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# COPERNICUS POD REGULAR SERVICE REVIEW JUL - SEP 2022

COPERNICUS SENTINEL-1, -2, -3 AND -6 PRECISE ORBIT DETERMINATION SERVICE (CPOD)

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# 1. INTRODUCTION

#### 1.1. PURPOSE

This document describes the results of the Copernicus POD (CPOD) Regular Service Review (RSR) #26 covering the period between July and September 2022 (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**, PosiTim, **TU Delft**, **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	KPI	Key Performance Indicator	
AIUB	Astronomical Institute University of Bern	LRR	Laser Retro-reflector	
ANX	Ascending Node	MACP	Manoeuvre Acceleration Profile	
ARP	Antenna Reference Point	MLI	Multi Layered Insulation	
BRDC	Broadcast ephemeris file	MSI	Multi-Spectral Instrument	
CLS	Collecte Localisation Satellites	NAPEOS	NAvigation Package for Earth Orbiting Satellites	
CNES	Centre National d'Études Spatiales	NASA	National Aeronautics and Space Agency	
CODE	Center for Orbit Determination in Europe	NAVATT	NAVigation and ATTitude information	
CPF	Consolidated Prediction Format	NAVSOL	Navigation Solution	
CPOD	Copernicus POD	NCR	Non-Conformance Report	
DCB	Differential Code Biases	NOAA	National Oceanic and Atmospheric Administration	
DIL	Document Item List	NRT	Near Real Time	
DLR	Deutsche Zentrum für Luft- und Raumfahrt	NTC	Non Time Critical	
DOP	Dilution of Precision	ODA	On-Line Data Access	
DORIS	Doppler Orbytography and Radiopositioning Integrated by Satellite	OFLPOD	Offline POD	
DORNAV	Doris Navigation	OLCI	Ocean & Land Colour Instrument	
DOY	Day of Year	OPOD	Offline POD	
DPM	Data Processing Model	OSV	Orbit State Vector	
ECMWF	European Center for Medium-range Weather Forecasts	JPL	Jet Propulsion Laboratory	
EDDS	External Data Distribution System	PAC	Processing Archiving Centre	
EGP	External GPS Provider	PCO	Phase Centre Offset	
EIGEN	European Improved Gravity model of the Earth by New techniques	PDAP	Payload Data and Acquisition Processing	
EOF	Earth Observation File	PDGS	Payload Data Ground Segment	
EOP	Earth Orientation Parameters	PDI	Product Data Item	





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Acronym	Definition	Acronym	Definition
ERA	Earth Rotation Angle	PDMC	Payload Data Management Centre
ESA	European Space Agency	PDOP	Position DOP
ESOC	European Space Operation Centre	PFS	Product Format Specification
EUM	EUMETSAT	PMP	Project Management Plan
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
НКТМ	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

# 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	2.0	2022/04/01





 Code:
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Ref.	Title	Code	Version	Date
[AD.2]	Sentinel-1 PDGS to Copernicus POD Service ICD	GMV-CPOD-ICD-0009	2.0	2021/04/09
[AD.3]	Copernicus POD Service to Sentinel-1 PDGS ICD	GMV-CPOD-ICD-0008	2.0	2021/04/09
[AD.4]	External Auxiliary Data Providers to Copernicus POD Service ICD	GMV-GMESPOD-ICD-0002	2.0	2021/06/02
[AD.5]	Sentinel-2 PDGS and Copernicus POD Service ICD	GMV-CPOD-ICD-0010	2.0	2021/04/09
[AD.6]	Sentinel-3 PDGS to Copernicus POD Service ICD	GMV-CPOD-ICD-0012	2.0	2021/04/09
[AD.7]	Copernicus POD Service to Sentinel-3 PDGS ICD	GMV-CPOD-ICD-0011	2.0	2021/04/09
[AD.8]	EUMETSAT and Copernicus POD Service ICD for Sentinel-6A	GMV-CPOD-ICD-0007	1.1	2021/02/02

# 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	1.8	2020/05/18
[RD.4]	Sentinel-6 POD Context	JC-TN-ESA-SY-0420	1.4	2021/02/01





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# 2. OVERVIEW OF THE COPERNICUS POD SERVICE OPERATIONS

The Copernicus POD (CPOD) Service is currently operating seven 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

U	Jnit	Sentinel-1	Sentinel-2	Sentinel-3	Sentinel-6
	Α	2014/04/03	2015/06/23	2016/02/16	2020/11/21
	В	2016/04/25 - 2022/06/28	2017/03/07	2018/04/25	_

Note that the download of GNSS L0 data from Sentinel-1B was discontinued on the 28/06/2022, so it is not included in this RSR.

