DORIS observations simultaneously. The GSFC solution is based on SLR+DORIS. This RSR document continues the analysis considering the geographical and spectral distribution of the orbital comparisons started on the previous RSR.

This chapter finally includes the quality control of all STC products generated by CPOD, CNES (only S-3 and S-6), and TUD.

3.1. SENTINEL-1A

3.1.1. STATISTICS OF THE GENERATION OF THE SOLUTION COMB

Figure 3-1 shows the daily distribution per orbit solution of the weights used to generate the combined Sentinel-1A orbit solution. A summary of these values can be found in Table 3-2, where the mean values of these calculated weights are presented. It must be remarked that a higher value on the weights means a more contribution of the orbit solution to the generation of the combined orbit solution.

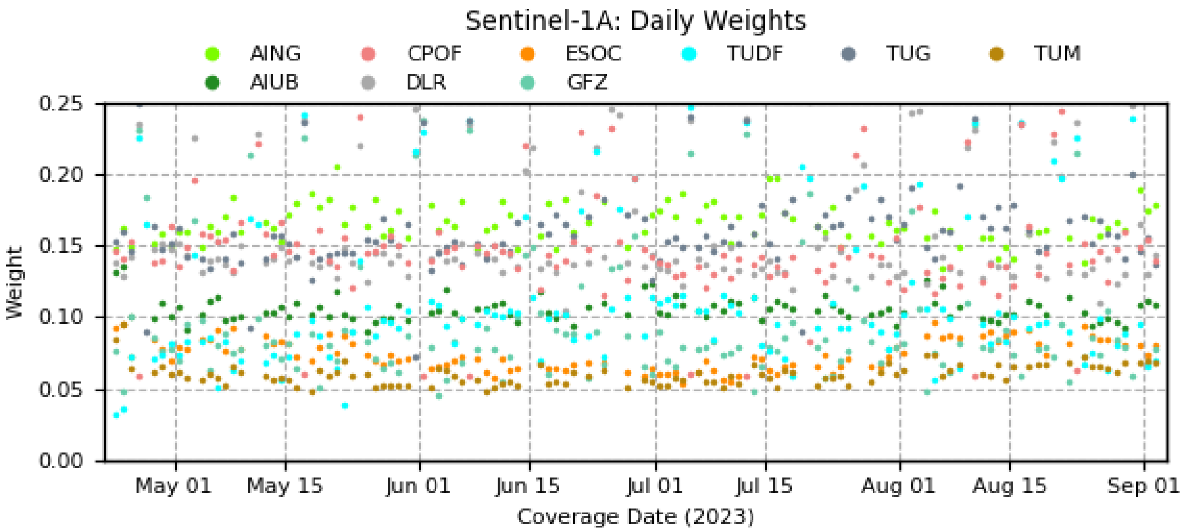


Figure 3-1: Sentinel-1A COMB generation – Daily weights of ALL orbit solutions

Table 3-2: Sentinel-1A COMB generation – Mean of the daily weights of ALL orbit solutions

Daily Weights		
Orbit Solution	Centre	Mean
AING	**AIUB**	0.17
AIUB	**AIUB**	0.11
CPOF	**CPOD**	0.15
DLR	**DLR**	0.16
ESOC	**ESOC**	0.07
GFZ	**GFZ**	0.10
TUDF	**TUD**	0.11
TUG	**TUG**	0.18
TUM	**TUM**	0.06

3.1.2. TEMPORAL EVOLUTION OF THE ORBITS COMPARISONS

Figure 3-2 shows the temporal evolution of the orbit comparisons [3D RMS] between all Sentinel-1A orbit solutions provided by the different QWG centres and the combined orbit solution. A summary of these orbit comparisons can be found in Figure 3-3 and Table 3-3, where the mean of the daily RMS is calculated not only for the 3D RMS but also for other satellite components.

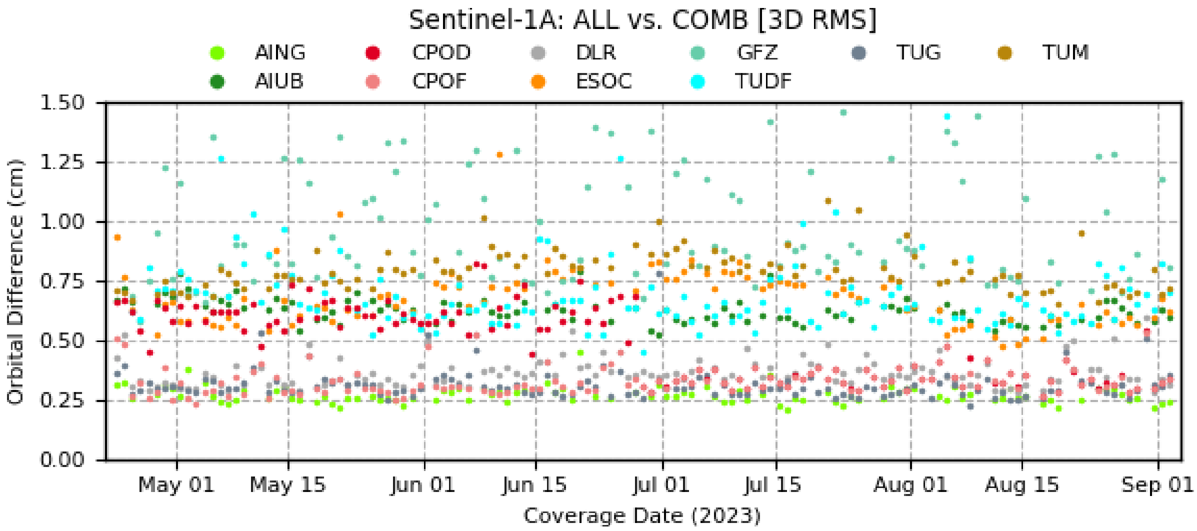


Figure 3-2: Sentinel-1A orbit comparisons – All vs. COMB [3D RMS; cm]

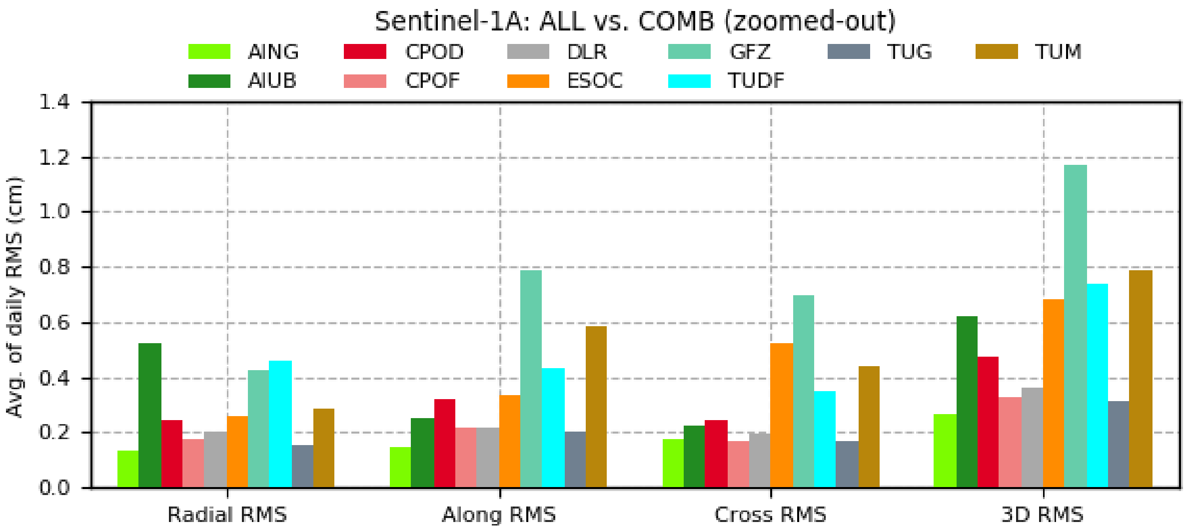


Figure 3-3: Sentinel-1A orbit comparisons – Mean of daily RMS [cm] (All vs. COMB [radial, along, cross and 3D RMS])

Table 3-3: Sentinel-1A orbit comparisons – Mean of daily RMS [cm] (All vs. COMB)

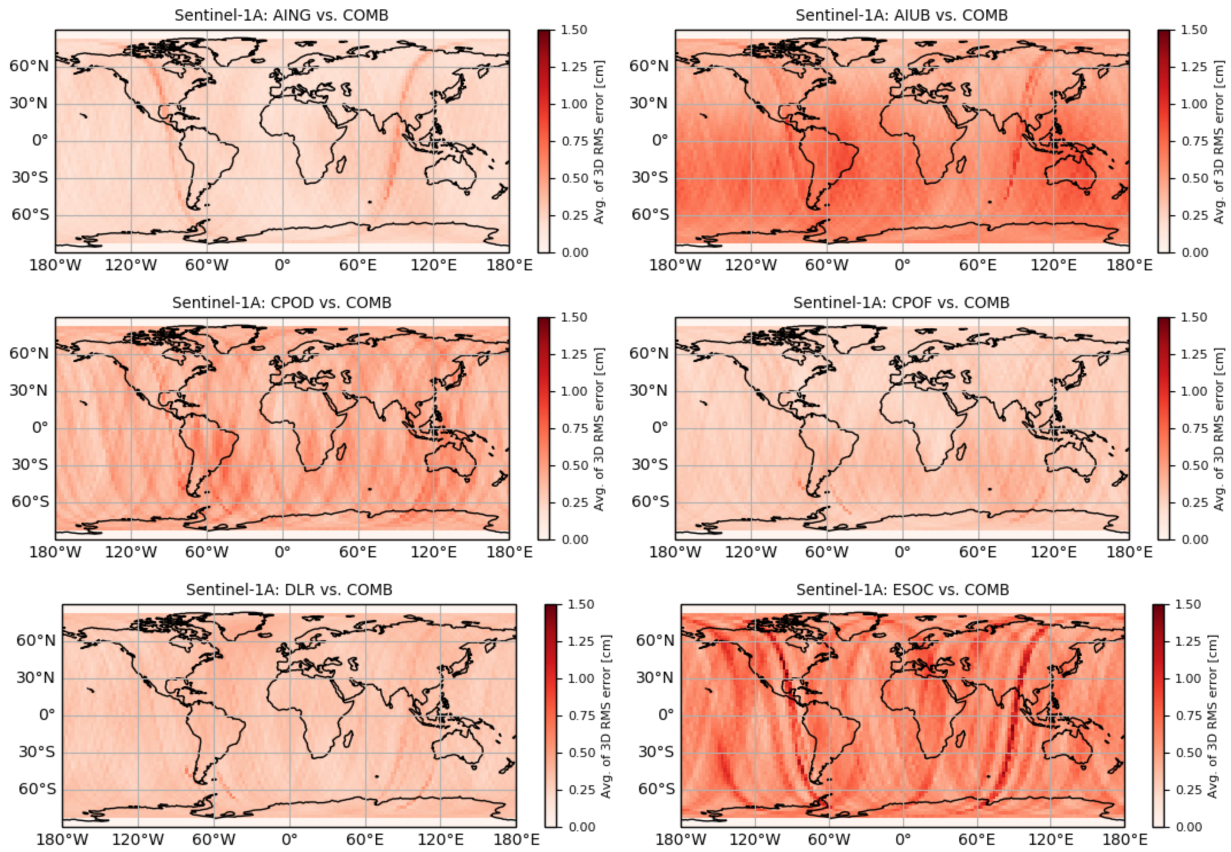
Orbit Comparisons (Mean of daily RMS [cm])					
Orbit Solution	Centre	Satellite component			
		Radial	Along-track	Cross-track	3D
AING	**AIUB**	0.13	0.15	0.17	0.27
AIUB	**AIUB**	0.52	0.25	0.22	0.62
CPOD	**CPOD**	0.24	0.32	0.25	0.47
CPOF	**CPOD**	0.18	0.22	0.17	0.33
DLR	**DLR**	0.21	0.22	0.20	0.36

Orbit Comparisons (Mean of daily RMS [cm])					
Orbit Solution	Centre	Satellite component			
		Radial	Along-track	Cross-track	3D
ESOC	**ESOC**	0.26	0.34	0.52	0.68
GFZ	**GFZ**	0.43	0.78	0.70	1.17
TUDF	**TUD**	0.46	0.43	0.35	0.74
TUG	**TUG**	0.15	0.21	0.17	0.31
TUM	**TUM**	0.29	0.59	0.44	0.79

The Sentinel-1A orbit solutions generated by the CPOD Service show a performance in line with the results obtained on the other solutions.

3.1.3. GEOGRAPHICAL ANALYSIS

Figure 3-4 shows the 3D RMS orbit comparisons calculated on the previous subsection projected on an equi-rectangular map plot. Each cell of the map contains the mean value of all orbit comparisons falling on this cell during the reported period.



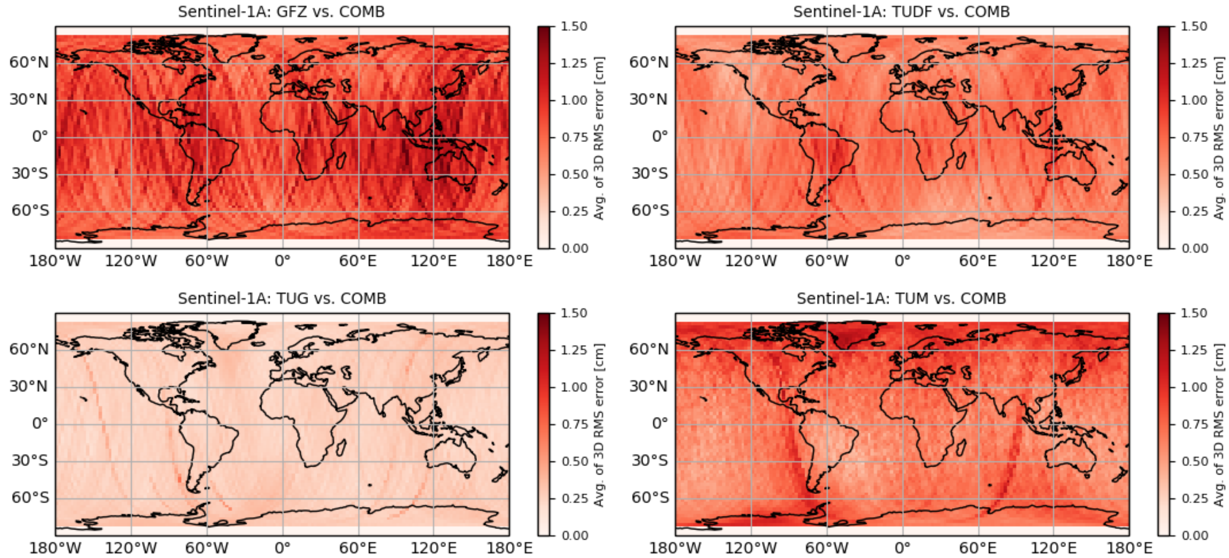
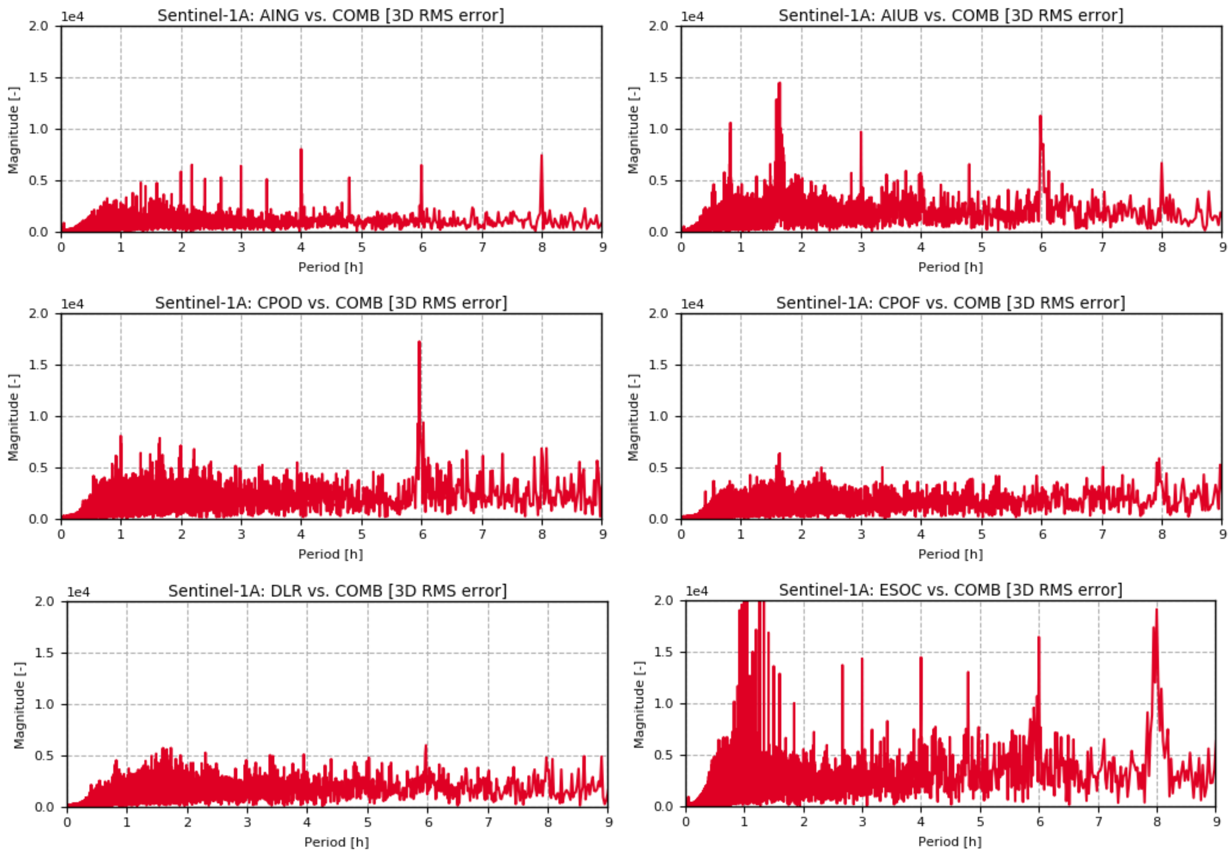


Figure 3-4: Sentinel-1A geographical analysis – Average of the 3D RMS orbit comparisons (All vs. COMB)

3.1.4. SPECTRAL ANALYSIS

Figure 3-5 shows the FFT of the 3D RMS orbit comparisons calculated on the previous subsection.



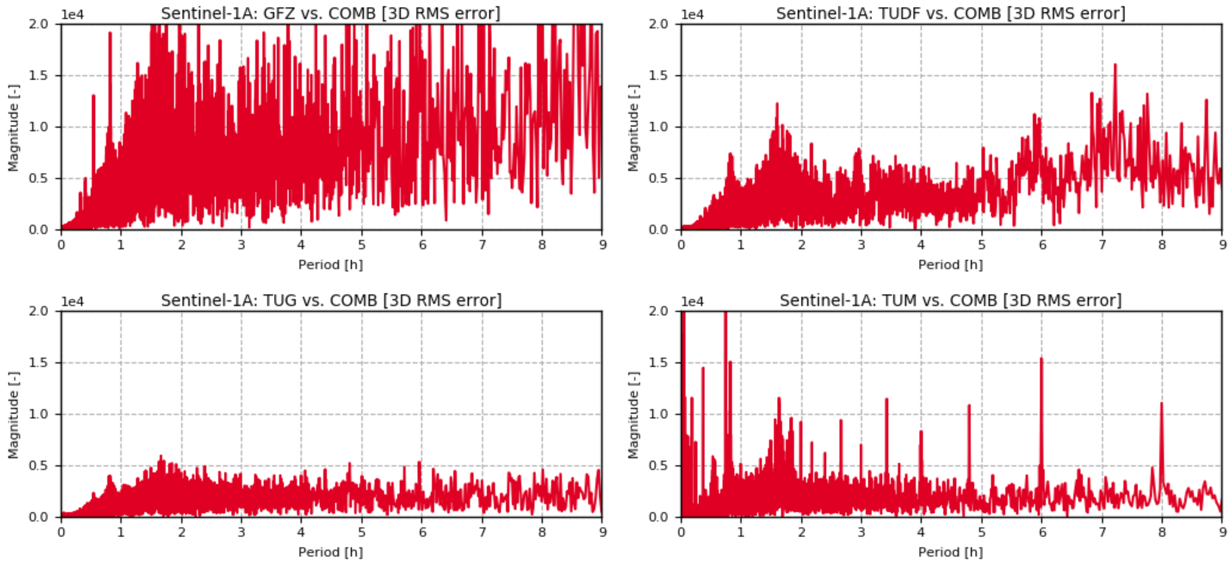


Figure 3-5: Sentinel-1A spectral analysis – 3D RMS orbit comparisons (All vs. COMB)

3.1.5. ORBIT COMPARISONS OF S-1A STC ORBIT SOLUTIONS

The operational S-1 STC solutions from the CPOD Service (labelled as CPOR) and TUD rapid solution are compared here against the combined solution.

TUD is currently generating one STC orbit solution for Sentinel-1A, which has been labelled as **TUDR.** This STC orbit solution is based on rapid GNSS products from JPL (with high-rate clocks).

Figure 3-29 shows the 3D RMS accuracy of the orbit solutions for all the reported period. As seen in the figure, the TUD solutions offer the best performance, similar to the performance shown by the TUDF NTC solution, thanks to the use of integer ambiguity resolution.

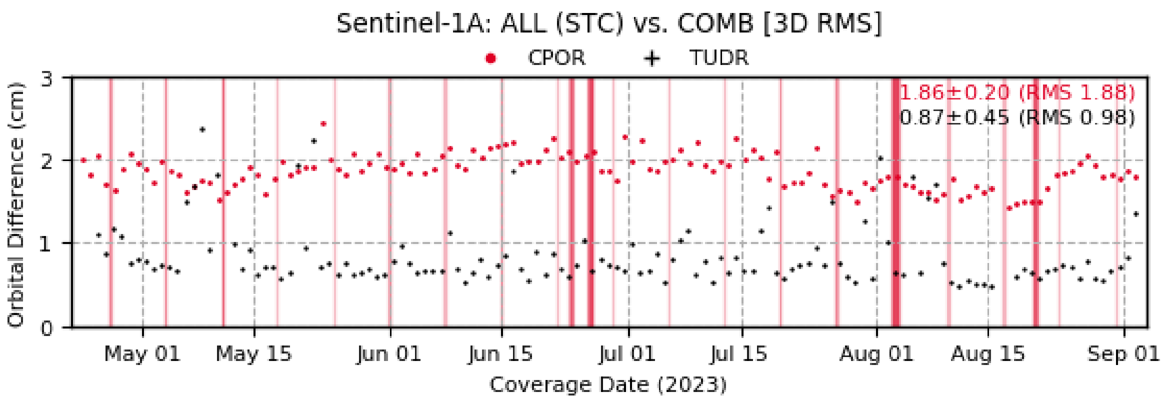


Figure 3-6: Sentinel-1A orbit comparisons – All (STC) vs. COMB [3D RMS; cm]

A more detailed distribution of the obtained accuracy can be found in Table 3-16, where the percentiles of the 3D RMS is calculated for different thresholds.

Table 3-4: Sentinel-1A STC (all) solutions – Accuracy percentiles (orbit comparisons against COMB solution [3D RMS], respectively)

Product Accuracy		
Threshold	Percentage of Fulfilment	
	CPOR	TUDR
< 1 cm	0.00 %	80.62 %
< 2 cm	74.24 %	96.90 %
< 3 cm	100.00 %	99.22 %
< 4 cm	100.00 %	100.00 %

3.2. SENTINEL-2A

3.2.1. STATISTICS OF THE GENERATION OF THE SOLUTION COMB

Figure 3-7 shows the daily distribution per orbit solution of the weights used to generate the combined Sentinel-2A orbit solution. A summary of these values can be found in Table 3-5, where the mean values of these calculated weights are presented. It must be remarked that a higher value on the weights means a more contribution of the orbit solution to the generation of the combined orbit solution.

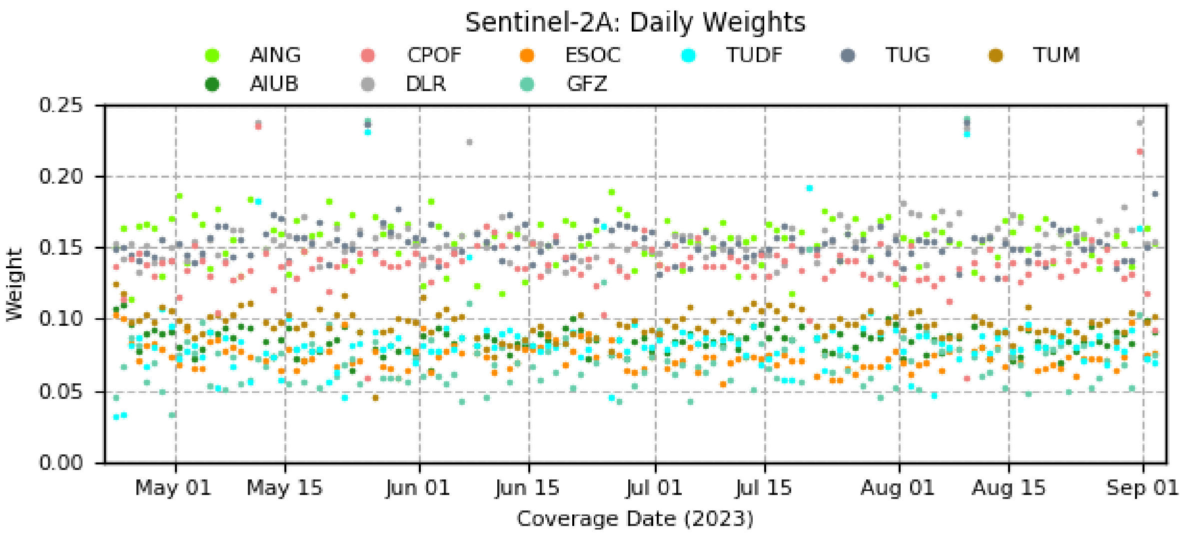


Figure 3-7: Sentinel-2A COMB generation – Daily weights of ALL orbit solutions

Table 3-5: Sentinel-2A COMB generation – Mean of the daily weights of ALL orbit solutions

Daily Weights		
Orbit Solution	**Centre**	**Mean**
AING	**AIUB**	0.15
AIUB	**AIUB**	0.08
CPOF	**CPOD**	0.14
DLR	**DLR**	0.16
ESOC	**ESOC**	0.07
GFZ	**GFZ**	0.07
TUDF	**TUD**	0.08
TUG	**TUG**	0.16
TUM	**TUM**	0.10

3.2.2. TEMPORAL EVOLUTION OF THE ORBITS COMPARISONS

Figure 3-8 shows the temporal evolution of the orbit comparisons [3D RMS] between all Sentinel-2A orbit solutions provided by the different QWG centres and the combined orbit solution. A summary of these orbit comparisons can be found in Figure 3-9 and Table 3-6, where the mean of the daily RMS is calculated not only for the 3D RMS but also for other satellite components.

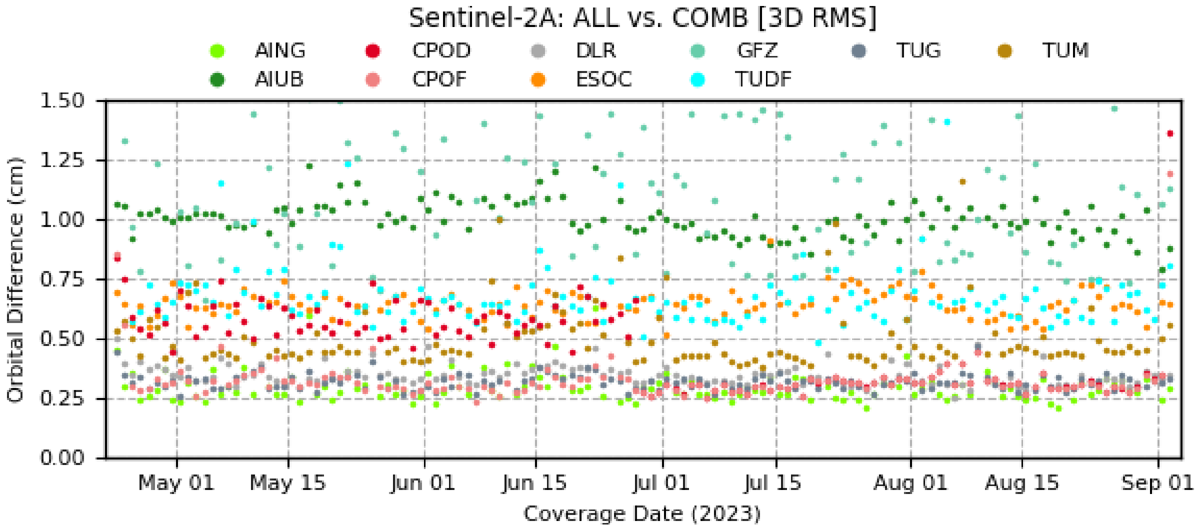


Figure 3-8: Sentinel-2A orbit comparisons – All vs. COMB [3D RMS; cm]

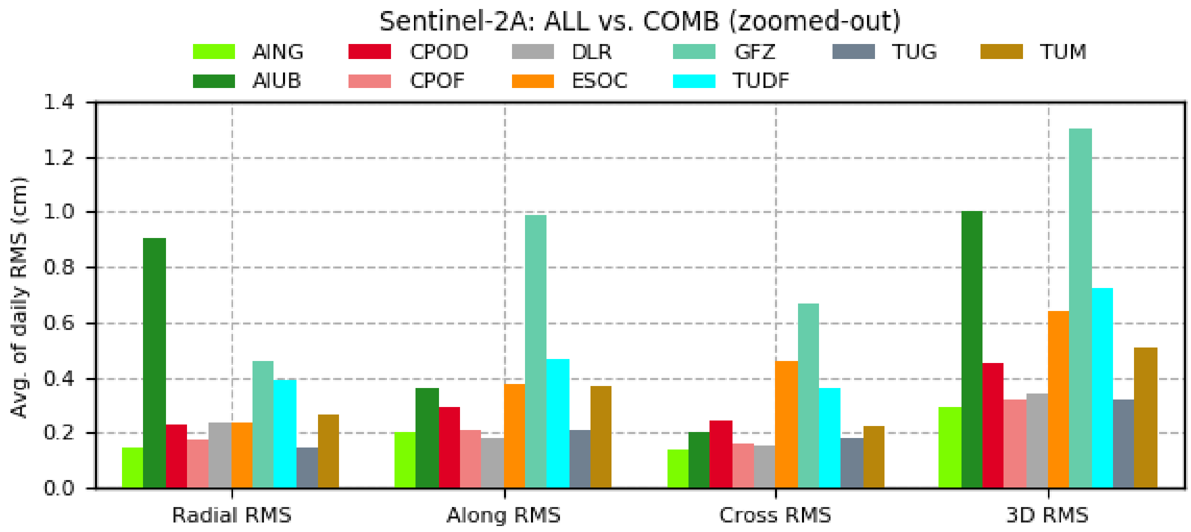


Figure 3-9: Sentinel-2A orbit comparisons – Mean of daily RMS [cm] (All vs. COMB [radial, along, cross and 3D RMS])

Table 3-6: Sentinel-2A orbit comparisons – Mean of daily RMS [cm] (All vs. COMB)

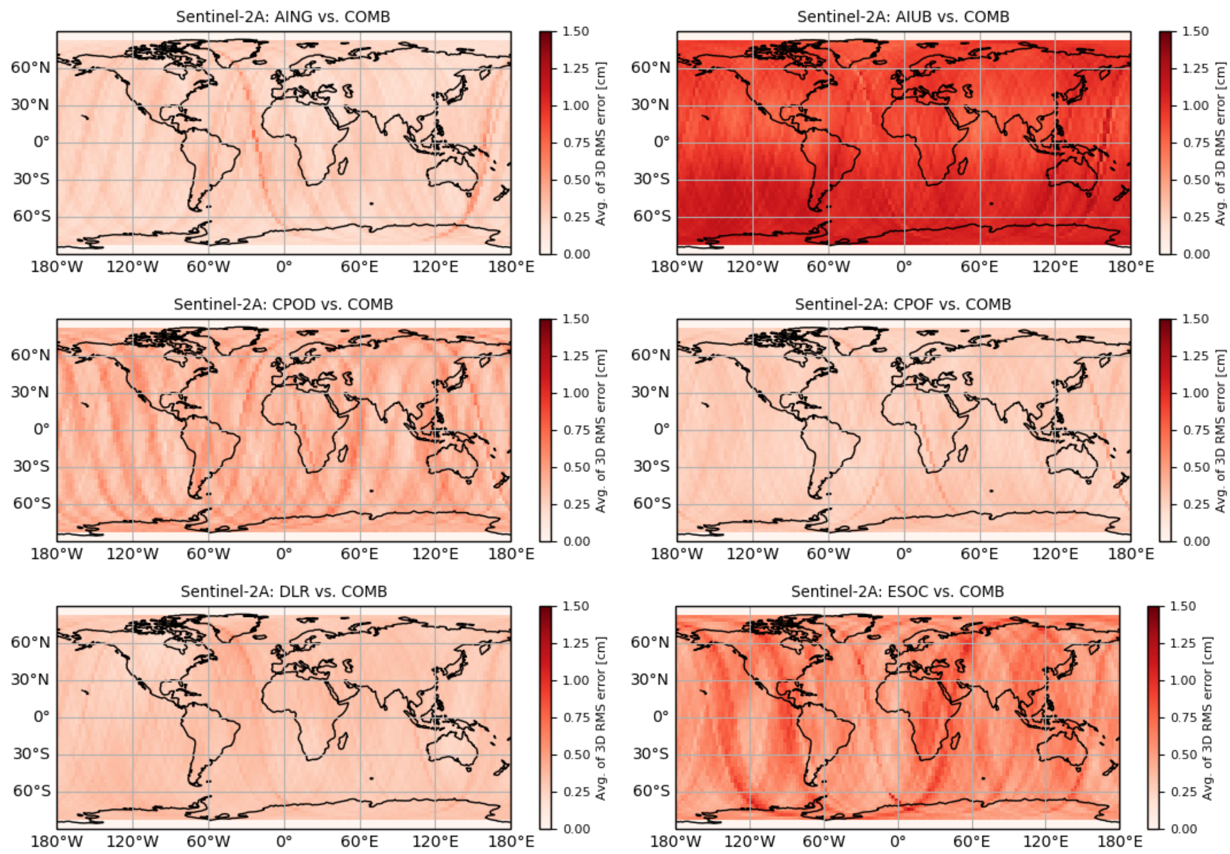
Orbit Comparisons (Mean of daily RMS [cm])					
Orbit Solution	Centre	Satellite component			
		Radial	Along-track	Cross-track	3D
AING	**AIUB**	0.15	0.20	0.14	0.29
AIUB	**AIUB**	0.91	0.36	0.21	1.00
CPOD	**CPOD**	0.23	0.30	0.24	0.45
CPOF	**CPOD**	0.18	0.21	0.16	0.32
DLR	**DLR**	0.24	0.18	0.16	0.34

Orbit Comparisons (Mean of daily RMS [cm])					
Orbit Solution	Centre	Satellite component			
		Radial	Along-track	Cross-track	3D
ESOC	**ESOC**	0.24	0.38	0.46	0.64
GFZ	**GFZ**	0.46	0.99	0.67	1.30
TUDF	**TUD**	0.39	0.47	0.36	0.73
TUG	**TUG**	0.15	0.21	0.18	0.32
TUM	**TUM**	0.27	0.37	0.22	0.51

The Sentinel-2A orbit solutions generated by the CPOD Service show a performance in line with the results obtained on the other solutions.

3.2.3. GEOGRAPHICAL ANALYSIS

Figure 3-10 shows the 3D RMS orbit comparisons calculated on the previous sub section projected on an equi-rectangular map plot. Each cell of the map contains the mean value of all orbit comparisons falling on this cell during the reported period.



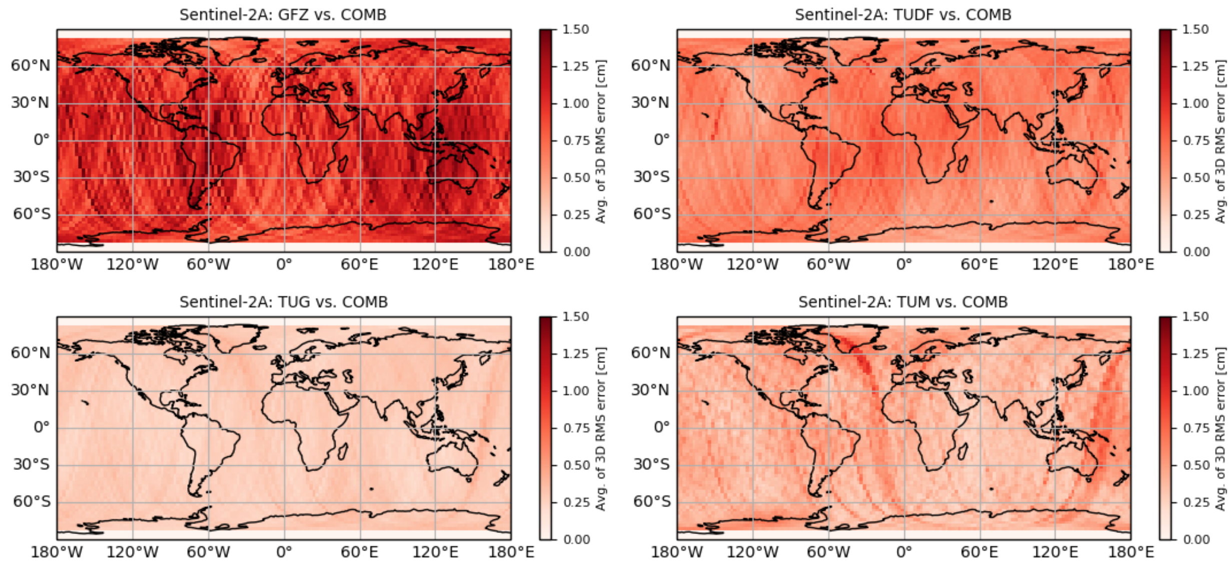
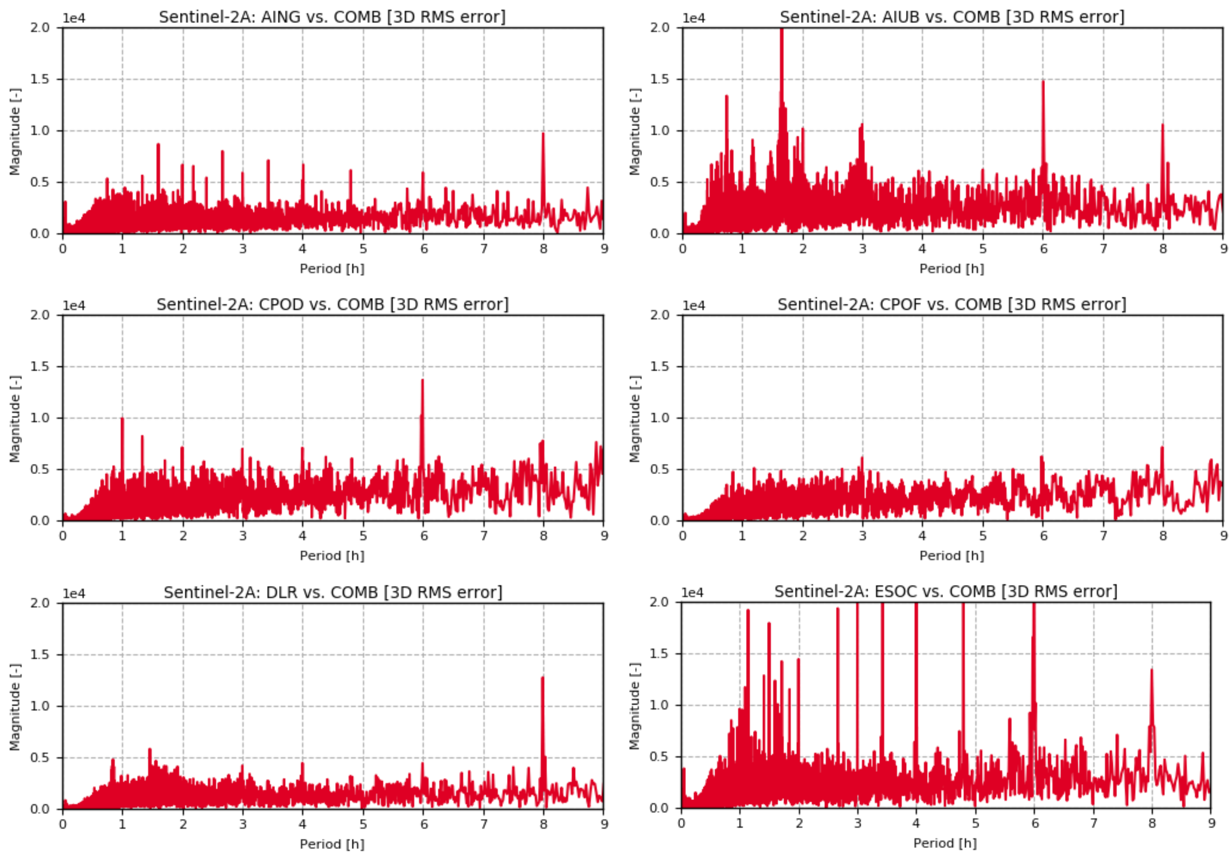


Figure 3-10: Sentinel-2A geographical analysis – Average of the 3D RMS orbit comparisons (All vs. COMB)

3.2.4. SPECTRAL ANALYSIS

Figure 3-11 shows the FFT of the 3D RMS orbit comparisons calculated on the previous sub section.



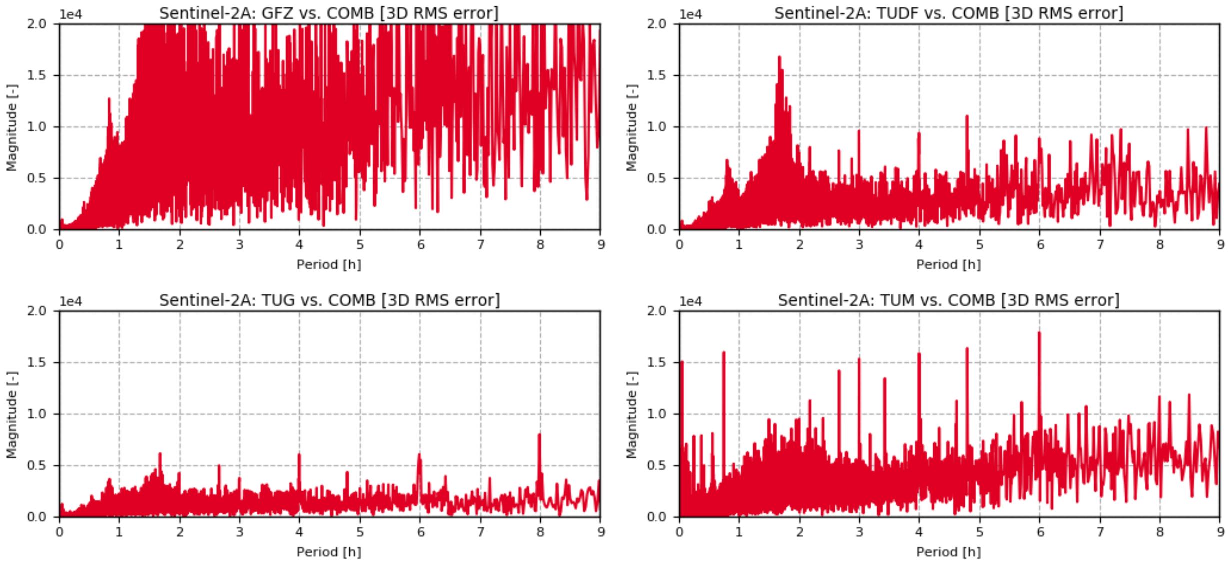


Figure 3-11: Sentinel-2A spectral analysis – 3D RMS orbit comparisons (All vs. COMB)

3.2.5. ORBIT COMPARISONS OF S-2A STC ORBIT SOLUTIONS

The operational S-2 STC solutions from the CPOD Service (labelled as CPOR) and TUD rapid solution are compared here against the combined solution.

TUD is currently generating one STC orbit solution for Sentinel-2A, which has been labelled as **TUDR.** This STC orbit solution is based on rapid GNSS products from JPL (with high-rate clocks).

Figure 3-29 shows the 3D RMS accuracy of the orbit solutions for all the reported period. As seen in the figure, the TUD solutions offer the best performance, similar to the performance shown by the TUDF NTC solution, thanks to the use of integer ambiguity resolution.

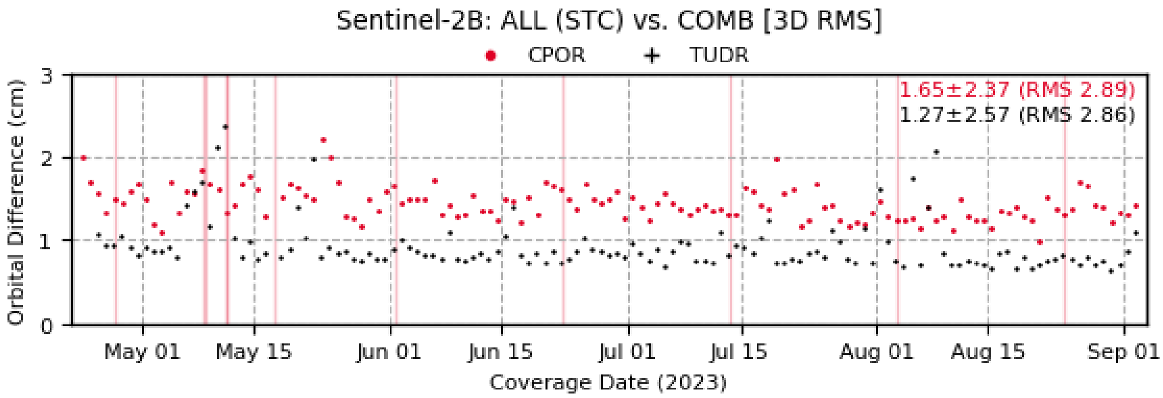


Figure 3-12: Sentinel-2A orbit comparisons – All (STC) vs. COMB [3D RMS; cm]

A more detailed distribution of the obtained accuracy can be found in Table 3-16, where the percentiles of the 3D RMS is calculated for different thresholds.

Table 3-7: Sentinel-2A STC (all) solutions – Accuracy percentiles (orbit comparisons against COMB solution [3D RMS], respectively)

Product Accuracy		
Threshold	Percentage of Fulfilment	
	CPOR	TUDR
< 1 cm	0.00 %	81.20 %
< 2 cm	96.24 %	97.74 %
< 3 cm	100.00 %	97.74 %
< 4 cm	100.00 %	98.50 %

3.3. SENTINEL-2B

3.3.1. STATISTICS OF THE GENERATION OF THE SOLUTION COMB

Figure 3-13 shows the daily distribution per orbit solution of the weights used to generate the combined Sentinel-2B orbit solution. A summary of these values can be found in Table 3-8, where the mean values of these calculated weights are presented. It must be remarked that a higher value on the weights means a more contribution of the orbit solution to the generation of the combined orbit solution.

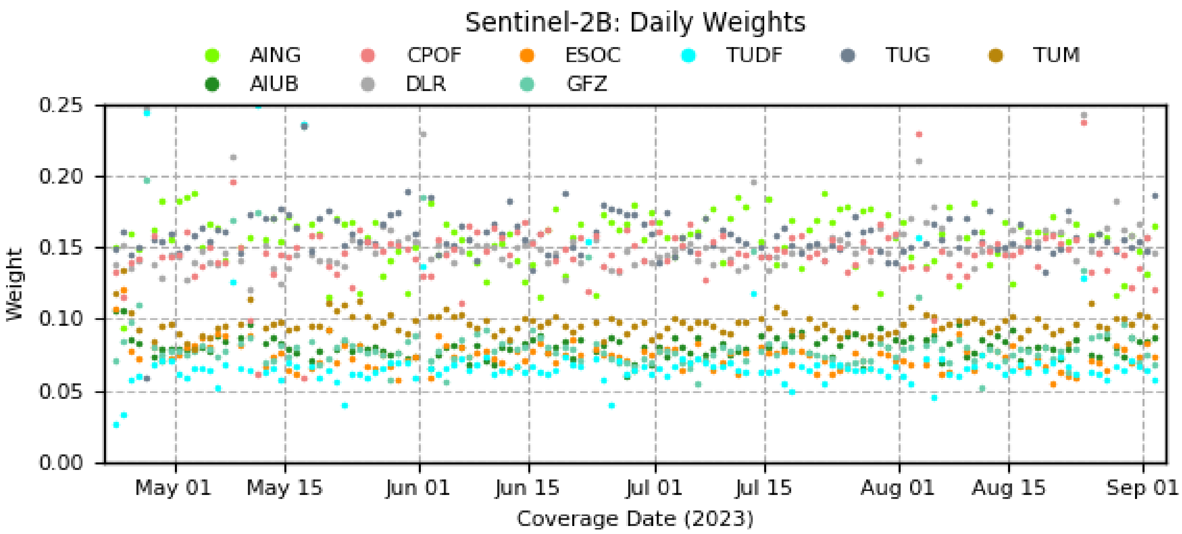


Figure 3-13: Sentinel-2B COMB generation – Daily weights of ALL orbit solutions

Table 3-8: Sentinel-2B COMB generation – Mean of the daily weights of ALL orbit solutions

Daily Weights		
Orbit Solution	**Centre**	**Mean**
AING	**AIUB**	0.16
AIUB	**AIUB**	0.08
CPOF	**CPOD**	0.15
DLR	**DLR**	0.15
ESOC	**ESOC**	0.07
GFZ	**GFZ**	0.08
TUDF	**TUD**	0.07
TUG	**TUG**	0.16
TUM	**TUM**	0.10

3.3.2. TEMPORAL EVOLUTION OF THE ORBITS COMPARISONS

Figure 3-14 shows the temporal evolution of the orbit comparisons [3D RMS] between all Sentinel-2B orbit solutions provided by the different QWG centres and the combined orbit solution. A summary of these orbit comparisons can be found in Figure 3-15 and Table 3-8, where the mean of the daily RMS is calculated not only for the 3D RMS but also for other satellite components.