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 2022/07/01 until 2022/09/30 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.





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# 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	GRGG
Centre National d'Études Spatiales	CNES	CNES (operational solution)
Copernicus POD Service	CPOD	CPOD (operational solution) CPOF (solution with new developments) CPOK (kinematic solution)
Deutsche Zentrum für Luft- und Raumfahrt	DLR	DLRR
European Space Operation Centre	ESOC	ESOC
European organisation for the exploitation of Meteorological Satellites	EUM	EUMB (Bernese GNSS software)
Deutsches GeoForschungsZentrum	GFZ	GFZZ
Goddard Space Flight Center	GSFC	GSFC
Jet Propulsion Laboratory	JPL	JPLL
Technische Universiteit Delft	TUD	TUDF
Technische Universität München	TUM	TUMM

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 2022/06/19 (i.e., 22150 GPS week) to 2022/09/17 (i.e., 22275 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 S-3 and S-6 STC products generated by CPOD, CNES, and TUD.





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#### 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.

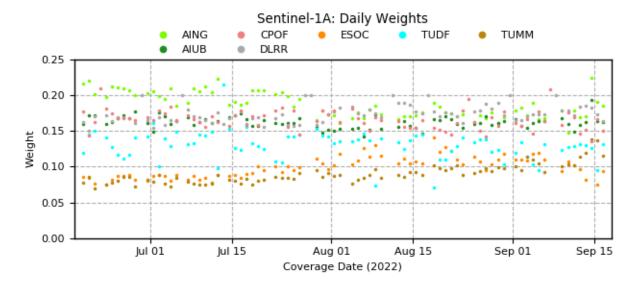


Figure 3-1: Sentinel-1A COMB generation - Daily weights of ALL orbit solutions

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

Daily Weights						
Orbit Solution	Centre	Mean				
AING	AIUB	0.19				
AIUB	AIUB	0.16				
CPOF	CPOD	0.20				
DLRR	DLR	0.18				
ESOC	ESOC	0.10				
TUDF	TUD	0.17				
TUMM	TUM	0.09				

# 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.





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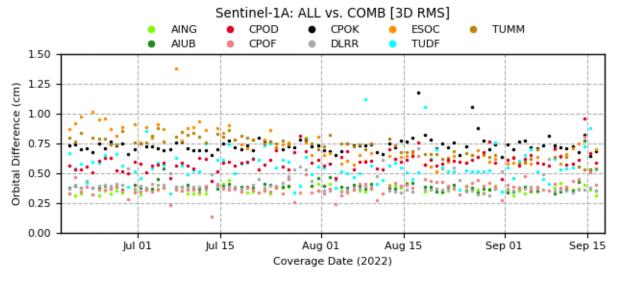


Figure 3-2: Sentinel-1A orbit comparisons - All vs. COMB [3D RMS; cm]

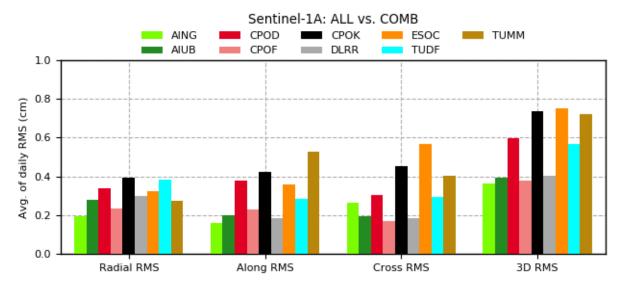


Figure 3-3: Sentinel-1A orbit comparisons – Mean of daily RMS [cm] (All vs. COMB [radial, along, cross and 3D RMS])