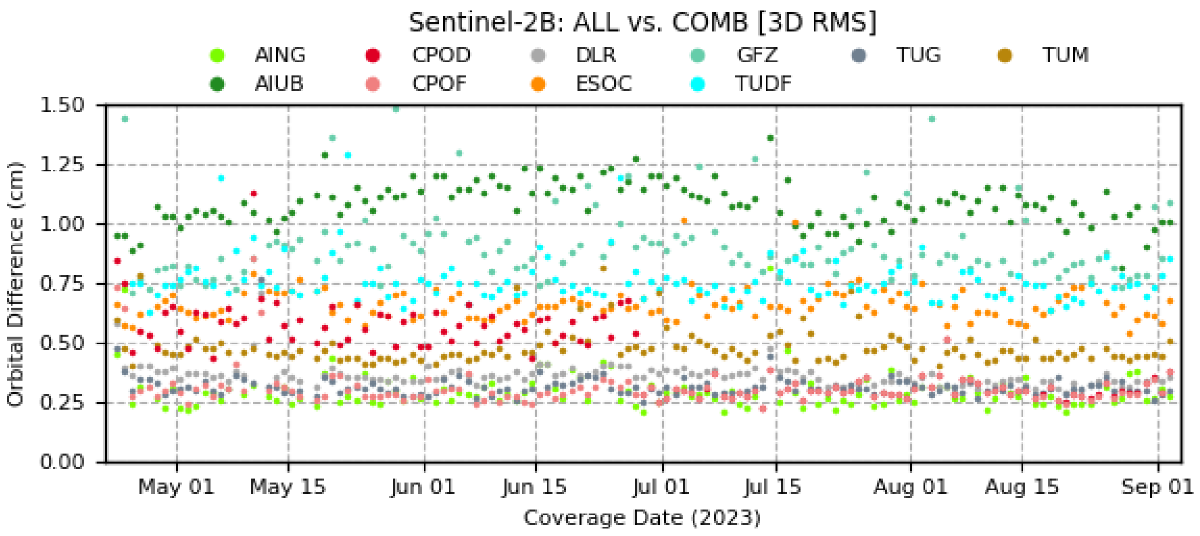


Figure 3-14: Sentinel-2B orbit comparisons – All vs. COMB [3D RMS; cm]

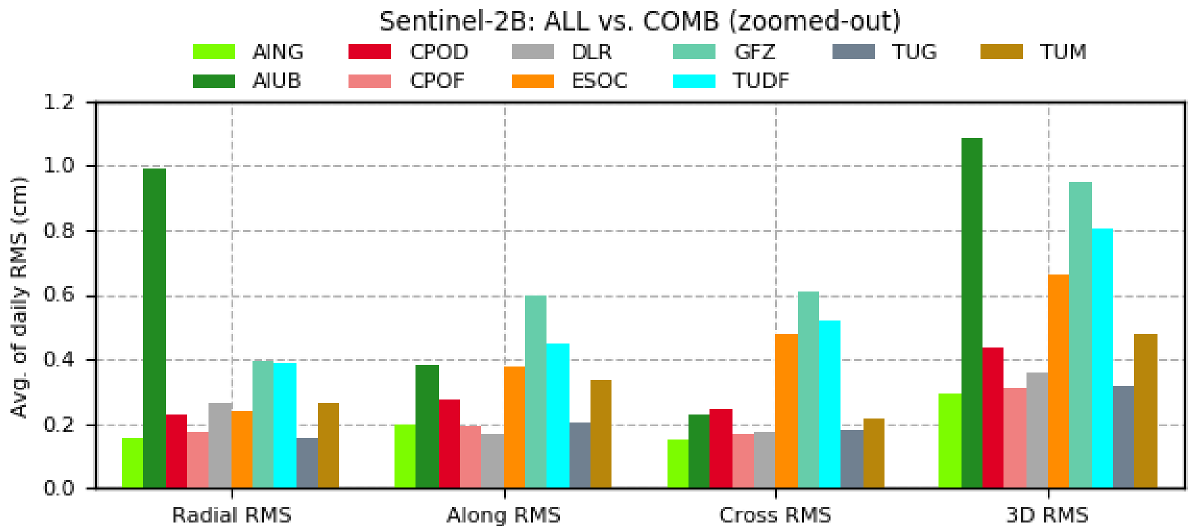


Figure 3-15: Sentinel-2B orbit comparisons – Mean of daily RMS [cm] (All vs. COMB [radial, along, cross and 3D RMS])

Table 3-9: Sentinel-2B orbit comparisons – Mean of daily RMS [cm] (All vs. COMB)

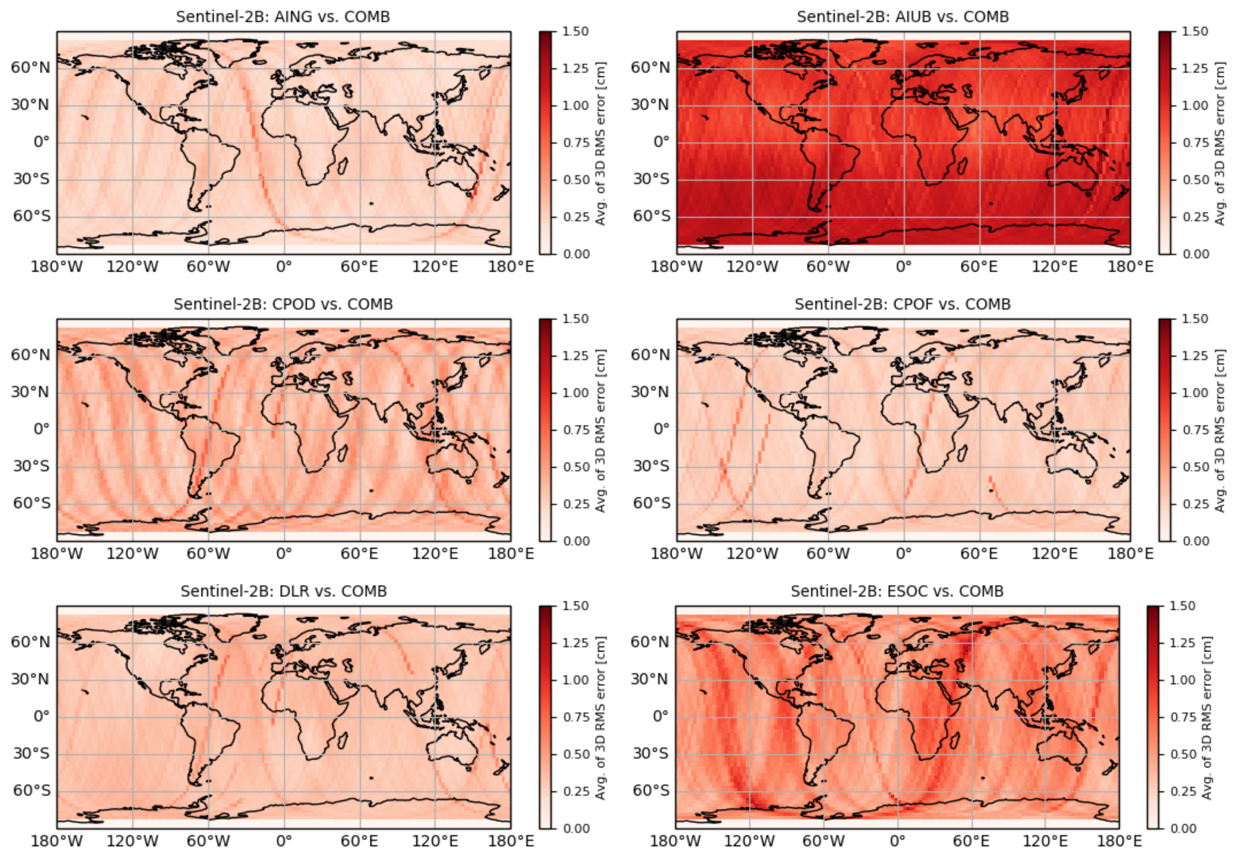
Orbit Comparisons (Mean of daily RMS [cm])					
Orbit Solution	Centre	Satellite component			
		Radial	Along-track	Cross-track	3D
AING	**AIUB**	0.15	0.20	0.15	0.29
AIUB	**AIUB**	0.99	0.38	0.23	1.08
CPOD	**CPOD**	0.23	0.28	0.24	0.44
CPOF	**CPOD**	0.17	0.19	0.17	0.31
DLR	**DLR**	0.26	0.17	0.17	0.36

Orbit Comparisons (Mean of daily RMS [cm])					
Orbit Solution	Centre	Satellite component			
		Radial	Along-track	Cross-track	3D
ESOC	**ESOC**	0.24	0.38	0.48	0.66
GFZ	**GFZ**	0.39	0.60	0.61	0.95
TUDF	**TUD**	0.39	0.45	0.52	0.81
TUG	**TUG**	0.15	0.20	0.18	0.31
TUM	**TUM**	0.27	0.33	0.21	0.48

The Sentinel-2B orbit solutions generated by the CPOD Service show a performance in line with the results obtained on the other solutions.

3.3.3. GEOGRAPHICAL ANALYSIS

Figure 3-16 shows the 3D RMS orbit comparisons calculated on the previous sub section projected on an equi-rectangular map plot. Each cell of the map contains the mean value of all orbit comparisons falling on this cell during the reported period.



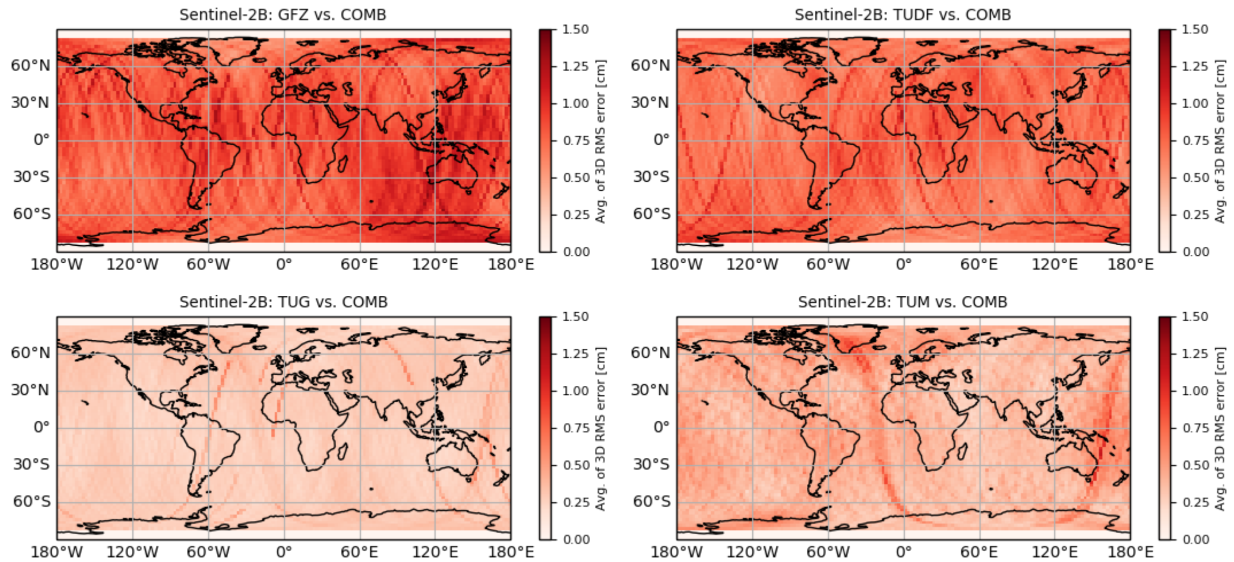
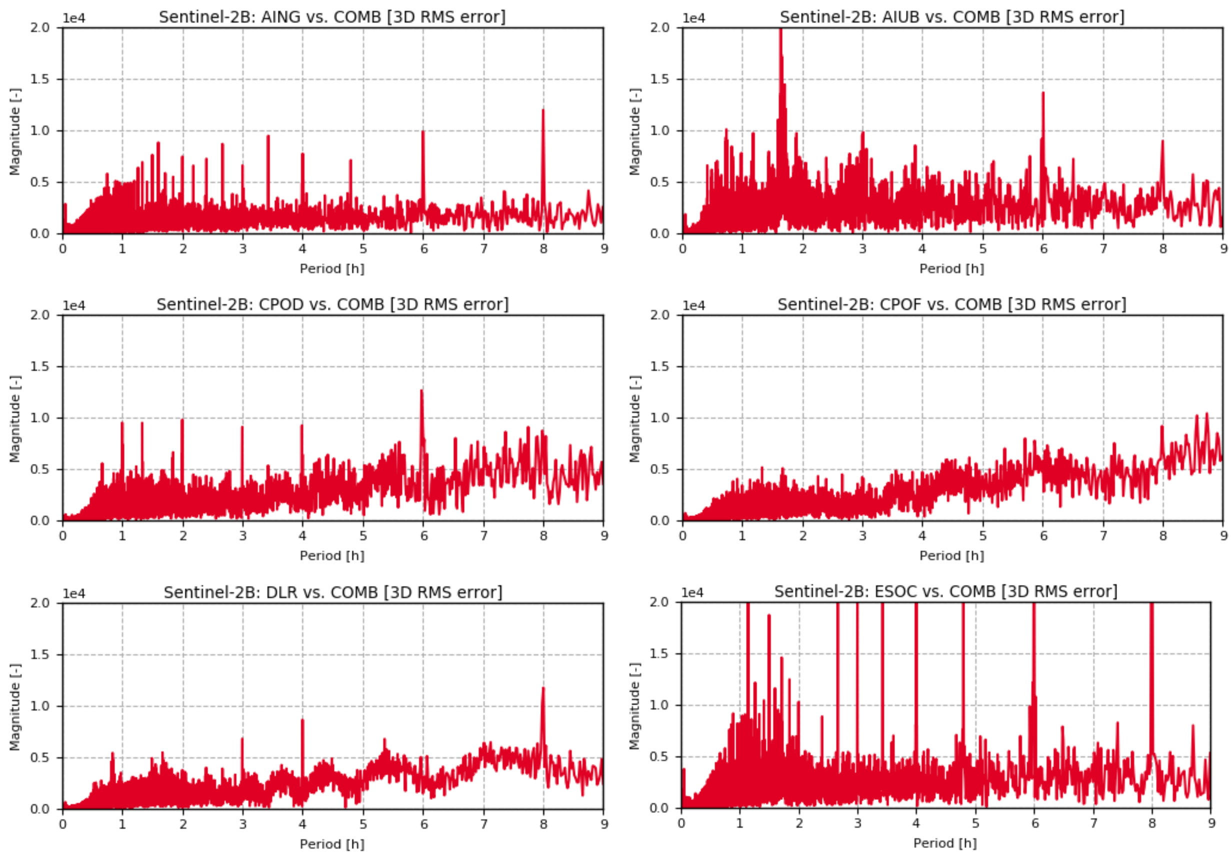


Figure 3-16: Sentinel-2B geographical analysis – Average of the 3D RMS orbit comparisons (All vs. COMB)

3.3.4. SPECTRAL ANALYSIS

Figure 3-17 shows the FFT of the 3D RMS orbit comparisons calculated on the previous sub section.



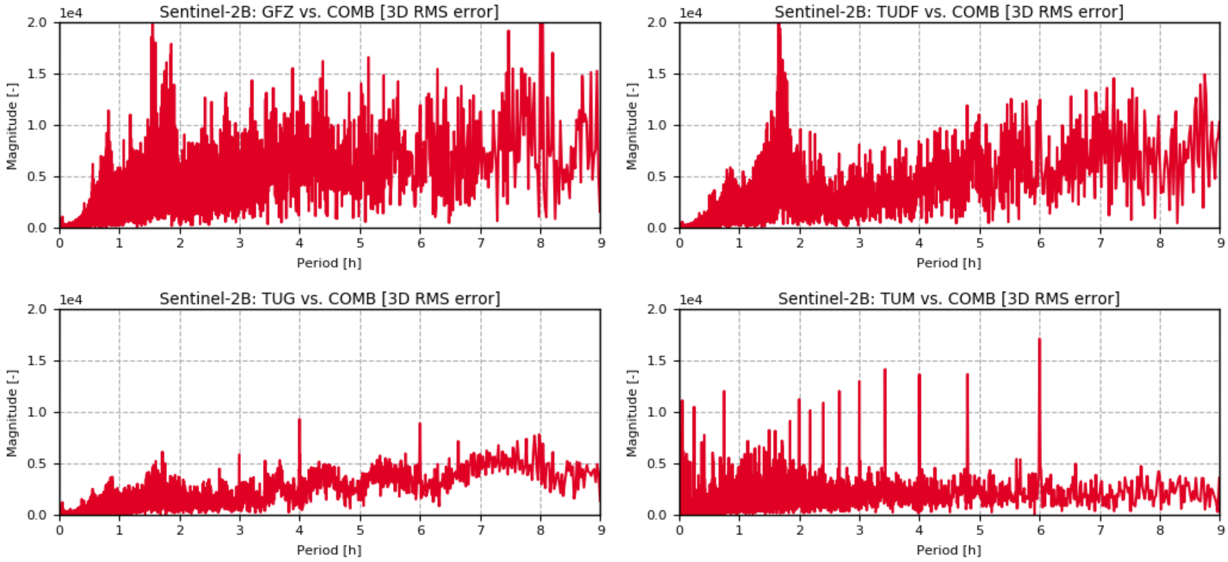


Figure 3-17: Sentinel-2B spectral analysis – 3D RMS orbit comparisons (All vs. COMB)

3.3.5. ORBIT COMPARISONS OF S-2B STC ORBIT SOLUTIONS

The operational S-2 STC solutions from the CPOD Service (labelled as CPOR) and TUD rapid solution are compared here against the combined solution.

TUD is currently generating one STC orbit solution for Sentinel-2B, which has been labelled as **TUDR.** This STC orbit solution is based on rapid GNSS products from JPL (with high-rate clocks).

Figure 3-29 shows the 3D RMS accuracy of the orbit solutions for all the reported period. As seen in the figure, the TUD solutions offer the best performance, similar to the performance shown by the TUDF NTC solution, thanks to the use of integer ambiguity resolution.

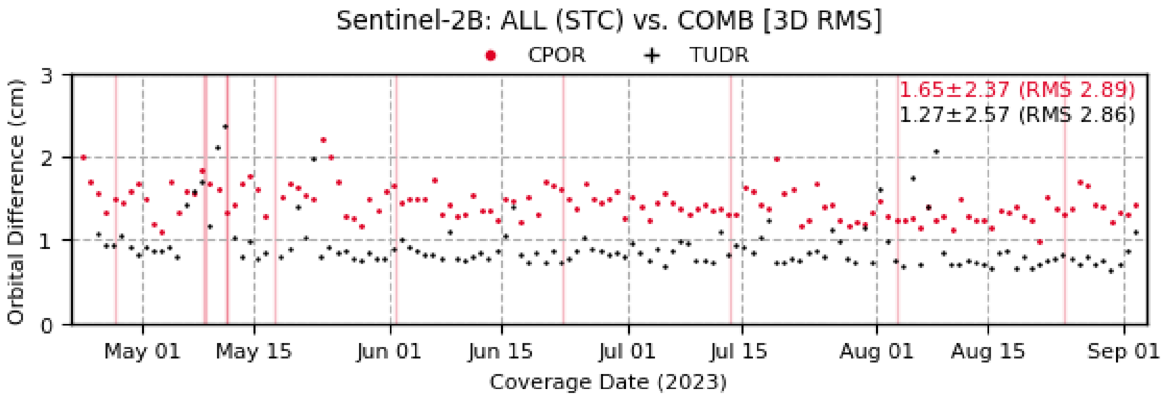


Figure 3-18: Sentinel-2B orbit comparisons – All (STC) vs. COMB [3D RMS; cm]

A more detailed distribution of the obtained accuracy can be found in Table 3-16, where the percentiles of the 3D RMS is calculated for different thresholds.

Table 3-10: Sentinel-2B STC (all) solutions – Accuracy percentiles (orbit comparisons against COMB solution [3D RMS], respectively)

Product Accuracy		
Threshold	Percentage of Fulfilment	
	CPOR	TUDR
< 1 cm	0.75 %	77.44 %
< 2 cm	97.74 %	95.49 %
< 3 cm	99.25 %	97.74 %
< 4 cm	99.25 %	97.74 %

3.4. SENTINEL-3A

3.4.1. STATISTICS OF THE GENERATION OF THE SOLUTION COMB

Figure 3-19 shows the daily distribution per orbit solution of the weights used to generate the combined Sentinel-3A orbit solution. A summary of these values can be found in Table 3-11, where the mean values of these calculated weights are presented. It must be remarked that a higher value on the weights means a more contribution of the orbit solution to the generation of the combined orbit solution.

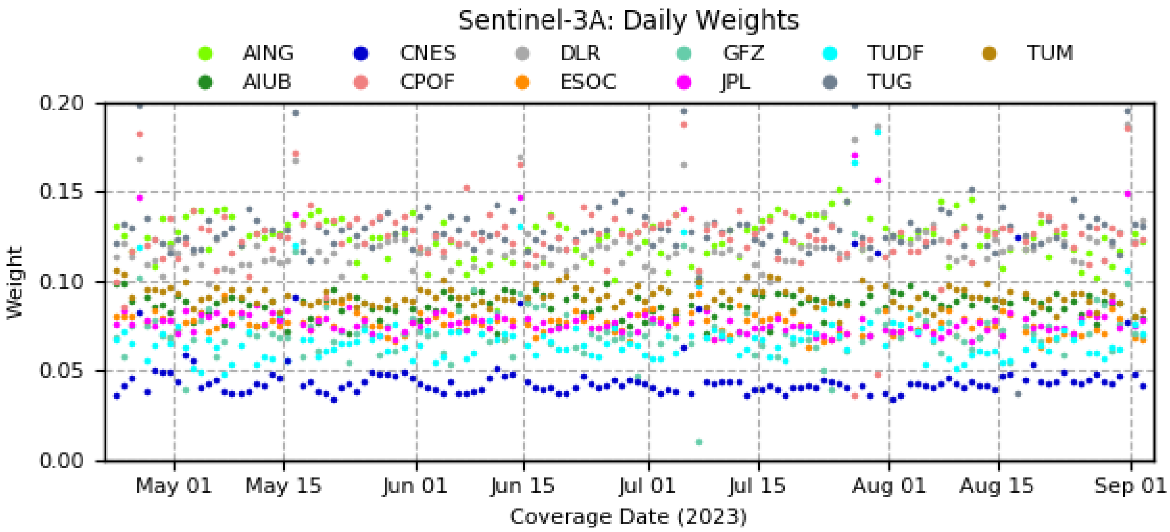


Figure 3-19: Sentinel-3A COMB generation – Daily weights of ALL orbit solutions

Table 3-11: Sentinel-3A COMB generation – Mean of the daily weights of ALL orbit solutions

Daily Weights		
Orbit Solution	Centre	Mean
AING	**AIUB**	0.12
AIUB	**AIUB**	0.09
CNES	**CNES**	0.05
CPOF	**CPOD**	0.13
DLR	**DLR**	0.12
ESOC	**ESOC**	0.08
GFZ	**GFZ**	0.07
JPL	**JPL**	0.08
TUDF	**TUD**	0.07
TUG	**TUG**	0.13
TUM	**TUM**	0.09

3.4.2. TEMPORAL EVOLUTION OF THE ORBITS COMPARISONS

Figure 3-20 and Figure 3-21 show the temporal evolution of the orbit comparisons [radial and 3D RMS] between all Sentinel-3A orbit solutions provided by the different QWG centres and the combined

orbit solution. A summary of these orbit comparisons can be found in Figure 3-22 and Table 3-12, where the mean of the daily RMS is calculated not only for the 3D RMS but also for other satellite components.

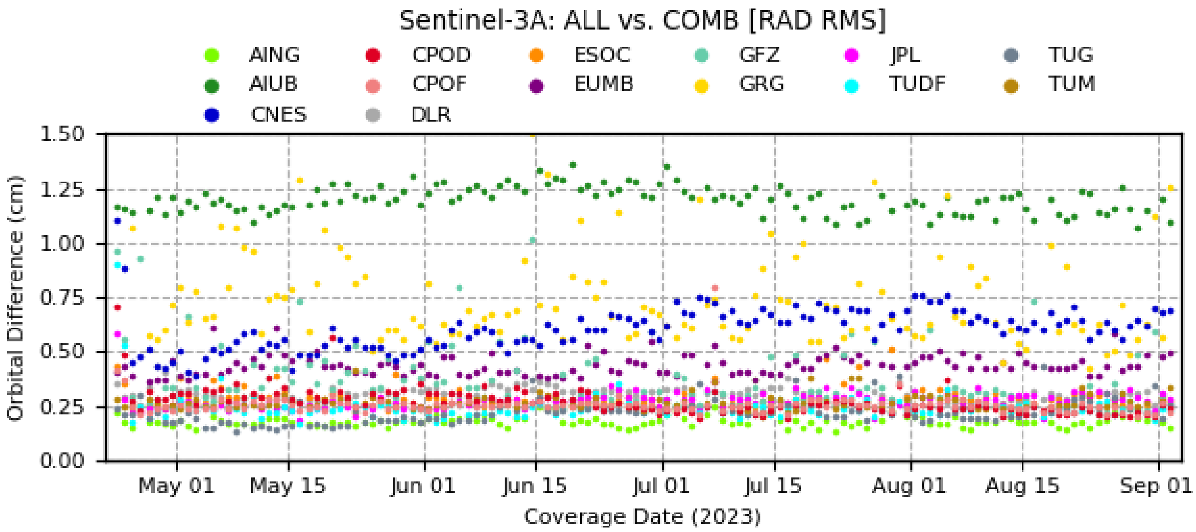


Figure 3-20: Sentinel-3A orbit comparisons – All vs. COMB [radial RMS; cm]

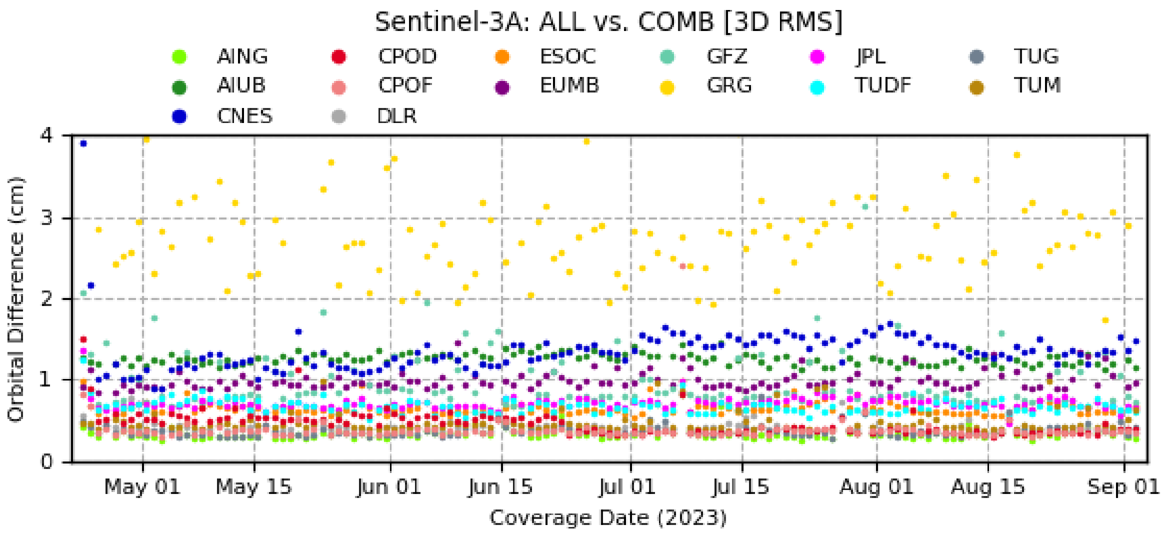


Figure 3-21: Sentinel-3A orbit comparisons – All vs. COMB [3D RMS; cm]

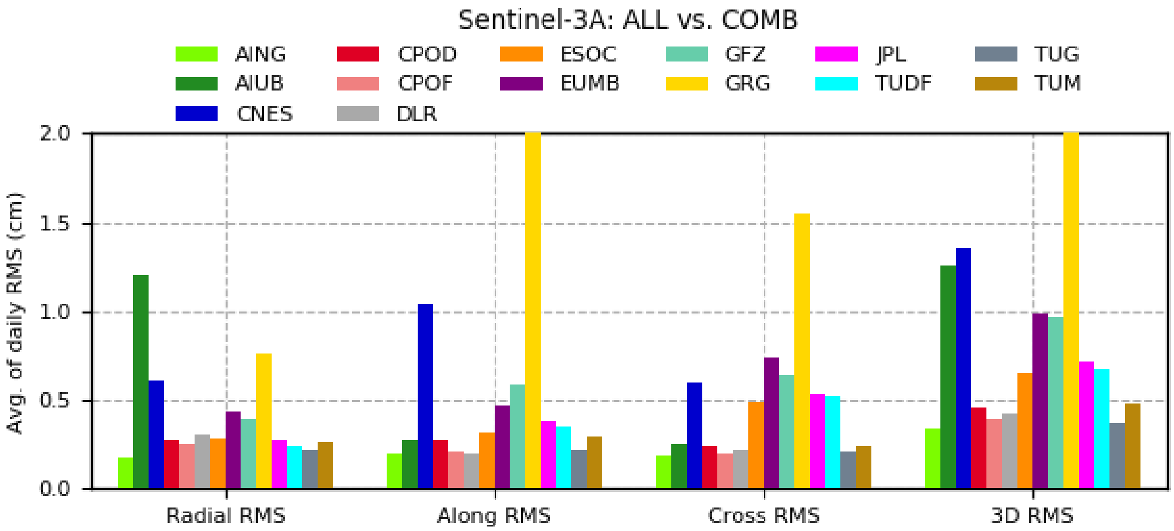


Figure 3-22: Sentinel-3A orbit comparisons – Mean of daily RMS [cm] (All vs. COMB [radial, along, cross and 3D RMS])

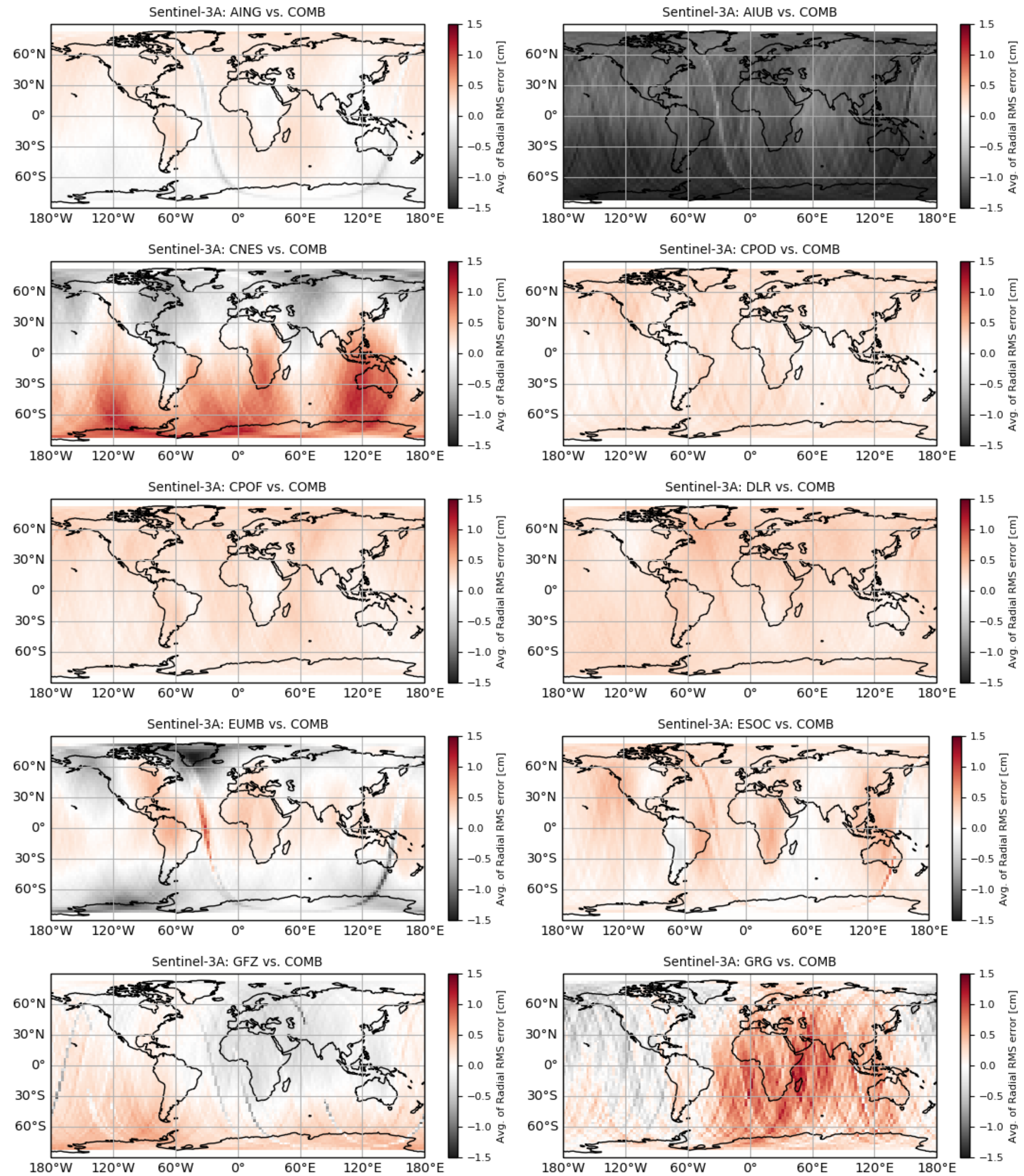
Table 3-12: Sentinel-3A orbit comparisons – Mean of daily RMS [cm] (All vs. COMB)

Orbit Comparisons (Mean of daily RMS [cm])					
Orbit Solution	Centre	Satellite component			
		Radial	Along-track	Cross-track	3D
AING	**AIUB**	0.18	0.20	0.19	0.33
AIUB	**AIUB**	1.20	0.27	0.25	1.26
CNES	**CNES**	0.61	1.05	0.60	1.35
CPOD	**CPOD**	0.27	0.28	0.24	0.46
CPOF	**CPOD**	0.26	0.21	0.19	0.39
DLR	**DLR**	0.30	0.19	0.22	0.43
ESOC	**ESOC**	0.28	0.31	0.49	0.65
EUMB	**EUMB**	0.44	0.47	0.74	0.99
GFZ	**GFZ**	0.39	0.58	0.64	0.97
GRG	**GRG**	0.76	2.41	1.55	3.02
JPL	**JPL**	0.27	0.38	0.53	0.71
TUDF	**TUD**	0.24	0.35	0.52	0.68
TUG	**TUG**	0.22	0.22	0.20	0.37
TUM	**TUM**	0.27	0.30	0.24	0.47

The Sentinel-3A orbit solutions generated by the CPOD Service show a performance in line with the results obtained on the other solutions.

3.4.3. GEOGRAPHICAL ANALYSIS

Figure 3-23 shows the 3D RMS orbit comparisons calculated on the previous sub section projected on an equi-rectangular map plot. Each cell of the map contains the mean value of all orbit comparisons falling on this cell during the reported period.



Sentinel-3A: AING vs. COMB
Sentinel-3A: AIUB vs. COMB
Sentinel-3A: CNES vs. COMB
Sentinel-3A: CPOD vs. COMB
Sentinel-3A: CPOF vs. COMB
Sentinel-3A: DLR vs. COMB
Sentinel-3A: EUMB vs. COMB
Sentinel-3A: ESOC vs. COMB
Sentinel-3A: GFZ vs. COMB
Sentinel-3A: GRG vs. COMB
Avg. of Radial RMS error [cm]
180°W 120°W 60°W 0° 60°E 120°E 180°E
60°N 30°N 0° 30°S 60°S
1.5 1.0 0.5 0.0 −0.5 −1.0 −1.5

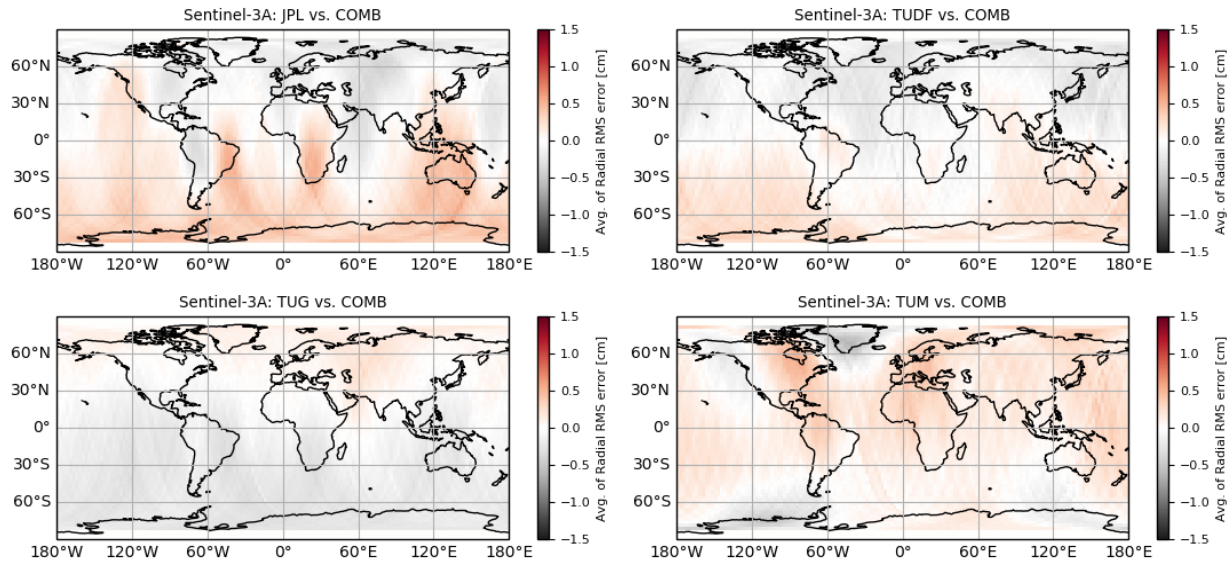
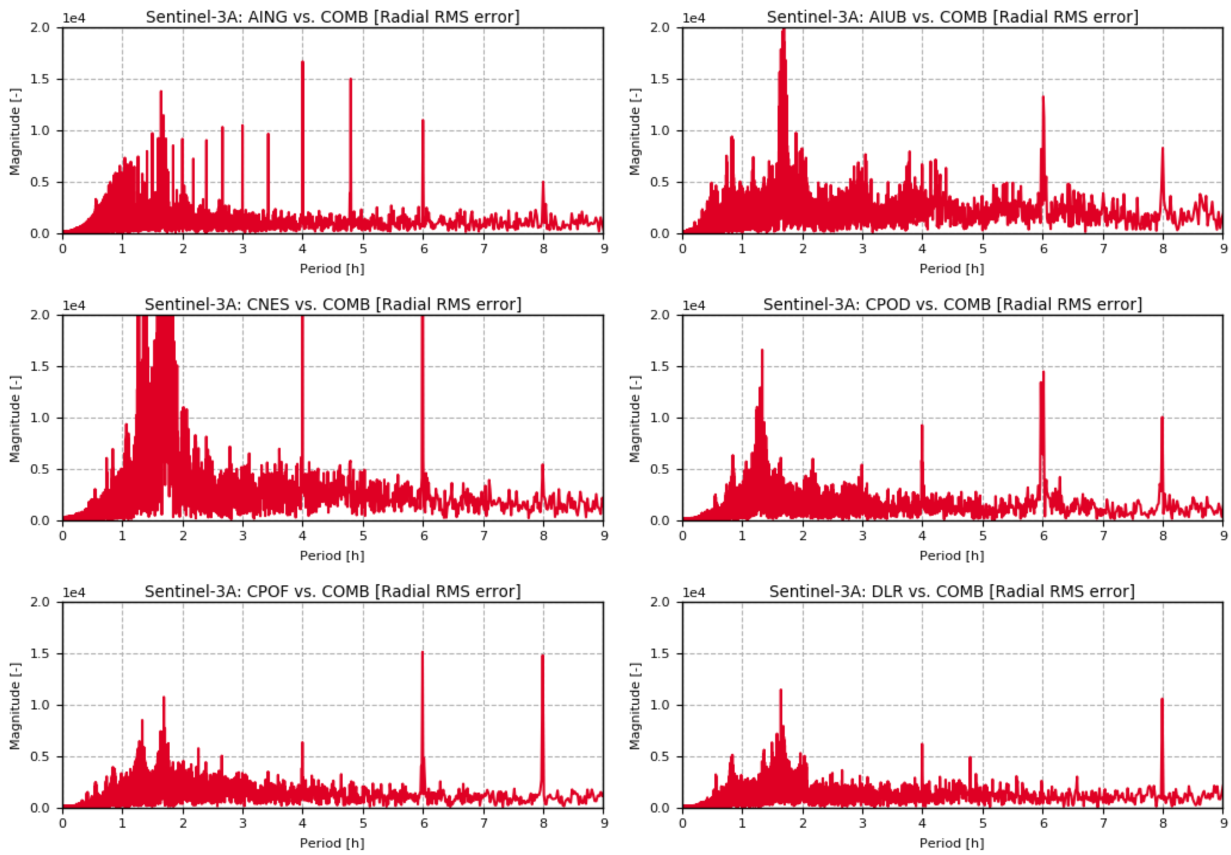


Figure 3-23: Sentinel-3A geographical analysis – Average of the radial RMS orbit comparisons (All vs. COMB)

3.4.4. SPECTRAL ANALYSIS

Figure 3-24 shows the FFT of the 3D RMS orbit comparisons calculated on the previous sub section.



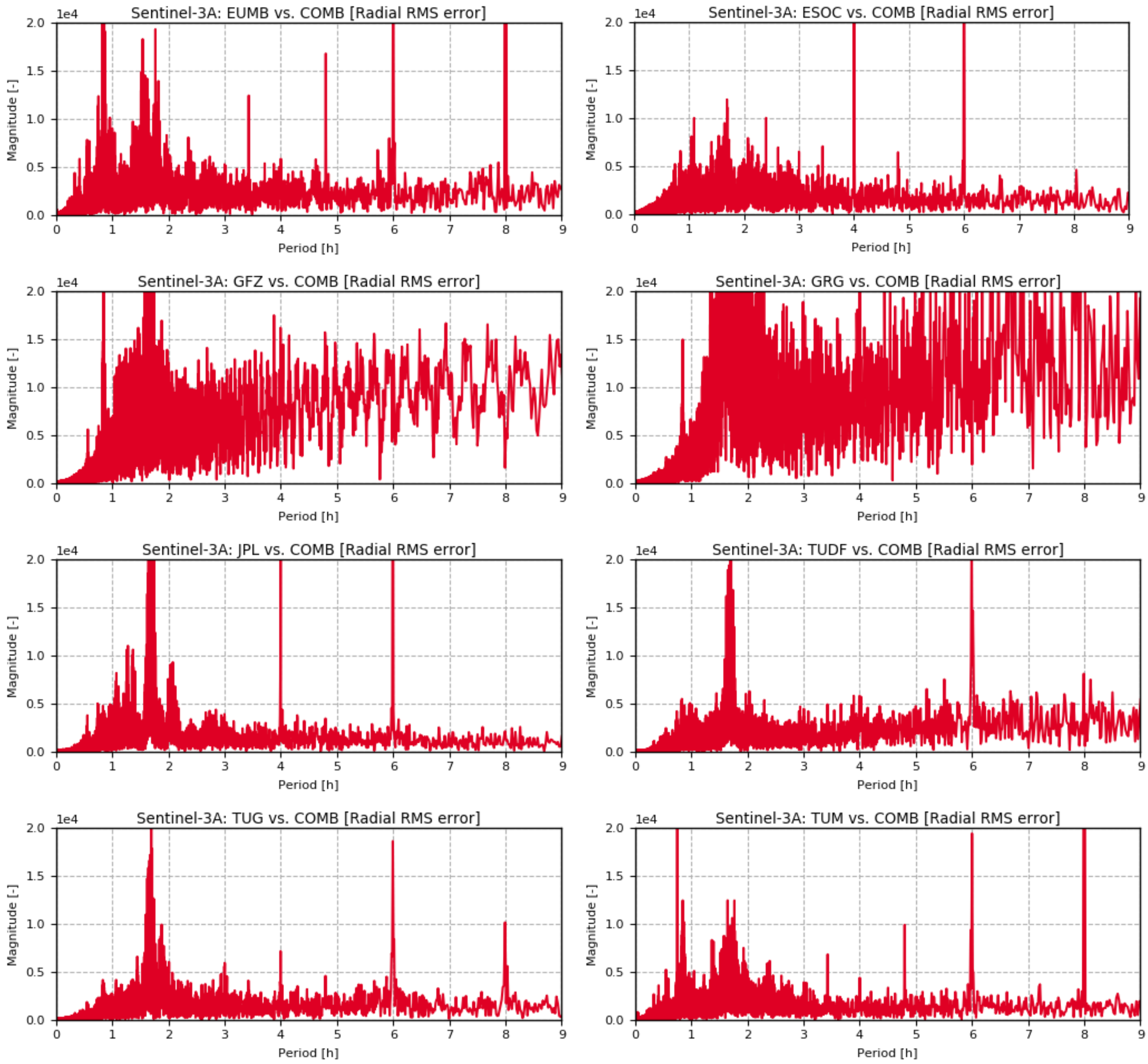


Figure 3-24: Sentinel-3A spectral analysis – Radial RMS orbit comparisons (All vs. COMB)

3.4.5. SLR VALIDATION

Figure 3-25 shows the accepted Sentinel-3A observations that the SLR stations have retrieved from the tracking of Sentinel-3A satellite during the reported period.

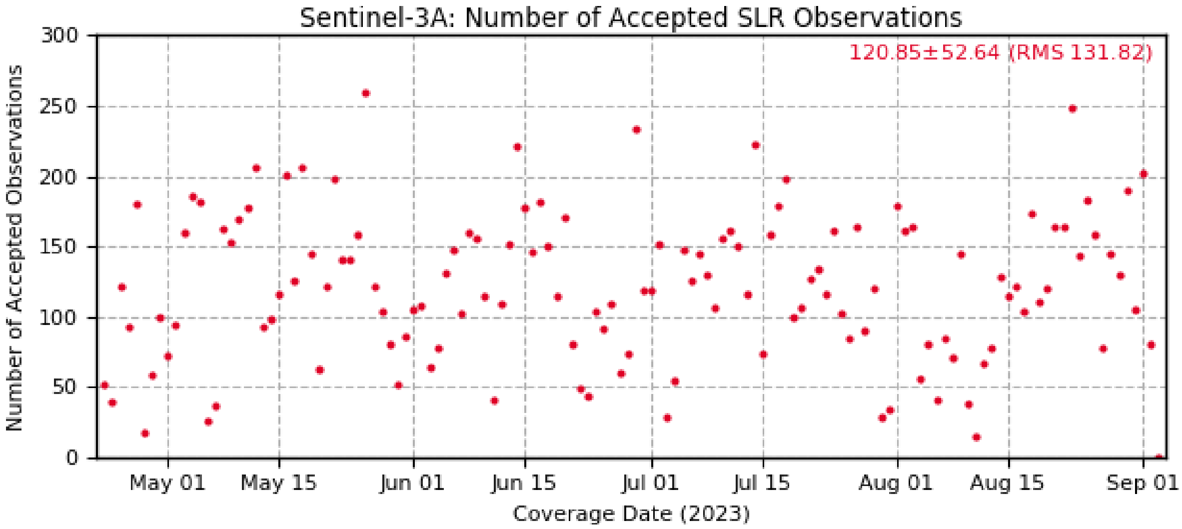
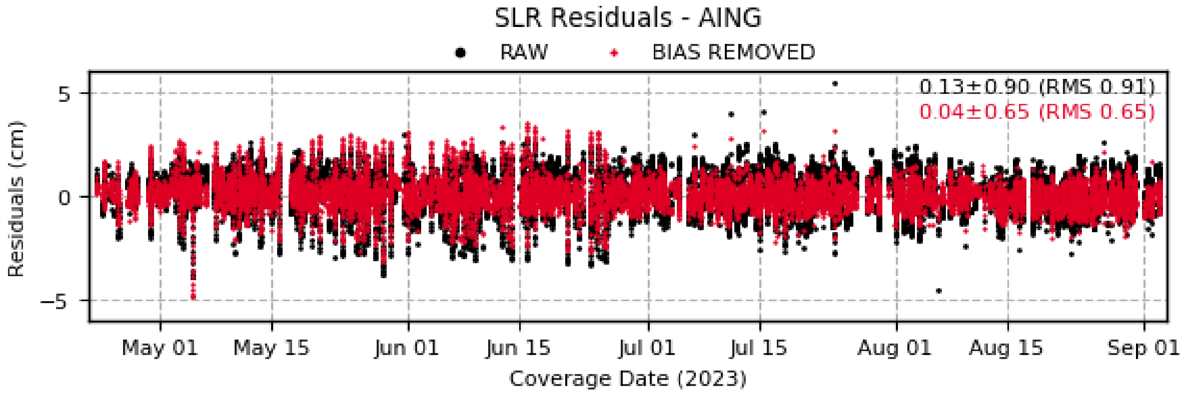


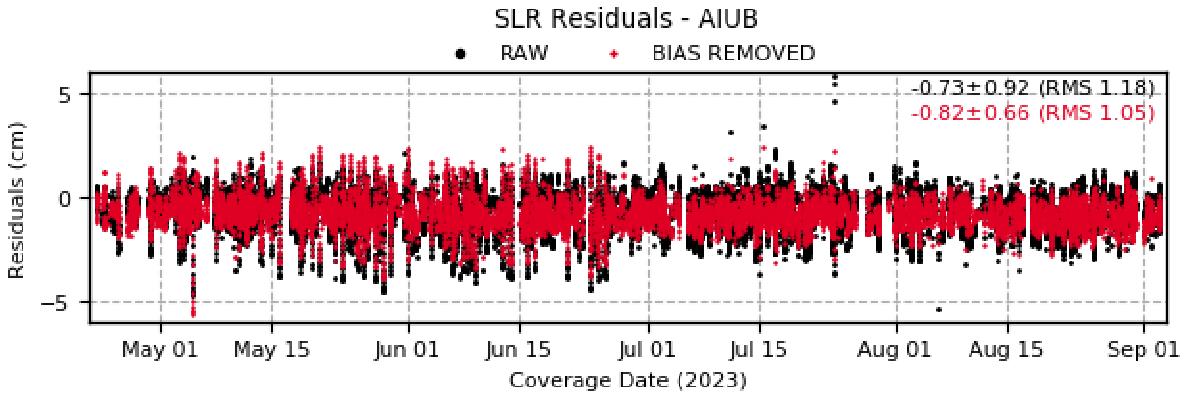
Figure 3-25: Sentinel-3A SLR validation – Number of accepted SLR observations

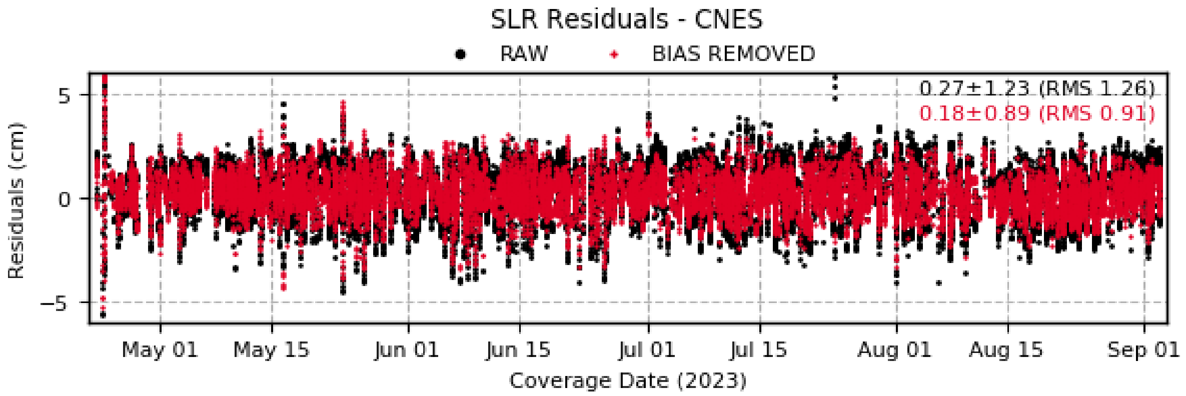
Figure 3-26 presents the temporal evolution of the Sentinel-3A SLR residuals that have been calculated from each orbit solution (**RAW**). It also shows the SLR residual that have been calculated by removing a constant bias affecting their generation (**BIAS REMOVED**). These biases are computed using the COMB solution, for elevations higher than 10 degrees, and estimating a single value per station for the whole period and all satellites (S-3A, S-3B, S-6A). Table 3-13 summarises the range biases per SLR station that have been considered during the processing of the SLR residuals.

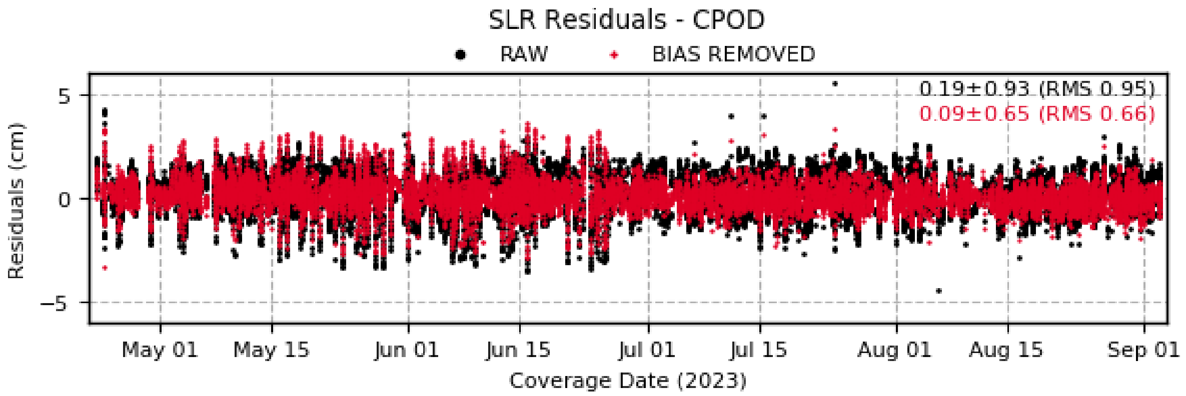
In Figure 3-26, the white spaces are due to punctual missing orbit solutions mainly caused by either manoeuvres or large gaps of data. Despite this fact, all SLR residuals of the different orbit solutions have behaved nominally, obtaining similar values as previous RSR documents. It can be seen that there is a decrease in the dispersion of the residuals since the end of June, which is due to the residuals obtained from the observations of one of the stations (7840) that improve after this date.

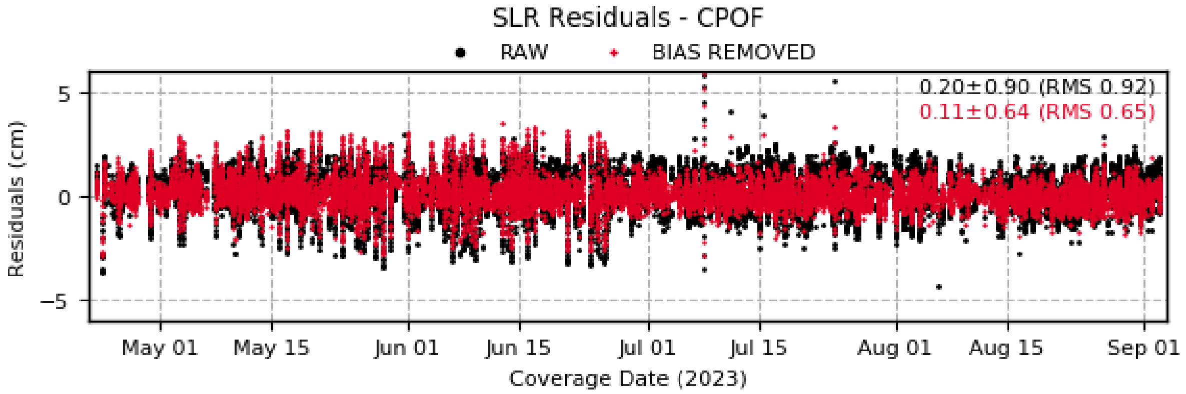
As a comment, the CNES SLR residuals may be higher than expected since the orbit solution **CNES** makes use of a POE-F standard, and the orbits have not been treated consistently regarding the geocentre motion they apply.

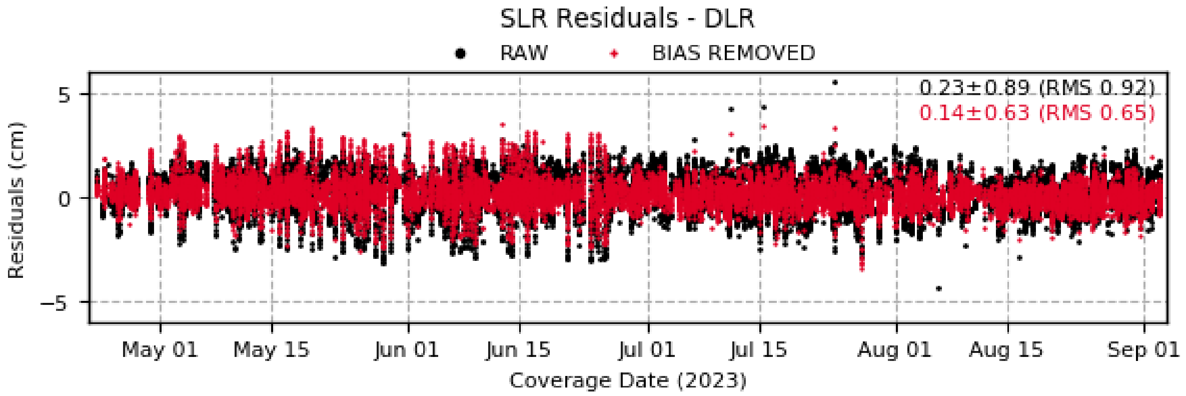

SLR Residuals - AING
RAW
BIAS REMOVED
0.13±0.90 (RMS 0.91)
0.04±0.65 (RMS 0.65)
Residuals (cm)
Coverage Date (2023)

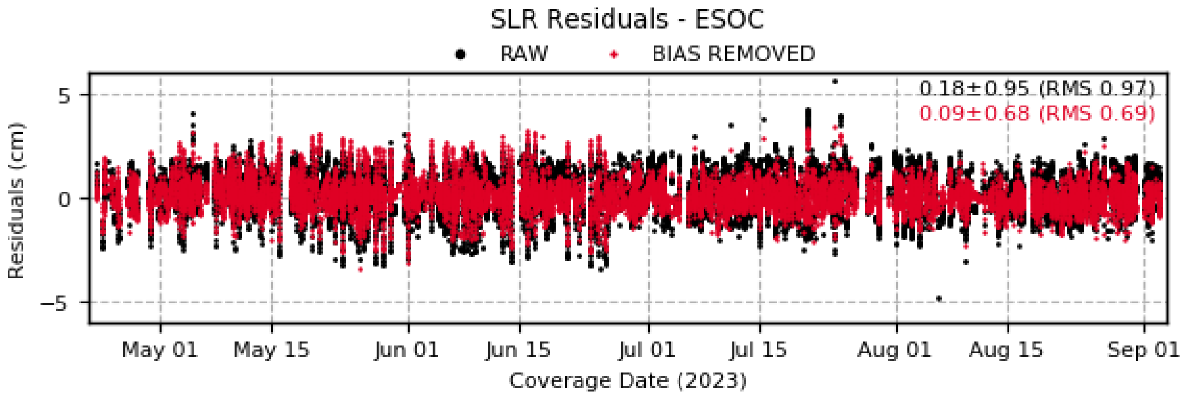

SLR Residuals - AIUB
RAW
BIAS REMOVED
-0.73±0.92 (RMS 1.18)
-0.82±0.66 (RMS 1.05)
Residuals (cm)
Coverage Date (2023)

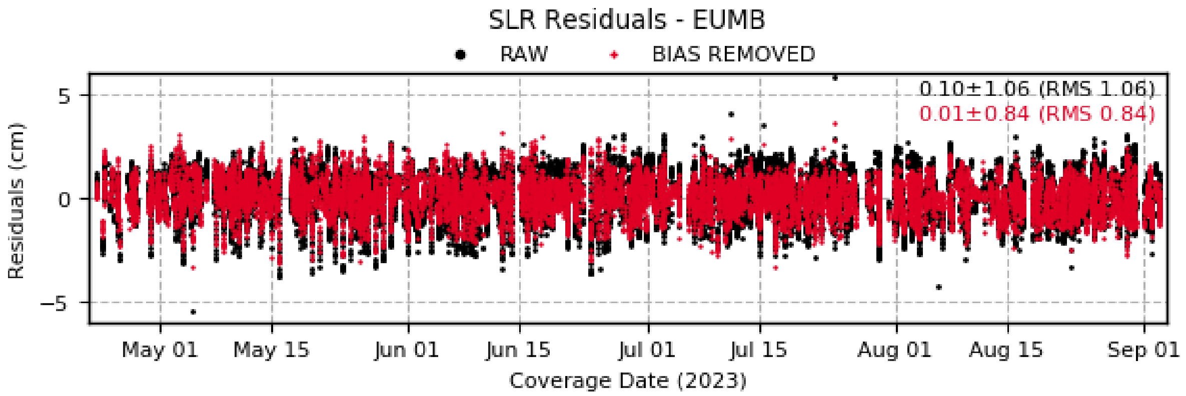

SLR Residuals - CNES
RAW
BIAS REMOVED
0.27±1.23 (RMS 1.26)
0.18±0.89 (RMS 0.91)
Residuals (cm)
Coverage Date (2023)

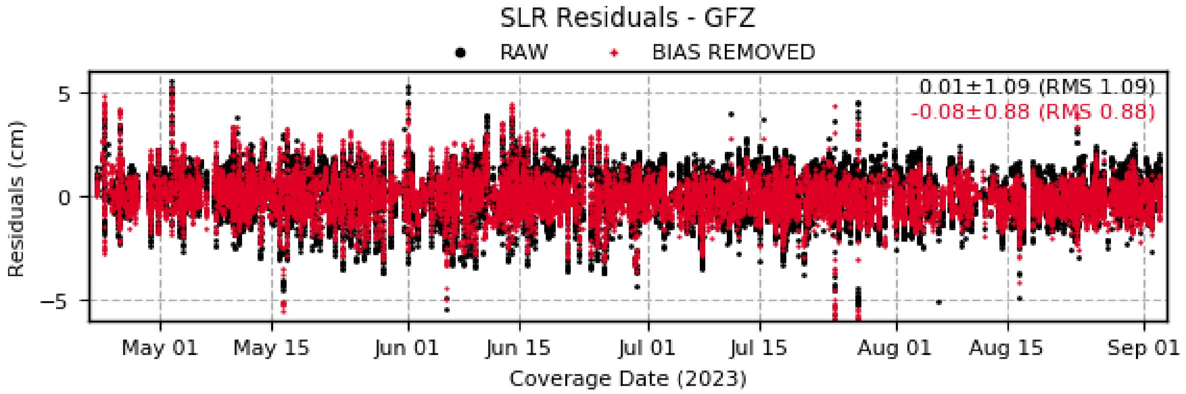

SLR Residuals - CPOD
RAW
BIAS REMOVED
0.19±0.93 (RMS 0.95)
0.09±0.65 (RMS 0.66)
Residuals (cm)
Coverage Date (2023)

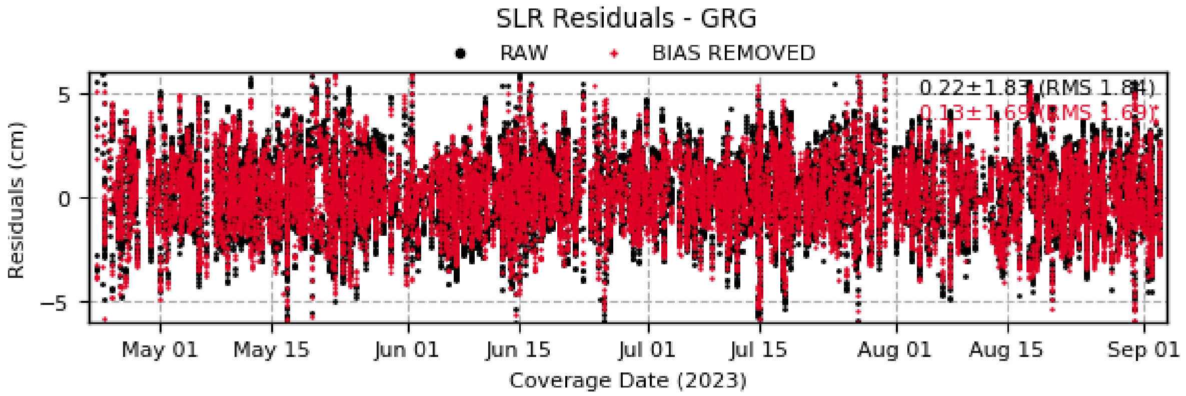

SLR Residuals - CPOF
RAW
BIAS REMOVED
0.20±0.90 (RMS 0.92)
0.11±0.64 (RMS 0.65)
Residuals (cm)
Coverage Date (2023)

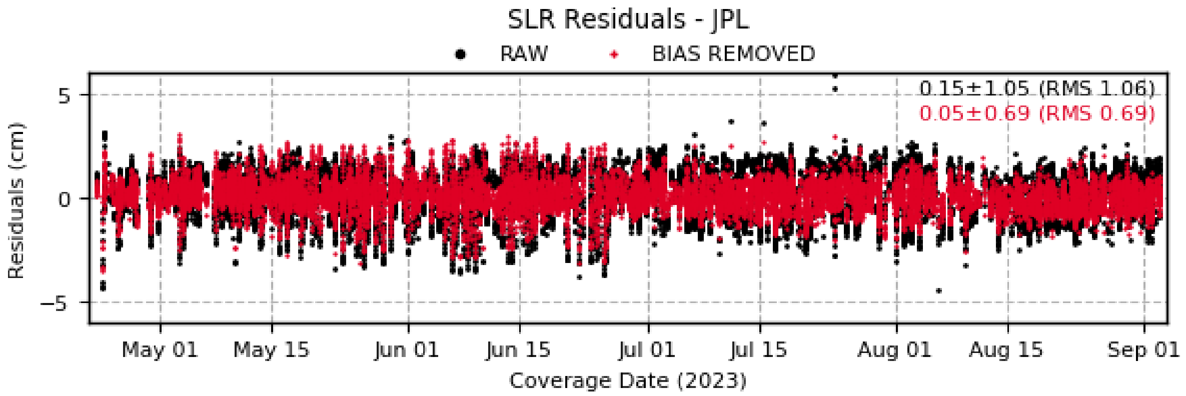

SLR Residuals - DLR
RAW
BIAS REMOVED
0.23±0.89 (RMS 0.92)
0.14±0.63 (RMS 0.65)
Residuals (cm)
Coverage Date (2023)

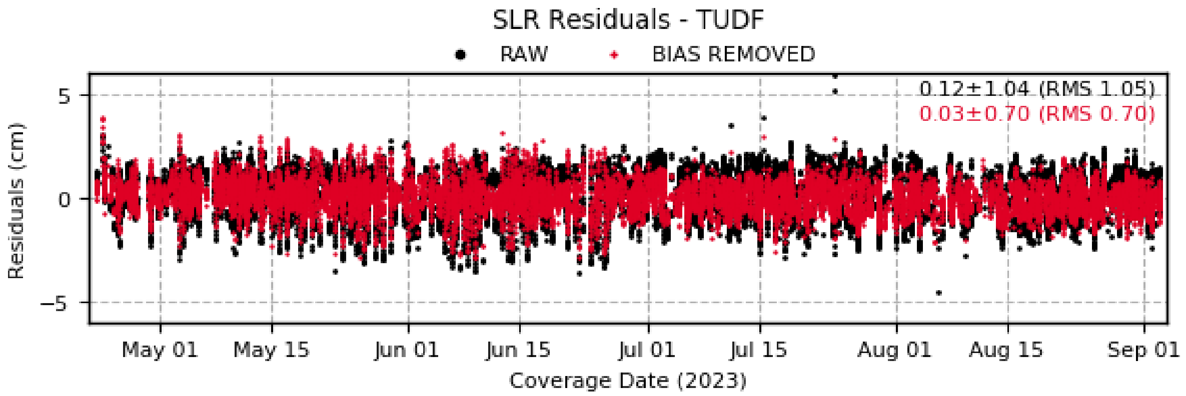

SLR Residuals - ESOC
RAW
BIAS REMOVED
0.18±0.95 (RMS 0.97)
0.09±0.68 (RMS 0.69)
Residuals (cm)
Coverage Date (2023)


SLR Residuals - EUMB
RAW
BIAS REMOVED
0.10±1.06 (RMS 1.06)
0.01±0.84 (RMS 0.84)
Residuals (cm)
Coverage Date (2023)


SLR Residuals - GFZ
RAW
BIAS REMOVED
0.01±1.09 (RMS 1.09)
-0.08±0.88 (RMS 0.88)
Residuals (cm)
5
0
−5
May 01
May 15
Jun 01
Jun 15
Jul 01
Jul 15
Aug 01
Aug 15
Sep 01
Coverage Date (2023)


SLR Residuals - GRG
RAW
BIAS REMOVED
0.22±1.83 (RMS 1.84)
0.13±1.69 (RMS 1.69)
Residuals (cm)
5
0
−5
May 01
May 15
Jun 01
Jun 15
Jul 01
Jul 15
Aug 01
Aug 15
Sep 01
Coverage Date (2023)


SLR Residuals - JPL
RAW
BIAS REMOVED
0.15±1.05 (RMS 1.06)
0.05±0.69 (RMS 0.69)
Residuals (cm)
5
0
−5
May 01
May 15
Jun 01
Jun 15
Jul 01
Jul 15
Aug 01
Aug 15
Sep 01
Coverage Date (2023)


SLR Residuals - TUDF
RAW
BIAS REMOVED
0.12±1.04 (RMS 1.05)
0.03±0.70 (RMS 0.70)
Residuals (cm)
5
0
−5
May 01
May 15
Jun 01
Jun 15
Jul 01
Jul 15
Aug 01
Aug 15
Sep 01
Coverage Date (2023)

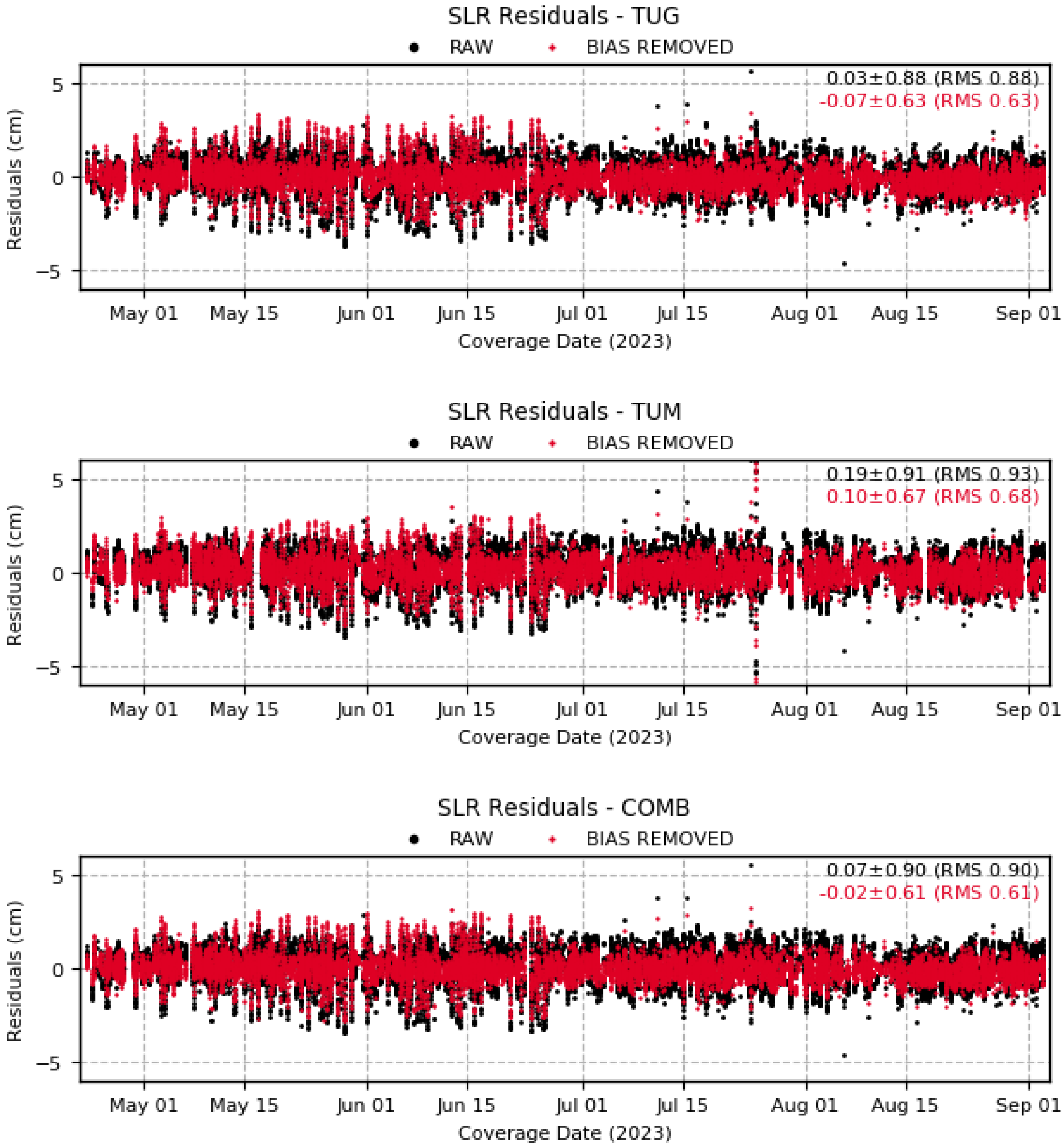


Figure 3-26: Sentinel-3A SLR validation – SLR residuals [cm]

Table 3-13: Sentinel-3A SLR validation – Estimated two-way biases per SLR station

Two-Way Biases		
SLR station		Bias [mm]
Monument	Code	
7090	**YARL**	8.28
7105	**GODL**	-14.51
7110	**MONL**	-9.11
7119	**HA4T**	19.27
7501	**HARL**	10.94
7825	**STL3**	18.57
7839	**GRZL**	1.35
7840	**HERL**	-13.32
7841	**POT3**	-14.73
7941	**MATM**	-16.27

Two-Way Biases		
SLR station		Bias [mm]
Monument	Code	
7810	**ZIML**	-

Two-Way Biases		
SLR station		Bias [mm]
Monument	Code	
8834	**WETL**	-

The previous outcome of the residuals before removing the bias is summarised in Figure 3-27 and Table 3-14 where the mean, standard deviation (STD) and RMS values of the calculated SLR residuals are shown.

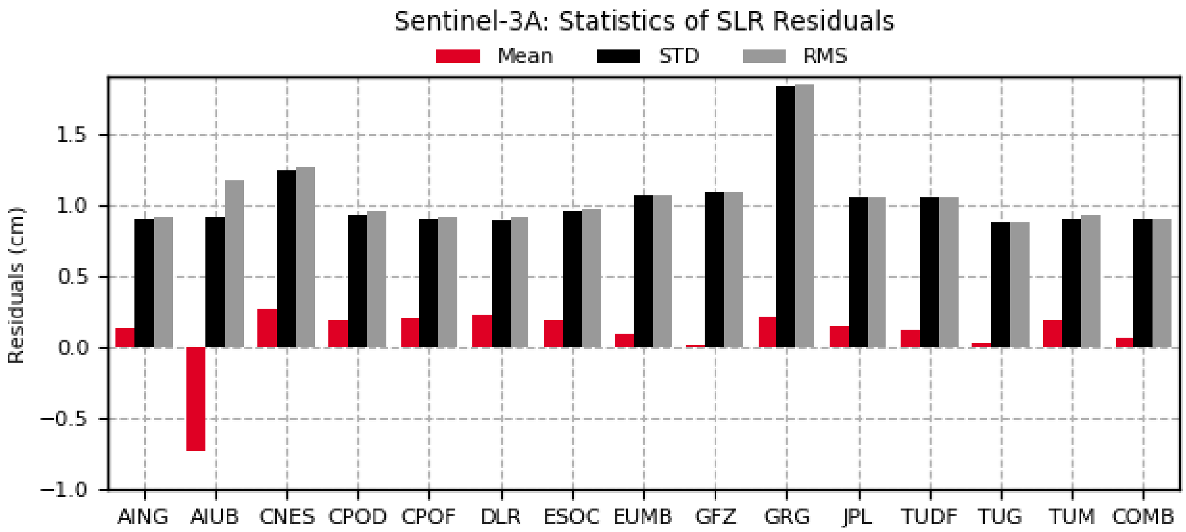


Figure 3-27: Sentinel-3A SLR validation – SLR residuals [cm] (mean, STD and RMS)

Table 3-14: Sentinel-3A SLR validation – SLR residuals [cm] (mean, STD and RMS)

SLR Residuals [cm]				
Orbit Solution	Centre	Mean	Standard Deviation	RMS
AING	**AIUB**	0.13	0.90	0.91
AIUB	**AIUB**	-0.73	0.92	1.18
CNES	**CNES**	0.27	1.23	1.26
CPOD	**CPOD**	0.19	0.93	0.95
CPOF	**CPOD**	0.20	0.90	0.92
DLR	**DLR**	0.23	0.89	0.92
ESOC	**ESOC**	0.18	0.95	0.97
EUMB	**EUMB**	0.10	1.06	1.06
GFZ	**GFZ**	0.01	1.09	1.09
GRG	**GRG**	0.22	1.83	1.84
JPL	**JPL**	0.15	1.05	1.06
TUDF	**TUD**	0.12	1.04	1.05
TUG	**TUG**	0.03	0.88	0.88
TUM	**TUM**	0.19	0.91	0.93

SLR Residuals [cm]				
Orbit Solution	Centre	Mean	Standard Deviation	RMS
COMB	**-**	0.07	0.90	0.90

Moreover, the previous outcome of the residuals after removing the bias is summarised in Figure 3-28 and Table 3-15 where the mean, standard deviation (STD) and RMS values of the calculated SLR residuals are shown.

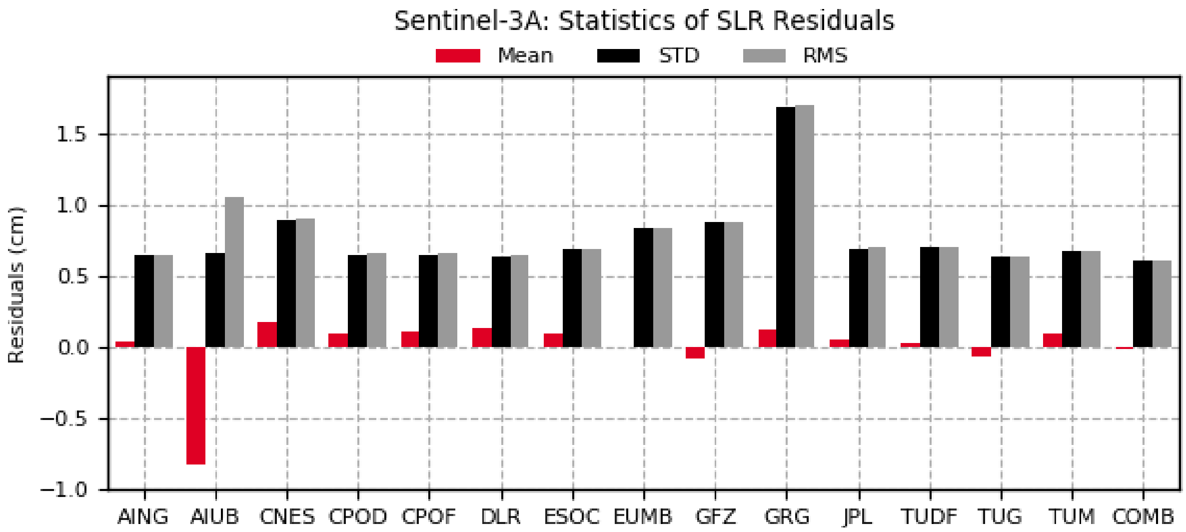


Figure 3-28: Sentinel-3A SLR validation – SLR residuals after removing the bias [cm] (mean, STD and RMS)

Table 3-15: Sentinel-3A SLR validation – SLR residuals after removing the bias [cm] (mean, STD and RMS)

SLR Residuals [cm]				
Orbit Solution	Centre	Mean	Standard Deviation	RMS
AING	**AIUB**	0.04	0.65	0.65
AIUB	**AIUB**	-0.82	0.66	1.05
CNES	**CNES**	0.18	0.89	0.91
CPOD	**CPOD**	0.09	0.65	0.66
CPOF	**CPOD**	0.11	0.64	0.65
DLR	**DLR**	0.14	0.63	0.65
ESOC	**ESOC**	0.09	0.68	0.69
EUMB	**EUMB**	0.01	0.84	0.84
GFZ	**GFZ**	-0.08	0.88	0.88
GRG	**GRG**	0.13	1.69	1.69
JPL	**JPL**	0.05	0.69	0.69
TUDF	**TUD**	0.03	0.70	0.70
TUG	**TUG**	-0.07	0.63	0.63

SLR Residuals [cm]				
Orbit Solution	Centre	Mean	Standard Deviation	RMS
TUM	**TUM**	0.10	0.67	0.68
COMB	**-**	-0.02	0.61	0.61

The Sentinel-3A orbit solutions generated by the CPOD Service show a performance in line with the results obtained on the other solutions.

3.4.6. ORBIT COMPARISONS OF S-3A STC ORBIT SOLUTIONS

The operational S-3 STC solutions from the CPOD Service (labelled as CPOR), CNES (the MDO solution, which has been labelled as CNER), and two TUD solutions are compared here against the combined solution.

TUD generates two STC orbit solutions for Sentinel-3A, which have been labelled as **TUDU** and **TUDR.** These STC orbit solutions are based on ultra GNSS products from JPL (using standard clocks) and rapid GNSS products from JPL (with high-rate clocks), respectively.

Figure 3-29 shows the radial RMS accuracy of the orbit solutions for all the reported period. As seen in the figure, the TUD solutions offer the best performance, similar to the performance shown by the TUDF NTC solution, thanks to the use of integer ambiguity resolution.

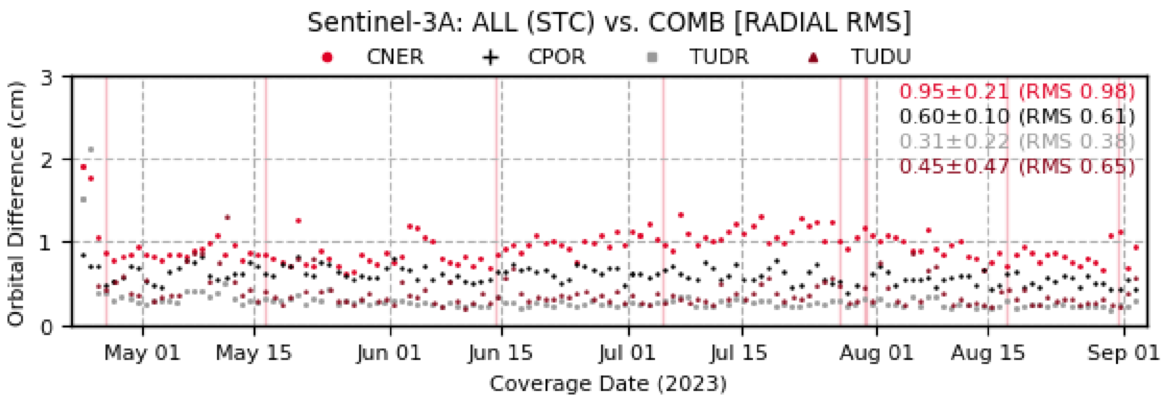


Figure 3-29: Sentinel-3A orbit comparisons – All (STC) vs. COMB [radial RMS; cm]

A more detailed distribution of the obtained accuracy can be found in Table 3-16, where the percentiles of the radial RMS is calculated for different thresholds.

Table 3-16: Sentinel-3A STC (all) solutions – Accuracy percentiles (orbit comparisons against COMB solution [radial RMS], respectively)

Product Accuracy				
Threshold	Percentage of Fulfilment			
	CNER	CPOR	TUDR	TUDU
< 1 cm	65.19 %	100.00 %	97.76 %	97.74 %
< 2 cm	100.00 %	100.00 %	99.25 %	98.50 %
< 3 cm	100.00 %	100.00 %	100.00 %	98.50 %
< 4 cm	100.00 %	100.00 %	100.00 %	99.25 %

3.5. SENTINEL-3B

3.5.1. STATISTICS OF THE GENERATION OF THE SOLUTION COMB

Figure 3-30 shows the daily distribution per orbit solution of the weights used to generate the combined Sentinel-3B orbit solution. A summary of these values can be found in Table 3-17, where the mean values of these calculated weights are presented. It must be remarked that a higher value on the weights means a more contribution of the orbit solution to the generation of the combined orbit solution.

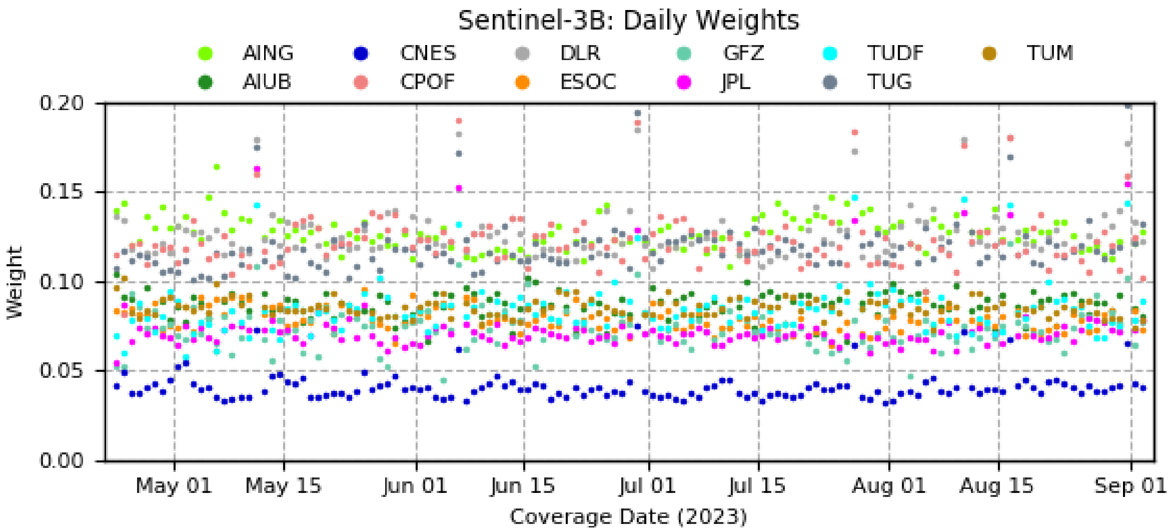


Figure 3-30: Sentinel-3B COMB generation – Daily weights of ALL orbit solutions

Table 3-17: Sentinel-3B COMB generation – Mean of the daily weights of ALL orbit solutions

Daily Weights		
Orbit Solution	**Centre**	**Mean**
AING	**AIUB**	0.13
AIUB	**AIUB**	0.09
CNES	**CNES**	0.04
CPOF	**CPOD**	0.12
DLR	**DLR**	0.13
ESOC	**ESOC**	0.08
GFZ	**GFZ**	0.07
JPL	**JPL**	0.07
TUDF	**TUD**	0.08
TUG	**TUG**	0.12
TUM	**TUM**	0.09

3.5.2. TEMPORAL EVOLUTION OF THE ORBITS COMPARISONS

Figure 3-31 and Figure 3-32 show the temporal evolution of the orbit comparisons [radial and 3D RMS] between all Sentinel-3B orbit solutions provided by the different QWG centres and the combined

orbit solution. A summary of these orbit comparisons can be found in Figure 3-33 and Table 3-18, where the mean of the daily RMS is calculated not only for the 3D RMS but also for other satellite components.

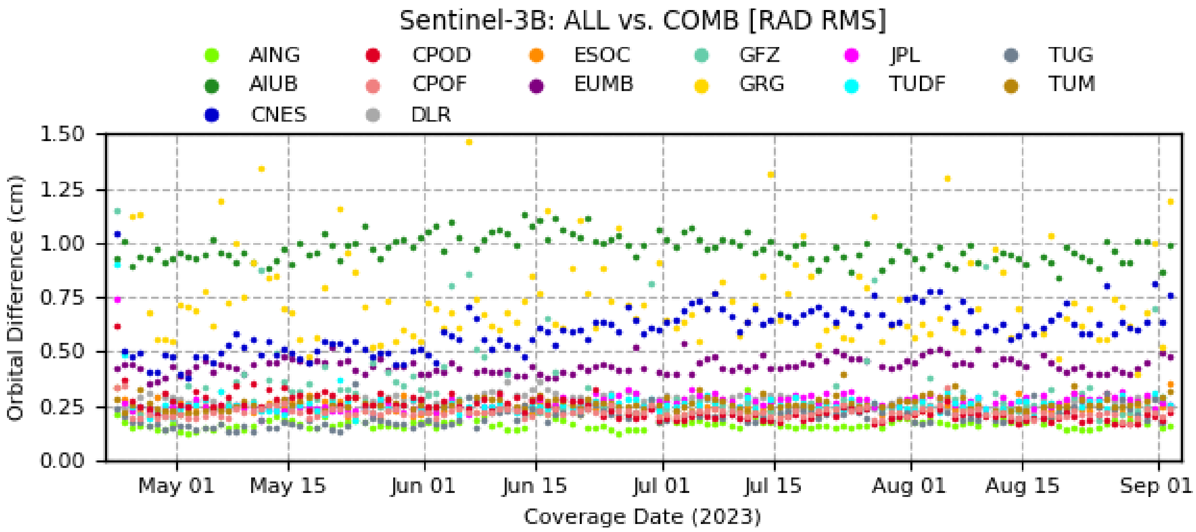


Figure 3-31: Sentinel-3B orbit comparisons – All vs. COMB [radial RMS; cm]

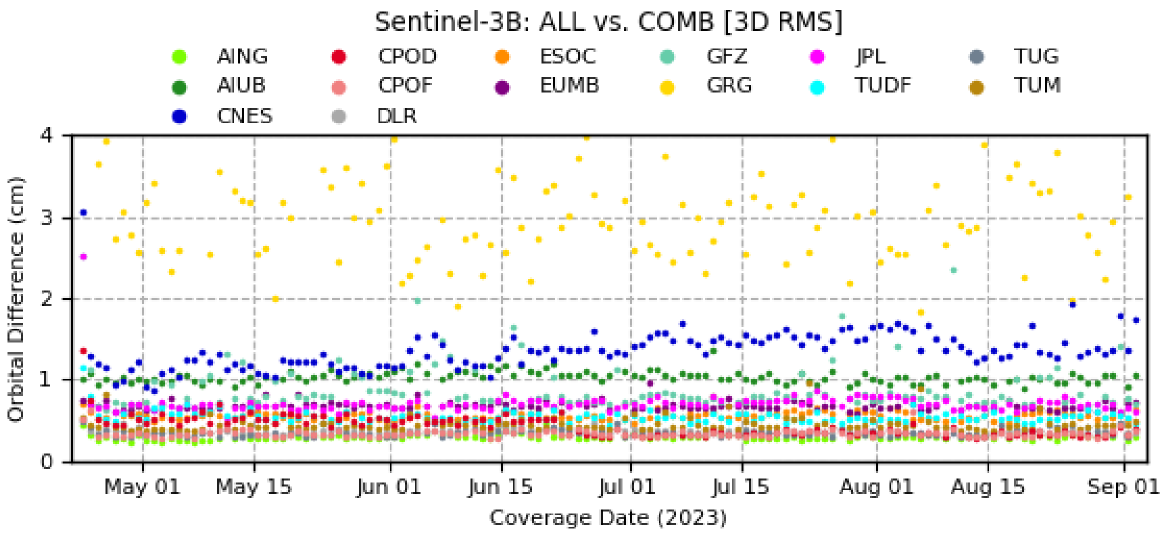


Figure 3-32: Sentinel-3B orbit comparisons – All vs. COMB [3D RMS; cm]

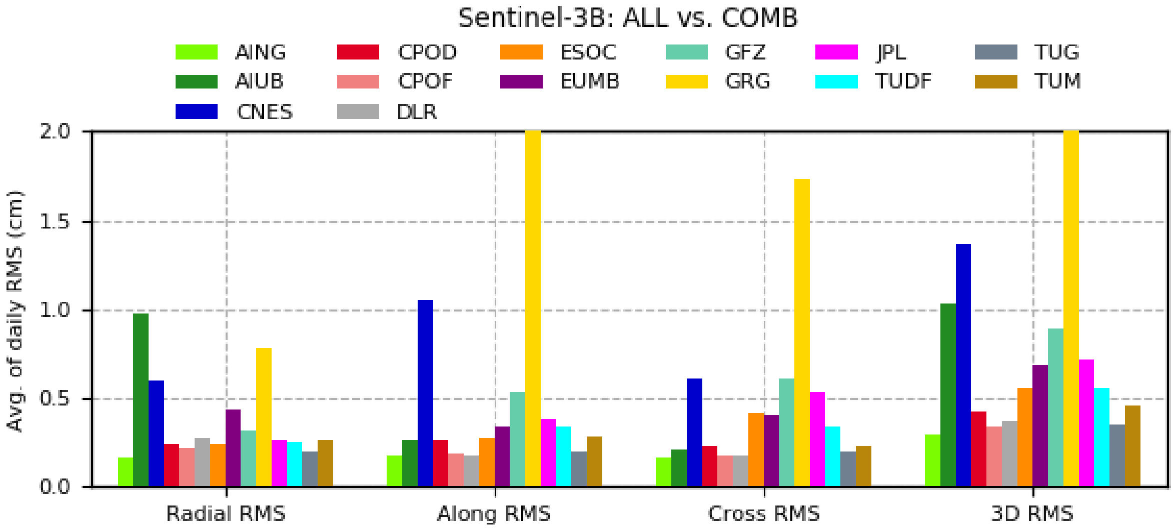


Figure 3-33: Sentinel-3B orbit comparisons – Mean of daily RMS [cm] (All vs. COMB [radial, along, cross and 3D RMS])

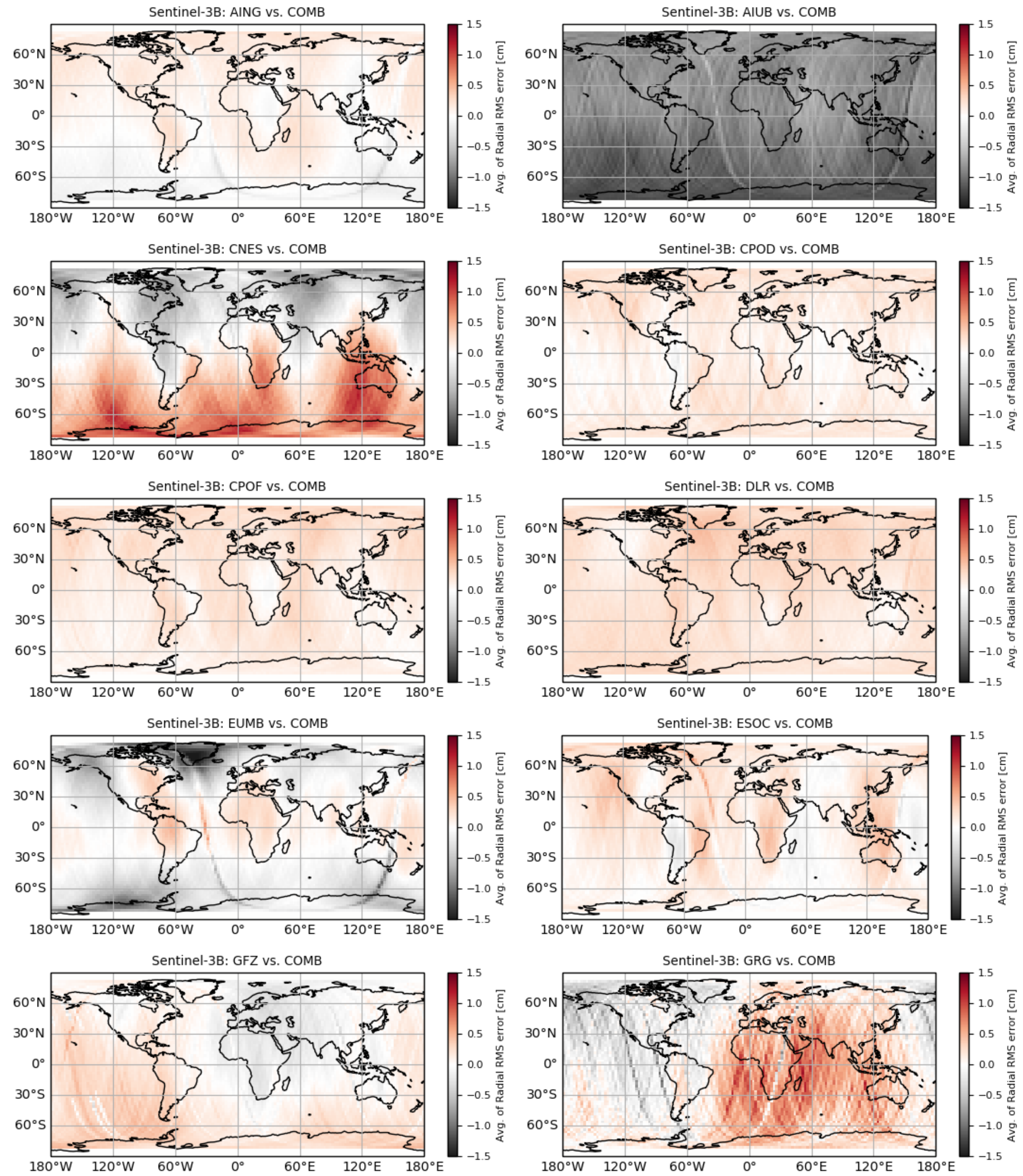
Table 3-18: Sentinel-3B orbit comparisons – Mean of daily RMS [cm] (All vs. COMB)

Orbit Comparisons (Mean of daily RMS [cm])					
Orbit Solution	Centre	Satellite component			
		Radial	Along-track	Cross-track	3D
AING	**AIUB**	0.17	0.18	0.17	0.30
AIUB	**AIUB**	0.97	0.26	0.21	1.03
CNES	**CNES**	0.60	1.06	0.61	1.36
CPOD	**CPOD**	0.24	0.27	0.23	0.43
CPOF	**CPOD**	0.22	0.19	0.18	0.34
DLR	**DLR**	0.27	0.17	0.17	0.37
ESOC	**ESOC**	0.24	0.28	0.42	0.56
EUMB	**EUMB**	0.43	0.34	0.40	0.68
GFZ	**GFZ**	0.32	0.53	0.61	0.89
GRG	**GRG**	0.78	2.57	1.73	3.27
JPL	**JPL**	0.27	0.38	0.53	0.71
TUDF	**TUD**	0.26	0.34	0.34	0.55
TUG	**TUG**	0.20	0.20	0.20	0.35
TUM	**TUM**	0.26	0.28	0.24	0.45

The Sentinel-3B orbit solutions generated by the CPOD Service show a performance in line with the results obtained on the other solutions.

3.5.3. GEOGRAPHICAL ANALYSIS

Figure 3-34 shows the 3D RMS orbit comparisons calculated on the previous sub section projected on an equi-rectangular map plot. Each cell of the map contains the mean value of all orbit comparisons falling on this cell during the reported period.