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

Orbit Comparisons (Mean of daily RMS [cm])								
Orbit	Contro		Satellite component					
Solution	Centre	Radial	Along-track	Cross-track	3D	Typical		
AING	AIUB	0.19	0.16	0.26	0.37	0.21		
AIUB	AIUB	0.28	0.20	0.19	0.40	0.23		
CPOD	CPOD	0.34	0.38	0.30	0.59	0.34		
CPOF	CPOD	0.24	0.23	0.17	0.38	0.22		
СРОК	CPOD	0.39	0.42	0.45	0.73	0.42		
DLRR	DLR	0.30	0.18	0.19	0.40	0.23		





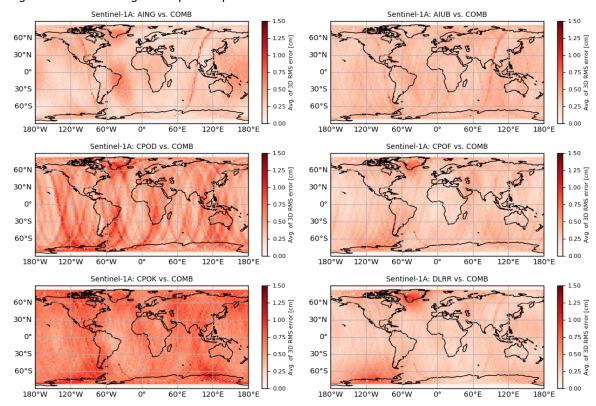
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Orbit Comparisons (Mean of daily RMS [cm])								
Orbit Solution	Centre	Satellite component						
		Radial	Along-track	Cross-track	3D	Typical		
ESOC	ESOC	0.32	0.36	0.57	0.75	0.43		
TUDF	TUD	0.39	0.29	0.29	0.57	0.33		
TUMM	TUM	0.28	0.53	0.40	0.72	0.42		

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.







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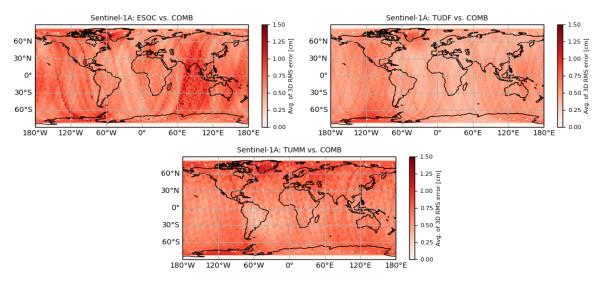
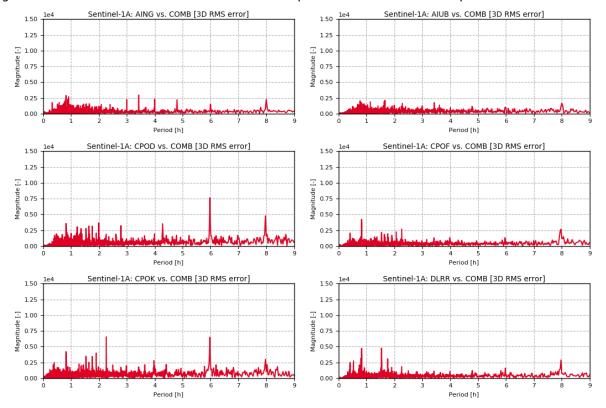


Figure 3-4: Sentinel-1A geographical analysis – Average of the 3D RMS orbit comparisons (All vs. COMB)

# 3.1.4. SPECTRAL ANALYSIS

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







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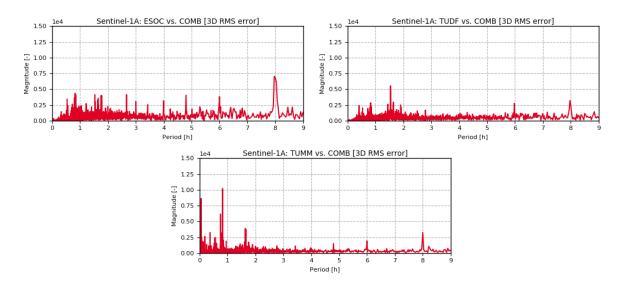


Figure 3-5: Sentinel-1A spectral analysis – 3D RMS orbit comparisons (All vs. COMB)





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#### 3.2. SENTINEL-2A

#### 3.2.1. STATISTICS OF THE GENERATION OF THE SOLUTION COMB

Figure 3-6 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 3-4, 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.