Sentinel-3B: AING vs. COMB
Sentinel-3B: AIUB vs. COMB
Sentinel-3B: CNES vs. COMB
Sentinel-3B: CPOD vs. COMB
Sentinel-3B: CPOF vs. COMB
Sentinel-3B: DLR vs. COMB
Sentinel-3B: EUMB vs. COMB
Sentinel-3B: ESOC vs. COMB
Sentinel-3B: GFZ vs. COMB
Sentinel-3B: GRG vs. COMB
Avg. of Radial RMS error [cm]
180°W 120°W 60°W 0° 60°E 120°E 180°E
60°N 30°N 0° 30°S 60°S
1.5 1.0 0.5 0.0 −0.5 −1.0 −1.5

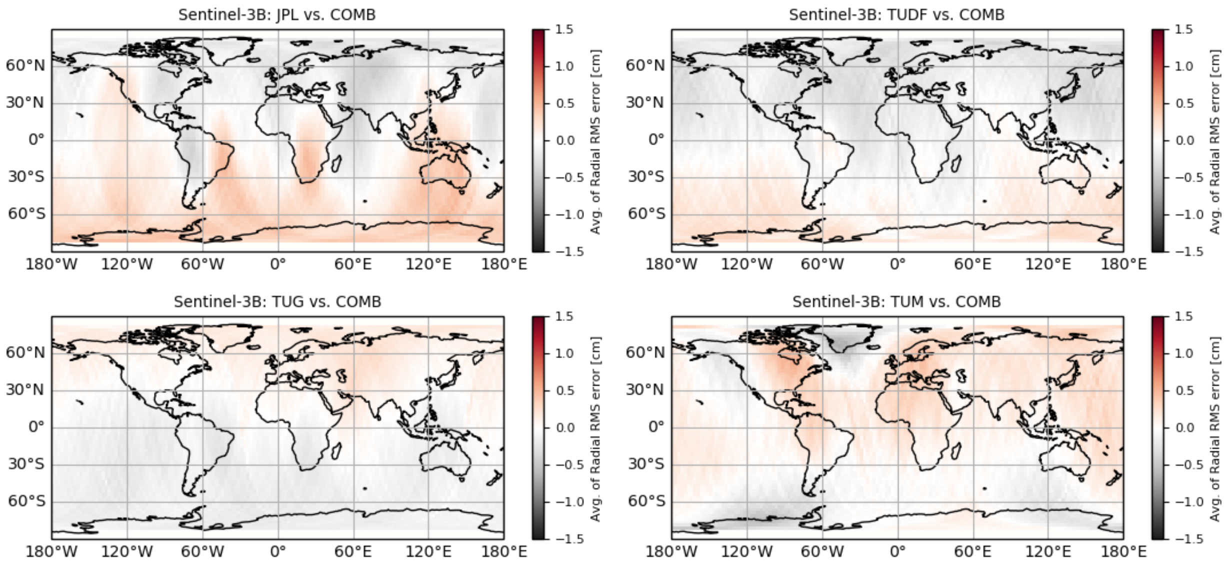
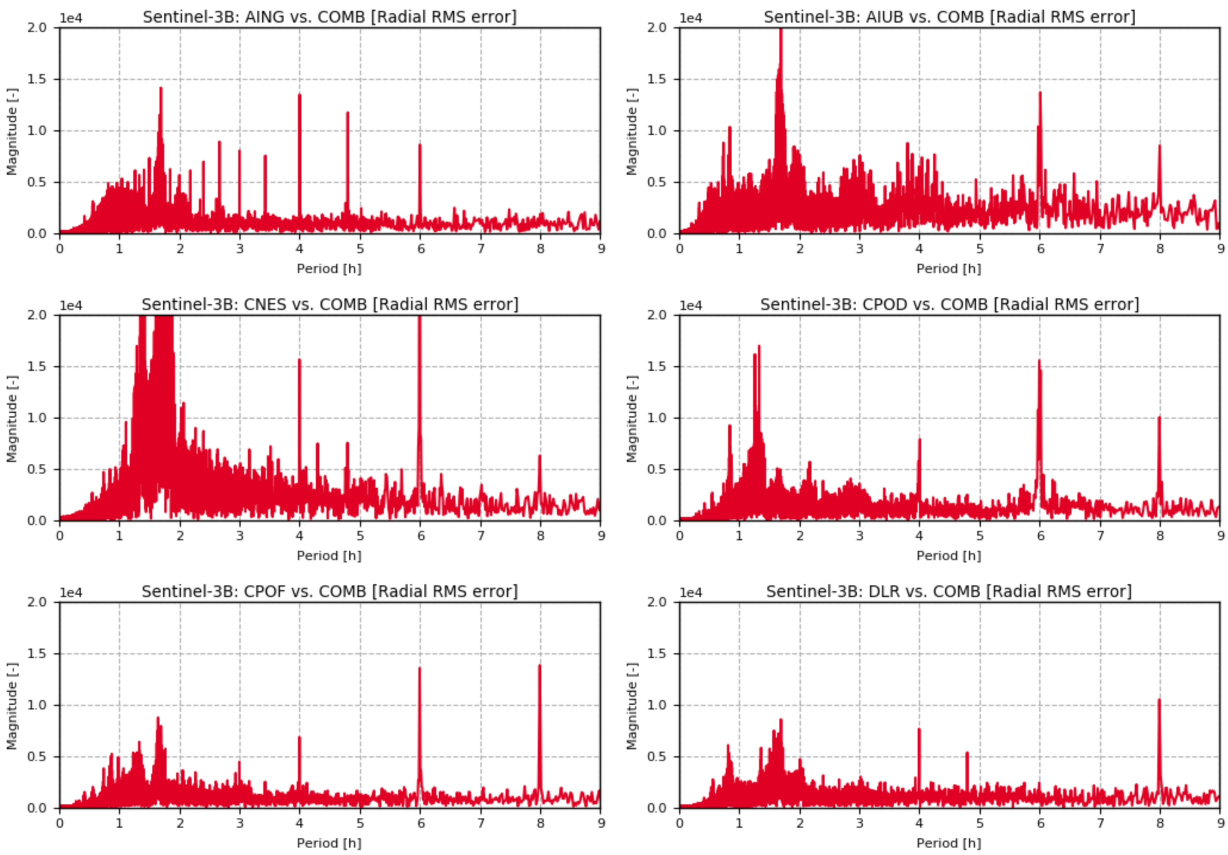


Figure 3-34: Sentinel-3B geographical analysis – Average of the radial RMS orbit comparisons (All vs. COMB)

3.5.4. SPECTRAL ANALYSIS

Figure 3-35 shows the FFT of the 3D RMS orbit comparisons calculated on the previous sub section.



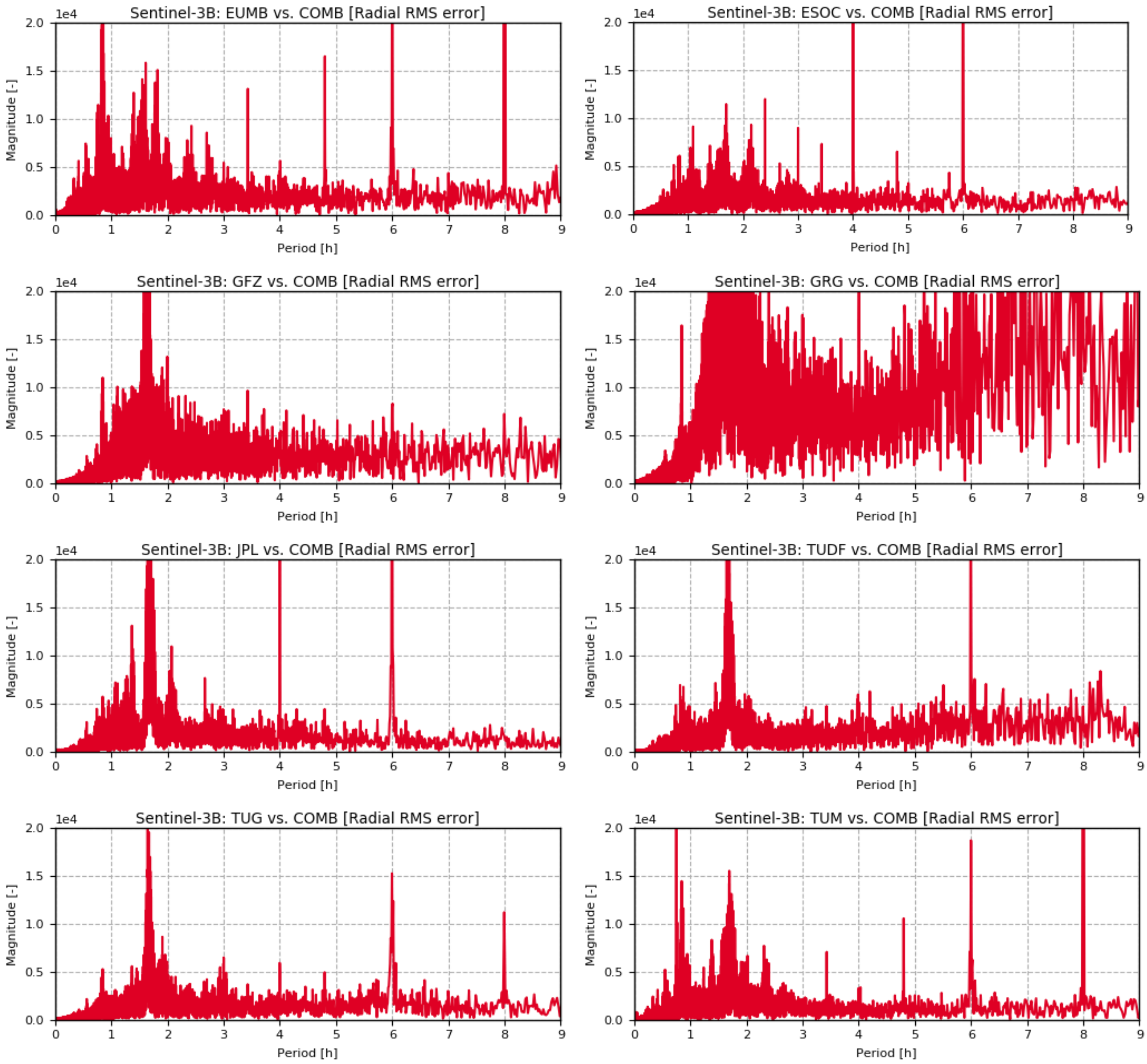


Figure 3-35: Sentinel-3B spectral analysis – Radial RMS orbit comparisons (All vs. COMB)

3.5.5. SLR VALIDATION

Figure 3-36 shows the accepted Sentinel-3B observations that the SLR stations have retrieved from the tracking of Sentinel-3B satellite during the reported period.

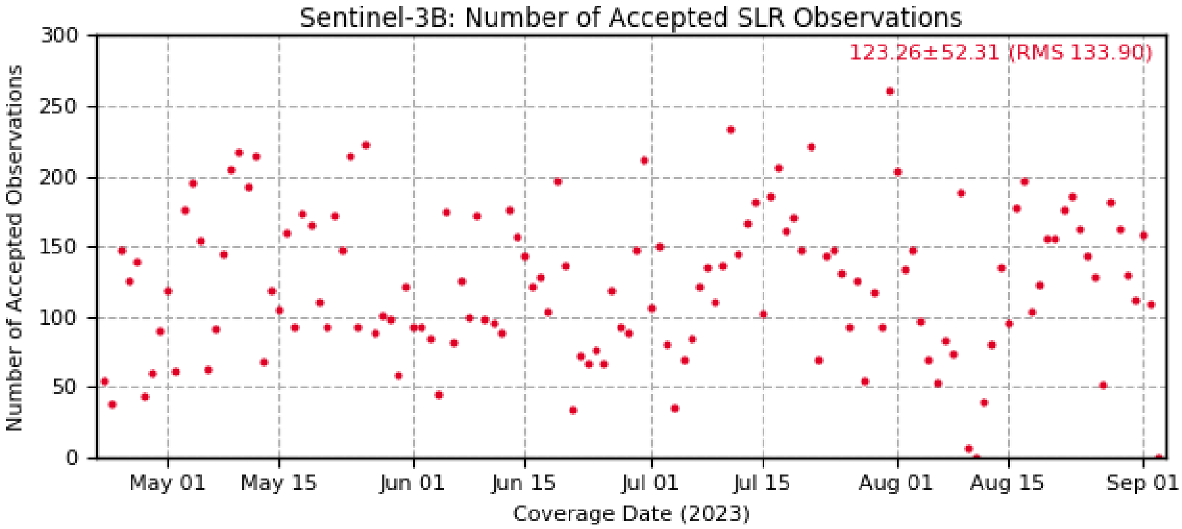
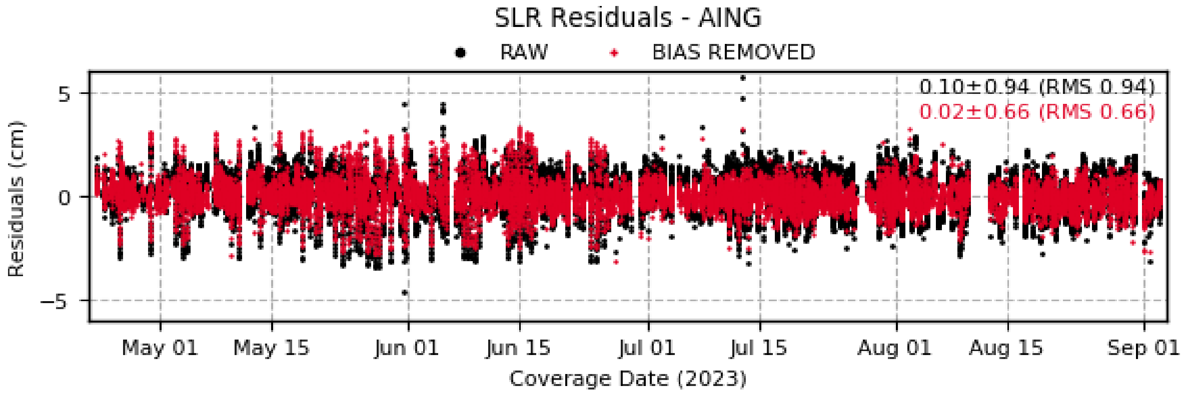


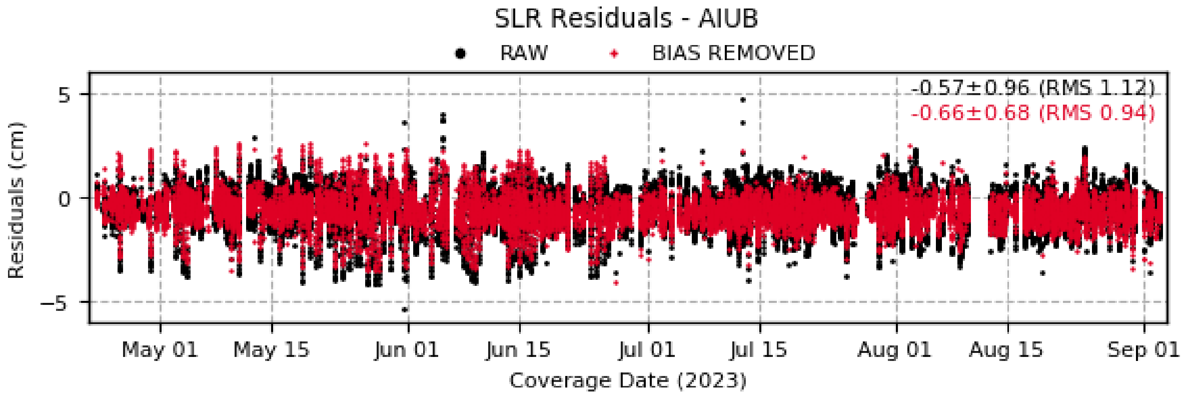
Figure 3-36: Sentinel-3B SLR validation – Number of accepted SLR observations

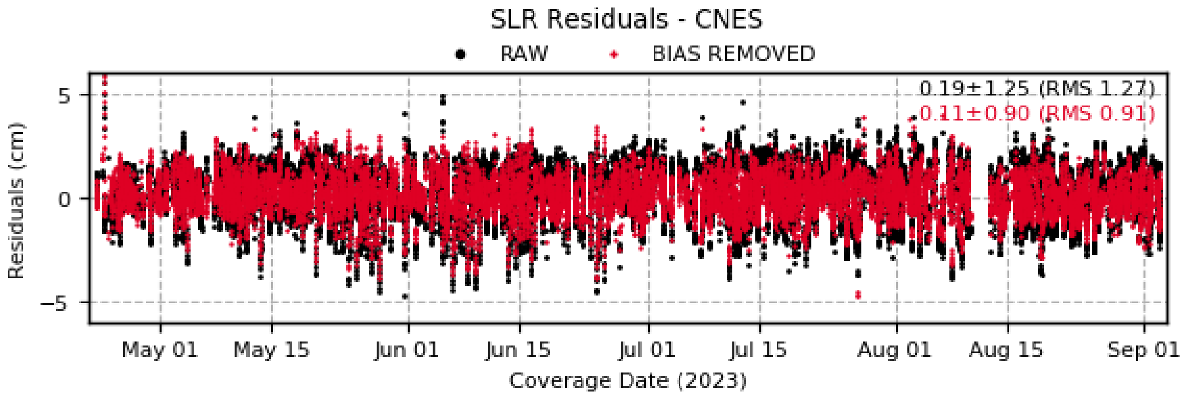
Figure 3-37 presents the temporal evolution of the Sentinel-3B SLR residuals that have been calculated from each orbit solution (**RAW**). It also shows the SLR residuals that have been calculated by removing a constant bias affecting their generation (**BIAS REMOVED**). These biases are computed using the COMB solution, for elevations higher than 10 degrees, and estimating a single value per station for the whole period and all satellites (S-3A, S-3B, S-6A). Table 3-19 summarises the range biases per SLR station that have been considered during the processing of the SLR residuals.

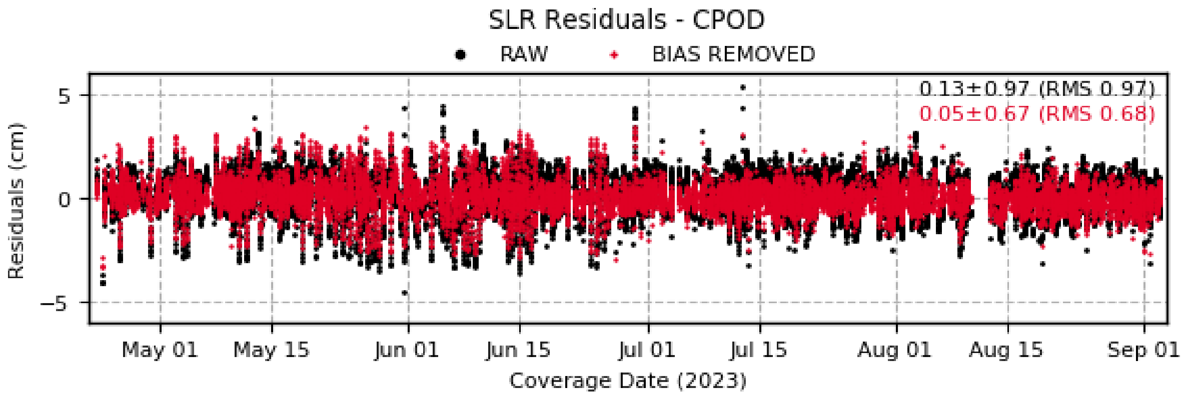
In Figure 3-37, the white spaces are due to punctual missing orbit solutions mainly caused by either manoeuvres or large gaps of data. Despite this fact, all SLR residuals of the different orbit solutions have behaved nominally, obtaining similar values as previous RSR documents. It can be seen that there is a decrease in the dispersion of the residuals since the end of June, which is due to the residuals obtained from the observations of one of the stations (7840) that improve after this date.

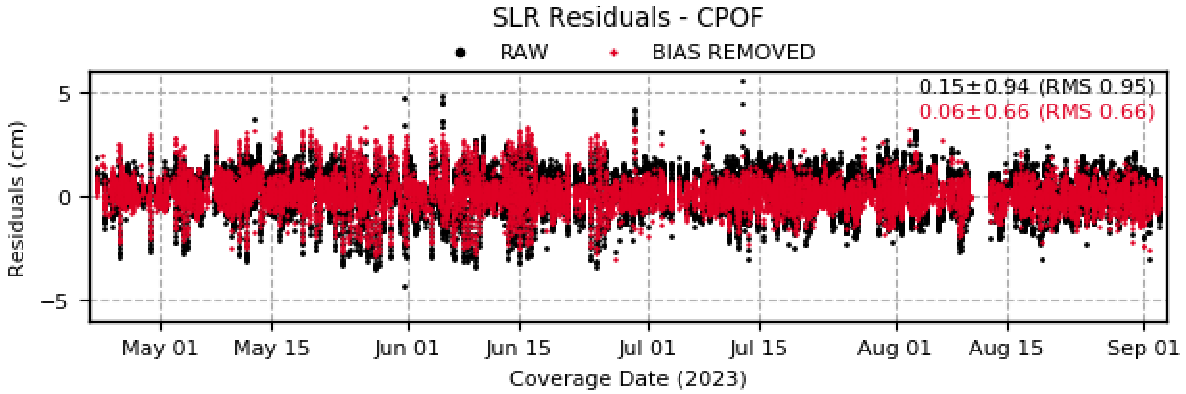
As a comment, the CNES SLR residuals may be higher than expected since the orbit solution **CNES** makes use of a POE-F standard, and the orbits have not been treated consistently regarding the geocentre motion they apply.

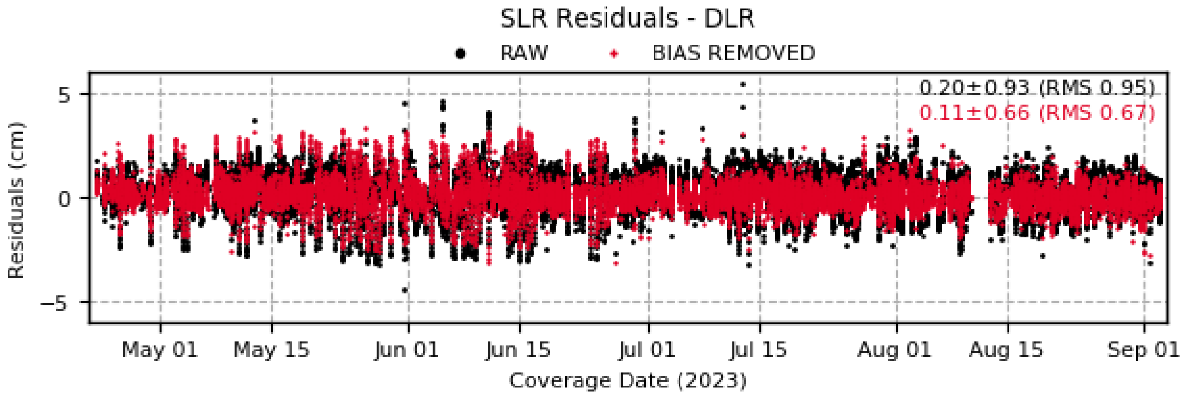

SLR Residuals - AING
RAW
BIAS REMOVED
0.10±0.94 (RMS 0.94)
0.02±0.66 (RMS 0.66)
Residuals (cm)
Coverage Date (2023)
May 01
May 15
Jun 01
Jun 15
Jul 01
Jul 15
Aug 01
Aug 15
Sep 01

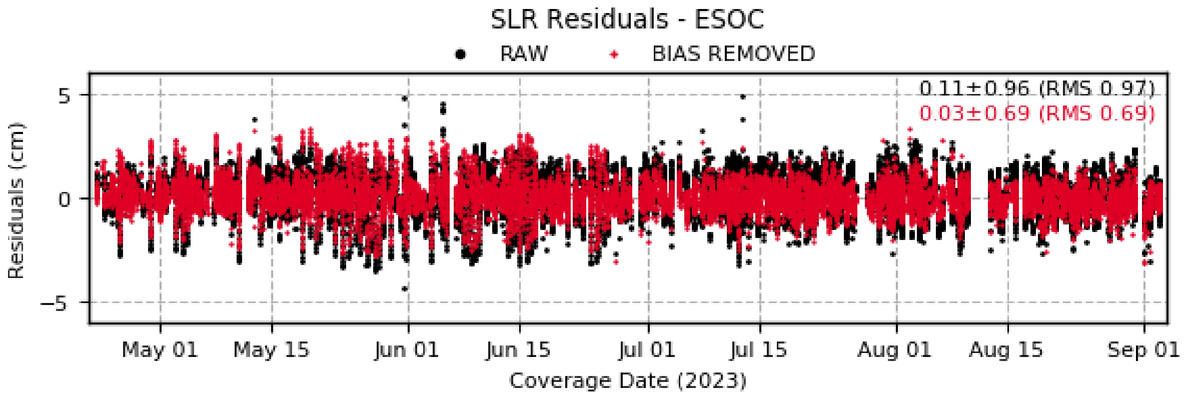

SLR Residuals - AIUB
RAW
BIAS REMOVED
-0.57±0.96 (RMS 1.12)
-0.66±0.68 (RMS 0.94)
Residuals (cm)
Coverage Date (2023)

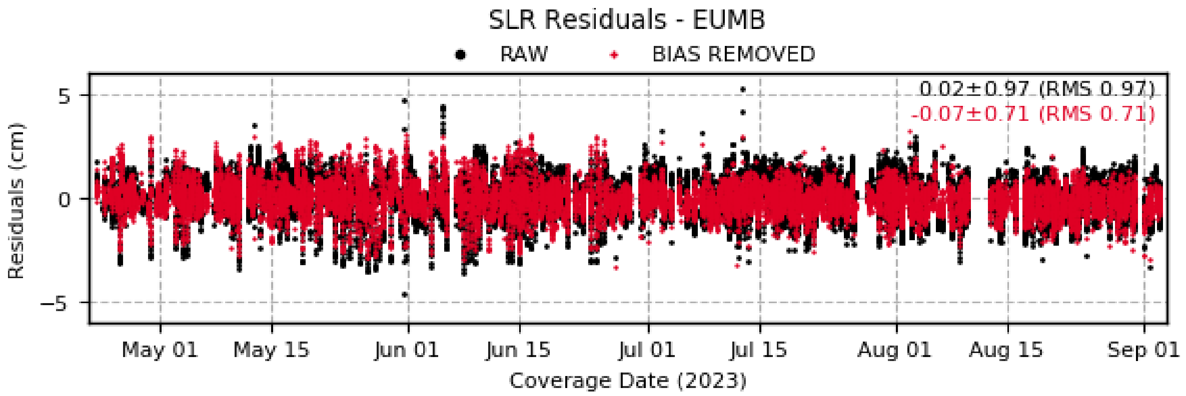

SLR Residuals - CNES
RAW
BIAS REMOVED
0.19±1.25 (RMS 1.27)
0.11±0.90 (RMS 0.91)
Residuals (cm)
Coverage Date (2023)

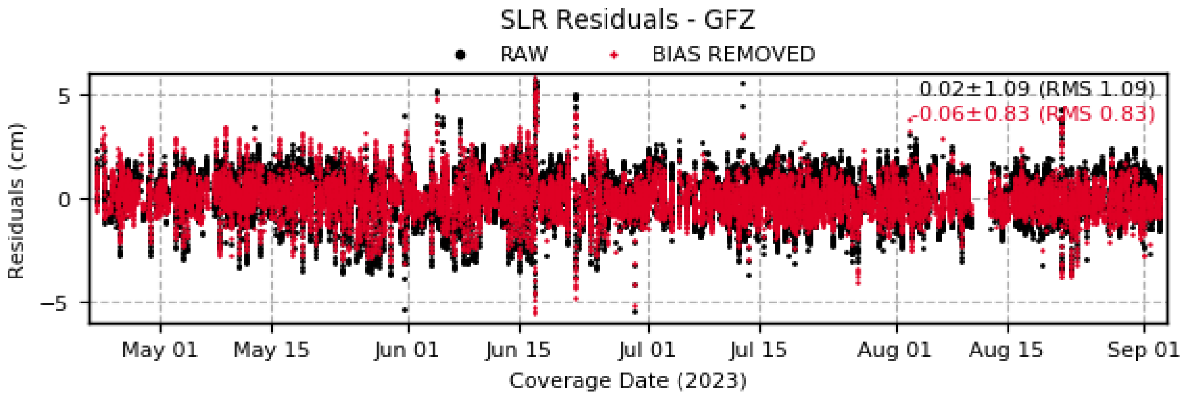

SLR Residuals - CPOD
RAW
BIAS REMOVED
0.13±0.97 (RMS 0.97)
0.05±0.67 (RMS 0.68)
Residuals (cm)
Coverage Date (2023)

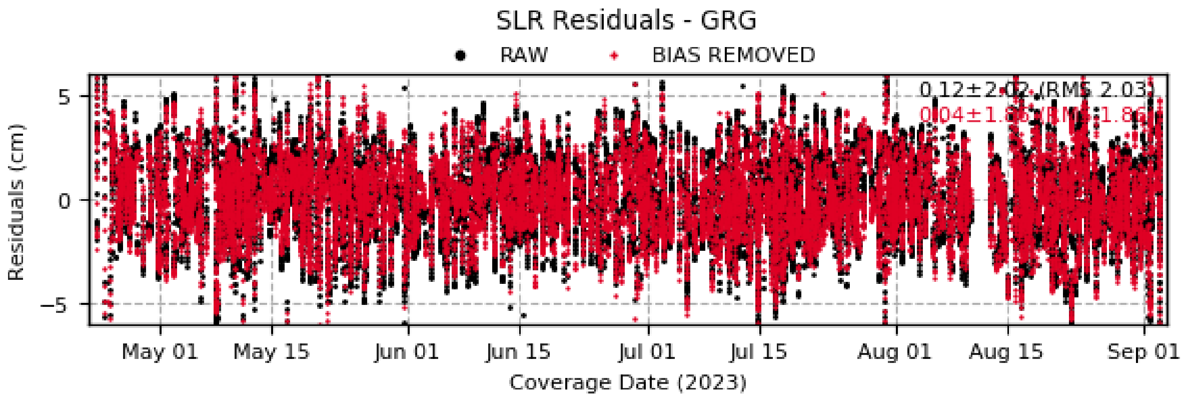

SLR Residuals - CPOF
RAW
BIAS REMOVED
0.15±0.94 (RMS 0.95)
0.06±0.66 (RMS 0.66)
Residuals (cm)
5
0
−5
May 01
May 15
Jun 01
Jun 15
Jul 01
Jul 15
Aug 01
Aug 15
Sep 01
Coverage Date (2023)

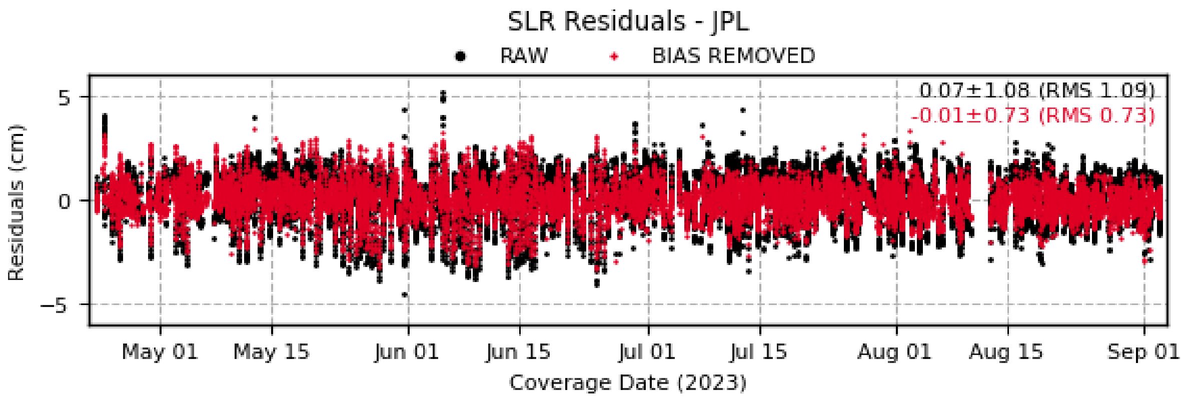

SLR Residuals - DLR
RAW
BIAS REMOVED
0.20±0.93 (RMS 0.95)
0.11±0.66 (RMS 0.67)
Residuals (cm)
5
0
−5
May 01
May 15
Jun 01
Jun 15
Jul 01
Jul 15
Aug 01
Aug 15
Sep 01
Coverage Date (2023)

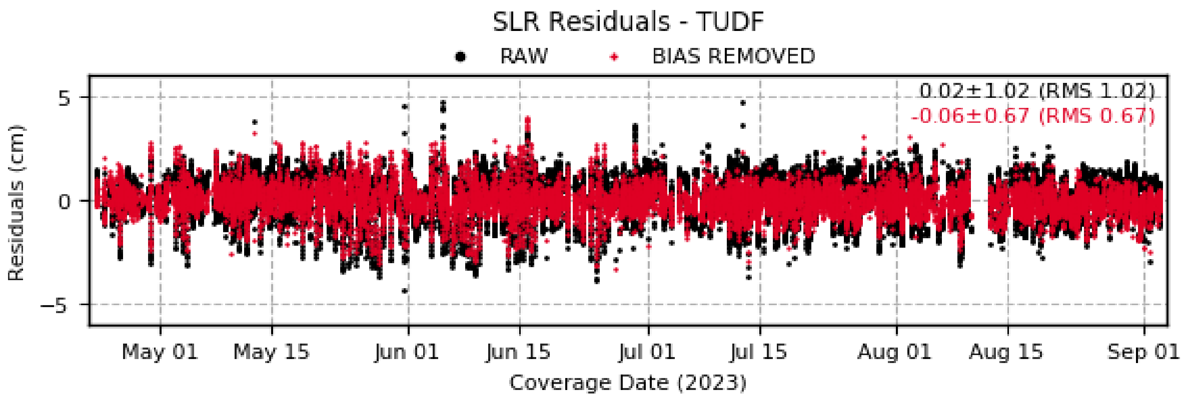

SLR Residuals - ESOC
RAW
BIAS REMOVED
0.11±0.96 (RMS 0.97)
0.03±0.69 (RMS 0.69)
Residuals (cm)
5
0
−5
May 01
May 15
Jun 01
Jun 15
Jul 01
Jul 15
Aug 01
Aug 15
Sep 01
Coverage Date (2023)


SLR Residuals - EUMB
RAW
BIAS REMOVED
0.02±0.97 (RMS 0.97)
-0.07±0.71 (RMS 0.71)
Residuals (cm)
5
0
−5
May 01
May 15
Jun 01
Jun 15
Jul 01
Jul 15
Aug 01
Aug 15
Sep 01
Coverage Date (2023)


SLR Residuals - GFZ
RAW
BIAS REMOVED
0.02±1.09 (RMS 1.09)
-0.06±0.83 (RMS 0.83)
Residuals (cm)
5
0
−5
May 01
May 15
Jun 01
Jun 15
Jul 01
Jul 15
Aug 01
Aug 15
Sep 01
Coverage Date (2023)


SLR Residuals - GRG
RAW
BIAS REMOVED
0.12±2.02 (RMS 2.03)
0.04±1.86 (RMS 1.86)
Residuals (cm)
5
0
−5
May 01
May 15
Jun 01
Jun 15
Jul 01
Jul 15
Aug 01
Aug 15
Sep 01
Coverage Date (2023)


SLR Residuals - JPL
RAW
BIAS REMOVED
0.07±1.08 (RMS 1.09)
-0.01±0.73 (RMS 0.73)
Residuals (cm)
5
0
−5
May 01
May 15
Jun 01
Jun 15
Jul 01
Jul 15
Aug 01
Aug 15
Sep 01
Coverage Date (2023)


SLR Residuals - TUDF
RAW
BIAS REMOVED
0.02±1.02 (RMS 1.02)
-0.06±0.67 (RMS 0.67)
Residuals (cm)
5
0
−5
May 01
May 15
Jun 01
Jun 15
Jul 01
Jul 15
Aug 01
Aug 15
Sep 01
Coverage Date (2023)

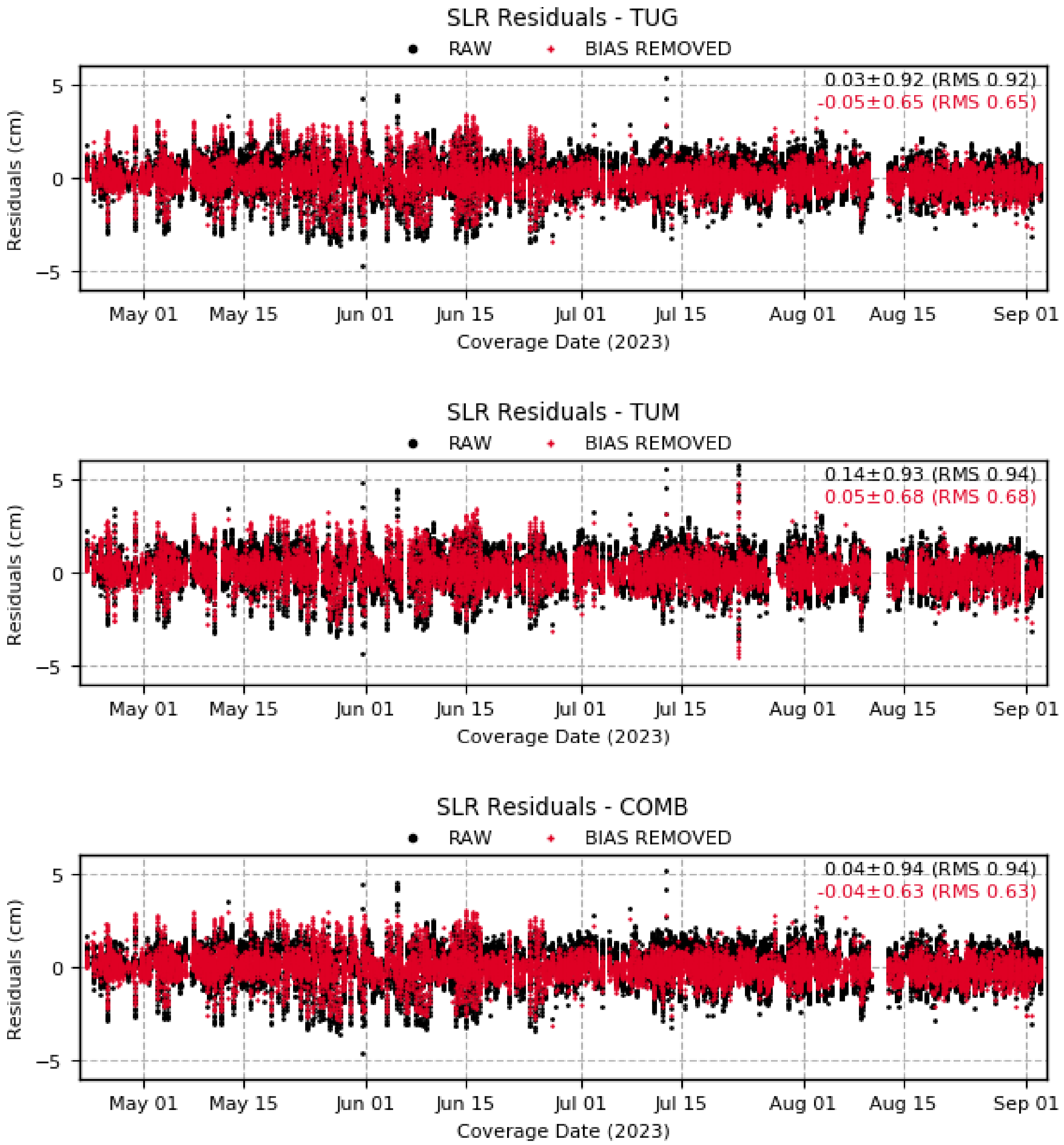


Figure 3-37: Sentinel-3B SLR validation – SLR residuals [cm]

Table 3-19: Sentinel-3B SLR validation – Estimated two-way biases per SLR station

Two-Way Biases			Two-Way Biases		
SLR station		Bias [mm]	SLR station		Bias [mm]
Monument	Code		Monument	Code	
7090	**YARL**	8.28	**7825**	**STL3**	18.57
7105	**GODL**	-14.51	**7839**	**GRZL**	1.35
7110	**MONL**	-9.11	**7840**	**HERL**	-13.32
7119	**HA4T**	19.27	**7841**	**POT3**	-14.73
7501	**HARL**	10.94	**7941**	**MATM**	-16.27
7810	**ZIML**	-	**8834**	**WETL**	-

The previous outcome of the residuals before removing the bias is summarised in Figure 3-38 and Table 3-20 where the mean, standard deviation (STD) and RMS values of the calculated SLR residuals are shown.

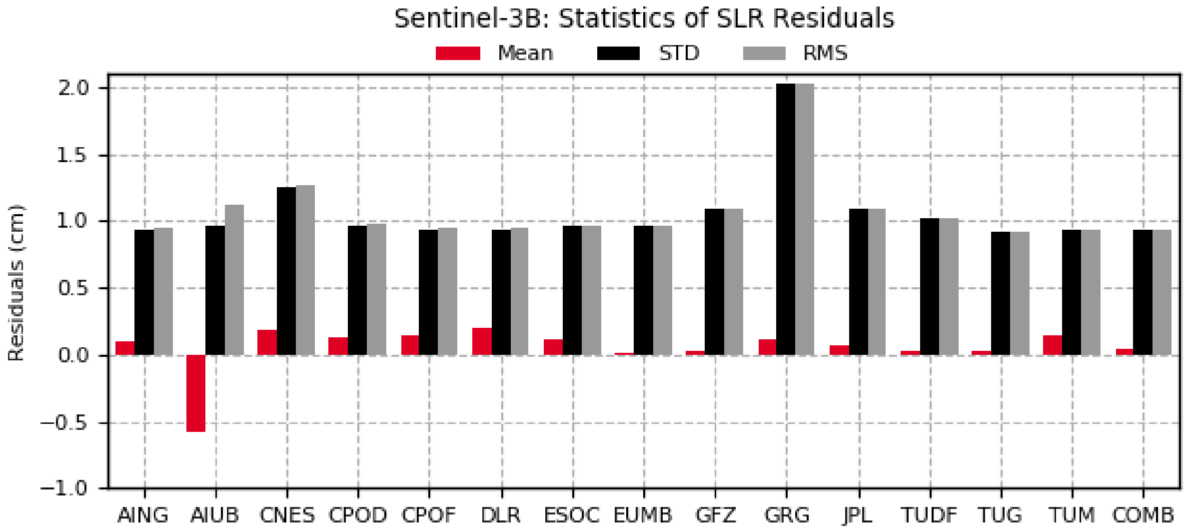


Figure 3-38: Sentinel-3B SLR validation – SLR residuals [cm] (mean, STD and RMS)

Table 3-20: Sentinel-3B SLR validation – SLR residuals [cm] (mean, STD and RMS)

SLR Residuals [cm]				
Orbit Solution	**Centre**	**Mean**	**Standard Deviation**	**RMS**
AING	**AIUB**	0.10	0.94	0.94
AIUB	**AIUB**	-0.57	0.96	1.12
CNES	**CNES**	0.19	1.25	1.27
CPOD	**CPOD**	0.13	0.97	0.97
CPOF	**CPOD**	0.15	0.94	0.95
DLR	**DLR**	0.20	0.93	0.95
ESOC	**ESOC**	0.11	0.96	0.97
EUMB	**EUMB**	0.02	0.97	0.97
GFZ	**GFZ**	0.02	1.09	1.09
GRG	**GRG**	0.12	2.02	2.03
JPL	**JPL**	0.07	1.08	1.09
TUDF	**TUD**	0.02	1.02	1.02
TUG	**TUG**	0.03	0.92	0.92
TUM	**TUM**	0.14	0.93	0.94
COMB	**-**	0.04	0.94	0.94

Moreover, the previous outcome of the residuals after removing the bias is summarised in Figure 3-39 and Table 3-21 where the mean, standard deviation (STD) and RMS values of the calculated SLR residuals are shown.

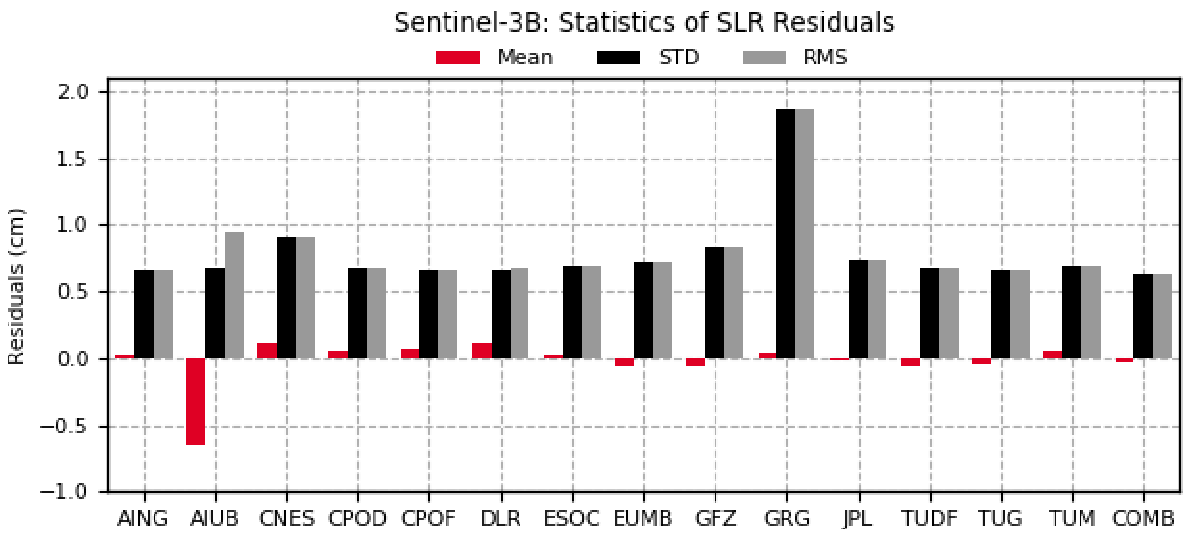


Figure 3-39: Sentinel-3B SLR validation – SLR residuals after removing the bias [cm] (mean, STD and RMS)

Table 3-21: Sentinel-3B SLR validation – SLR residuals after removing the bias [cm] (mean, STD and RMS)

SLR Residuals [cm]				
Orbit Solution	Centre	Mean	Standard Deviation	RMS
AING	**AIUB**	0.02	0.66	0.66
AIUB	**AIUB**	-0.66	0.68	0.94
CNES	**CNES**	0.11	0.90	0.91
CPOD	**CPOD**	0.05	0.67	0.68
CPOF	**CPOD**	0.06	0.66	0.66
DLR	**DLR**	0.11	0.66	0.67
ESOC	**ESOC**	0.03	0.69	0.69
EUMB	**EUMB**	-0.07	0.71	0.71
GFZ	**GFZ**	-0.06	0.83	0.83
GRG	**GRG**	0.04	1.86	1.86
JPL	**JPL**	-0.01	0.73	0.73
TUDF	**TUD**	-0.06	0.67	0.67
TUG	**TUG**	-0.05	0.65	0.65
TUM	**TUM**	0.05	0.68	0.68
COMB	**-**	-0.04	0.63	0.63

The Sentinel-3B orbit solutions generated by the CPOD Service show a performance in line with the results obtained on the other solutions.

3.5.6. ORBIT COMPARISONS OF S-3B STC ORBIT SOLUTIONS

The operational S-3 STC solutions from the CPOD Service (labelled as CPOR), CNES (the MDO solution, which has been labelled as CNER), and two TUD solutions are compared here against the combined solution.

TUD generates two STC orbit solutions for Sentinel-3B, which have been labelled as **TUDU** and **TUDR.** These STC orbit solutions are based on ultra GNSS products from JPL (using standard clocks) and rapid GNSS products from JPL (with high-rate clocks), respectively.

Figure 3-40 shows the radial RMS accuracy of the orbit solutions for all the reported period. As seen in the figure, the TUD solutions offer the best performance, similar to the performance shown by the TUDF NTC solution, thanks to the use of integer ambiguity resolution.

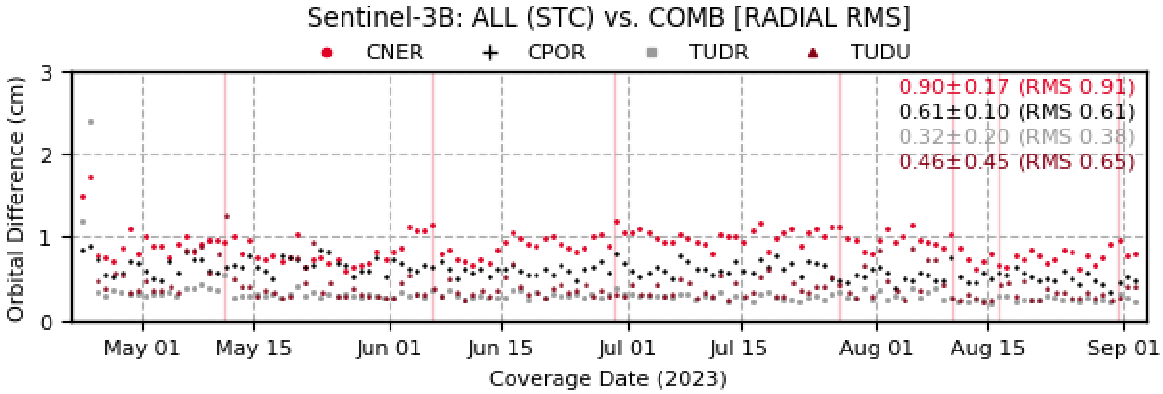


Figure 3-40: Sentinel-3B orbit comparisons – All (STC) vs. COMB [radial RMS; cm]

A more detailed distribution of the obtained accuracy can be found in Table 3-22, where the percentiles of the radial RMS is calculated for different thresholds.

Table 3-22: Sentinel-3B STC (all) solutions – Accuracy percentiles (orbit comparisons against COMB solution [radial RMS], respectively)

Product Accuracy				
Threshold	Percentage of Fulfilment			
	CNER	CPOR	TUDR	TUDU
< 1 cm	75.37 %	100.00 %	98.50 %	97.74 %
< 2 cm	100.00 %	100.00 %	99.25 %	98.50 %
< 3 cm	100.00 %	100.00 %	100.00 %	98.50 %
< 4 cm	100.00 %	100.00 %	100.00 %	99.25 %

3.6. SENTINEL-6A

3.6.1. STATISTICS OF THE GENERATION OF THE SOLUTION COMB

Figure 3-41 shows the daily distribution per orbit solution of the weights used to generate the combined Sentinel-6A orbit solution. A summary of these values can be found in Table 3-23 where the mean values of these calculated weights are presented. It must be remarked that a higher value on the weights means a more contribution of the orbit solution to the generation of the combined orbit solution.