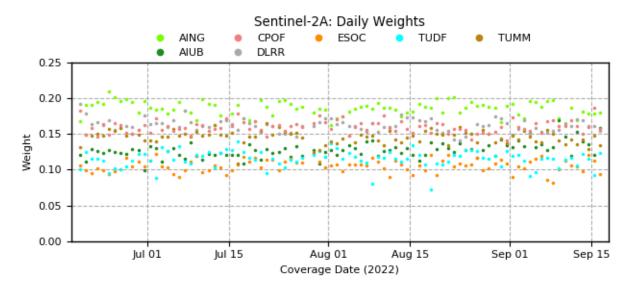


Figure 3-6: Sentinel-2A COMB generation - Daily weights of ALL orbit solutions

Table 3-4: Sentinel-2A COMB generation - Mean of the daily weights of ALL orbit solutions

Daily Weights						
Orbit Solution	Centre	Mean				
AING	AIUB	0.19				
AIUB	AIUB	0.13				
CPOF	CPOD	0.16				
DLRR	DLR	0.16				
ESOC	ESOC	0.11				
TUDF	TUD	0.12				
TUMM	TUM	0.15				

# 3.2.2. TEMPORAL EVOLUTION OF THE ORBITS COMPARISONS

Figure 3-7 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 3-8 and Table 3-5, where the mean of the daily RMS is calculated not only for the 3D RMS but also for other satellite components.





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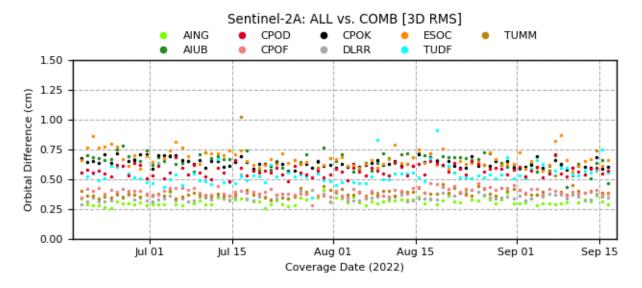


Figure 3-7: Sentinel-2A orbit comparisons – All vs. COMB [3D RMS; cm]

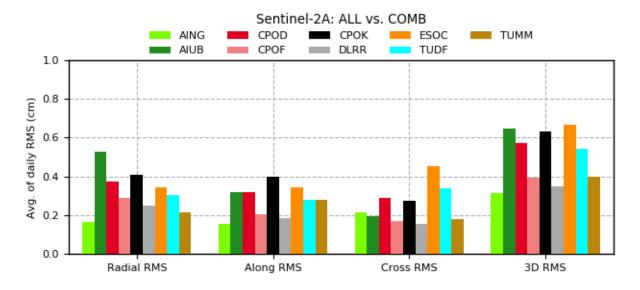


Figure 3-8: Sentinel-2A orbit comparisons – Mean of daily RMS [cm] (All vs. COMB [radial, along, cross and 3D RMS])

Table 3-5: Sentinel-2A orbit comparisons - Mean of daily RMS [cm] (All vs. COMB)

Orbit Comparisons (Mean of daily RMS [cm])							
Orbit	Contro		Satellite component				
Solution	Centre	Radial	Along-track	Cross-track	3D	Typical	
AING	AIUB	0.16	0.16	0.22	0.31	0.18	
AIUB	AIUB	0.53	0.32	0.20	0.65	0.37	
CPOD	CPOD	0.37	0.32	0.29	0.57	0.33	
CPOF	CPOD	0.29	0.20	0.17	0.40	0.23	
СРОК	CPOD	0.41	0.40	0.28	0.63	0.36	





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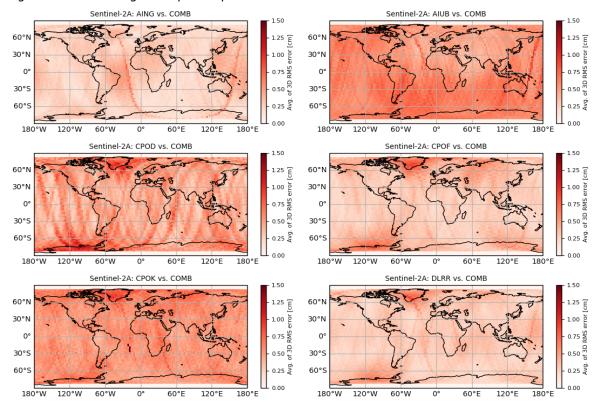
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Orbit Comparisons (Mean of daily RMS [cm])								
Orbit	Centre	Satellite component						
Solution		Radial	Along-track	Cross-track	3D	Typical		
DLRR	DLR	0.25	0.18	0.16	0.35	0.20		
ESOC	ESOC	0.34	0.34	0.45	0.67	0.39		
TUDF	TUD	0.30	0.28	0.34	0.54	0.31		
TUMM	TUM	0.22	0.28	0.18	0.40	0.23		

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 3-9 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.