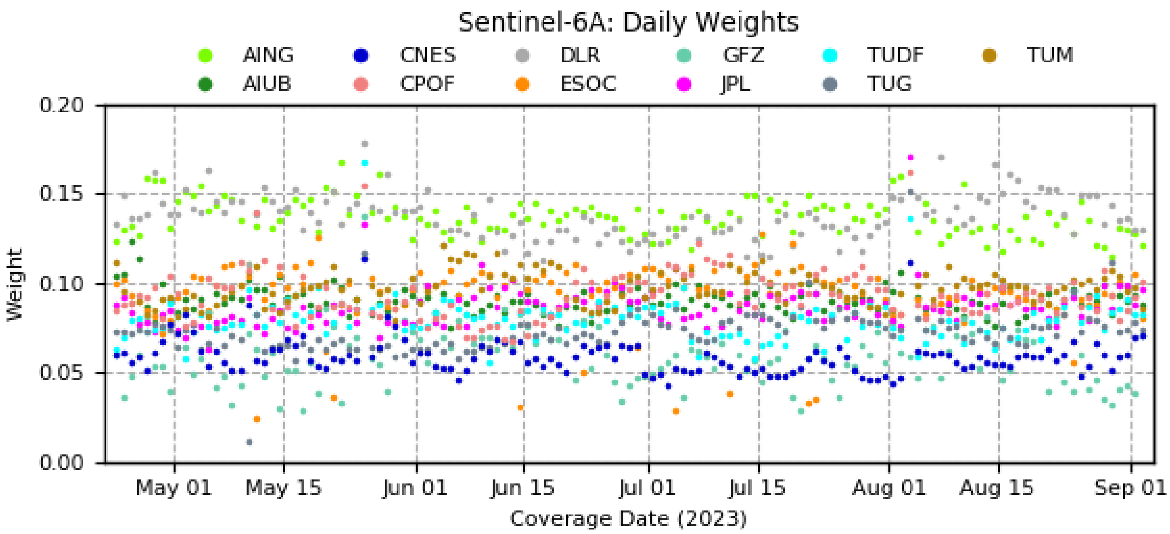


Figure 3-41: Sentinel-6A COMB generation – Daily weights of ALL orbit solutions

Table 3-23: Sentinel-6A COMB generation – Mean of the daily weights of ALL orbit solutions

Daily Weights		
Orbit Solution	Centre	Mean
AING	**AIUB**	0.14
AIUB	**AIUB**	0.09
CNES	**CNES**	0.06
CPOF	**CPOD**	0.09
DLR	**DLR**	0.14
ESOC	**ESOC**	0.09
GFZ	**GFZ**	0.06
JPL	**JPL**	0.09
TUDF	**TUD**	0.08
TUG	**TUG**	0.07
TUM	**TUM**	0.10

3.6.2. TEMPORAL EVOLUTION OF THE ORBITS COMPARISONS

Figure 3-42 and Figure 3-43 show the temporal evolution of the orbit comparisons [radial and 3D RMS] between all Sentinel-6A orbit solutions provided by the different QWG centres and the combined

orbit solution. A summary of these orbit comparisons can be found in Figure 3-44 and Table 3-24, where the mean of the daily RMS is calculated not only for the 3D RMS but also for other satellite components.

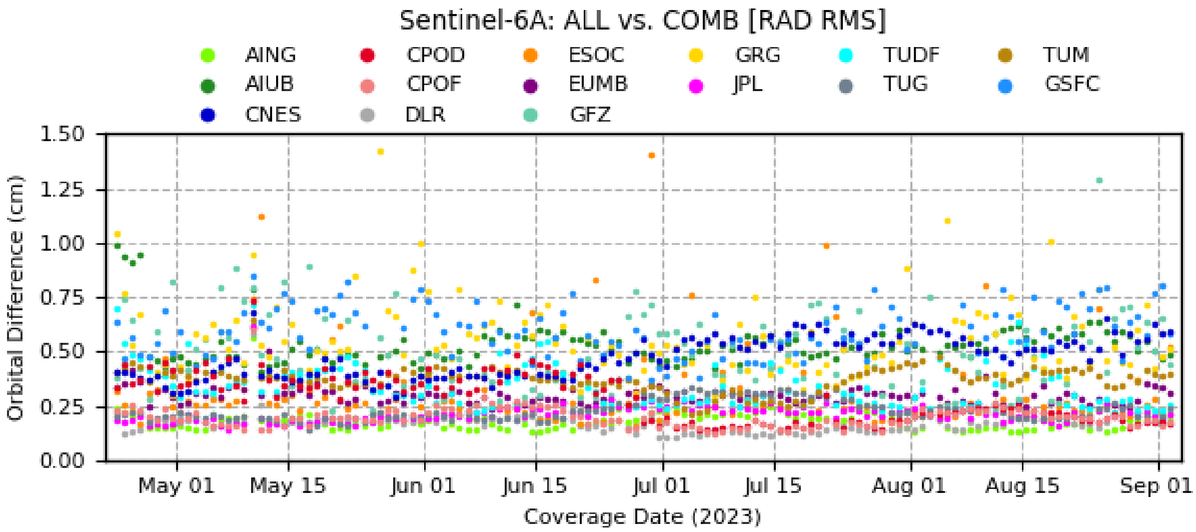


Figure 3-42: Sentinel-6A orbit comparisons – All vs. COMB [radial RMS; cm]

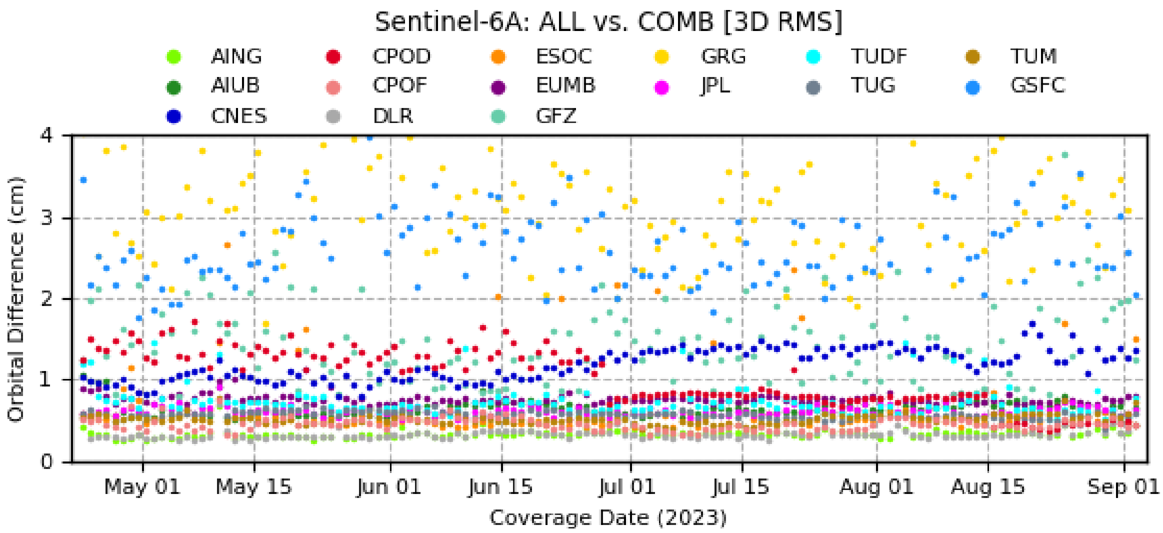


Figure 3-43: Sentinel-6A orbit comparisons – All vs. COMB [3D RMS; cm]

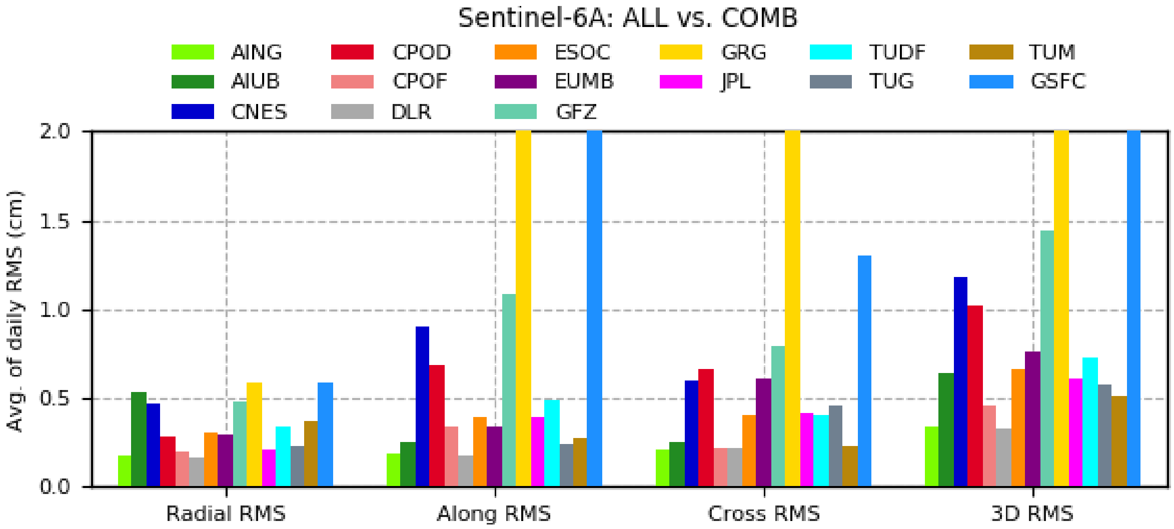


Figure 3-44: Sentinel-6A orbit comparisons – Mean of daily RMS [cm] (All vs. COMB [radial, along, cross and 3D RMS])

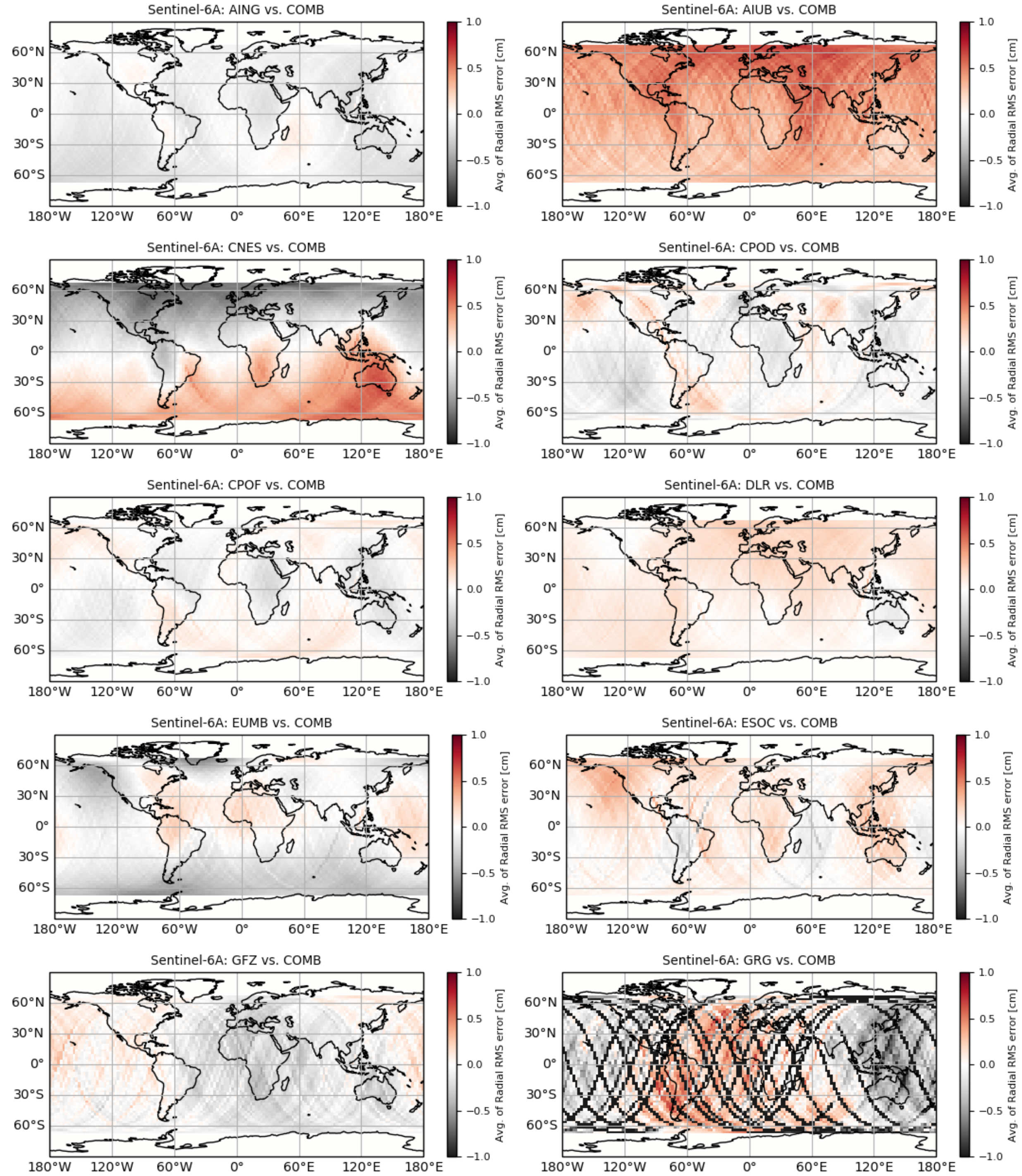
Table 3-24: Sentinel-6A orbit comparisons – Mean of daily RMS [cm] (All vs. COMB)

Orbit Comparisons (Mean of daily RMS [cm])					
Orbit Solution	Centre	Satellite component			
		Radial	Along-track	Cross-track	3D
AING	**AIUB**	0.18	0.19	0.21	0.34
AIUB	**AIUB**	0.53	0.25	0.26	0.64
CNES	**CNES**	0.47	0.90	0.60	1.19
CPOD	**CPOD**	0.28	0.68	0.66	1.02
CPOF	**CPOD**	0.20	0.34	0.22	0.45
DLR	**DLR**	0.17	0.18	0.22	0.33
ESOC	**ESOC**	0.31	0.39	0.41	0.66
EUMB	**EUMB**	0.30	0.33	0.61	0.76
GFZ	**GFZ**	0.47	1.08	0.79	1.44
GRG	**GRG**	0.59	2.14	2.20	3.19
JPL	**JPL**	0.21	0.40	0.41	0.61
TUDF	**TUD**	0.34	0.49	0.41	0.73
TUG	**TUG**	0.23	0.25	0.46	0.57
TUM	**TUM**	0.37	0.27	0.23	0.52
GSFC	**GSFC**	0.59	2.16	1.30	2.62

The Sentinel-6A orbit solutions generated by the CPOD Service show a performance in line with the results obtained on the other solutions.

3.6.3. GEOGRAPHICAL ANALYSIS

Figure 3-23 shows the 3D RMS orbit comparisons calculated on the previous sub section projected on an equi-rectangular map plot. Each cell of the map contains the mean value of all orbit comparisons falling on this cell during the reported period.



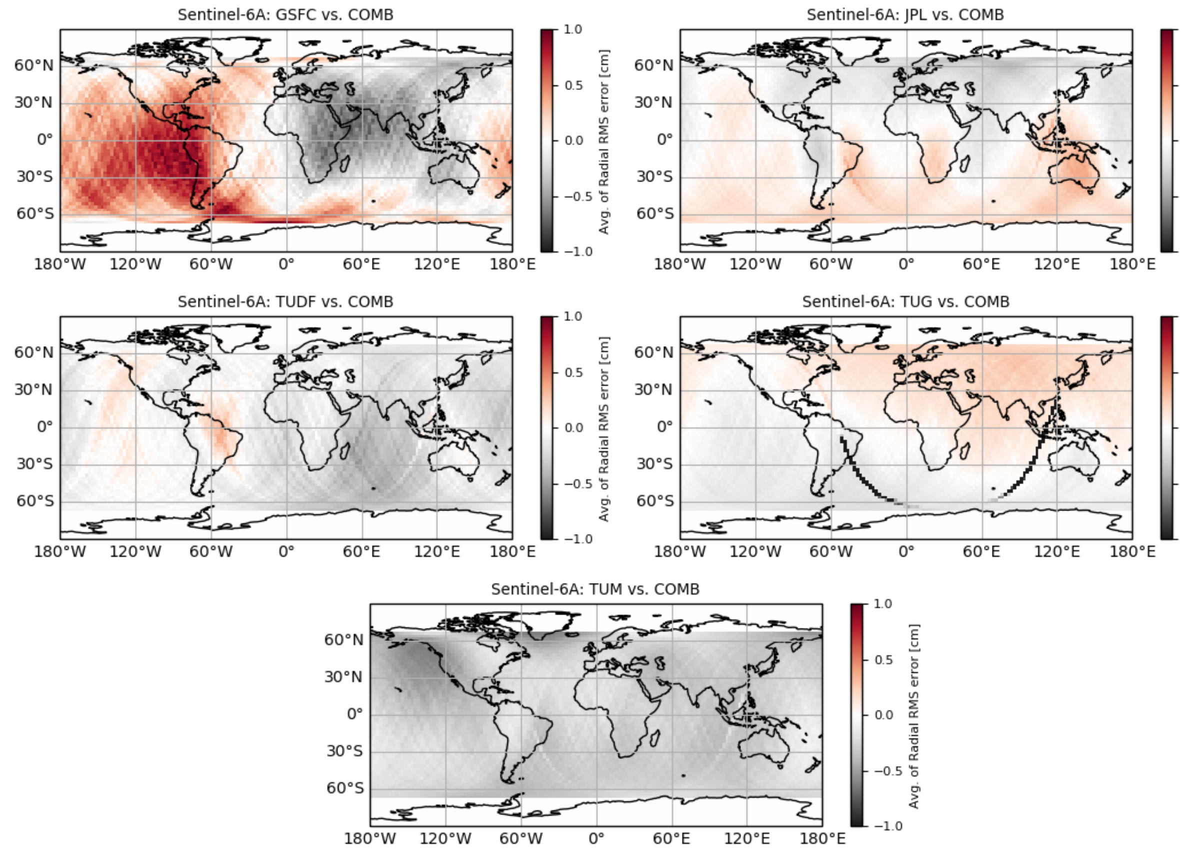
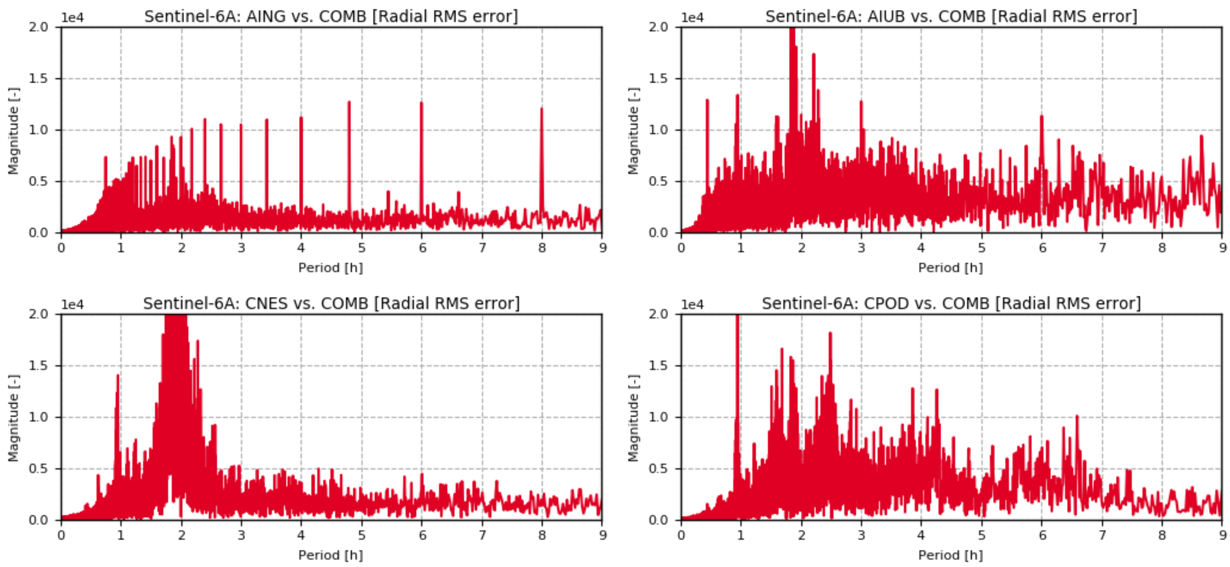


Figure 3-45: Sentinel-3A geographical analysis – Average of the radial RMS orbit comparisons (All vs. COMB)

3.6.4. SPECTRAL ANALYSIS

Figure 3-46 shows the FFT of the 3D RMS orbit comparisons calculated on the previous sub section.



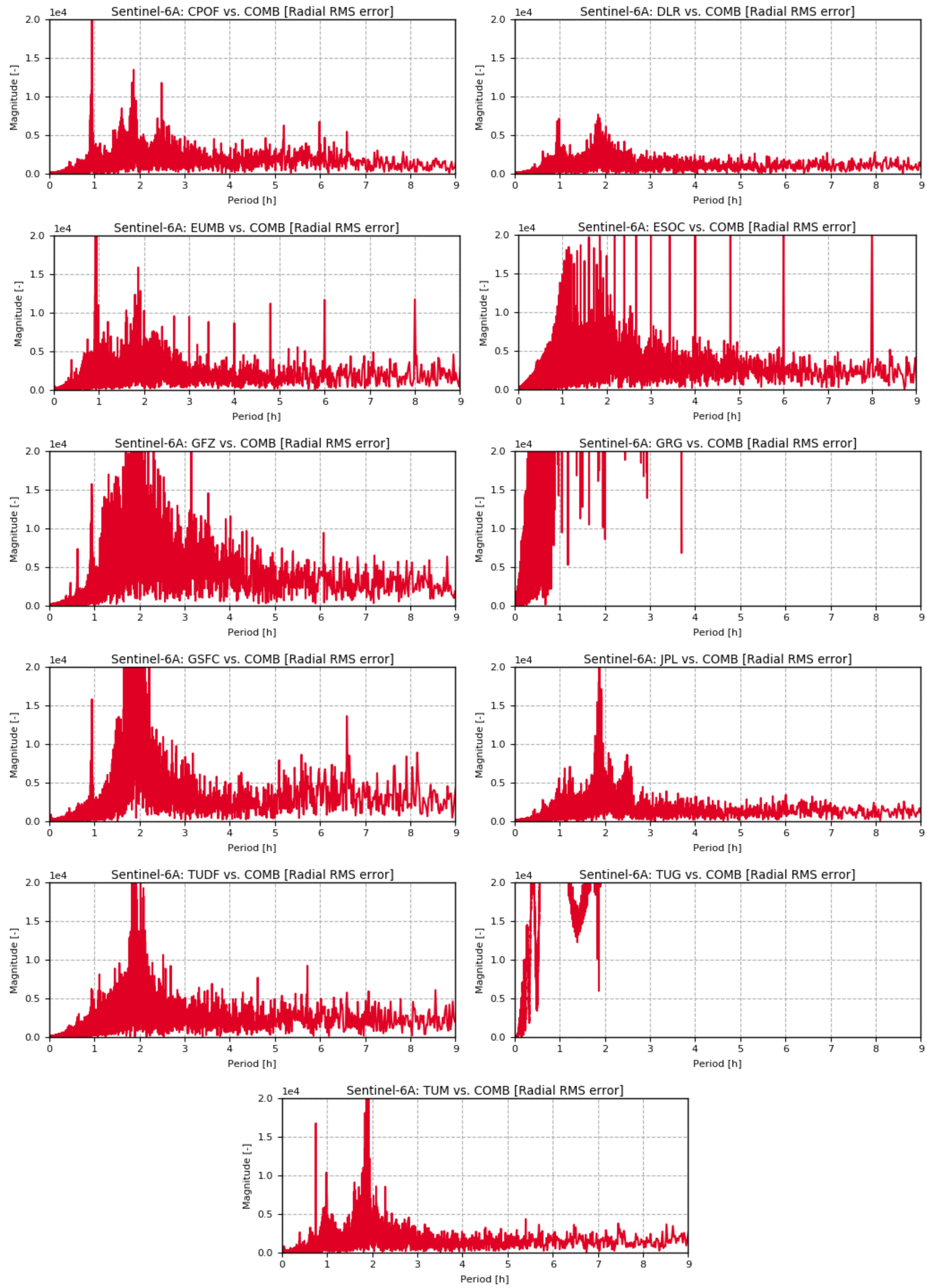


Figure 3-46: Sentinel-6A spectral analysis – Radial RMS orbit comparisons (All vs. COMB)

3.6.5. SLR VALIDATION

Figure 3-47 shows the accepted Sentinel-6A observations that the SLR stations have retrieved from the tracking of Sentinel-6A satellite during the reported period.

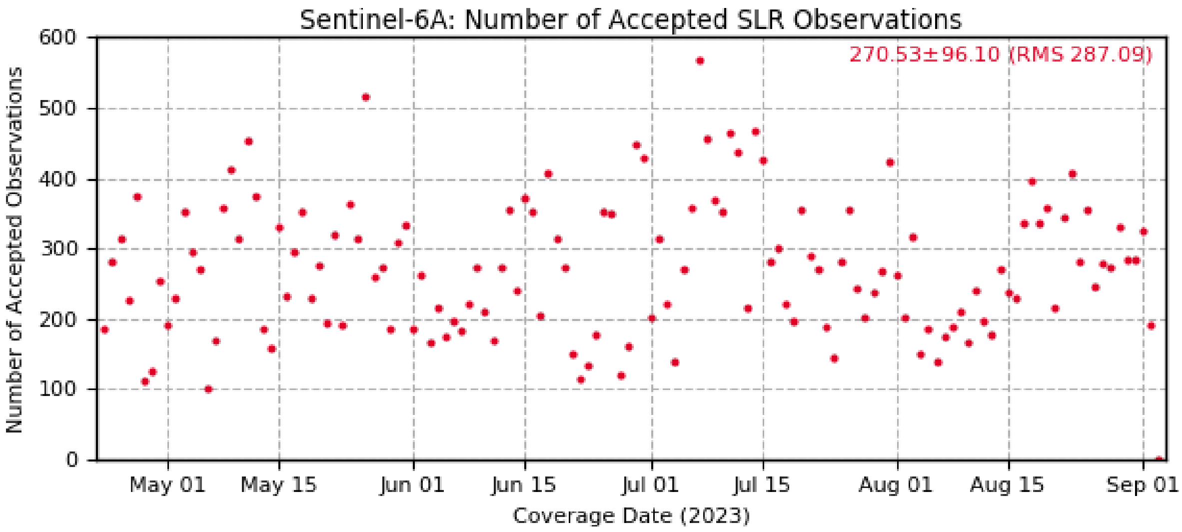
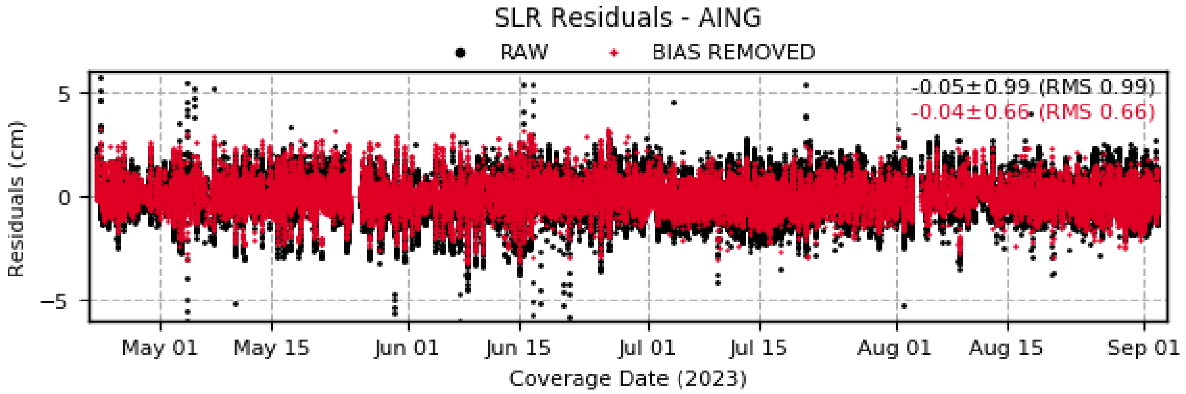


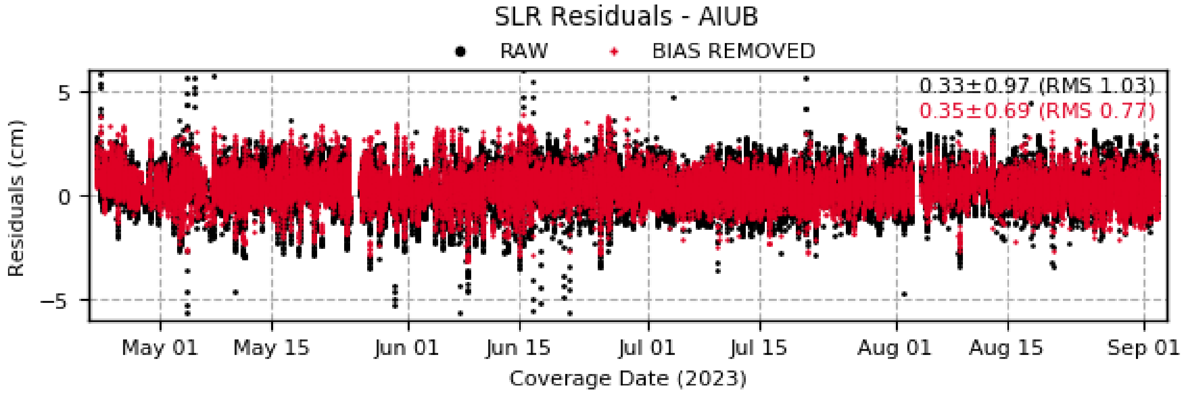
Figure 3-47: Sentinel-6A SLR validation – Number of accepted SLR observations

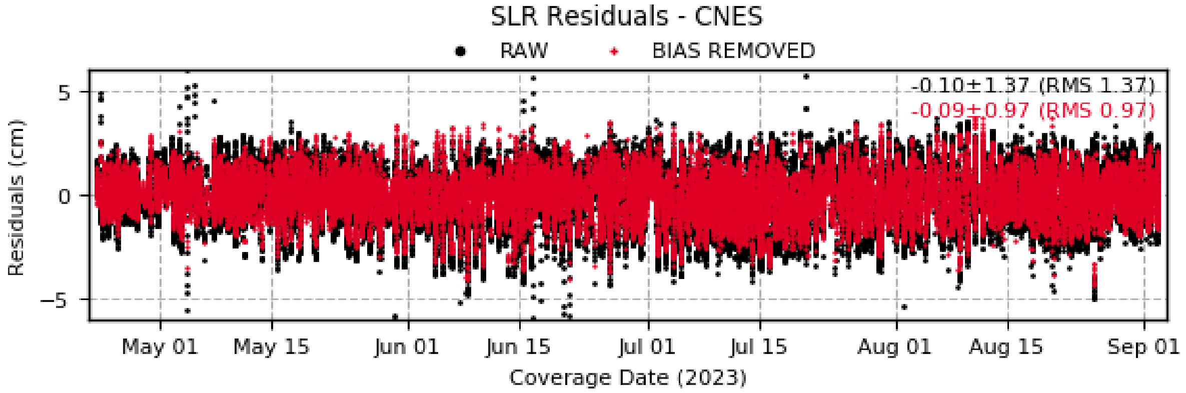
Figure 3-48 presents the temporal evolution of the Sentinel-6A SLR residuals that have been calculated from each orbit solution (**RAW**). It also shows the SLR residuals that have been calculated by removing a constant bias affecting their generation (**BIAS REMOVED**). These biases are computed using the COMB solution, for elevations higher than 10 degrees, and estimating a single value per station for the whole period and all satellites (S-3A, S-3B, S-6A). Table 3-25 summarises the range biases per SLR station that have been considered during the processing of the SLR residuals.

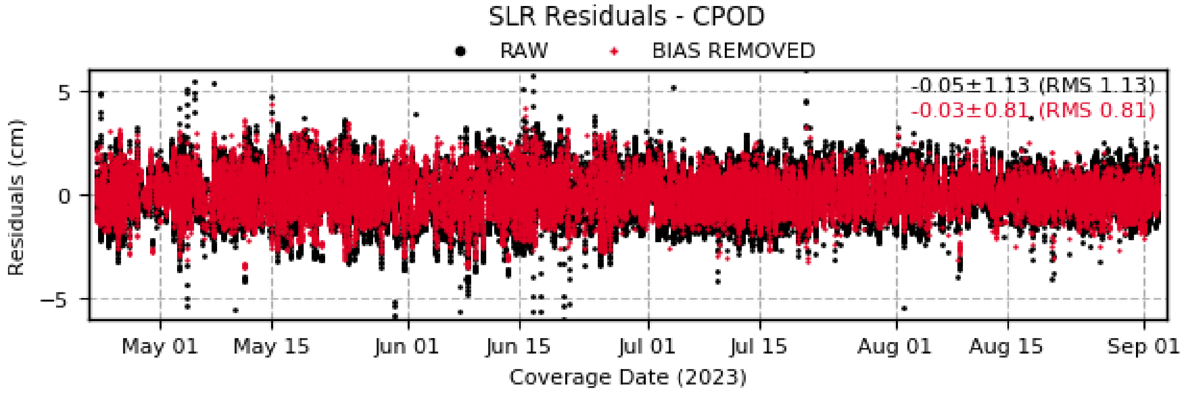
In Figure 3-48, the white spaces are due to punctual missing orbit solutions mainly caused by either manoeuvres or large gaps of data. Despite this fact, all SLR residuals of the different orbit solutions have behaved nominally, obtaining similar values as previous RSR documents. It can be seen that there is a decrease in the dispersion of the residuals since the end of June, which is due to the residuals obtained from the observations of one of the stations (7840) that improve after this date.

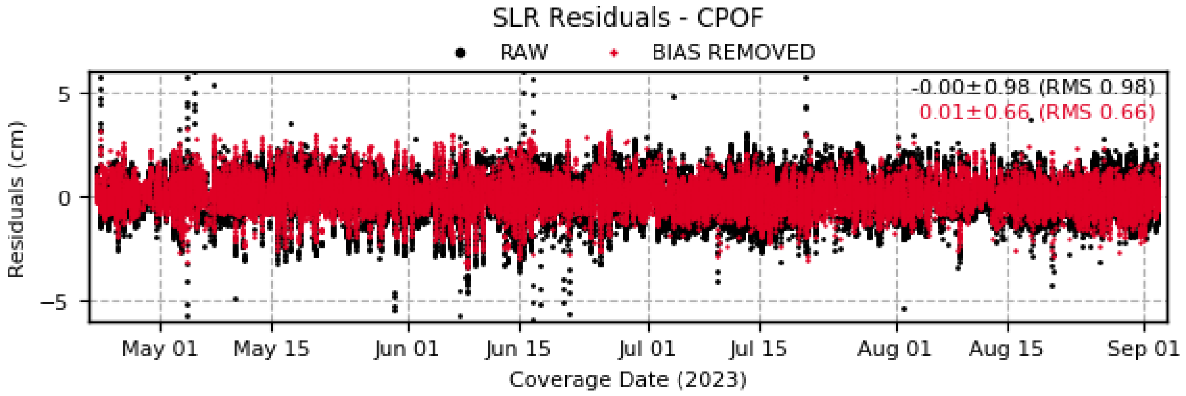
As a comment, the CNES SLR residuals may be higher than expected since the orbit solution **CNES** makes use of a POE-F standard, and the orbits have not been treated consistently regarding the geocentre motion they apply.

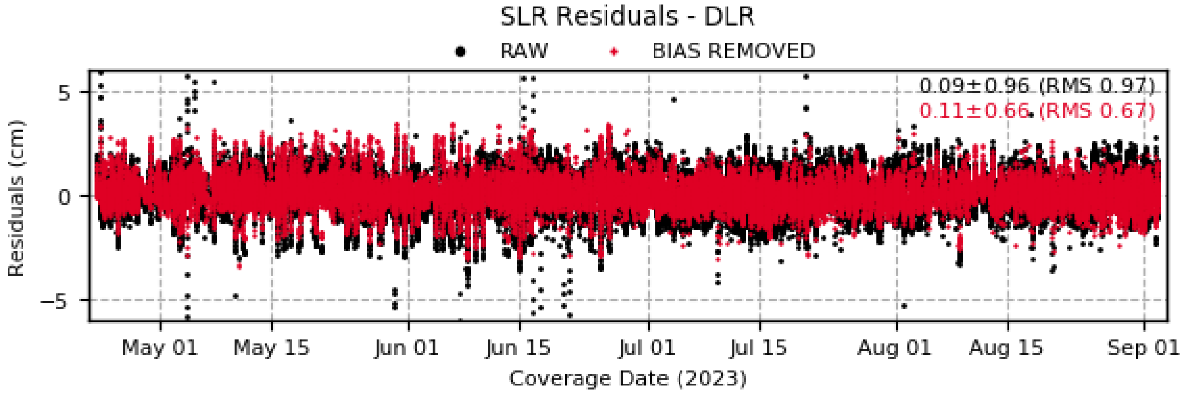

SLR Residuals - AING
RAW
BIAS REMOVED
-0.05±0.99 (RMS 0.99)
-0.04±0.66 (RMS 0.66)
Residuals (cm)
5
0
−5
May 01
May 15
Jun 01
Jun 15
Jul 01
Jul 15
Aug 01
Aug 15
Sep 01
Coverage Date (2023)

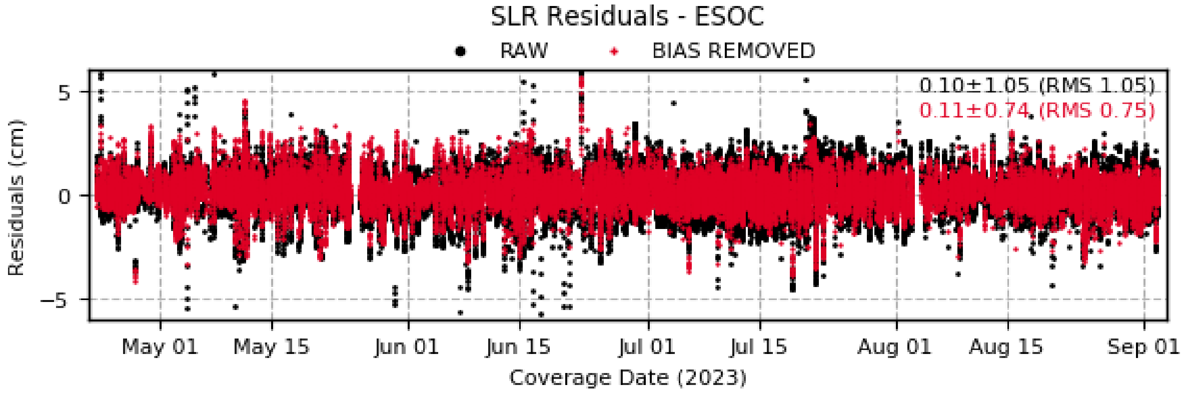

SLR Residuals - AIUB
RAW
BIAS REMOVED
0.33±0.97 (RMS 1.03)
0.35±0.69 (RMS 0.77)
Residuals (cm)
5
0
−5
May 01
May 15
Jun 01
Jun 15
Jul 01
Jul 15
Aug 01
Aug 15
Sep 01
Coverage Date (2023)

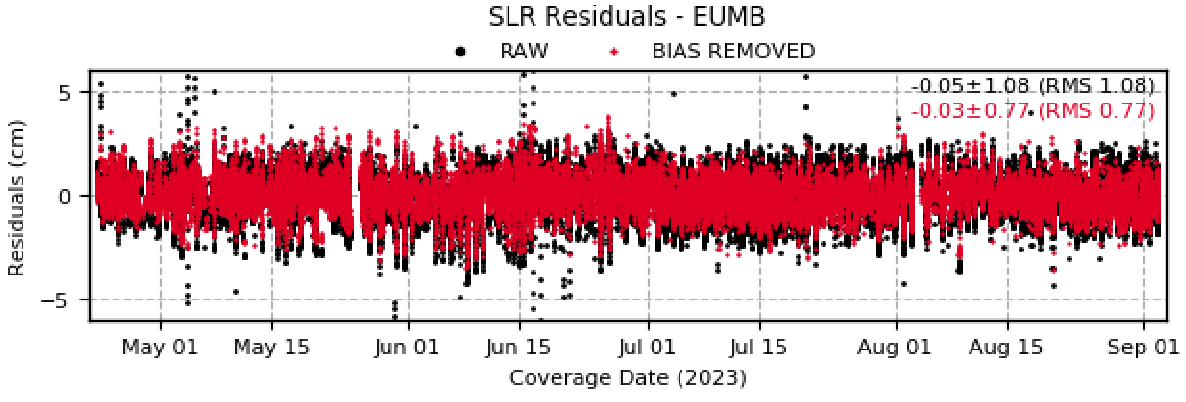

SLR Residuals - CNES
RAW
BIAS REMOVED
-0.10±1.37 (RMS 1.37)
-0.09±0.97 (RMS 0.97)
Residuals (cm)
5
0
−5
May 01
May 15
Jun 01
Jun 15
Jul 01
Jul 15
Aug 01
Aug 15
Sep 01
Coverage Date (2023)

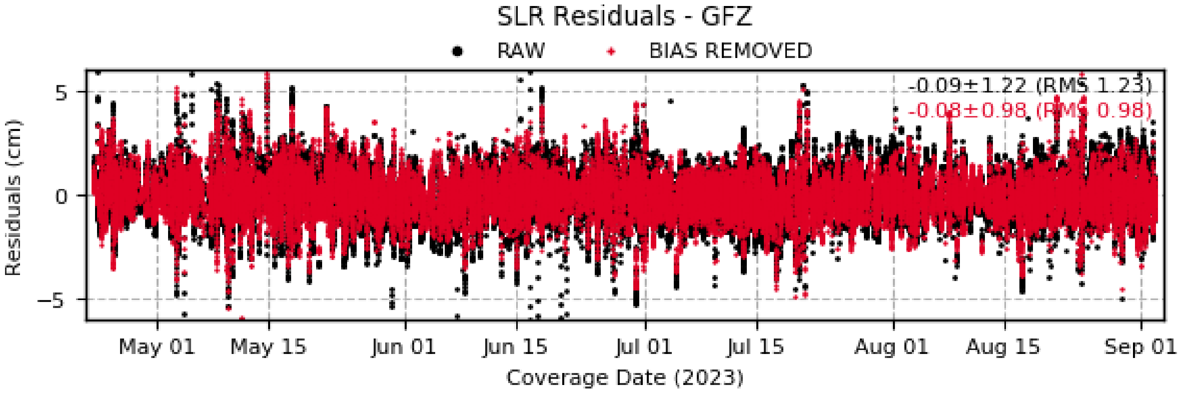

SLR Residuals - CPOD
RAW
BIAS REMOVED
-0.05±1.13 (RMS 1.13)
-0.03±0.81 (RMS 0.81)
Residuals (cm)
5
0
−5
May 01
May 15
Jun 01
Jun 15
Jul 01
Jul 15
Aug 01
Aug 15
Sep 01
Coverage Date (2023)

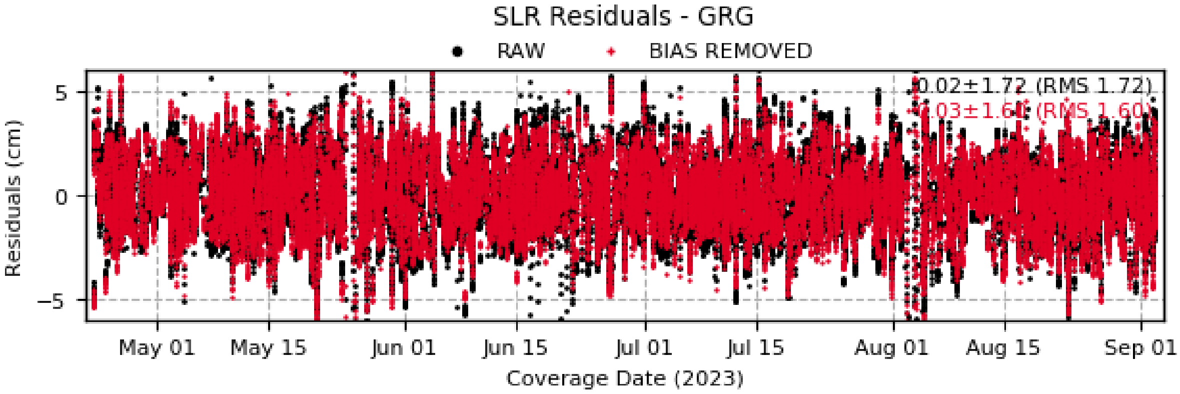

SLR Residuals - CPOF
RAW
BIAS REMOVED
-0.00±0.98 (RMS 0.98)
0.01±0.66 (RMS 0.66)
Residuals (cm)
5
0
−5
May 01
May 15
Jun 01
Jun 15
Jul 01
Jul 15
Aug 01
Aug 15
Sep 01
Coverage Date (2023)

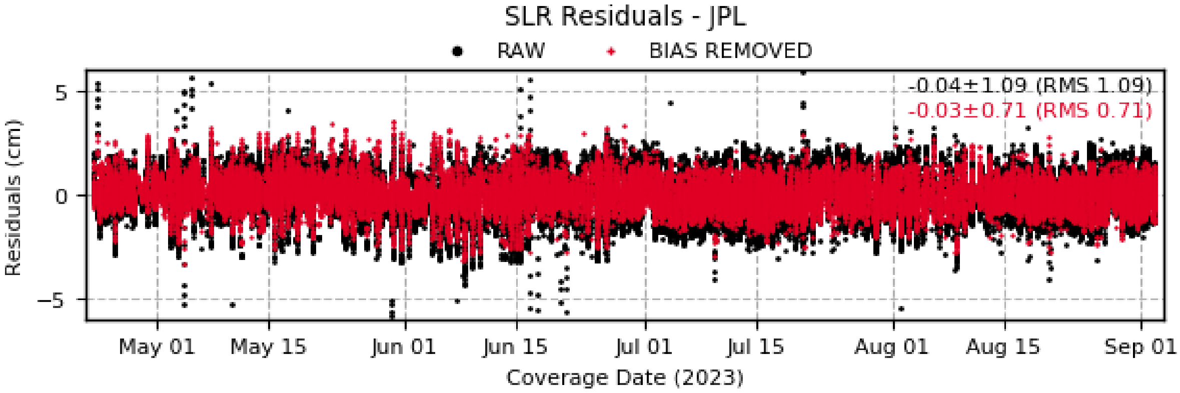

SLR Residuals - DLR
RAW
BIAS REMOVED
0.09±0.96 (RMS 0.97)
0.11±0.66 (RMS 0.67)
Residuals (cm)
5
0
−5
May 01
May 15
Jun 01
Jun 15
Jul 01
Jul 15
Aug 01
Aug 15
Sep 01
Coverage Date (2023)

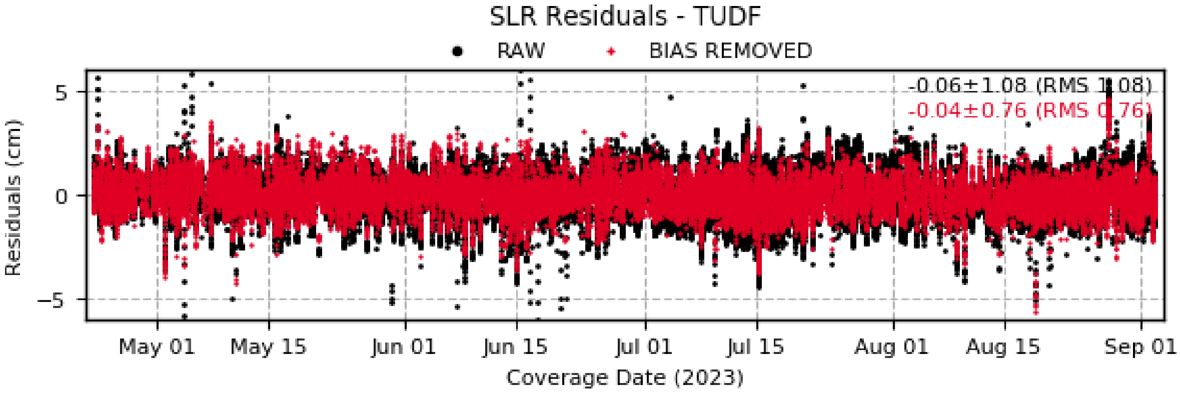

SLR Residuals - ESOC
RAW
BIAS REMOVED
0.10±1.05 (RMS 1.05)
0.11±0.74 (RMS 0.75)
Residuals (cm)
5
0
−5
May 01
May 15
Jun 01
Jun 15
Jul 01
Jul 15
Aug 01
Aug 15
Sep 01
Coverage Date (2023)


SLR Residuals - EUMB
RAW
BIAS REMOVED
-0.05±1.08 (RMS 1.08)
-0.03±0.77 (RMS 0.77)
Residuals (cm)
5
0
−5
May 01
May 15
Jun 01
Jun 15
Jul 01
Jul 15
Aug 01
Aug 15
Sep 01
Coverage Date (2023)


SLR Residuals - GFZ
RAW
BIAS REMOVED
-0.09±1.22 (RMS 1.23)
-0.08±0.98 (RMS 0.98)
Residuals (cm)
Coverage Date (2023)


SLR Residuals - GRG
RAW
BIAS REMOVED
0.02±1.72 (RMS 1.72)
0.03±1.60 (RMS 1.60)
Residuals (cm)
Coverage Date (2023)


SLR Residuals - JPL
RAW
BIAS REMOVED
-0.04±1.09 (RMS 1.09)
-0.03±0.71 (RMS 0.71)
Residuals (cm)
Coverage Date (2023)


SLR Residuals - TUDF
RAW
BIAS REMOVED
-0.06±1.08 (RMS 1.08)
-0.04±0.76 (RMS 0.76)
Residuals (cm)
Coverage Date (2023)

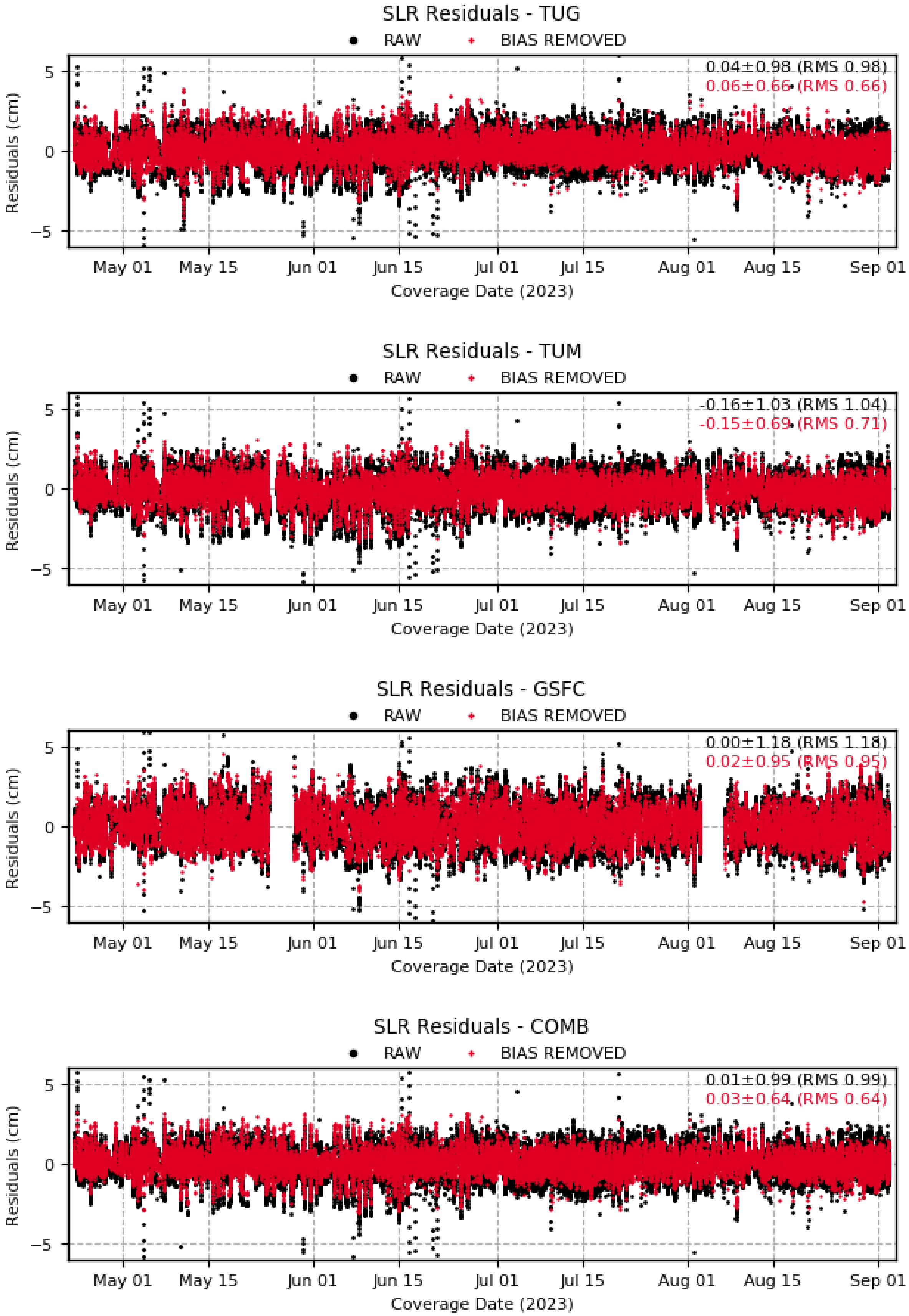


Figure 3-48: Sentinel-6A SLR validation – SLR residuals [cm]

Table 3-25: Sentinel-6A SLR validation – Estimated two-way biases per SLR station

Two-Way Biases			Two-Way Biases		
SLR station		Bias [mm]	SLR station		Bias [mm]
Monument	Code		Monument	Code	
7090	**YARL**	8.28	**7825**	**STL3**	18.57
7105	**GODL**	-14.51	**7839**	**GRZL**	1.35
7110	**MONL**	-9.11	**7840**	**HERL**	-13.32
7119	**HA4T**	19.27	**7841**	**POT3**	-14.73
7501	**HARL**	10.94	**7941**	**MATM**	-16.27
7810	**ZIML**	-	**8834**	**WETL**	-6.35

The previous outcome of the residuals before removing the bias is summarised in Figure 3-49 and Table 3-26 where the mean, standard deviation (STD) and RMS values of the calculated SLR residuals are shown.

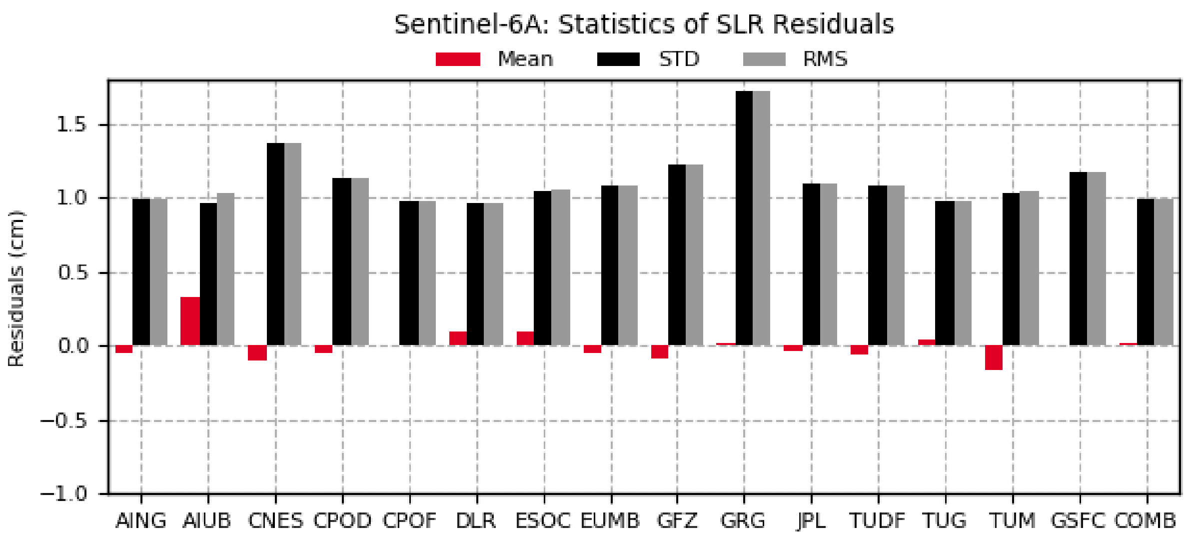


Figure 3-49: Sentinel-6A SLR validation – SLR residuals [cm] (mean, STD and RMS)

Table 3-26: Sentinel-6A SLR validation – SLR residuals [cm] (mean, STD and RMS)

SLR Residuals [cm]				
Orbit Solution	Centre	Mean	Standard Deviation	RMS
AING	**AIUB**	-0.05	0.99	0.99
AIUB	**AIUB**	0.33	0.97	1.03
CNES	**CNES**	-0.10	1.37	1.37
CPOD	**CPOD**	-0.05	1.13	1.13
CPOF	**CPOD**	-0.00	0.98	0.98
DLR	**DLR**	0.09	0.96	0.97
ESOC	**ESOC**	0.10	1.05	1.05
EUMB	**EUMB**	-0.05	1.08	1.08

SLR Residuals [cm]				
Orbit Solution	**Centre**	**Mean**	**Standard Deviation**	**RMS**
GFZ	**GFZ**	-0.09	1.22	1.23
GRG	**GRG**	0.02	1.72	1.72
JPL	**JPL**	-0.04	1.09	1.09
TUDF	**TUD**	-0.06	1.08	1.08
TUG	**TUG**	0.04	0.98	0.98
TUM	**TUM**	-0.16	1.03	1.04
GSFC	**GSFC**	0.00	1.18	1.18
COMB	**-**	0.01	0.99	0.99

Moreover, the previous outcome of the residuals after removing the bias is summarised in Figure 3-50 and Table 3-27 where the mean, standard deviation (STD) and RMS values of the calculated SLR residuals are shown.

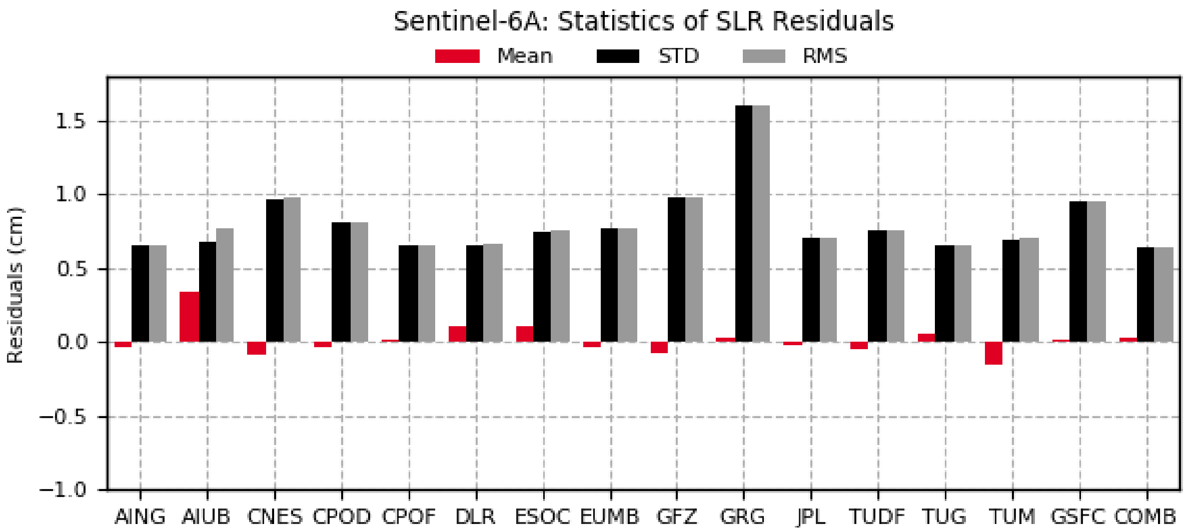


Figure 3-50: Sentinel-6A SLR validation – SLR residuals after removing the bias [cm] (mean, STD and RMS)

Table 3-27: Sentinel-6A SLR validation – SLR residuals after removing the bias [cm] (mean, STD and RMS)

SLR Residuals [cm]				
Orbit Solution	**Centre**	**Mean**	**Standard Deviation**	**RMS**
AING	**AIUB**	-0.04	0.66	0.66
AIUB	**AIUB**	0.35	0.69	0.77
CNES	**CNES**	-0.09	0.97	0.97
CPOD	**CPOD**	-0.03	0.81	0.81
CPOF	**CPOD**	0.01	0.66	0.66
DLR	**DLR**	0.11	0.66	0.67
ESOC	**ESOC**	0.11	0.74	0.75

SLR Residuals [cm]				
Orbit Solution	**Centre**	**Mean**	**Standard Deviation**	**RMS**
EUMB	**EUMB**	-0.03	0.77	0.77
GFZ	**GFZ**	-0.08	0.98	0.98
GRG	**GRG**	0.03	1.60	1.60
JPL	**JPL**	-0.03	0.71	0.71
TUDF	**TUD**	-0.04	0.76	0.76
TUG	**TUG**	0.06	0.66	0.66
TUM	**TUM**	-0.15	0.69	0.71
GSFC	**GSFC**	0.02	0.95	0.95
COMB	**-**	0.03	0.64	0.64

The Sentinel-6A orbit solutions generated by the CPOD Service show a performance in line with the results obtained on the other solutions.

3.6.6. ORBIT COMPARISONS OF S-6A STC ORBIT SOLUTIONS

The operational S-6 STC solutions from the CPOD Service (labelled as CPOR), CNES (the MOED solution, which has been labelled as CNER), and TUD rapid solution are compared here against the combined solution.

TUD is currently generating one STC orbit solution for Sentinel-6A, which has been labelled as **TUDR.** This STC orbit solution is based on rapid GNSS products from JPL (with high-rate clocks).

Figure 3-40 shows the radial RMS accuracy of the orbit solutions for all the reported period. As seen in the figure, the TUD solutions offer the best performance, similar to the performance shown by the TUDF NTC solution, thanks to the use of integer ambiguity resolution.

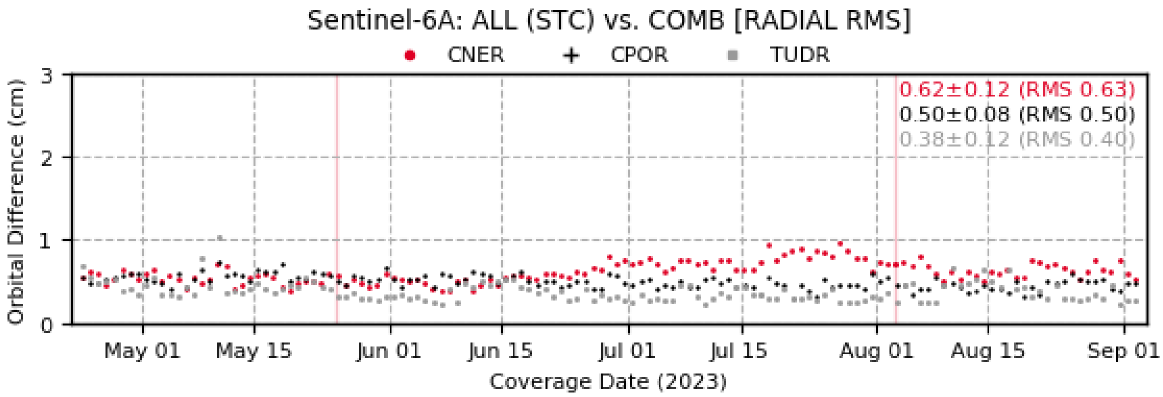


Figure 3-51: Sentinel-6A orbit comparisons – All (STC) vs. COMB [radial RMS; cm]

A more detailed distribution of the obtained accuracy can be found in Table 3-28, where the percentiles of the radial RMS is calculated for different thresholds.

Table 3-28: Sentinel-6A STC (all) solutions – Accuracy percentiles (orbit comparisons against COMB solution [radial RMS], respectively)

Product Accuracy			
Threshold	Percentage of Fulfilment		
	CNER	CPOR	TUDR
< 1 cm	100.00 %	100.00 %	99.25 %
< 2 cm	100.00 %	100.00 %	100.00 %
< 3 cm	100.00 %	100.00 %	100.00 %
< 4 cm	100.00 %	100.00 %	100.00 %

4. GNSS SENSOR PERFORMANCE ANALYSIS

The proper operation of the GNSS receiver is paramount in the POD processing, as it is based on GNSS measurements. Thus, this section is intended to analyse the GNSS sensor performance of each Sentinel. A very detailed analysis, taking the observations corresponding to every single day of the reported period, would overshoot the sought aim, which is to provide a general insight of the current GNSS status. Instead, a particular epoch has been chosen, **2023/07/28**, in which neither gaps nor manoeuvres took place (for any Sentinel). For this day, the GNSS data required for generating the corresponding NTC product (in S-1, S-2 and S-3) and STC product (in S-6, since it includes GPS+GAL, whereas its NTC uses only GAL) have been processed (i.e., the complete day plus four hours in its boundaries for S-1 and S-2; adding six hours before the beginning of the day and two hours after its end for S-3; and adding five hours before the beginning of the day and three hours after its end for S-6) to extract some valuable metrics that will be presented in the subsequent sections. Of course, the outcome obtained for the studied day can be generalized for the whole period.

4.1. TRACKING ANALYSIS

To assess the quality of the receiver, the observations are analysed geometrically and statistically. In Figure 4-1 and Figure 4-2, all observations tracked during the selected time interval (from GPS and GAL, respectively) are projected on the antenna frame, where the radial coordinate is the elevation angle from 90º (zenith) to 0º and the polar coordinate is equivalent to the antenna azimuth, oriented in a way where the zero-degree azimuth corresponds to the flight direction. It can be seen that the elevation cut-off angle is about 7º-10º. Furthermore, C1C observations are available slightly before the others, which also leads to a higher number of C1C observations. Indeed, as Figure 4-3 depicts, the frequency at which 8 simultaneous observations in S-1, S-2 and S-3 (i.e., the maximum number according to the receiver capabilities) are tracked is higher in the case of the C1C code, followed by the C2W code. Additionally, it is important to point out that most of the time the eight channels of the receiver are tracking the GPS signals at once, reflecting on its good performance. Regarding S-6, the maximum channel occupancy of 18 channels is never met, being the mean value for both constellations around 13. In this case, the frequency at which 8 or more simultaneous observations are tracked is again higher in GPS-C1C but followed by C2L code instead of C2W code.

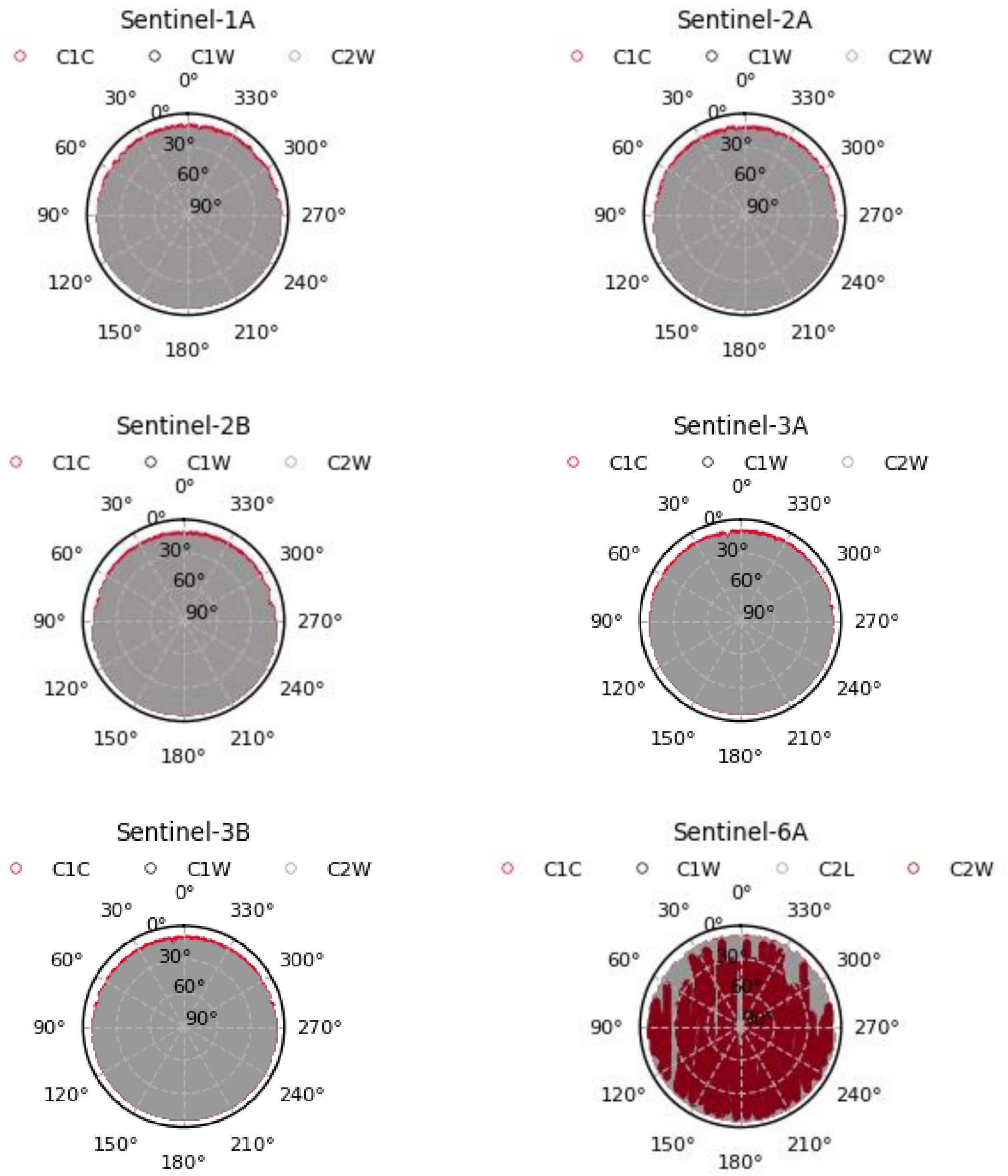


Figure 4-1: Projection of GPS observations onto the antenna frame (on 2023/07/28)

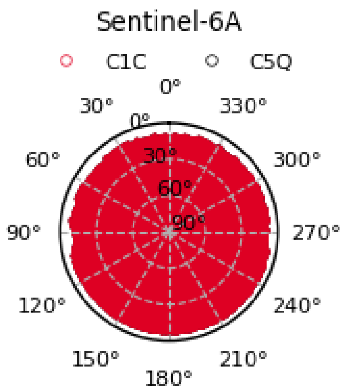
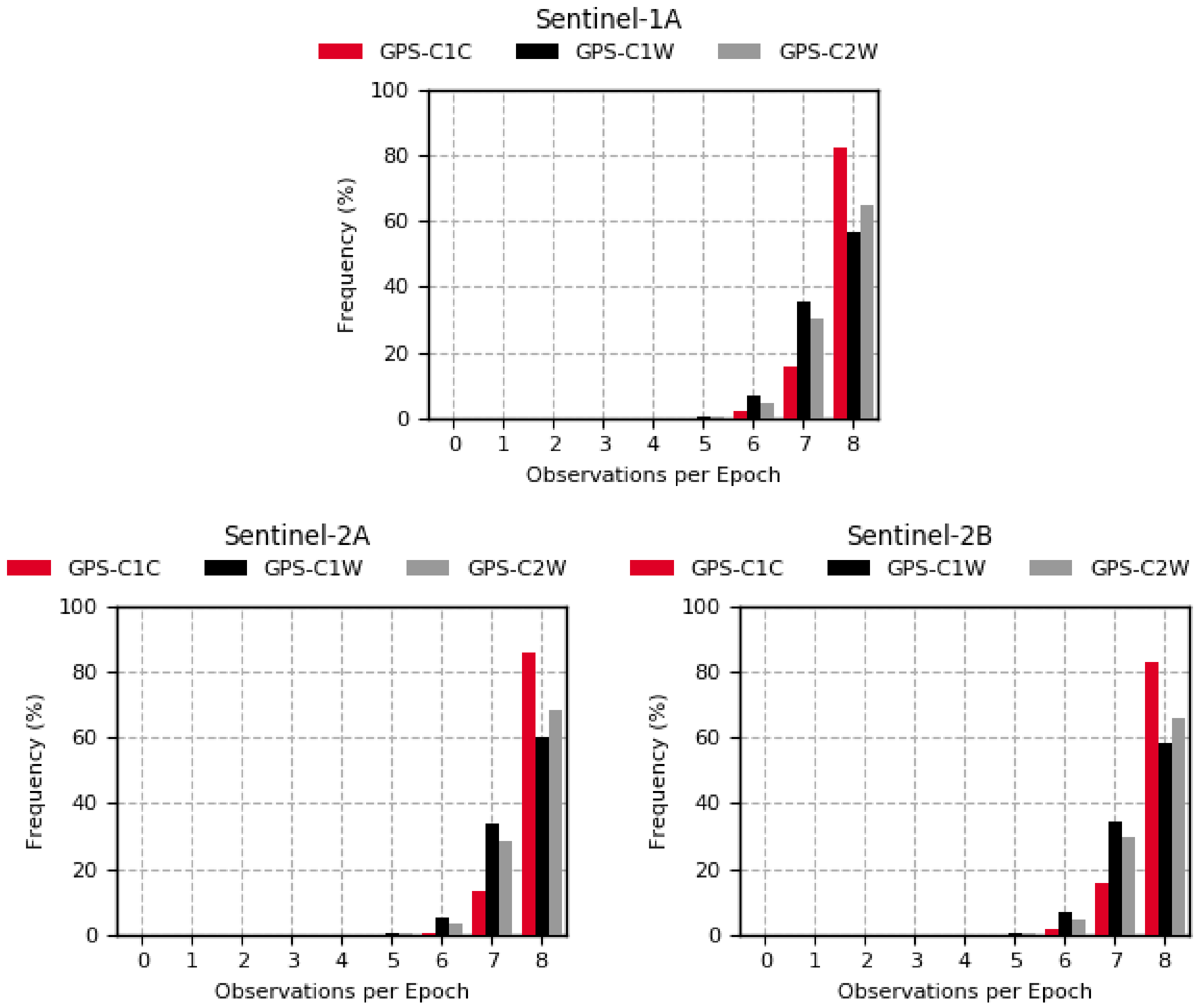


Figure 4-2: Projection of GAL observations onto the antenna frame (on 2023/07/28)



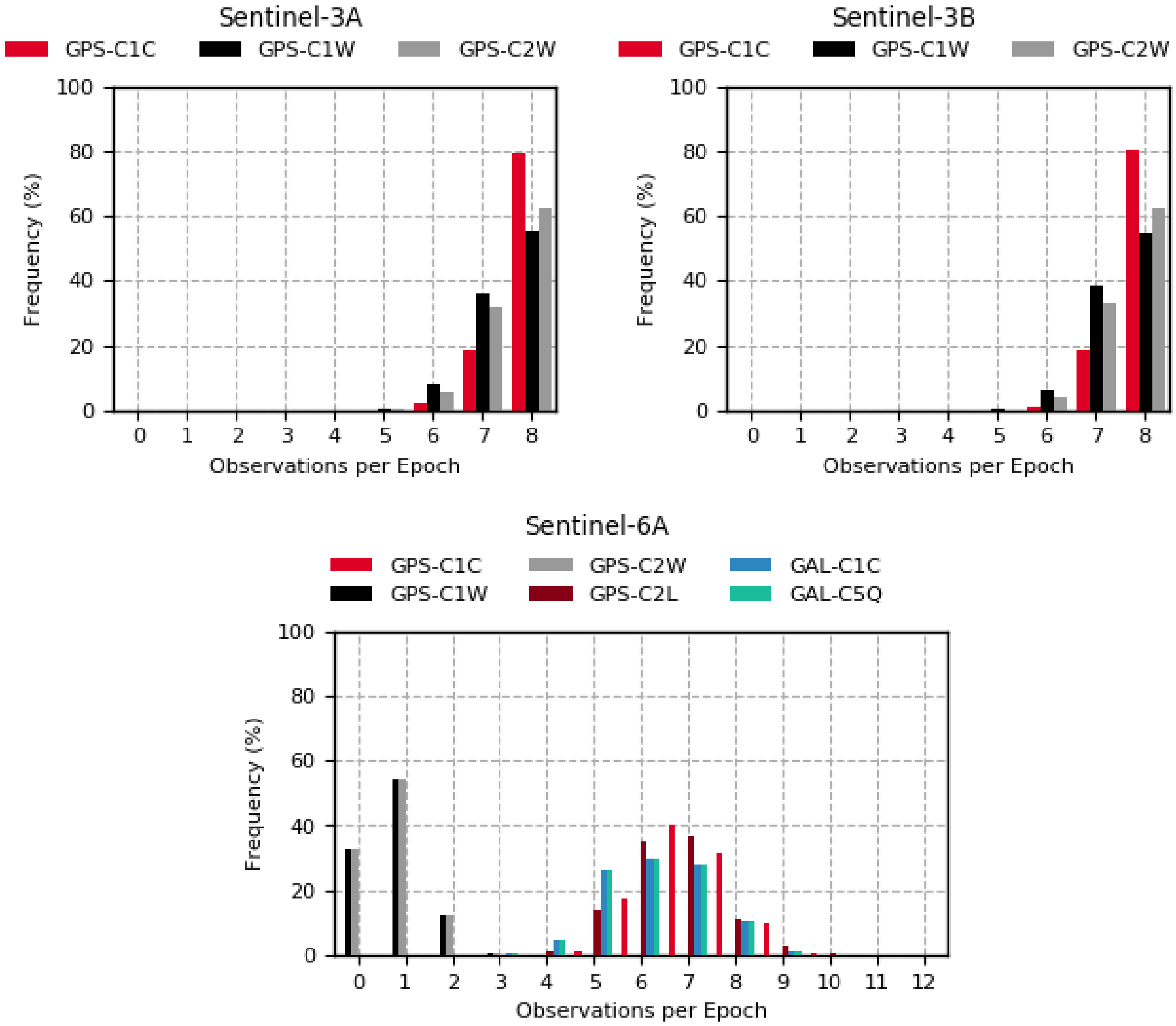


Figure 4-3: Histogram of GNSS observations (on 2023/07/28)

The results shown in Figure 4-3 for one particular day can be widened by keeping track of the daily average number of GPS and GAL satellites tracked by the S-1A (see Figure 4-4), the S-2A and S-2B satellites (see Figure 4-5), the S-3A and S-3B satellites (see Figure 4-6) and the S-6A satellite (see Figure 4-7 and Figure 4-8). For these Sentinel satellites and all mission days, the daily average number of tracked GPS satellites falls between 7.5 and 8, whereas the daily average number of tracked GAL satellites falls between 6 and 7. This shows the good performance of the GNSS receivers on board.

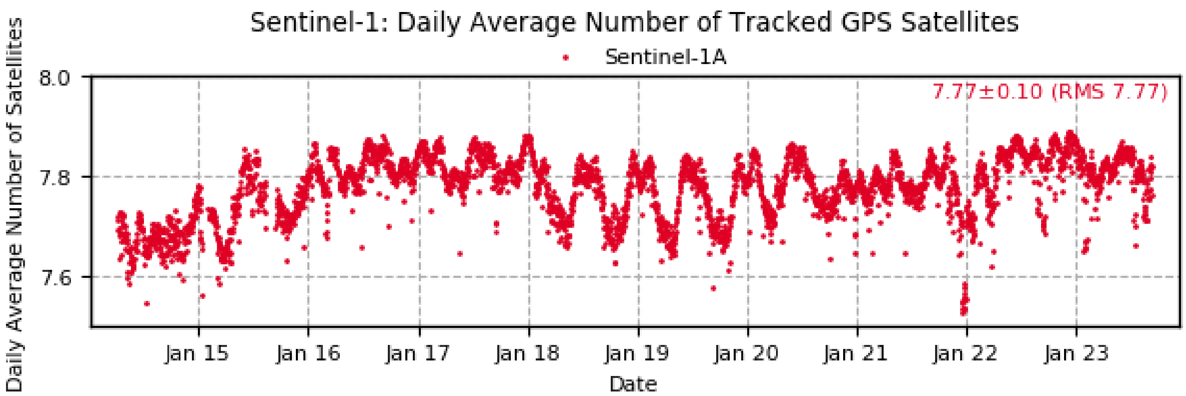


Figure 4-4: Daily average number of GPS satellites tracked by the S-1A satellite since the beginning of the mission

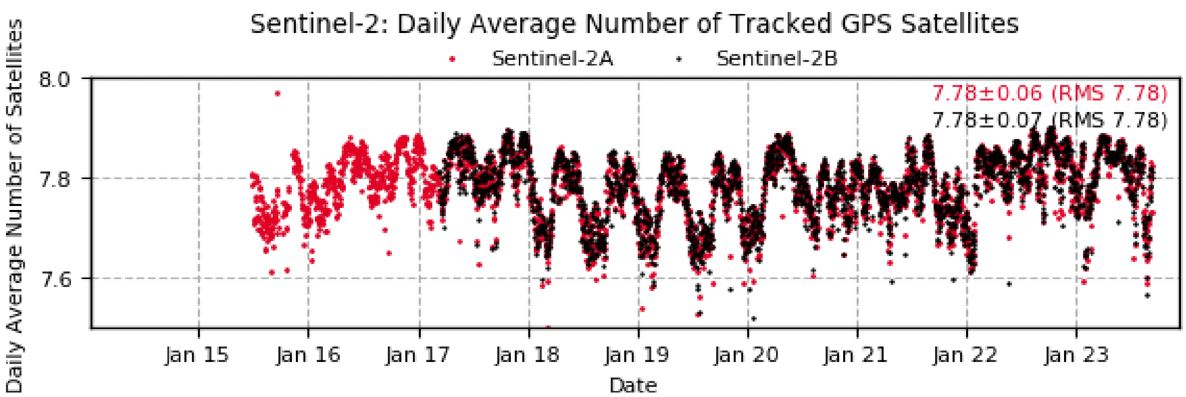


Figure 4-5: Daily average number of GPS satellites tracked by the S-2A and S-2B satellites since the beginning of the missions

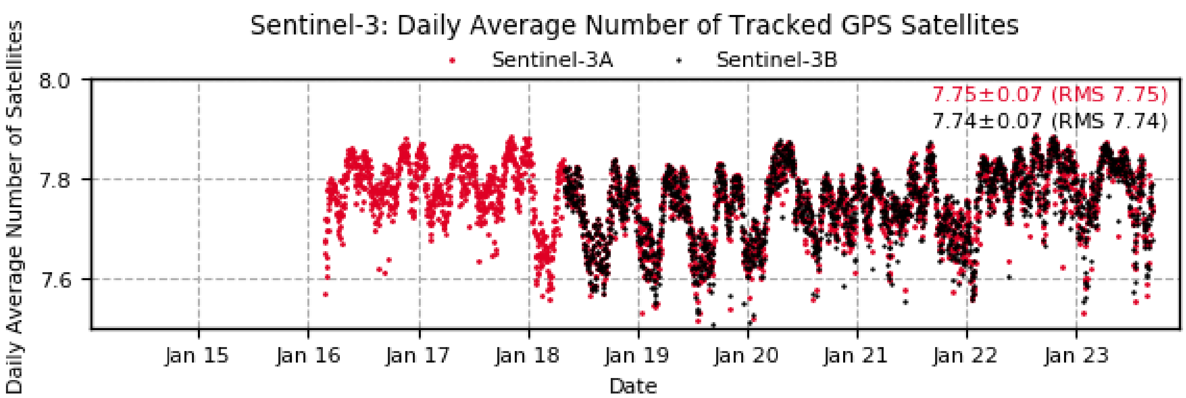


Figure 4-6: Daily average number of GPS satellites tracked by the S-3A and S-3B satellites since the beginning of the missions

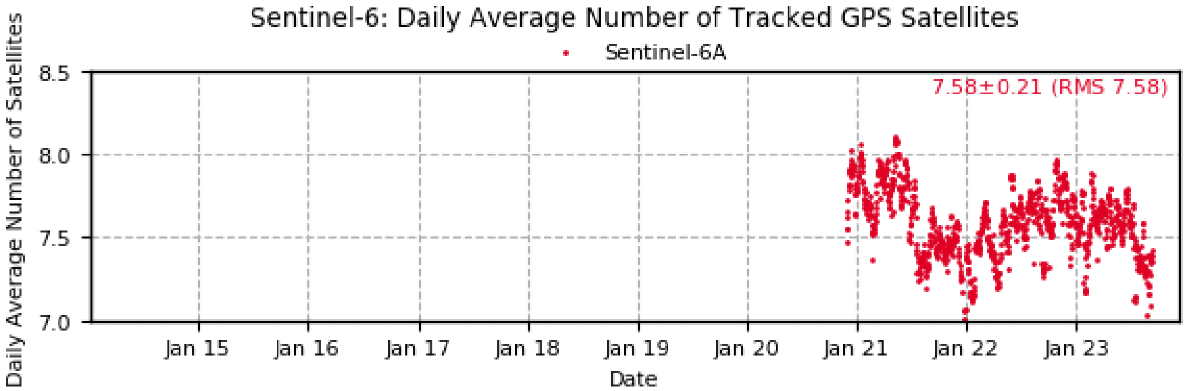


Figure 4-7: Daily average number of GPS satellites tracked by the S-6A satellite since the beginning of the mission

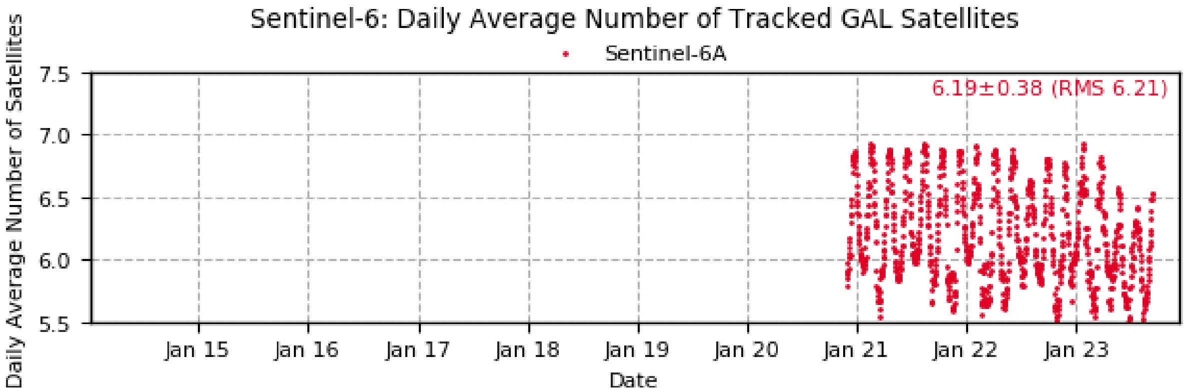


Figure 4-8: Daily average number of GAL satellites tracked by the S-6A satellite since the beginning of the missions

4.2. ANALYSIS OF SIGNAL STRENGTH

Figure 4-9 and Figure 4-10 show the signal-to-noise ratios C/N_0 observed for GPS and GAL signals, respectively, as a function of elevation. Note that S1W values are not shown in Figure 4-9 since they are not directly available. These values should match the values obtained by S2W. S1C has a C/N_0 that ranges between 50-60 dB-Hz at zenith, and drop down to 35-45 dB-Hz at cut-off elevation; whereas, in the case of S2W, two bands can be distinguished, one ranging between 45-55 dB-Hz at zenith and 10-25 dB-Hz around the cut-off elevation, and the other spanning 55-60 dB-Hz at zenith and 25-35 dB-Hz at cut-off elevation. These values are in agreement with expectations and show that the receivers are working well. With respect to the dual band of S2W, it is observed that power levels are split in two separate bands. GPS satellites from blocks IIF and IIR-M can change the power level depending on the geographical location, so the S2W curves on the upper side correspond to those satellites transmitting higher power over specific geographical locations. The fact that the scattering of points evolves with a certain dispersion is due to the C/N_0 is not symmetric with respect to the azimuth: the closer the measurements to the flight direction region, the lower noise they have. Regarding S-6A, both S1C and S2W follow a similar behaviour than the one explained previously, but showing only the lower band of S2W. GPS S2L and GAL S5Q signals depict a slightly better performance than C1C, but in the same ranges.

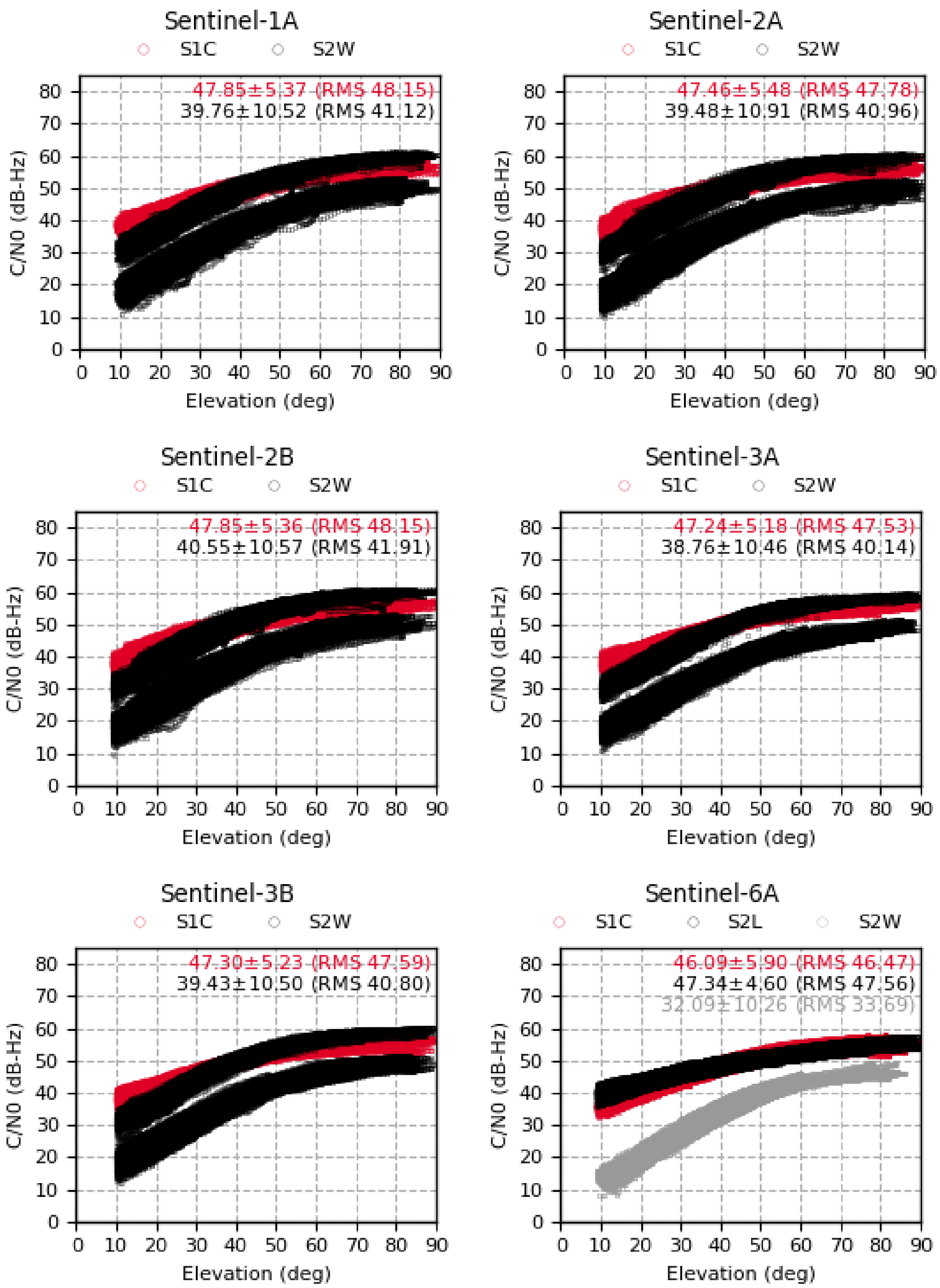


Figure 4-9: Signal strength of GPS observations (on 2023/07/28)

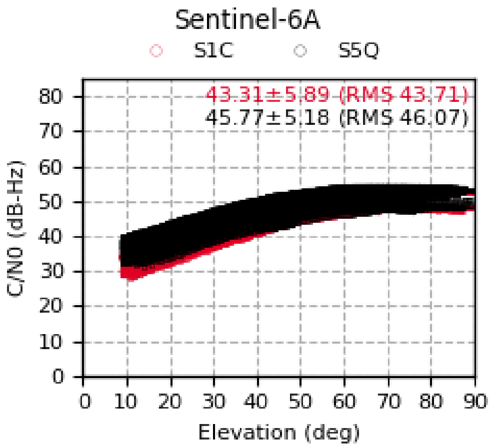


Figure 4-10: Signal strength of GAL observations (on 2023/07/28)

4.3. DILUTION OF PRECISION (DOP) PARAMETERS

The Dilution of Precision (DOP) is an indicator of the uncertainties caused by the tracked GNSS satellites geometrical distribution and temporal errors (i.e., related to the clock biases) with respect to the receiver. These values are desired to be small to guarantee a heterogeneous distribution of them.

Three different DOP parameters are commonly defined: the Position DOP (PDOP), which accounts only for the geometrical part; the Time DOP (TDOP), which accounts for the temporal errors, and the Geometric DOP (GDOP), which gathers both effects. Figure 4-11 shows their evolution along the studied time interval (i.e., the day 2023/07/28) for each Sentinel. Despite the noise, the values are quite stable: GDOP oscillates around 2.5-3; PDOP takes slightly lower values, around 2-2.5; and TDOP has the smallest values (as expected), around 1-1.5.

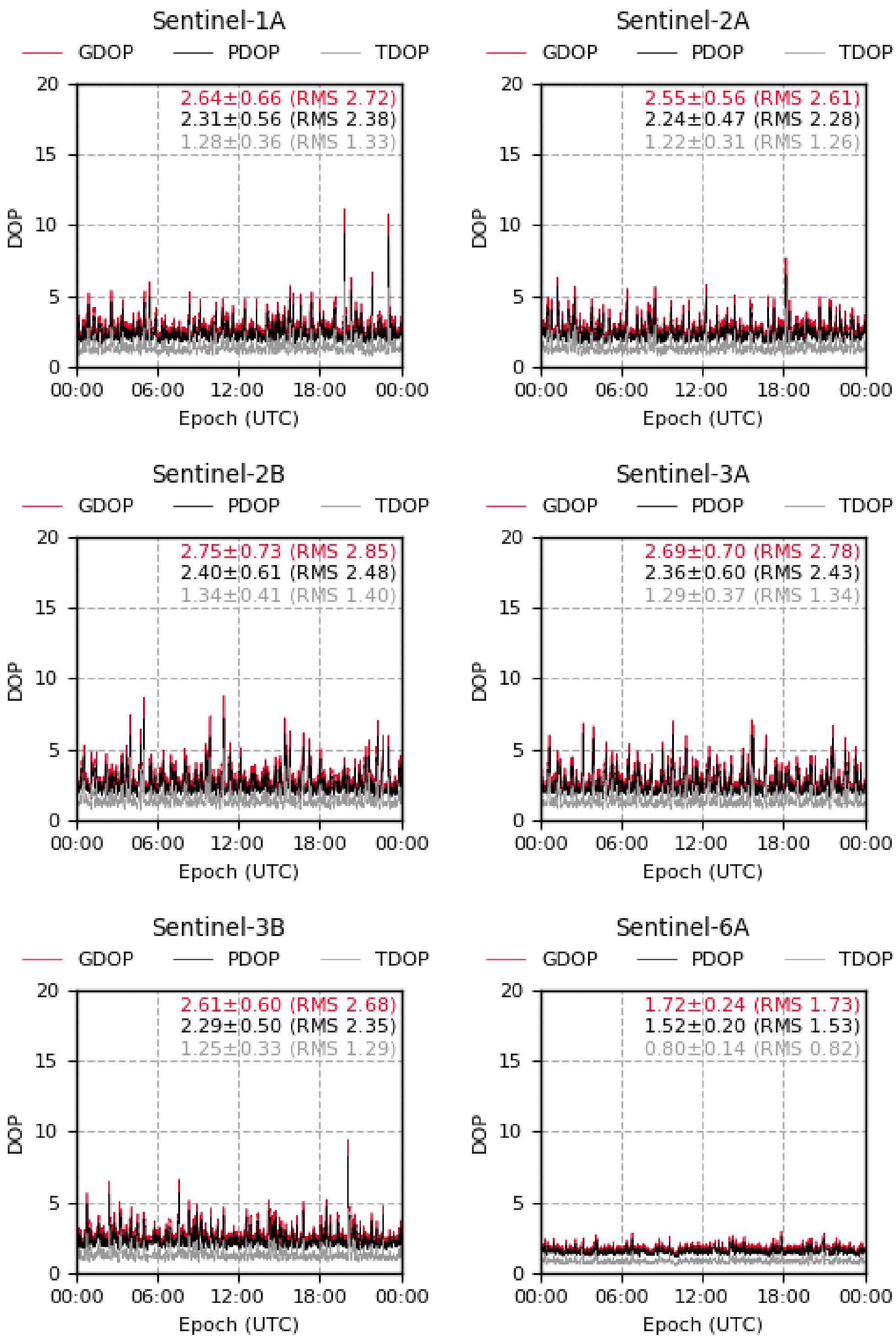


Figure 4-11: Evolution of Dilution of Precision (DOP) Parameters (on 2023/07/28)

4.4. GNSS USO FREQUENCY

The Ultra Stable Oscillator (USO), on-board the satellites Sentinel-3A, -3B and Sentinel-6A, generates a pulse used by the GNSS receiver and called Instrument Measurement Time (IMT).

Assuming that this frequency does not change, there will be no significant drift between the GNSS Time (GPST) computed by the GNSS receiver and the IMT. Figure 4-12 shows the daily drift of each USO for Sentinel-3, and Figure 4-13 for Sentinel-6.

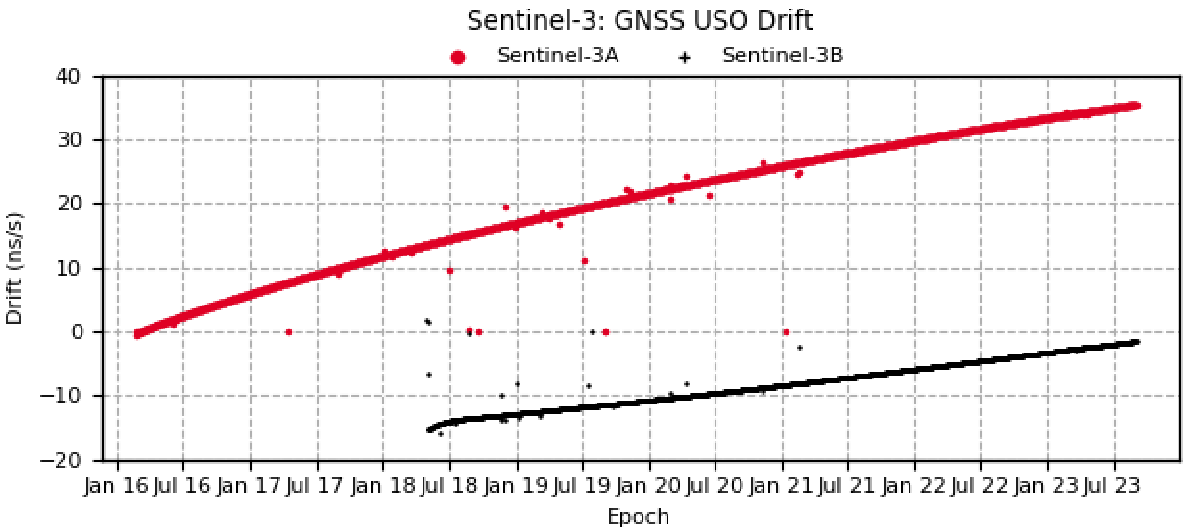


Figure 4-12: Sentinel-3 GNSS USO drift (ns/s)

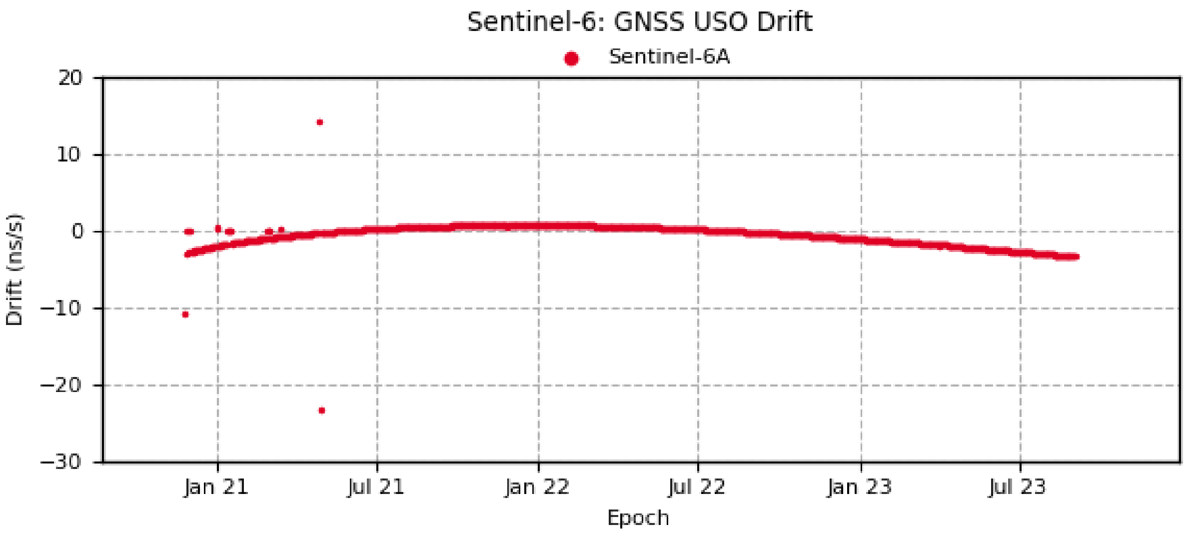


Figure 4-13: Sentinel-6 GNSS USO drift (ns/s)

ANNEX A. LIST OF SLR STATIONS

The following table provides the monument, code, location, and other relevant information about the SLR stations that have ever tracked any of the Sentinel-3 and Sentinel-6 satellites.