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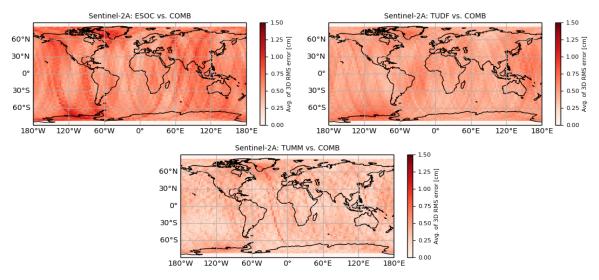
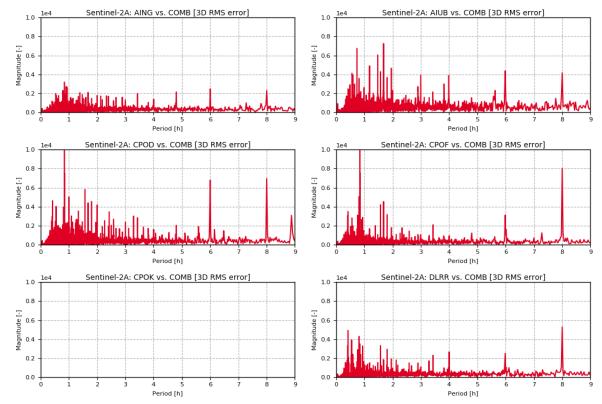


Figure 3-9: Sentinel-2A geographical analysis – Average of the 3D RMS orbit comparisons (All vs. COMB)

# 3.2.4. SPECTRAL ANALYSIS

Figure 3-10 shows the FFT of the 3D RMS orbit comparisons calculated on the previous sub section.







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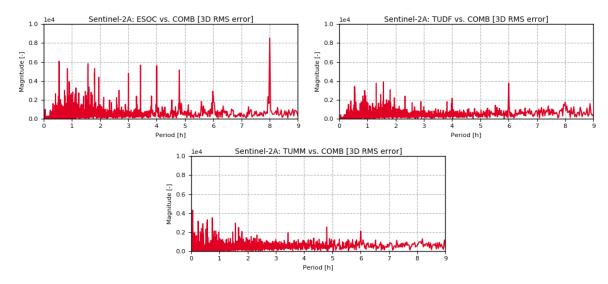


Figure 3-10: Sentinel-2A spectral analysis – 3D RMS orbit comparisons (All vs. COMB)





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#### 3.3. SENTINEL-2B

#### 3.3.1. STATISTICS OF THE GENERATION OF THE SOLUTION COMB

Figure 3-11 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 3-6, 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.

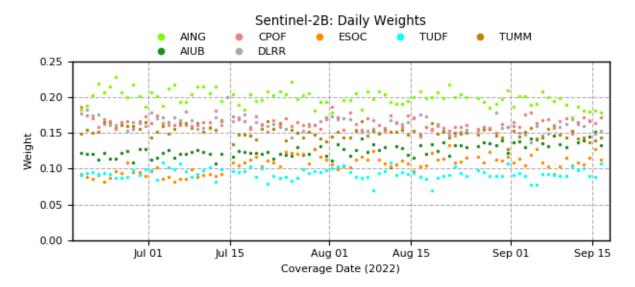


Figure 3-11: Sentinel-2B COMB generation - Daily weights of ALL orbit solutions

Table 3-6: Sentinel-2B COMB generation - Mean of the daily weights of ALL orbit solutions

Daily Weights						
Orbit Solution	Centre	Mean				
AING	AIUB	0.20				
AIUB	AIUB	0.13				
CPOF	CPOD	0.17				
DLRR	DLR	0.16				
ESOC	ESOC	0.11				
TUDF	TUD	0.10				
TUMM	TUM	0.15				

# 3.3.2. TEMPORAL EVOLUTION OF THE ORBITS COMPARISONS

Figure 3-12 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 3-13 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.