Table A-1: List of the SLR stations

Monument	Code	Location Name (Country)	Closed / Inactive	Allowed to Track S-3 Satellites	Used for SLR Validation(*)
1824	GLSL	Golosiiv (Ukraine)		X	
1873	SIML	Simeiz (Ukraine)		X	
1884	RIGL	Riga (Latvia)		X	
1888	SVEL	Svetloe (Russia)		X	
1889	ZELL	Zelenchukskya (Russia)		X	
1890	BADL	Badary (Russia)		X	
1893	KTZL	Katsively (Ukraine)		X	
7080	MDOL	McDonald Observatory, TX (USA)	X		
7090	YARL	Yarragadee (Australia)		X	X
7105	GODL	Greenbelt, MD (USA)		X	X
7110	MONL	Monument Peak, CA (USA)		X	X
7119	HA4T	Haleakala, Hawaii (USA)		X	X
7124	THTL	Tahiti (French Polynesia)		X	
7237	CHAL	Changchun (China)			
7249	BEIL	Beijing (China)		X	
7396	JFNL	Wuhan (China)			
7403	AREL	Arequipa (Peru)		X	
7501	HARL	Hartebeesthoek (South Africa)		X	X
7810	ZIML	Zimmerwald (Switzerland)		X	X
7811	BORL	Borowiec (Poland)		X	
7819	KUN2	Kunming (China)			
7821	SHA2	Shanghai (China)		X	
7824	SFEL	San Fernando (Spain)		X	
7825	STL3	Mt. Stromlo (Australia)		X	X
7838	SISL	Simosato (Japan)			
7839	GRZL	Graz (Austria)		X	X
7840	HERL	Herstmonceux (UK)		X	X
7841	POT3	Potsdam (Germany)		X	X
7845	GRSM	Grasse, (France)			
7941	MATM	Matera (Italy)		X	X
8834	WETL	Wettzell (Germany)			X

(*) Group of SLR stations that is used for SLR validation of Section 3.4.5, Section 3.5.5 and Section 3.6.5.

ANNEX B. DESCRIPTION OF THE POD PROCESSING OF EACH QWG SOLUTIONS

The following tables present the POD processing overview for each orbit solution provided by the different centres of the QWG.

Table B-1: Data processing summary (I)

Data Processing Summary				
Parameter/Model	Analysis Centre (Orbit Solution)			
	AIUB (AIUB)	AIUB (AING)	CLS (GRG)	CNES (CNES)
Contact	Adrian Jäggi (adrian.jaeggi@aiub.unibe.ch)	Adrian Jäggi (adrian.jaeggi@aiub.unibe.ch)	Capdeville Hugues (hcapdeville@groupcls.com)	Flavien Mercier (flavien.mercier@cnes.fr)
Additional contacts	Daniel Arnold (daniel.arnold@aiub.unibe.ch)	Daniel Arnold (daniel.arnold@aiub.unibe.ch)	Lemoine Jean-Michel (Jean-Michel.Lemoine@cnes.fr)	Alexandre Couhert (alexandre.couhert@cnes.fr)
Software				
Name and version	**Bernese GNSS Software v5.5**	**Bernese GNSS Software v5.5**	GINS/DYNAMO	ZOOM 6.0
Arc cut				
Arc lengths	24 h	24 h	84 h	36 h
Handle of Manoeuvers	Only days processed w/o manoeuvres	Only days processed w/o manoeuvres	Manoeuvres are calibrated in the POD process	Manoeuvres are calibrated in the POD process
Handle of Data gaps	No	No	Yes	Yes
Reference system				
Polar motion and UT1	CODE final products	CODE final products	IERS14-C04	IERS14-C04
Pole model	IERS 2010 Conventions	IERS 2010 Conventions	IERS 2010 Conventions (linear pole model)	IERS 2010 Conventions (linear pole model)
Precession/Nutation	IERS 2010 Conventions	IERS 2010 Conventions	IERS 2010 Conventions	IAU 2006/2000A
Geocenter				
Satellite reference				
Mass and center of gravity	Variable with input from FOS	Variable with input from FOS	Variable with input from FOS	Variable with input from FOS
Attitude Model	S1: Quaternions S2: Quaternions S3: Quaternions S6: Quaternions	S1: Quaternions S2: Quaternions S3: Quaternions S6: Quaternions	S3: Nominal attitude law S6: Nominal attitude law	S3: Nominal attitude law S6: Quaternions

Data Processing Summary				
Parameter/Model	Analysis Centre (Orbit Solution)			
	AIUB (AIUB)	AIUB (AING)	CLS (GRG)	CNES (CNES)
GNSS antenna reference point (X,Y,Z)	S1A-GPSA: -0.9371 / +0.3321 / +0.1310 m S1A-GPSB: -0.9465 / +0.5587 / +0.2362 m S1B-GPSA: -0.9371 / +0.3321 / +0.1310 m S2A-GPSA: +0.2320 / +0.2275 / -0.8100 m S2B-GPSA: +0.2320 / +0.2275 / -0.8100 m S3A-GPSA: +2.8810 / -0.1900 / -0.7940 m S3B-GPSA: +2.8810 / -0.2000 / -0.7940 m S6A-GPSA: +2.47483 / +0.00012 / -1.08031 m	S1A-GPSA: -0.9371 / +0.3321 / +0.1310 m S1A-GPSB: -0.9465 / +0.5587 / +0.2362 m S1B-GPSA: -0.9371 / +0.3321 / +0.1310 m S2A-GPSA: +0.2320 / +0.2275 / -0.8100 m S2B-GPSA: +0.2320 / +0.2275 / -0.8100 m S3A-GPSA: +2.8810 / -0.1900 / -0.7940 m S3B-GPSA: +2.8810 / -0.2000 / -0.7940 m S6A-GPSA: +2.47483 / +0.00012 / -1.08031 m	S3A-GPSA: +2.8810 / -0.1900 / -0.7940 m S3B-GPSA: +2.8810 / -0.2000 / -0.7940 m S6A-GPSA: +2.47483 / +0.00012 / -1.08031 m	Adjusted

Data Processing Summary				
Parameter/Model	Analysis Centre (Orbit Solution)			
	AIUB (AIUB)	AIUB (AING)	CLS (GRG)	CNES (CNES)
GNSS antenna orientation (Euler angles, Z,Y,X)	S1A-GPSA: Boresight: -0.2315 / +0.4018 / -0.8860 Azimuth: +0.0372 / -0.9064 / -0.4207 S1A-GPSB: Boresight: -0.2315 / +0.4018 / -0.8860 Azimuth: +0.0372 / -0.9064 / -0.4207 S1B-GPSA: Boresight: -0.2315 / +0.4018 / -0.8860 Azimuth: +0.0372 / -0.9064 / -0.4207 S2A-GPSA: Boresight: -0.2590 / +0.0000 / -0.9660 Azimuth: +0.0000 / +1.0000 / +0.0000 S2B-GPSA: Boresight: -0.2590 / +0.0000 / -0.9660 Azimuth: +0.0000 / +1.0000 / +0.0000 S3A-GPSA: Boresight: +0.0000 / +0.0000 / -1.0000 Azimuth: +1.0000 / +0.0000 / +0.0000 S3B-GPSA: Boresight: +0.0000 / +0.0000 / -1.0000 Azimuth: +1.0000 / +0.0000 / +0.0000 S6A-GPSA: Boresight: +0.0000 / +0.0000 / -1.0000 Azimuth: +0.0000 / -1.0000 / +0.0000	S1A-GPSA: Boresight: -0.2315 / +0.4018 / -0.8860 Azimuth: +0.0372 / -0.9064 / -0.4207 S1A-GPSB: Boresight: -0.2315 / +0.4018 / -0.8860 Azimuth: +0.0372 / -0.9064 / -0.4207 S1B-GPSA: Boresight: -0.2315 / +0.4018 / -0.8860 Azimuth: +0.0372 / -0.9064 / -0.4207 S2A-GPSA: Boresight: -0.2590 / +0.0000 / -0.9660 Azimuth: +0.0000 / +1.0000 / +0.0000 S2B-GPSA: Boresight: -0.2590 / +0.0000 / -0.9660 Azimuth: +0.0000 / +1.0000 / +0.0000 S3A-GPSA: Boresight: +0.0000 / +0.0000 / -1.0000 Azimuth: +1.0000 / +0.0000 / +0.0000 S3B-GPSA: Boresight: +0.0000 / +0.0000 / -1.0000 Azimuth: +1.0000 / +0.0000 / +0.0000 S6A-GPSA: Boresight: +0.0000 / +0.0000 / -1.0000 Azimuth: +0.0000 / -1.0000 / +0.0000	S3A-GPSA: Boresight: +0.0000 / +0.0000 / -1.0000 Azimuth: +1.0000 / +0.0000 / +0.0000 S3B-GPSA: Boresight: +0.0000 / +0.0000 / -1.0000 Azimuth: +1.0000 / +0.0000 / +0.0000 S6A-GPSA: Boresight: +0.0000 / +0.0000 / -1.0000 Azimuth: +0.0000 / -1.0000 / +0.0000	Nadir pointing
DORIS Reference Point (X, Y, Z)				
SLR Reference Point (X, Y, Z)				
Gravity				

Data Processing Summary				
Parameter/Model	Analysis Centre (Orbit Solution)			
	AIUB (AIUB)	AIUB (AING)	CLS (GRG)	CNES (CNES)
Gravity field (static)	GOCO05s (120x120)	**GSM-2_MODEL_GRFO_COSTG_BF01_02op_2303 (90x90)**	EIGEN-GRGS.RL04-v2.MEAN-FIELD (95x95)	GRACE+SLR CNES/GRGS RL04 [EIGEN.GRGS.RL04.v1 (90x90)]
Gravity field (time varying)	IERS 2010 Conventions	IERS 2010 Conventions	Drift/annual/semi-annual piece wise linear terms up to degree/order 95	Drift/annual/semi-annual/bias piece wise linear terms up to degree/order 90
Solid Earth tides	Applied (IERS 2010)	Applied (IERS 2010)	Applied (IERS 2010)	Applied (IERS 2010)
Ocean tides	EOT11A (50x50)	EOT11A (50x50)	FES2014	FES2014
Atmospheric gravity	None	None	AOD1B RL06 (100x100)	AOD1B RL06 (100x100)
Atmospheric tides	None	None	AOD1B RL06 (100x100)	AOD1B RL06 (100x100)
Earth pole tide	IERS 2010	IERS 2010	IERS 2010	IERS 2010
Ocean pole tide	IERS 2010	IERS 2010	IERS 2010	IERS 2010
Third bodies	Sun, Moon, Planets DE421	Sun, Moon, Planets DE421	Sun, Moon, Planets DE421	Sun, Moon, Planets INPOP08
Relativity				
Surface forces and empiricals				
Radiation Pressure model	No explicit modelling	Macro model	Box-wing model	Box-wing model
Earth radiation	No explicit modelling	Albedo and infrared	Albedo and Infra-red applied	Albedo and Infra-red applied (Knocke et al. 1988)
Total Solar Irradiance (TSI)				
Atmospheric density model	No explicit modelling	DTM2013	DTM2000	NRLMSISE-00
Radiation pressure coefficient	No explicit modelling	1/day	1 per day but strongly constrained	Fixed (1.0)
Drag coefficients	No explicit modelling	1/day	1 per 4 h (estimated)	Fixed (1.0)
1/rev empiricals	n/a	n/a	2 sets per arc in along-track and cross-track direction (sin/cos)	1/rev along track and cross track per orbit, constrained (5E-10, 2E-9)
Other empiricals	Piecewise constant empiricals in R,S,W, every 6' (constrained)	Piecewise constant empiricals in R,S,W, every 6', constrained to zero with 5E-10 m/s^2	n/a	Constant empirical accelerations along track at 30 min intervals constrained (1E-9 m/s2)
GNSS measurements				
Relativity	Applied	Applied	Applied	Applied (IGS conventions, Shapiro)

Data Processing Summary				
Parameter/Model	Analysis Centre (Orbit Solution)			
	AIUB (AIUB)	AIUB (AING)	CLS (GRG)	CNES (CNES)
Sampling	10 s	10 s	10 s	30 s
Observations	Iono-free linear combination of phase measurements	Iono-free linear combination of phase measurements	Iono-free linear combination	Iono-free linear combinations of phase and pseudo-range (normal points) measurements
Weight	n/a	n/a	n/a	2 m (pseudo-range) / 20 mm (carrier-phase)
Elevation angle cut-off	0 deg	0 deg	10 deg	10 deg
Down-weighting law	None	None	For elevation 620_; weight of the observation is multiplied by the square of the elevation divided by 400 with elevation in degrees	Applied for DORIS data
Antenna phase-centre wind-up correction	Applied	Applied	Applied	Applied
Antenna phase-centre variation	Applied (AIUB maps)	Applied (AIUB maps)	n/a	Applied (CNES map)
GNSS/DORIS/SLR parameters				
Receiver clocks	Per epoch, every 10 s	Per epoch, every 10 s	n/a	Per epoch, every 30 s
Receiver ambiguities	Estimated (integer)	Estimated (integer)	n/a	Estimated (integer)
GNSS orbits	Fixed (CODE final products)	Fixed (CODE final products)	n/a	Fixed (GRG finals)
GNSS clocks	Fixed (CODE final products, 5 s clocks)	Fixed (CODE final products, 5 s clocks)	n/a	Fixed (GRG finals)
GNSS antex				
GNSS satellite biases	**Fixed (CODE final products)**	**Fixed (CODE final products)**	n/a	n/a
Inter-system biases				
DORIS troposphere	n/a	n/a	GPT2+VMF1 + one gradient per station in North & East directions	GPT2/VMF1 + one gradient per station in North & East directions
DORIS coordinates	n/a	n/a	ITRF2014 (DPOD2014)	DPOD2014
SLR Coordinates				
SLR Troposphere				
SLR Mapping Function				
SLR Elevation Cutoff Angle				

Data Processing Summary				
Parameter/Model	Analysis Centre (Orbit Solution)			
	AIUB (AIUB)	AIUB (AING)	CLS (GRG)	CNES (CNES)
DORIS Ground Antenna Phase Law				
DORIS Elevation Cutoff Angle				
DORIS Elevation Down-weighting Function				

Table B-2: Data processing summary (II)

Data Processing Summary				
Parameter/Model	Analysis Centre (Orbit Solution)			
	DLR (DLR)	ESOC (ESOC)	EUM (EUMB)	GFZ (GFZ)
Contact	Martin Wermuth (martin.wermuth@dlr.de)	Francesco Gini (francesco.gini@esa.int)	Francisco Sancho (francisco.sancho@eumetsat.int)	Patrick Schreiner (patrick.schreiner@gfz-potsdam.de)
Additional contacts	Oliver Montenbruck (oliver.montenbruck@dlr.de) Stefan Hackel (stefan.hackel@dlr.de)	**Alfonso Molina Montilla (alfonso.molina.montilla@ext.esa.int) Mark Van Kints (mark.van.kints@ext.esa.int) Erik Schoenemann (erik.schoenemann@esa.int)**	**Sebastiano Padovan (sebastiano.padovan@external.eumetsat.int) Veronica Rivas Boscan (Veronica.RivasBoscan@external.eumetsat.int)**	Anton Reinhold (reinh_a@gfz-potsdam.de) Frank Flechtner (frank.flechtner@gfz-potsdam.de)
Software				
Name and version	GHOST	**NAPEOS 4.9**	**Bernese GNSS Software v5.5**	EPOS-OC (v6.74)
Arc cut				
Arc lengths	30 h	**24 h**	24 h	28 h
Handle of Manoeuvers	Manoeuvres are calibrated in the POD process	Only days processed w/o manouvres and observation gaps<=1h	Only days processed w/o manoeuvres	Manoeuvres are calibrated in the POD process (Only days processed w/o major manoeuvres)
Handle of Data gaps	Yes	Yes	No	Yes
Reference system				
Polar motion and UT1	igs96p02.erp	IERS Bulletin A (IERS rapids)	CODE final products	IERS Bulletin A/B
Pole model	n/a	IERS 2010 Conventions	IERS 2010 Conventions	Linear Meanpole (J. Ries 07/2017)
Precession/Nutation	IERS 2010 Conventions	IERS 2010 Conventions	IERS 2010 Conventions	IERS 2010 Conventions

Data Processing Summary				
Parameter/Model	Analysis Centre (Orbit Solution)			
	DLR (DLR)	ESOC (ESOC)	EUM (EUMB)	GFZ (GFZ)
Geocenter				
Satellite reference				
Mass and center of gravity	Variable with input from FOS	Variable with input from FOS	Variable with input from FOS	Variable with input from FOS
Attitude Model	S1: Nominal attitude law S2: Quaternions S3: Quaternions S6: Quaternions	S1: Nominal attitude law S2: Nominal attitude law S3: Nominal attitude law S6A: quaternions	S3: Quaternions S6: Quaternions	S1A: Quaternions S1B: Quaternions S2A: Quaternions S2B: Quaternions S3A: Quaternions S3B: Quaternions S6A: Quaternions
GNSS antenna reference point (X,Y,Z)	S1A-GPSA: -0.9371 / +0.3321 / +0.1310 m S1A-GPSB: -0.9465 / +0.5587 / +0.2362 m S1B-GPSA: -0.9371 / +0.3321 / +0.1310 m S2A-GPSA: +0.2320 / +0.2275 / -0.8100 m S2B-GPSA: +0.2320 / +0.2275 / -0.8100 m S3A-GPSA: +2.8810 / -0.1900 / -0.7940 m S3B-GPSA: +2.8810 / -0.2000 / -0.7940 m S6A-GPSA: +2.47483 / +0.00012 / -1.08031 m	S1A-GPSA: -0.9371 / +0.3321 / +0.1310 m S1A-GPSB: -0.9465 / +0.5587 / +0.2362 m S1B-GPSA: -0.9371 / +0.3321 / +0.1310 m S2A-GPSA: +0.2320 / +0.2275 / -0.8100 m S2B-GPSA: +0.2320 / +0.2275 / -0.8100 m S3A-GPSA: +2.8810 / -0.1900 / -0.7940 m S3B-GPSA: +2.8810 / -0.2000 / -0.7940 m S6A-GPSA: +2.4748 / +0.0001 / -1.0803 m	S3A-GPSA: +2.8810 / -0.2000 / -0.7940 m S3B-GPSA: +2.8810 / -0.2000 / -0.7940 m S6A-GPSA: +2.47483 / 0.00012 / -1.08031 m	**S1A-GPSA:** **-0.93710 / +0.33210 / +0.13100 m** **S1A-GPSB:** **-0.94650 / +0.55870 / +0.23620 m** **S1B-GPSA:** **-0.93710 / +0.33210 / +0.13100 m** **S1B-GPSB:** **-0.94650 / +0.55870 / +0.23620 m** **S2A-GPSA:** **+0.23200 / +0.22750 / -0.81000 m** **S2A-GPSB:** **+0.23200 / -0.07250 / -0.81000 m** **S2B-GPSA:** **+0.23200 / +0.22750 / -0.81000 m** **S2B-GPSB:** **+0.23200 / -0.07250 / -0.81000 m** **S3A-GPSA:** **+2.88100 / -0.19000 / -0.79400 m** **S3B-GPSA:** **+2.88100 / -0.20000 / -0.79400 m** **S6A-GPS-N:** **+2.47483 / +0.00012 / -1.08031 m** **S6A-GPS-R:** **+2.87486 / +0.00016 / -1.08054 m**

Data Processing Summary				
Parameter/Model	Analysis Centre (Orbit Solution)			
	DLR (DLR)	ESOC (ESOC)	EUM (EUMB)	GFZ (GFZ)
GNSS antenna orientation (Euler angles, Z,Y,X)	S1A-GPSA: Boresight: -0.2315 / +0.4018 / -0.8860 Azimuth: +0.0372 / -0.9064 / -0.4207 S1A-GPSB: Boresight: -0.2315 / +0.4018 / -0.8860 Azimuth: +0.0372 / -0.9064 / -0.4207 S1B-GPSA: Boresight: -0.2315 / +0.4018 / -0.8860 Azimuth: +0.0372 / -0.9064 / -0.4207 S2A-GPSA: Boresight: -0.2590 / +0.0000 / -0.9660 Azimuth: +0.0000 / +1.0000 / +0.0000 S2B-GPSA: Boresight: -0.2590 / +0.0000 / -0.9660 Azimuth: +0.0000 / +1.0000 / +0.0000 S3A-GPSA: Boresight: +0.0000 / +0.0000 / -1.0000 Azimuth: +1.0000 / +0.0000 / +0.0000 S3B-GPSA: Boresight: +0.0000 / +0.0000 / -1.0000 Azimuth: +1.0000 / +0.0000 / +0.0000 S6A-GPSA: Boresight: +0.0000 / +0.0000 / -1.0000 Azimuth: +0.0000 / -1.0000 / +0.0000	S1A-GPSA: Boresight: -0.2315 / +0.4018 / -0.8860 Azimuth: +0.0372 / -0.9064 / -0.4207 S1A-GPSB: Boresight: -0.2315 / +0.4018 / -0.8860 Azimuth: +0.0372 / -0.9064 / -0.4207 S1B-GPSA: Boresight: -0.2315 / +0.4018 / -0.8860 Azimuth: +0.0372 / -0.9064 / -0.4207 S2A-GPSA: Boresight: -0.2590 / +0.0000 / -0.9660 Azimuth: +0.0000 / +1.0000 / +0.0000 S2B-GPSA: Boresight: -0.2590 / +0.0000 / -0.9660 Azimuth: +0.0000 / +1.0000 / +0.0000 S3A-GPSA: Boresight: +0.0000 / +0.0000 / -1.0000 Azimuth: +1.0000 / +0.0000 / +0.0000 S3B-GPSA: Boresight: +0.0000 / +0.0000 / -1.0000 Azimuth: +1.0000 / +0.0000 / +0.0000 S6A-GPSA: Boresight: +0.0000 / +0.0000 / -1.0000 Azimuth: +1.0000 / +0.0000 / +0.0000	S3A-GPSA: Boresight: +0.0000 / +0.0000 / -1.0000 Azimuth: +1.0000 / +0.0000 / +0.0000 S3B-GPSA: Boresight: +0.0000 / +0.0000 / -1.0000 Azimuth: +1.0000 / +0.0000 / +0.0000 S6A-GPSA: Boresight: +0.0000 / +0.0000 / -1.0000 Azimuth: +0.0000 / -1.0000 / +0.0000	**S1A-GPSA: Boresight: -0.23147 / +0.40177 / -0.88600 Azimuth: +0.03716 / -0.90642 / -0.42074 S1A-GPSB: Boresight: -0.23147 / +0.40177 / -0.88600 Azimuth: +0.03716 / -0.90642 / -0.42074 S1B-GPSA: Boresight: -0.23147 / +0.40177 / -0.88600 Azimuth: +0.03716 / -0.90642 / -0.42074 S1B-GPSB: Boresight: -0.23147 / +0.40177 / -0.88600 Azimuth: +0.03716 / -0.90642 / -0.42074 S2A-GPSA: Boresight: -0.25900 / +0.00000 / -0.96600 Azimuth: +0.00000 / +1.00000 / +0.00000 S2A-GPSB: Boresight: -0.25900 / +0.00000 / -0.96600 Azimuth: +0.00000 / +1.00000 / +0.00000 S2B-GPSA: Boresight: -0.25900 / +0.00000 / -0.96600 Azimuth: +0.00000 / +1.00000 / +0.00000 S2B-GPSB: Boresight: -0.25900 / +0.00000 / -0.96600 Azimuth: +0.00000 / +1.00000 / +0.00000 S3A-GPSA: Boresight: +0.00000 / +0.00000 / -1.00000 Azimuth: +1.00000 / +0.00000 / +0.00000 S3B-GPSA: Boresight: +0.00000 / +0.00000 / -1.00000 Azimuth: +1.00000 / +0.00000 / +0.00000 S6A-GPS-N: Boresight: -0.00024 / +0.00000 / -1.00000 Azimuth: -0.00071 / -1.00000 / +0.00000 S6A-GPS-R: Boresight: +0.00047 / -0.00012 / -1.00000 Azimuth: +0.00047 / +1.00000 / -0.00012**
DORIS Reference Point (X, Y, Z)				

Data Processing Summary				
Parameter/Model	**Analysis Centre (Orbit Solution)**			
	DLR (DLR)	**ESOC (ESOC)**	**EUM (EUMB)**	**GFZ (GFZ)**
SLR Reference Point (X, Y, Z)				S3A: +1.13403/+0.647905/+0.80118 S3B: +1.13403/+0.637905/+0.80118 S6A: +1.624841/-0.400638/+0.664777
Gravity				
Gravity field (static)	GOCO06S (120x120)	EIGEN.GRGS.RL04.MEAN-FIELD with quadratic_mean_pole	EGM2008 (120x120)	GOCO06s (180x180)
Gravity field (time varying)	GOCO06S (120x120)	Drift/annual/semi-annual piece wise lineair terms up to degree/order 80	IERS 2010 Conventions	GOCO06s (180x180)
Solid Earth tides	Applied	Applied (IERS 2010)	Applied (IERS 2010)	IERS 2010
Ocean tides	Applied (FES 2004)	EOT11a (50x50)	**FES 2014**	FES2014 (180x180)
Atmospheric gravity	n/a	AOD1B RL06 (100x100)	None	AOD1B RL07 (180x180)
Atmospheric tides	n/a	Ray-Ponte 2003	None	BB2003
Earth pole tide	n/a	IERS 2010	IERS 2010	IERS 2010
Ocean pole tide	n/a	IERS 2010	IERS 2010	Desai (180x180)
Third bodies	Sun, Moon (analytical series)	Sun, Moon, Planets DE405	**Sun, Moon, Planets DE421**	FERRARI77, DE430
Relativity				Applied
Surface forces and empiricals				
Radiation Pressure model	Macro-model	S1,2,3: QWG Box-wing model S6: ESOC Box-wing model	**Macro Model**	Macro model
Earth radiation	Albedo and Infra-red	Albedo and Infra-red applied	**Albedo and IR**	Heurtel
Total Solar Irradiance (TSI)				Analytically variable
Atmospheric density model	NRLMSISE-00, macro model, drag, lift	msise90	**DTM2013**	MSISE-90

Data Processing Summary				
Parameter/Model	Analysis Centre (Orbit Solution)			
	DLR (DLR)	ESOC (ESOC)	EUM (EUMB)	GFZ (GFZ)
Radiation pressure coefficient	1 per arc (estimated)	Fixed	**1/day**	S1: 1 per arc (estimated) S2: 1 per arc (estimated) S3: 1 per arc (estimated) S6: 1 set per arc (estimated) S6: 1 set per arc (estimated)
Drag coefficients	1 per arc (estimated)	1 per day	**1/day**	5 per arc (estimated)
1/rev empiricals	n/a	S1,2,3: 18 sets in along (constant/sine/cosine) and cross track (sine/cosine) S6: 18 sets in along (constant/sine/cosine) and cross track (constant/sine/cosine)	n/a	1/rev (sin/cos) along- and cross-track direction every 75', polygonal amplitude modelling, constrained
Other empiricals	Constant empirical accelerations in RTN at 10 min intervals (constrained to zero)	n/a	Piecewise constant empiricals in R,S,W, every 6' (constrained)	n/a
GNSS measurements				
Relativity	Applied	Applied (IERS 2010)	Applied	Applied
Sampling	30 s	10 s	**30 s**	30 s
Observations	Iono-free linear combinations of phase and pseudo-range measurements (undifferenced)	S1,2,3: GPS Iono-free linear combinations of phase and pseudo-range measurements S6: Galileo Iono-free linear combinations of phase and pseudo-range measurements	Iono-free linear combinations of phase measurements (pseudo-range measurements only used for clock synchronisation)	Iono-free linear combinations of phase and pseudo-range measurements (zero differenced)
Weight	1.0 m (pseudo-ranges), 10 mm (carrier-phase)	1.0 m (pseudo-range) / 10 mm (carrier-phase)	n/a	**S1A: 0.48 m (pseudo-ranges), 5.0 mm (carrier-phase)** **S2A: 0.43 m (pseudo-ranges), 5.6 mm (carrier-phase)** **S2B: 0.37 m (pseudo-ranges), 4.9 mm (carrier-phase)** **S3A: 0.45 m (pseudo-ranges), 3.5 mm (carrier-phase)** **S3B: 0.43 m (pseudo-ranges), 3.5 mm (carrier-phase)** **S6A: 0.82 m (pseudo-ranges), 4.0 mm (carrier-phase)**
Elevation angle cut-off	0 deg	7 deg	10 deg	0 deg
Down-weighting law	None	None	None	None

Data Processing Summary				
Parameter/Model	Analysis Centre (Orbit Solution)			
	DLR (DLR)	ESOC (ESOC)	EUM (EUMB)	GFZ (GFZ)
Antenna phase-centre wind-up correction	Applied	Applied	Applied	Applied
Antenna phase-centre variation	Applied (DLR maps)	**Applied sen20_2236.atx**	S3A/B: Applied (AIUB maps) S6A: Applied (In-flight calibrated AIUB maps)	Applied (GFZ inflight calibration)
GNSS/DORIS/SLR parameters				
Receiver clocks	Per epoch, every 10 s	Per epoch, every 10 s	**Per epoch, every 30 s**	Per epoch, every 30 s
Receiver ambiguities	Estimated (integer)	Estimated (integer)	**Estimated (integer)**	Estimated (CS fixed)
GNSS orbits	Fixed (CODE final)	**Fixed (ESOC Final GPS and Galileo)**	Fixed (CODE finals)	Fixed (consistent model constellation, 30s)
GNSS clocks	Fixed (CODE final, 5 s)	**Fixed (ESOC Final GPS and Galileo)**	**Fixed (CODE finals, 30 s clocks)**	Fixed (consistent model constellation, 30s)
GNSS antex		**ITRF20 GNSS Antex with Galileo chamber-calibrated PCO/PCV**		
GNSS satellite biases	CODE final	ESOC final	n/a	n/a
Inter-system biases		Estimated (one x day x GPS sat.)		
DORIS troposphere	n/a	n/a	n/a	n/a
DORIS coordinates	n/a	n/a	n/a	n/a
SLR Coordinates				
SLR Troposphere				
SLR Mapping Function				
SLR Elevation Cutoff Angle				
DORIS Ground Antenna Phase Law				
DORIS Elevation Cutoff Angle				
DORIS Elevation Down-weighting Function				

Table B-3: Data processing summary (III)

Data Processing Summary				
Parameter/Model	Analysis Centre (Orbit Solution)			
	GMV (CPOD)	GMV (CPOF)	JPL (JPL)	TU Delft (TUDF)
Contact	Carlos Fernández Martín (cfernandez@gmv.com)	Carlos Fernández Martín (cfernandez@gmv.com)	Shailen Desai (shailen.d.desai@jpl.nasa.gov)	Wim Simons (W.J.F.Simons@tudelft.nl)
Additional contacts	Marc Fernández Usón (mffernandez@gmv.com) Jaime Fernández Sánchez (jfernandez@gmv.com)	Marc Fernández Usón (mffernandez@gmv.com) Jaime Fernández Sánchez (jfernandez@gmv.com)	Shailen Desai (shailen.d.desai@jpl.nasa.gov)	Pieter Visser (P.N.A.M.Visser@tudelft.nl)
Software				
Name and version	FOCUSPOD	FOCUSPOD	GIPSY-OASIS (v6.4)	GIPSY-X (v1.7)
Arc cut				
Arc lengths	32 h	32 h	30 h	30 h
Handle of Manoeuvers	Manoeuvres are calibrated in the POD process	Manoeuvres are calibrated in the POD process	Manoeuvres are detected and handled in the POD process	Manoeuvres are calibrated in the POD process
Handle of Data gaps	Yes	Yes	Yes	Yes
Reference system				
Polar motion and UT1	IERS finals2000A.data	IERS finals2000A.data	JPL Final products	JPL Final / Rapid_GE (S6A) products
Pole model	IERS 2010 Conventions	IERS 2010 Conventions	IERS 2010 Conventions (linear mean pole)	IERS 2010 Conventions
Precession/Nutation	IERS 2010 Conventions	IERS 2010 Conventions	IERS 2010 Conventions	IERS 2010 Conventions
Geocenter				
Satellite reference				
Mass and center of gravity	Variable with input from FOS	Variable with input from FOS	variable with input from FOS	Variable with input from FOS
Attitude Model	S1: Quaternions S2: Quaternions S3: Quaternions S6: Quaternions	**S1: Quaternions** **S2: Quaternions** **S3: Quaternions** **S6: Quaternions, yaw bias applied**	S3: Quaternions S6: Quaternions	S1: Quaternions S2: Quaternions S3: Quaternions S6: Quaternions

Data Processing Summary				
Parameter/Model	Analysis Centre (Orbit Solution)			
	GMV (CPOD)	GMV (CPOF)	JPL (JPL)	TU Delft (TUDF)
GNSS antenna reference point (X,Y,Z)	S1A-GPSA: -0.9371 / +0.3321 / +0.1310 m S1A-GPSB: -0.9465 / +0.5587 / +0.2362 m S1B-GPSA: -0.9371 / +0.3321 / +0.1310 m S2A-GPSA: +0.2320 / +0.2275 / -0.8100 m S2B-GPSA: +0.2320 / +0.2275 / -0.8100 m S3A-GPSA: +2.8810 / -0.1900 / -0.7940 m S3B-GPSA: +2.8810 / -0.2000 / -0.7940 m S6A-GPSA: +2.4748 / +0.0001 / -1.0803 m	S1A-GPSA: -0.9371 / +0.3321 / +0.1310 m S1A-GPSB: -0.9465 / +0.5587 / +0.2362 m S1B-GPSA: -0.9371 / +0.3321 / +0.1310 m S2A-GPSA: +0.2320 / +0.2275 / -0.8100 m S2B-GPSA: +0.2320 / +0.2275 / -0.8100 m S3A-GPSA: +2.8810 / -0.1900 / -0.7940 m S3B-GPSA: +2.8810 / -0.2000 / -0.7940 m S6A-GPSA: +2.4748 / +0.0001 / -1.0803 m	S3A-GPSA: +2.881 / -0.190 / -0.794 m S3B-GPSA: +2.881 / -0.200 / -0.794 m S6A-GPS-RO-POD: +0.599952 / -0.000408 / -1.095055 m	S1A-GPSA: -0.9371 / +0.3321 / +0.1310 m S1A-GPSB: -0.9465 / +0.5587 / +0.2362 m S1B-GPSA: -0.9371 / +0.3321 / +0.1310 m S2A-GPSA: +0.2320 / +0.2275 / -0.8100 m S2B-GPSA: +0.2320 / +0.2275 / -0.8100 m S3A-GPSA: +2.8810 / -0.1900 / -0.7940 m S3B-GPSA: +2.8810 / -0.2000 / -0.7940 m S6A-GPSA: +2.47483 / +0.00012 / -1.08031 m
GNSS antenna orientation (Euler angles, Z,Y,X)	S1A-GPSA: Boresight: -0.2315 / +0.4018 / -0.8860 Azimuth: +0.0372 / -0.9064 / -0.4207 S1A-GPSB: Boresight: -0.2315 / +0.4018 / -0.8860 Azimuth: +0.0372 / -0.9064 / -0.4207 S1B-GPSA: Boresight: -0.2315 / +0.4018 / -0.8860 Azimuth: +0.0372 / -0.9064 / -0.4207 S2A-GPSA: Boresight: -0.2590 / +0.0000 / -0.9660 Azimuth: +0.0000 / +1.0000 / +0.0000 S2B-GPSA: Boresight: -0.2590 / +0.0000 / -0.9660 Azimuth: +0.0000 / +1.0000 / +0.0000 S3A-GPSA: Boresight: +0.0000 / +0.0000 / -1.0000 Azimuth: +1.0000 / +0.0000 / +0.0000 S3B-GPSA: Boresight: +0.0000 / +0.0000 / -1.0000 Azimuth: +1.0000 / +0.0000 / +0.0000 S6A-GPSA: Boresight: +0.0000 / +0.0000 / -1.0000 Azimuth: +0.0000 / -1.0000 / +0.0000	S1A-GPSA: Boresight: -0.2315 / +0.4018 / -0.8860 Azimuth: +0.0372 / -0.9064 / -0.4207 S1A-GPSB: Boresight: -0.2315 / +0.4018 / -0.8860 Azimuth: +0.0372 / -0.9064 / -0.4207 S1B-GPSA: Boresight: -0.2315 / +0.4018 / -0.8860 Azimuth: +0.0372 / -0.9064 / -0.4207 S2A-GPSA: Boresight: -0.2590 / +0.0000 / -0.9660 Azimuth: +0.0000 / +1.0000 / +0.0000 S2B-GPSA: Boresight: -0.2590 / +0.0000 / -0.9660 Azimuth: +0.0000 / +1.0000 / +0.0000 S3A-GPSA: Boresight: +0.0000 / +0.0000 / -1.0000 Azimuth: +1.0000 / +0.0000 / +0.0000 S3B-GPSA: Boresight: +0.0000 / +0.0000 / -1.0000 Azimuth: +1.0000 / +0.0000 / +0.0000 S6A-GPSA: Boresight: +0.0000 / +0.0000 / -1.0000 Azimuth: +0.0000 / -1.0000 / +0.0000	S3A-GPSA: Boresight: +0.0000 / +0.0000 / -1.0000 Azimuth: +1.0000 / +0.0000 / +0.0000 S3B-GPSA: Boresight: +0.0000 / +0.0000 / -1.0000 Azimuth: +1.0000 / +0.0000 / +0.0000 S6A-S6A-GPS-RO-POD: Boresight: +0.0000 / +0.0000 / -1.0000 Azimuth: +1.0000 / +0.0000 / +0.0000	S1A-GPSA: Boresight: -0.2315 / +0.4018 / -0.8860 Azimuth: +0.0372 / -0.9064 / -0.4207 S1A-GPSB: Boresight: -0.2315 / +0.4018 / -0.8860 Azimuth: +0.0372 / -0.9064 / -0.4207 S1B-GPSA: Boresight: -0.2315 / +0.4018 / -0.8860 Azimuth: +0.0372 / -0.9064 / -0.4207 S2A-GPSA: Boresight: -0.2590 / +0.0000 / -0.9660 Azimuth: +0.0000 / +1.0000 / +0.0000 S2B-GPSA: Boresight: -0.2590 / +0.0000 / -0.9660 Azimuth: +0.0000 / +1.0000 / +0.0000 S3A-GPSA: Boresight: +0.0000 / +0.0000 / -1.0000 Azimuth: +1.0000 / +0.0000 / +0.0000 S3B-GPSA: Boresight: +0.0000 / +0.0000 / -1.0000 Azimuth: +1.0000 / +0.0000 / +0.0000 S6A-GPSA: Boresight: -0.000236 / +0.000556 / -1.000000 Azimuth: +1.000000 / -0.000707 / -0.000236
DORIS Reference Point (X, Y, Z)				

Data Processing Summary				
Parameter/Model	Analysis Centre (Orbit Solution)			
	GMV (CPOD)	GMV (CPOF)	JPL (JPL)	TU Delft (TUDF)
SLR Reference Point (X, Y, Z)				
Gravity				
Gravity field (static)	**EIGEN.GRGS.RL04 TVG (120x120), GSM-2_MODEL_GRFO_COSTG_BF01_01op_2212 (90x90) since 18th July**	GSM-2_MODEL_GRFO_COSTG_BF01_01op_2212 (90x90)	EIGEN.GRGS.RL04.MEAN-FIELD with linear mean pole (200x200)	EIGEN.GRGS.RL04.MEAN-FIELD with quadratic_mean_pole (200X200)
Gravity field (time varying)	Drift/annual/semi-annual piece wise linear terms up to degree/order 50	Drift/annual/semi-annual piece wise linear terms up to degree/order 90	Drift/annual/semi-annual/bias piece wise linear terms up to degree/order 90	Drift/annual/semi-annual piece wise lineair terms up to degree/order 90
Solid Earth tides	Applied (IERS 2010)	Applied (IERS 2010)	Applied (IERS2010)	Applied (IERS 2010)
Ocean tides	FES2014 (100x100, 142 tidal constituents)	FES2014 (100x100, 142 tidal constituents)	GOT4.8AC (50x50)	Applied (FES2004)
Atmospheric gravity	GFZ AOD L1B RL06 (100x100)	GFZ AOD L1B RL06 (100x100)	AOD1B RL06 (100x100)	AOD1B RL06 (180x180)
Atmospheric tides	GFZ AOD L1B RL06 (100x100)	GFZ AOD L1B RL06 (100x100)	None	n/a
Earth pole tide	IERS 2010	IERS 2010	IERS 2010	IERS 2010
Ocean pole tide	IERS 2010	IERS 2010	IERS 2010	IERS 2010
Third bodies	Sun, Moon, Planets DE421	Sun, Moon, Planets DE421	Sun, Moon, Planets DE421	Sun, Moon, Planets JPL DE421
Relativity				
Surface forces and empiricals				
Radiation Pressure model	Box-wing model (with re-radiation)	Box-wing model (with re-radiation)	Box-wing model	Box-wing model
Earth radiation	Albedo and Infra-red applied	Albedo and Infra-red applied	Albedo	Albedo
Total Solar Irradiance (TSI)				
Atmospheric density model	msise00	msise00	DTM2000	DTM2000
Radiation pressure coefficient	Fixed 1 coefficient to 1.0	Fixed 1 coefficient (S-[126] to 1.0, S-3A to 0.97 and S-3B to 0.96)	Fixed to 1.0	**1 per arc (estimated)**
Drag coefficients	Estimated 1 coefficient per arc (constrained with 0.3)	Estimated 1 coefficient per arc (constrained with 0.3)	1 per arc (estimated)	1 per arc (estimated) S6A: Fixed (1.0)
1/rev empiricals	Estimated 16 sets per arc: Alo: constant, sin+cos Cro: constant, sin+cos (constrained with 10e-12 km/s^2, 10e-11 km/s^2)	Estimated 16 sets per arc: Alo: constant, sin+cos Cro: constant, sin+cos (constrained with 10e-12 km/s^2, 10e-11 km/s^2)	In along-track and cross-track directions (sine/cosine), constrained 2e-9 m/s2	In along-track and cross-track directions (sine/cosine), constrained 5e-9 m/s2

Data Processing Summary				
Parameter/Model	Analysis Centre (Orbit Solution)			
	GMV (CPOD)	GMV (CPOF)	JPL (JPL)	TU Delft (TUDF)
Other empiricals	n/a	n/a	Constant empirical accelerations in cross-track and along-track directions, updated every 30 minutes (constrained 1e-9 m/s2)	constant empirical accelerations in radial, cross-track and (for Sentinel 3 and 6 along-track) directions, updated every ~10 minutes (T/600), constrained 5e-9 m/s2. Biases (S3:daily) removed in radial and cross-track direction.
GNSS measurements				
Relativity	Applied (IERS 2010)	Applied (IERS 2010)	Applied	Applied
Sampling	10 s	10 s	S3: 30 s S6: 300 s	30 s
Observations	Iono-free linear combinations of phase and pseudo-range measurements	Iono-free linear combinations of phase and pseudo-range measurements	Iono-free linear combinations of phase and pseudo-range measurements (undifferenced)	Iono-free linear combinations of phase and pseudo-range GPS measurements (undifferenced) S6A: Iono-free linear combinations of phase and pseudo-range Galileo (1C_5Q) + GPS Legacy (1W_2W) measurements (undifferenced)
Weight	0.8 m (pseudo-range) / 10 mm (carrier-phase)	0.8 m (pseudo-range) / 10 mm (carrier-phase)	1.0 m (pseudo-range) / 10 mm (carrier-phase)	1.0 m (pseudo range) / 10 mm (carrier-phase)
Elevation angle cut-off	7 deg	7 deg	0 deg	0 deg
Down-weighting law	None	None	S3: 1/sin(el) S6: None	None
Antenna phase-centre wind-up correction	Applied	Applied	Applied	Applied (IGS model)
Antenna phase-centre variation	Applied (sen20_2236.atx)	Applied (sen20_2236.atx)	Applied (JPL inflight calibration)	**Applied (sen20_2236.atx)**
GNSS/DORIS/SLR parameters				
Receiver clocks	Per epoch, every 10 s	Per epoch, every 10 s	S3: Per epoch, every 30 s S6: Per epoch, every 300 s	Per epoch, every 30 / 300 (S6A) s (no relativistic corrections applied)
Receiver ambiguities	Estimated (fixed)	Estimated (fixed)	Estimated (integer)	Estimated (resolved, typically 80% (S1,S2,S3) and 90% (S6A G(1W_2W)+E(1C_5Q):

Data Processing Summary				
Parameter/Model	Analysis Centre (Orbit Solution)			
	GMV (CPOD)	GMV (CPOF)	JPL (JPL)	TU Delft (TUDF)
GNSS orbits	Fixed (CODE final)	Fixed (CODE final)	Fixed (JPL Final / IGS14)	**Fixed (JPL GPS Final / IGb14) S6A: Fixed (JPL GNSS Rapid_GE / IGS20)**
GNSS clocks	Fixed (CODE final, 5 s)	Fixed (CODE final, 5 s)	S3: Fixed (JPL Final / IGS14, 30 s clocks) S6: Fixed (JPL Final / IGS14, 300 s clocks)	**Fixed (JPL GPS Final / IGb14, 30 s clocks) S6A: Fixed (JPL GNSS Rapid_GE / IGS20)**
GNSS antex				
GNSS satellite biases	CODE finals	CODE finals	n/a	**n/a**
Inter-system biases				**S6A: Constellation bias estimated (GPS Legacy (1W_2W) comes from AGGA 2)**
DORIS troposphere	n/a	n/a	n/a	n/a
DORIS coordinates	n/a	n/a	n/a	n/a
SLR Coordinates				
SLR Troposphere				
SLR Mapping Function				
SLR Elevation Cutoff Angle				
DORIS Ground Antenna Phase Law				
DORIS Elevation Cutoff Angle				
DORIS Elevation Down-weighting Function				

Table B-4: Data processing summary (IV)

Data Processing Summary				
Parameter/Model	Analysis Centre (Orbit Solution)			
	TUM (TUM)	GSC (GSFC)	TU Graz (TUG)	
Contact	Bingbing Duan (bingbing.duan@tum.de)	Nikita Zelensky (nzelensk@umd.edu)	Torsten Mayer-Gürr (mayer-guerr@tugraz.at)	
Additional contacts	Urs Hugentobler (urs.hugentobler@tum.de)	Frank Lemoine (Frank.G.Lemoine@nasa.gov)	Barbara Süsser-Rechberger (barbara.suesser-rechberger@tugraz.at)	
Software				
Name and version	Bernese GNSS Software v5.3 (mod)	GEODYN version 2002	GROOPS (https://github.com/groops-devs/groops)	
Arc cut				
Arc lengths	30 h	~10 days (1 cycle)	24 h	
Handle of Manoeuvers	Only days processed w/o manoeuvres	Truncate arcs at maneuvers	Truncate arcs at maneuvers	
Handle of Data gaps	No	No	No	
Reference system				
Polar motion and UT1	IERS finals2000A.data	IERS Bulletin A daily	TUG	
Pole model	IERS 2010 Conventions	IERS 2017 (linear mean pole)	IERS 2010 Conventions	
Precession/Nutation	IERS 2010 Conventions	IAU2000A	IERS 2010 Conventions	
Geocenter		Altamimi et al. (2016) (annual model)	ITRF2020 (annual, semiannual)	
Satellite reference				
Mass and center of gravity	Variable with input from FOS	Variable with input from FOS	from *.mhf files	
Attitude Model	S1: Nominal attitude law S2: Quaternions S3: Quaternions S6: Quaternions	S6 Quaternions	S1: Quaternions S2: Quaternions S3: Quaternions S6: Quaternions	

Data Processing Summary				
Parameter/Model	Analysis Centre (Orbit Solution)			
	TUM (TUM)	GSC (GSFC)	TU Graz (TUG)	
GNSS antenna reference point (X,Y,Z)	S1A-GPSA: -0.9371 / +0.3321 / +0.1310 m S1A-GPSB: -0.9465 / +0.5587 / +0.2362 m S1B-GPSA: -0.9371 / +0.3321 / +0.1310 m S2A-GPSA: +0.2320 / +0.2275 / -0.8100 m S2B-GPSA: +0.2320 / +0.2275 / -0.8100 m S3A-GPSA: +2.8810 / -0.1900 / -0.7940 m S3B-GPSA: +2.8810 / -0.2000 / -0.7940 m S6A-GPSA: +2.47483 / +0.00012 / -1.08031 m	n/a	S1A-GPSA: -0.9371 / +0.3321 / +0.1310 m S1A-GPSB: -0.9465 / +0.5587 / +0.2362 m S1B-GPSA: -0.9371 / +0.3321 / +0.1310 m S2A-GPSA: +0.2320 / +0.2275 / -0.8100 m S2B-GPSA: +0.2320 / +0.2275 / -0.8100 m S3A-GPSA: +2.8810 / -0.1900 / -0.7940 m S3B-GPSA: +2.8810 / -0.2000 / -0.7940 m S6A-GPSA: +2.47483 / +0.00012 / -1.08031 m	
GNSS antenna orientation (Euler angles, Z,Y,X)	S1A-GPSA: Boresight: -0.2315 / +0.4018 / -0.8860 Azimuth: +0.0372 / -0.9064 / -0.4207 S1A-GPSB: Boresight: -0.2315 / +0.4018 / -0.8860 Azimuth: +0.0372 / -0.9064 / -0.4207 S1B-GPSA: Boresight: -0.2315 / +0.4018 / -0.8860 Azimuth: +0.0372 / -0.9064 / -0.4207 S2A-GPSA: Boresight: -0.2590 / +0.0000 / -0.9660 Azimuth: +0.0000 / +1.0000 / +0.0000 S2B-GPSA: Boresight: -0.2590 / +0.0000 / -0.9660 Azimuth: +0.0000 / +1.0000 / +0.0000 S3A-GPSA: Boresight: +0.0000 / +0.0000 / -1.0000 Azimuth: +1.0000 / +0.0000 / +0.0000 S3B-GPSA: Boresight: +0.0000 / +0.0000 / -1.0000 Azimuth: +1.0000 / +0.0000 / +0.0000 S6A-GPSA: Boresight: +0.0000 / +0.0000 / -1.0000 Azimuth: +1.0000 / +0.0000 / +0.0000	n/a	S1A-GPSA: Boresight: -0.2315 / +0.4018 / -0.8860 Azimuth: +0.0372 / -0.9064 / -0.4207 S1A-GPSB: Boresight: -0.2315 / +0.4018 / -0.8860 Azimuth: +0.0372 / -0.9064 / -0.4207 S1B-GPSA: Boresight: -0.2315 / +0.4018 / -0.8860 Azimuth: +0.0372 / -0.9064 / -0.4207 S2A-GPSA: Boresight: -0.2590 / +0.0000 / -0.9660 Azimuth: +0.0000 / +1.0000 / +0.0000 S2B-GPSA: Boresight: -0.2590 / +0.0000 / -0.9660 Azimuth: +0.0000 / +1.0000 / +0.0000 S3A-GPSA: Boresight: +0.0000 / +0.0000 / -1.0000 Azimuth: +1.0000 / +0.0000 / +0.0000 S3B-GPSA: Boresight: +0.0000 / +0.0000 / -1.0000 Azimuth: +1.0000 / +0.0000 / +0.0000 S6A-GPSA: Boresight: +0.0000 / +0.0000 / -1.0000 Azimuth: +0.0000 / -1.0000 / +0.0000	
DORIS Reference Point (X, Y, Z)		S6 (ionofrees)		
SLR Reference Point (X, Y, Z)				

Data Processing Summary				
Parameter/Model	Analysis Centre (Orbit Solution)			
	TUM (TUM)	GSC (GSFC)	TU Graz (TUG)	
Gravity				
Gravity field (static)	**GOCO06s (120x120)**	GOCO05s	GOCO06s (180x180)	
Gravity field (time varying)	**GOCO06s**	L >= 6. GOCO05s. L = 2 to 5. derived from SLR/DORIS low degree solutions.	GOCO06s	
Solid Earth tides	Applied (IERS 2010)	IERS2010	IERS 2010	
Ocean tides	FES2004 (50x50)	GOT4.10c	FES2014b (180x180)	
Atmospheric gravity	None	AOD1B RL06 (99x99)	AOD1B RL06 (180x180)	
Atmospheric tides	None	Dobslaw et al (2017)	AOD1B RL06	
Earth pole tide	IERS 2010	IERS 2010	IERS 2010 (secular mean pole)	
Ocean pole tide	IERS 2010	IERS 2010	IERS 2010 (secular mean pole)	
Third bodies	Sun, Moon, Planets DE405	Sun, Moon, Planets DE421	Sun, Moon, Planets DE431	
Relativity		Schwarzchild, Lense-Thirring, DeSitter applied	IERS 2010	
Surface forces and empiricals				
Radiation Pressure model	Box-wing model	Bow-wing modlel	Macro model	
Earth radiation	Box-wing for Albedo and Infra-red	Knocke et al. (1988)	CERES monthly mean (Vis and IR)	
Total Solar Irradiance (TSI)		1360.45 W/m**2 (Kopp and Lean, 2011)		
Atmospheric density model	MSISE-90	MSIS-86 (Hedin, 1987)	DTM2020	
Radiation pressure coefficient	1 per arc (estimated)	1 per arc (pre-estimated)	fixed	
Drag coefficients	1 per arc (estimated)	3 /day (estimated)	fixed	
1/rev empiricals	1 set in along-track and cross-track direction (with sin/cos signals)	Along-track & Cross-track OPR/day		
Other empiricals	stoch. velocity changes every 15 min (constr. 5e-7m/s2)	N/A	Empirical accelerations in along, cross, radial, as linear splines with nodes every 20 min , constrained 1e-9 m/s2	
GNSS measurements				
Relativity	Applied		Applied	

Data Processing Summary				
Parameter/Model	Analysis Centre (Orbit Solution)			
	TUM (TUM)	GSC (GSFC)	TU Graz (TUG)	
Sampling	30 s for S6A, 10 s for others		S1/S6: 10s, S2/S3: 1s	
Observations	Iono-free linear combinations of phase and pseudo-range measurements		All available code and phase measurements without linear combinations (raw observation approach)	
Weight	n/a		Azimuth, elevation depedent, estimated from residuals	
Elevation angle cut-off	0 deg		0 deg	
Down-weighting law	None		Robust modified M-Huber estimator	
Antenna phase-centre wind-up correction	Applied (IGS model)		Applied	
Antenna phase-centre variation	**Applied (Estimated based on sen20_2236.atx for S6A, sen20_2236.atx for other Sentinel satellites)**		estimated based on sen20_2236.atx	
GNSS/DORIS/SLR parameters				
Receiver clocks	Per epoch, every 10 s		Per epoch	
Receiver ambiguities	Estimated (resolved, typically more than 95%)		Estimated (integer)	
GNSS orbits	Fixed (CODE final, CODE rapid for S6A)		Fixed (TUG /IGS20)	
GNSS clocks	Fixed (CODE final, 5 s, CODE rapid for S6A)		Fixed (TUG 30s, densified with CODE final 5s)	
GNSS antex				
GNSS satellite biases	n/a		Fixed (TUG)	
Inter-system biases				
DORIS troposphere	n/a	GPT/VMF-1		
DORIS coordinates	n/a	DPOD2014v5		
SLR Coordinates		SLRF2014/v200428		
SLR Troposphere		Sastamoinen (1972)		

Data Processing Summary				
Parameter/Model	Analysis Centre (Orbit Solution)			
	TUM (TUM)	GSC (GSFC)	TU Graz (TUG)	
SLR Mapping Function		Mendes et al. (2005)		
SLR Elevation Cutoff Angle		15 deg		
DORIS Ground Antenna Phase Law		Applied. Tourain et al. (2016)		
DORIS Elevation Cutoff Angle		10 deg		
DORIS Elevation Down-weighting Function		1/sin(elev)**(1/2)		

ANNEX C. WEIGHTS CALCULATION FOR THE GENERATION OF THE COMB ORBIT SOLUTION

The current annex aims to clarify how the combined orbit solution (and its weights) is computed.

Firstly, it deserves to be pointed out that the combined orbit solution for a particular satellite and a particular day is computed by averaging the state vectors, which contain the position and the velocity at time t^* , $\mathbf{SV}(t^*) = [\mathbf{r}(t^*)\,\mathbf{v}(t^*)]^T$, of the different solutions as follows (each orbit solution is represented by the index j),

$$\mathbf{SV}_{comb}(t^*) = \frac{\sum_j \mathbf{SV}_j(t^*)/w_j}{\sum_j 1/w_j},$$

where $1/w_j$ denotes the weight associated to each orbit solution j at a particular day. These weights are a measurement of the (inverse) distance between the orbits of each institution and the simple arithmetic mean combination (i.e., a priori combined solution setting $1/w_j = 1$). Let d_j be the module of the distance between the position of the a priori combined solution, $\boldsymbol{r}_0$, and the position of the solution for institution j, $\boldsymbol{r}_j$, at time t^*. This is:

$$d_j(t^*) = \left| \boldsymbol{r}_0(t^*) - \boldsymbol{r}_j(t^*) \right|$$

If $\mathbf{d}_j$ is the vector made up by the distances d_j computed for every t^* of the temporal discretization (defined by the combination step, which is equal to 30 seconds), a value $\overline{w}_j$ has been defined as the median (instead of mean to avoid overlaps) of $\mathbf{d}_j$. To ease their usage, these values are scaled with the following scaling factor:

$$sc = \max\{\overline{w}_1, \overline{w}_2, \dots, \overline{w}_j, \dots\}$$

Computing w_j as $w_j = \frac{\overline{w}_j}{sc}$, the wanted weight, $1/w_j$, corresponding to a particular day for institution j is obtained.

ANNEX D. VALIDATION OF THE CPOD SERVICE ORBIT PRODUCTS (OTHER STATISTICS)

As a complement of Section 3, the mean of the daily average of each orbit comparisons is shown for each satellite and orbit solution.

D.1. SENTINEL-1A

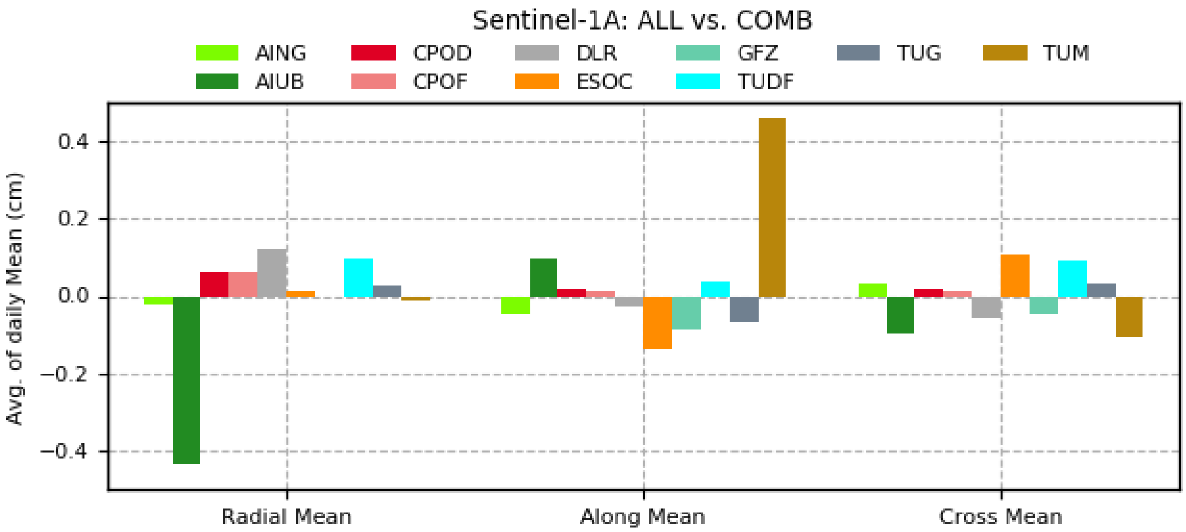


Figure D-1: Sentinel-1A orbit comparisons – Mean of daily average [cm] (All vs. COMB [radial, along, cross and 3D RMS])

Table D-1: Sentinel-1A orbit comparisons – Mean of daily average [cm] (All vs. COMB)

Orbit Comparisons (Mean of daily average [cm])				
Orbit Solution	Centre	Satellite component		
		Radial	Along-track	Cross-track
AING	**AIUB**	-0.02	-0.05	0.03
AIUB	**AIUB**	-0.44	0.10	-0.10
CPOD	**CPOD**	0.06	0.02	0.02
CPOF	**CPOD**	0.06	0.01	0.01
DLR	**DLR**	0.12	-0.03	-0.06
ESOC	**ESOC**	0.01	-0.14	0.11
GFZ	**GFZ**	-0.00	-0.09	-0.05
TUDF	**TUD**	0.10	0.04	0.09
TUG	**TUG**	0.03	-0.07	0.03
TUM	**TUM**	-0.01	0.46	-0.11

D.2. SENTINEL-2A

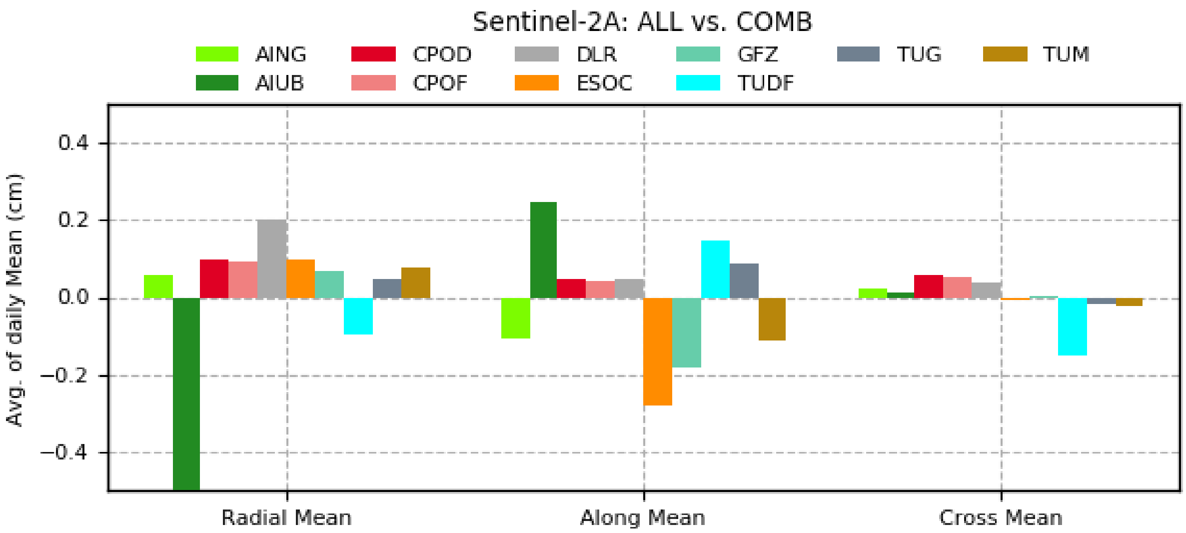


Figure D-2: Sentinel-2A orbit comparisons – Mean of daily average [cm] (All vs. COMB [radial, along, cross and 3D RMS])

Table D-2: Sentinel-2A orbit comparisons – Mean of daily average [cm] (All vs. COMB)

Orbit Comparisons (Mean of daily average [cm])				
Orbit Solution	Centre	Satellite component		
		Radial	Along-track	Cross-track
AING	**AIUB**	0.06	-0.11	0.02
AIUB	**AIUB**	-0.86	0.24	0.01
CPOD	**CPOD**	0.10	0.05	0.06
CPOF	**CPOD**	0.09	0.04	0.05
DLR	**DLR**	0.20	0.05	0.04
ESOC	**ESOC**	0.10	-0.28	-0.01
GFZ	**GFZ**	0.07	-0.18	0.00
TUDF	**TUD**	-0.10	0.15	-0.15
TUG	**TUG**	0.05	0.09	-0.02
TUM	**TUM**	0.08	-0.11	-0.02

D.3. SENTINEL-2B

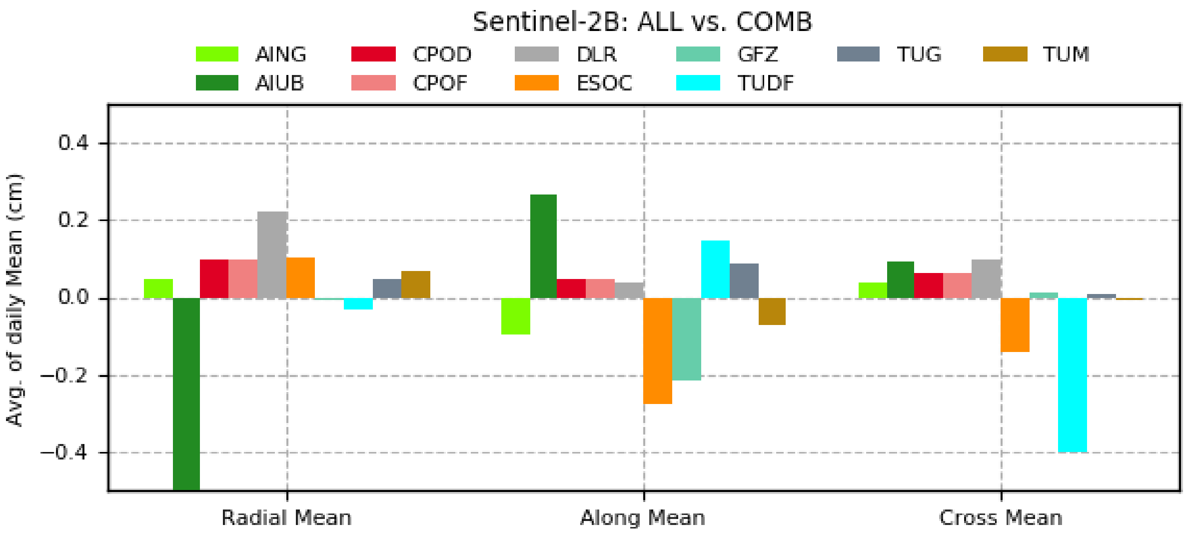


Figure D-3: Sentinel-2B orbit comparisons – Mean of daily average [cm] (All vs. COMB [radial, along, cross and 3D RMS])

Table D-3: Sentinel-2B orbit comparisons – Mean of daily average [cm] (All vs. COMB)

Orbit Comparisons (Mean of daily average [cm])				
Orbit Solution	Centre	Satellite component		
		Radial	Along-track	Cross-track
AING	**AIUB**	0.05	-0.10	0.03
AIUB	**AIUB**	-0.94	0.27	0.09
CPOD	**CPOD**	0.10	0.05	0.06
CPOF	**CPOD**	0.09	0.05	0.06
DLR	**DLR**	0.22	0.04	0.10
ESOC	**ESOC**	0.10	-0.27	-0.14
GFZ	**GFZ**	-0.01	-0.22	0.01
TUDF	**TUD**	-0.03	0.15	-0.40
TUG	**TUG**	0.05	0.09	0.01
TUM	**TUM**	0.07	-0.07	-0.01

D.4. SENTINEL-3A

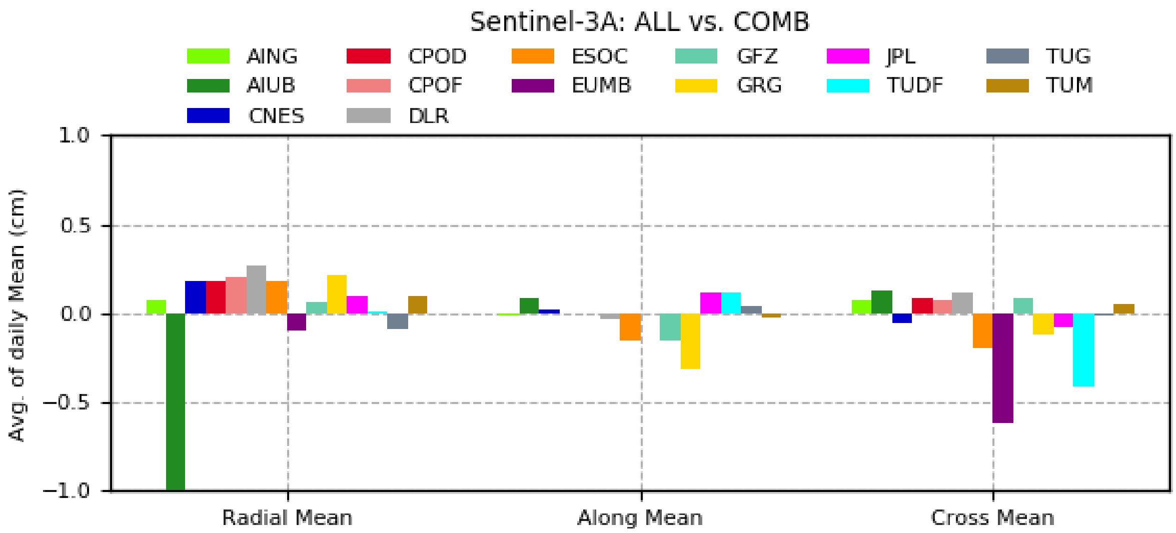


Figure D-4: Sentinel-3A orbit comparisons – Mean of daily average [cm] (All vs. COMB [radial, along, cross and 3D RMS])

Table D-4: Sentinel-3A orbit comparisons – Mean of daily average [cm] (All vs. COMB)

Orbit Comparisons (Mean of daily average [cm])				
Orbit Solution	Centre	Satellite component		
		Radial	Along-track	Cross-track
AING	**AIUB**	0.07	-0.01	0.07
AIUB	**AIUB**	-1.17	0.08	0.13
CNES	**CNES**	0.18	0.02	-0.06
CPOD	**CPOD**	0.18	-0.01	0.08
CPOF	**CPOD**	0.21	-0.00	0.08
DLR	**DLR**	0.27	-0.04	0.12
ESOC	**ESOC**	0.18	-0.16	-0.20
EUMB	**EUMB**	-0.10	-0.00	-0.61
GFZ	**GFZ**	0.06	-0.15	0.09
GRG	**GRG**	0.21	-0.32	-0.12
JPL	**JPL**	0.10	0.12	-0.08
TUDF	**TUD**	0.01	0.12	-0.42
TUG	**TUG**	-0.09	0.04	-0.01
TUM	**TUM**	0.10	-0.03	0.05

D.5. SENTINEL-3B

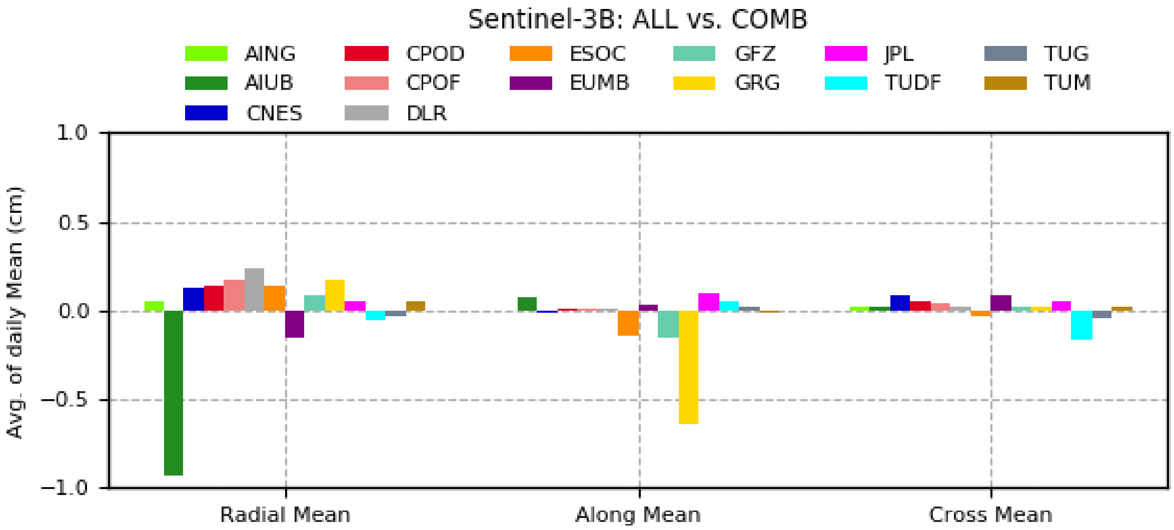


Figure D-5: Sentinel-3B orbit comparisons – Mean of daily average [cm] (All vs. COMB [radial, along, cross and 3D RMS])

Table D-5: Sentinel-3B orbit comparisons – Mean of daily average [cm] (All vs. COMB)

Orbit Comparisons (Mean of daily average [cm])				
Orbit Solution	Centre	Satellite component		
		Radial	Along-track	Cross-track
AING	**AIUB**	0.06	-0.00	0.02
AIUB	**AIUB**	-0.93	0.07	0.02
CNES	**CNES**	0.13	-0.01	0.08
CPOD	**CPOD**	0.14	0.01	0.05
CPOF	**CPOD**	0.17	0.01	0.04
DLR	**DLR**	0.23	0.01	0.02
ESOC	**ESOC**	0.14	-0.14	-0.04
EUMB	**EUMB**	-0.16	0.03	0.08
GFZ	**GFZ**	0.09	-0.15	0.02
GRG	**GRG**	0.17	-0.63	0.02
JPL	**JPL**	0.05	0.10	0.06
TUDF	**TUD**	-0.06	0.06	-0.17
TUG	**TUG**	-0.03	0.03	-0.04
TUM	**TUM**	0.05	-0.01	0.01

D.6. SENTINEL-6A

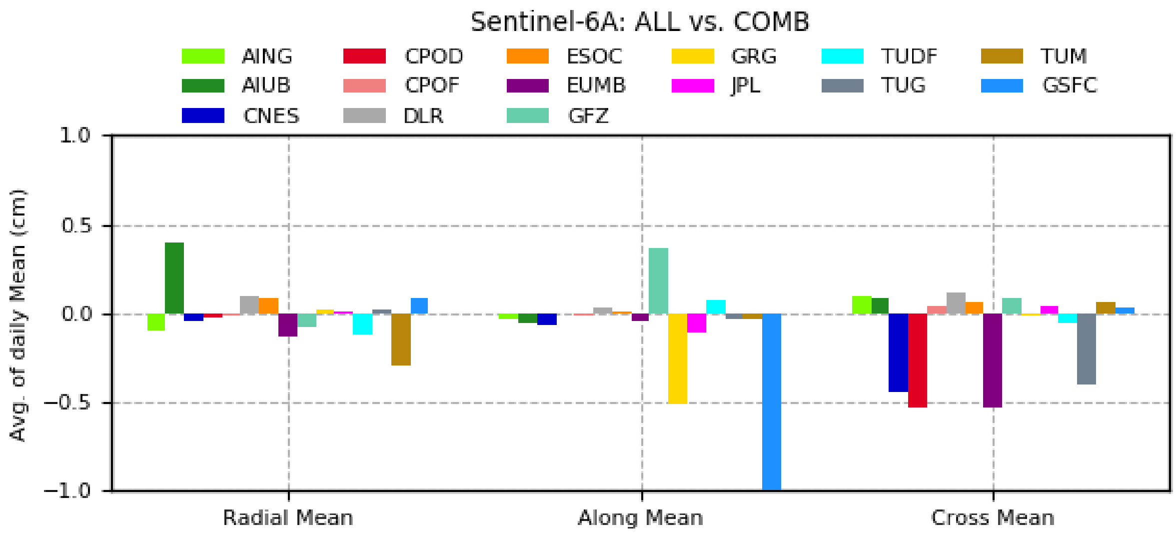


Figure D-6: Sentinel-6A orbit comparisons – Mean of daily average [cm] (All vs. COMB [radial, along, cross and 3D RMS])

Table D-6: Sentinel-6A orbit comparisons – Mean of daily average [cm] (All vs. COMB)

Orbit Comparisons (Mean of daily average [cm])				
Orbit Solution	Centre	Satellite component		
		Radial	Along-track	Cross-track
AING	**AIUB**	-0.10	-0.04	0.10
AIUB	**AIUB**	0.40	-0.06	0.08
CNES	**CNES**	-0.04	-0.07	-0.44
CPOD	**CPOD**	-0.02	-0.01	-0.54
CPOF	**CPOD**	-0.01	-0.01	0.05
DLR	**DLR**	0.10	0.03	0.11
ESOC	**ESOC**	0.08	0.01	0.06
EUMB	**EUMB**	-0.13	-0.05	-0.54
GFZ	**GFZ**	-0.07	0.37	0.08
GRG	**GRG**	0.02	-0.51	-0.01
JPL	**JPL**	0.01	-0.11	0.04
TUDF	**TUD**	-0.12	0.07	-0.06
TUG	**TUG**	0.02	-0.04	-0.40
TUM	**TUM**	-0.29	-0.04	0.06
GSFC	**GSFC**	0.08	-1.24	0.03

ANNEX E. PRODUCT PERFORMANCE

As a complement of the Regular Service Review, a summary of the performances of each of the POD products generated for Sentinel-1, -2, -3 and -6 is presented in terms of orbit comparisons and accuracy percentiles. Predicted, NRT and STC products comprise the period of the RSR #29, whereas the NTC products are shown from the beginning of each mission.

This section is prepared following the same format as the document to be sent to Sentinel Online.

SENTINEL-1

The operational Sentinel-1 AUX_PREORB, AUX_RESORB and AUX_POEORB solutions from the CPOD Service are compared here against the combined solution (COMB), which is computed as a weighted mean of several external solutions provided by the CPOD QWG. The AUX_PREORB solution is divided into its two orbits in order to analyse the difference between the first and the second prediction.

In the following figures, the position accuracy of each orbit solution is shown (in 2D or 3D RMS depending on the requirement). Each figure is presented along with the distribution of the obtained accuracy metrics, where the percentiles of these metrics are calculated for different thresholds.

The period of time for AUX_PREORB and AUX_RESORB products correspond to the latest RSR report. The period of time of the AUX_POEORB products includes the whole mission. Orbit comparisons considered as outliers (i.e., those mostly generated from periods of time with manoeuvres or data gaps) have been filtered-out from the statistics shown below.

AUX_PREORB (1st orbit)

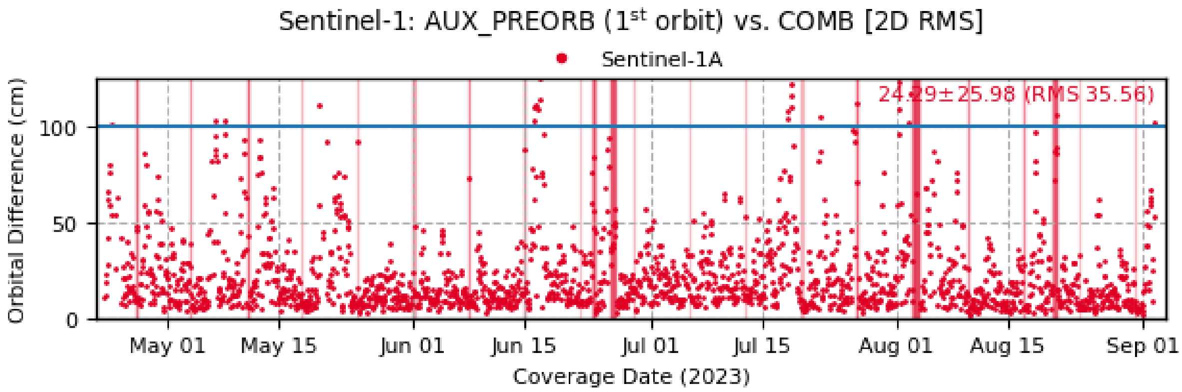


Figure E-1: Sentinel-1 AUX_PREORB (1st orbit) products – Orbit comparisons against COMB solution [2D RMS; cm] (the accuracy requirement is shown with a blue line; vertical lines indicate periods of manoeuvres or data gaps)

Table E-1: Sentinel-1 AUX_PREORB (1st orbit) products – Accuracy percentiles (they are calculated from the orbit comparisons against COMB solution [2D RMS])

Product Accuracy	
Threshold	Percentage of Fulfilment
	Sentinel-1A
5 cm	5.56 %
10 cm	29.61 %
20 cm	61.28 %
50 cm	89.19 %
100 cm	97.19 %

AUX_PREORB (2nd orbit)

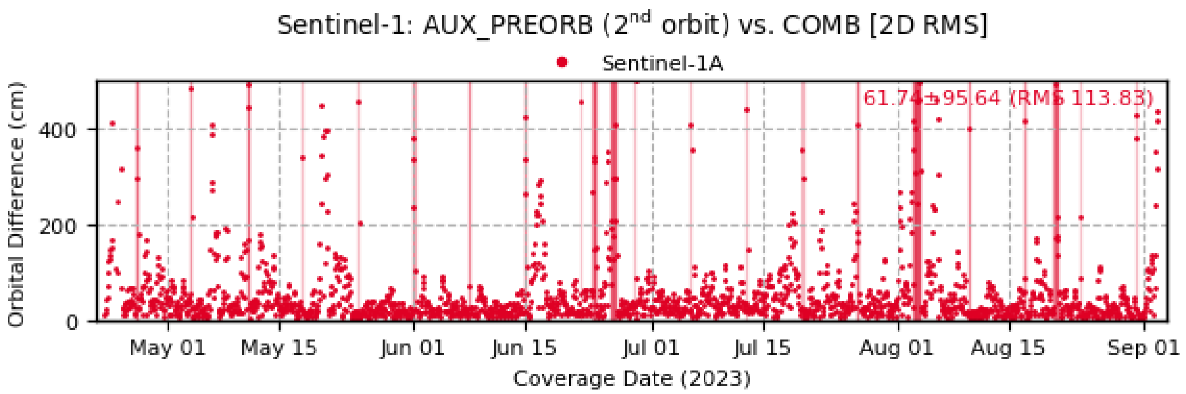


Figure E-2: Sentinel-1 AUX_PREORB (2nd orbit) products – Orbit comparisons against COMB solution [2D RMS; cm] (the accuracy requirement is shown with a blue line; vertical lines indicate periods of manoeuvres or data gaps)

Table E-2: Sentinel-1 AUX_PREORB (2nd orbit) products – Accuracy percentiles (they are calculated from the orbit comparisons against COMB solution [2D RMS])

Product Accuracy	
Threshold	Percentage of Fulfilment
	Sentinel-1A
5 cm	0.99 %
10 cm	9.83 %
20 cm	31.95 %
50 cm	68.99 %
100 cm	85.85 %

AUX_RESORB

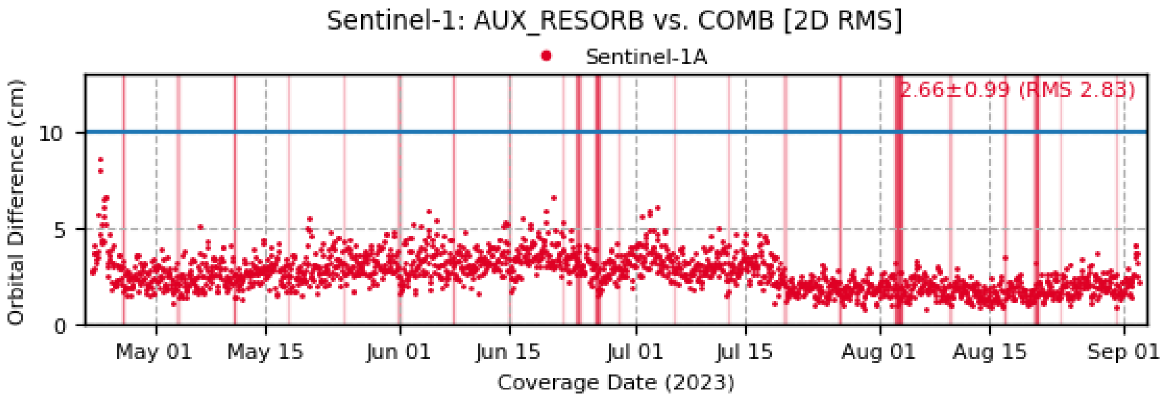


Figure E-3: Sentinel-1 AUX_RESORB products – Orbit comparisons against COMB solution [2D RMS; cm] (the accuracy requirement is shown with a blue line; vertical lines indicate periods of manoeuvres or data gaps)

Table E-3: Sentinel-1 AUX_RESORB products – Accuracy percentiles (they are calculated from the orbit comparisons against COMB solution [2D RMS])

Product Accuracy	
Threshold	Percentage of Fulfilment
	Sentinel-1A
1 cm	0.77 %
2 cm	27.71 %
3 cm	67.49 %
5 cm	98.40 %
10 cm	99.95 %

AUX_POEORB

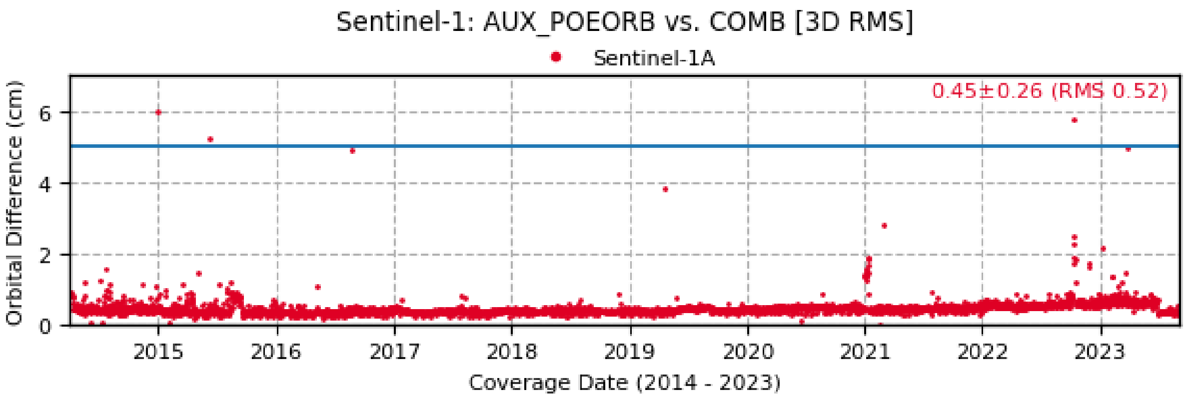


Figure E-4: Sentinel-1 AUX_POEORB products – Orbit comparisons against COMB solution [3D RMS; cm] (the accuracy requirement is shown with a blue line; neither gaps nor manoeuvres are depicted in this case)

Table E-4: Sentinel-1 orbit comparisons – Accuracy percentiles (the accuracy percentiles are from AUX_POEORB against COMB solution [3D RMS])

Product Accuracy	
Threshold	Percentage of Fulfilment
	Sentinel-1A
3 cm	100.00 %
5 cm	100.00 %
10 cm	100.00 %
20 cm	100.00 %

SENTINEL-2

The operational Sentinel-2 AUX_RESORB solutions from the CPOD Service are compared here against the combined solution (COMB), which is computed as a weighted mean of several external solutions provided by the CPOD QWG.

In the following figures, the position accuracy of each orbit solution is shown (in 2D or 3D RMS depending on the requirement). Each figure is presented along with the distribution of the obtained accuracy metrics, where the percentiles of these metrics are calculated for different thresholds.

The period of time for AUX_RESORB products correspond to the latest RSR report. Orbit comparisons considered as outliers (i.e., those mostly generated from periods of time with manoeuvres or data gaps) have been filtered-out from the statistics shown below.

AUX_RESORB

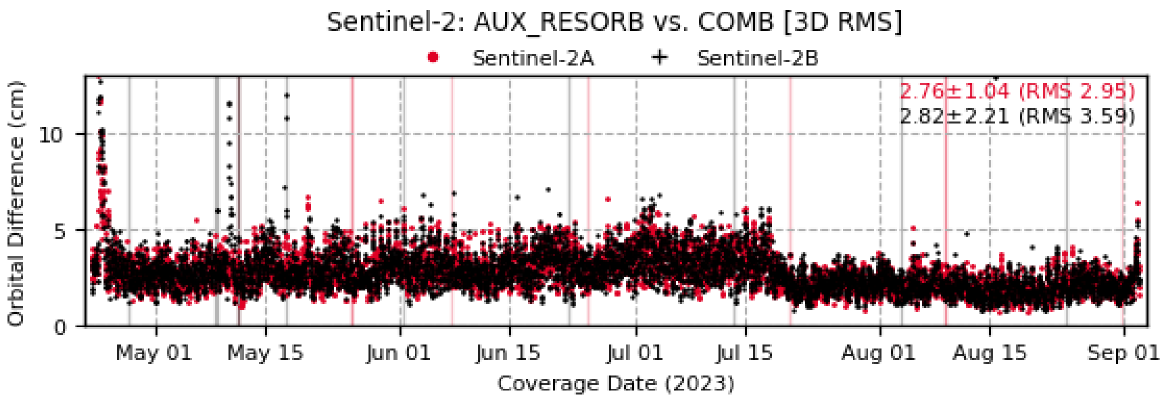


Figure E-5: Sentinel-2 AUX_RESORB products – Orbit comparisons against COMB solution [3D RMS; cm] (the accuracy requirement expressed as 1-sigma, if appears, is shown with a blue line; vertical lines indicate periods of manoeuvres or data gaps)

Table E-5: Sentinel-2 AUX_RESORB products – Accuracy percentiles (they are calculated from the orbit comparisons against COMB solution [3D RMS])

Product Accuracy		
Threshold	Percentage of Fulfilment	
	Sentinel-2A	Sentinel-2B
3 cm	65.10 %	65.97 %
5 cm	97.60 %	97.20 %

Product Accuracy		
Threshold	Percentage of Fulfilment	
	Sentinel-2A	Sentinel-2B
10 cm	99.85 %	99.57 %
50 cm	100.00 %	99.94 %
100 cm	100.00 %	100.00 %

SENTINEL-3

The operational Sentinel-3 SR___ROE_AX, AUX_MOEORB and AUX_POEORB solutions from the CPOD Service are compared here against the combined solution (COMB), which is computed as a weighted mean of several external solutions provided by the CPOD QWG.

In the following figures, the position accuracy of each orbit solution is shown (in radial RMS as per requirement). Each figure is presented along with the distribution of the obtained accuracy metrics, where the percentiles of these metrics are calculated for different thresholds.

The period of time for SR___ROE_AX and AUX_MOEORB products correspond to the latest RSR report. The period of time of the AUX_POEORB products includes the whole mission. Orbit comparisons considered as outliers (i.e., those mostly generated from periods of time with manoeuvres or data gaps) have been filtered-out from the statistics shown below.

SR___ROE_AX

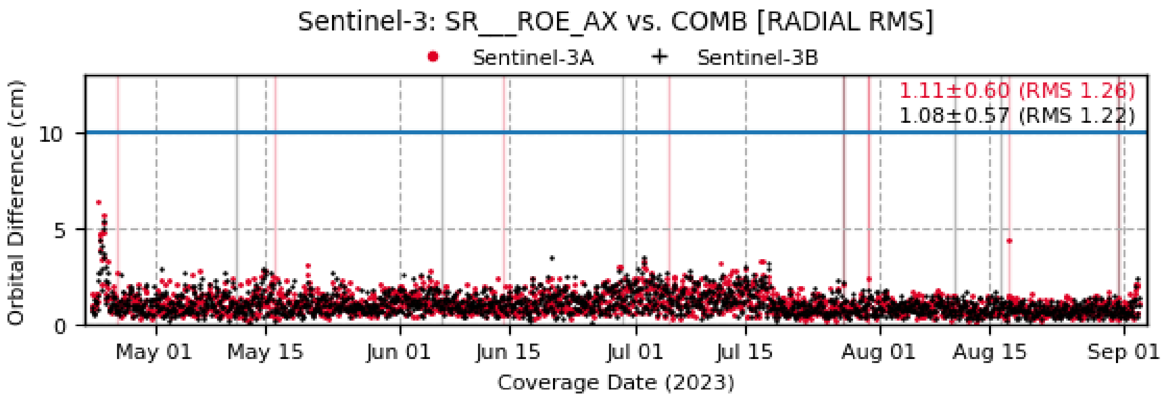


Figure E-6: Sentinel-3 SR___ROE_AX products – Orbit comparisons against COMB solution [radial RMS; cm] (the accuracy requirement is shown with a blue line; vertical lines indicate periods of manoeuvres or data gaps)

Table E-6: Sentinel-3 SR___ROE_AX products – Accuracy percentiles (they are calculated from the orbit comparisons against COMB solution [radial RMS])

Product Accuracy		
Threshold	Percentage of Fulfilment	
	Sentinel-3A	Sentinel-3B
1 cm	50.79 %	52.56 %

Product Accuracy		
Threshold	Percentage of Fulfilment	
	Sentinel-3A	Sentinel-3B
2 cm	92.96 %	92.94 %
5 cm	99.84 %	99.89 %
8 cm	100.00 %	100.00 %
10 cm	100.00 %	100.00 %

AUX_MOEORB

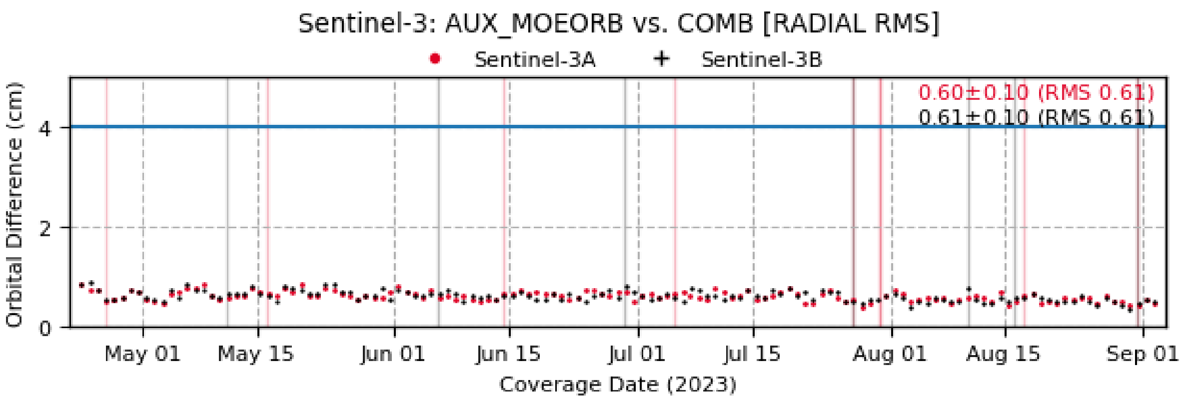


Figure E-7: Sentinel-3 AUX_MOEORB products – Orbit comparisons against COMB solution [radial RMS; cm] (the accuracy requirement is shown with a blue line; vertical lines indicate periods of manoeuvres or data gaps)

Table E-7: Sentinel-3 AUX_MOEORB products – Accuracy percentiles (they are calculated from the orbit comparisons against COMB solution [radial RMS])

Product Accuracy		
Threshold	Percentage of Fulfilment	
	Sentinel-3A	Sentinel-3B
0.5 cm	16.42 %	15.79 %
1 cm	100.00 %	100.00 %
2 cm	100.00 %	100.00 %
3 cm	100.00 %	100.00 %
4 cm	100.00 %	100.00 %

AUX_POEORB

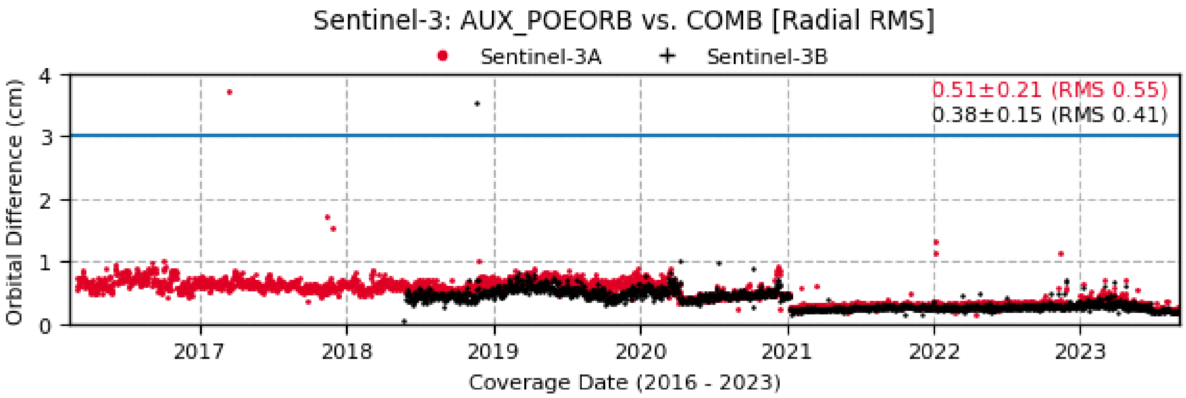


Figure E-8: Sentinel-3 AUX_POEORB products – Orbit comparisons against COMB solution [radial RMS; cm] (the accuracy requirement is shown with a blue line; neither gaps nor manoeuvres are depicted in this case)

Table E-8: Sentinel-3 AUX_POEORB products – Accuracy percentiles (they are calculated from the orbit comparisons against COMB solution [radial RMS])

Product Accuracy		
Threshold	Percentage of Fulfilment	
	Sentinel-3A	Sentinel-3B
0.5 cm	97.74 %	99.25 %
1 cm	100.00 %	100.00 %
2 cm	100.00 %	100.00 %
3 cm	100.00 %	100.00 %
4 cm	100.00 %	100.00 %

SENTINEL-6

The operational Sentinel-6 ROE__AX solution from the CPOD Service is compared here against the combined solution (COMB), which is computed as a weighted mean of several external solutions provided by the CPOD QWG.

In the following figure, the position accuracy of each orbit solution is shown (in radial RMS as per requirement). The figure is presented along with the distribution of the obtained accuracy metrics, where the percentiles of these metrics are calculated for different thresholds.

The period of time for ROE__AX products correspond to the latest RSR. Orbit comparisons considered as outliers (i.e., those mostly generated from periods of time with manoeuvres or data gaps) have been filtered-out from the statistics shown below.

ROE__AX

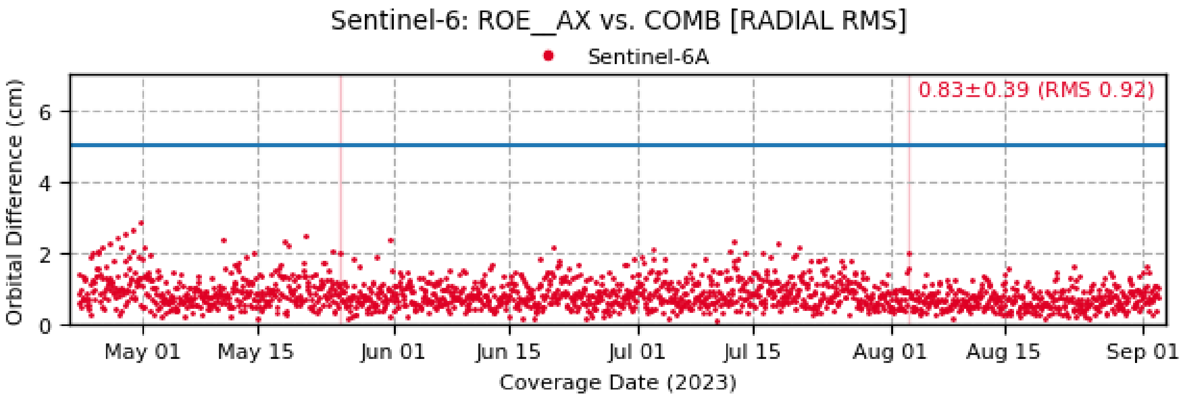


Figure E-9: Sentinel-6A ROE__AX products – Orbit comparisons against COMB solution [radial RMS; cm] (the accuracy requirement is shown with a blue line; vertical lines indicate periods of manoeuvres or data gaps)

Table E-9: Sentinel-6A ROE__AX products – Accuracy percentiles (they are calculated from the orbit comparisons against COMB solution [radial RMS])

Product Accuracy	
Threshold	Percentage of Fulfilment
	Sentinel-6A
1 cm	72.77 %
2 cm	98.64 %
3 cm	100.00 %
4 cm	100.00 %
5 cm	100.00 %

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