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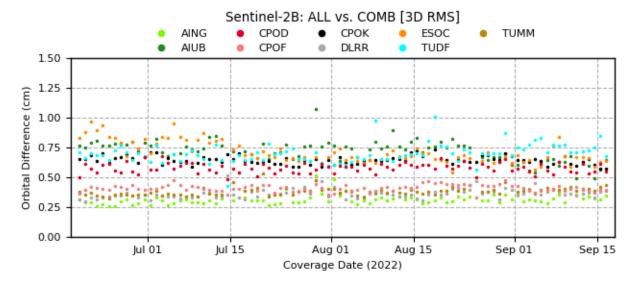


Figure 3-12: Sentinel-2B orbit comparisons - All vs. COMB [3D RMS; cm]

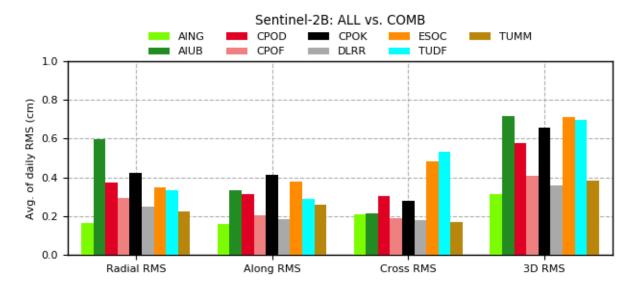


Figure 3-13: Sentinel-2B orbit comparisons – Mean of daily RMS [cm] (All vs. COMB [radial, along, cross and 3D RMS])

Table 3-7: Sentinel-2B orbit comparisons - Mean of daily RMS [cm] (All vs. COMB)

Orbit Comparisons (Mean of daily RMS [cm])							
Orbit	Contro		Satellite component				
Solution	Centre	Radial	Along-track	Cross-track	3D	Typical	
AING	AIUB	0.16	0.16	0.21	0.31	0.18	
AIUB	AIUB	0.60	0.33	0.22	0.72	0.41	
CPOD	CPOD	0.37	0.32	0.31	0.58	0.33	
CPOF	CPOD	0.29	0.21	0.19	0.41	0.23	
СРОК	CPOD	0.42	0.41	0.28	0.65	0.38	





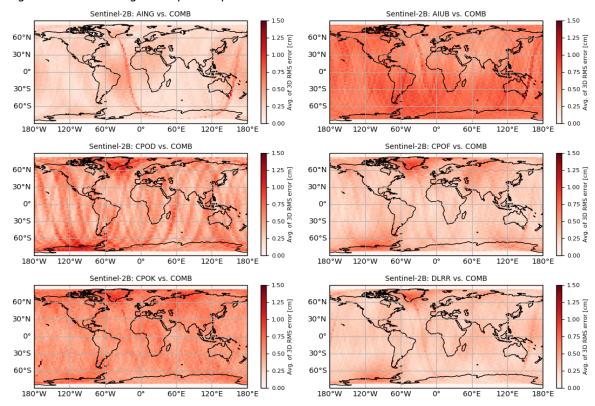
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Orbit Comparisons (Mean of daily RMS [cm])							
Orbit	Centre		Satellite component				
Solution		Radial	Along-track	Cross-track	3D	Typical	
DLRR	DLR	0.25	0.18	0.18	0.36	0.21	
ESOC	ESOC	0.35	0.38	0.48	0.71	0.41	
TUDF	TUD	0.33	0.29	0.53	0.70	0.40	
TUMM	TUM	0.22	0.26	0.17	0.38	0.22	

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 3-14 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.







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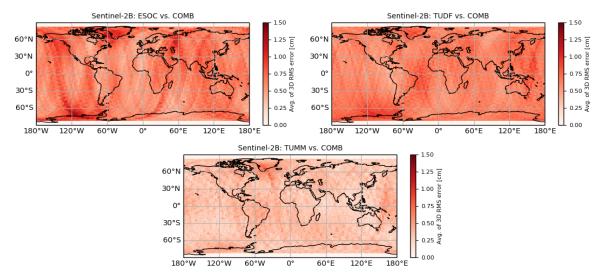
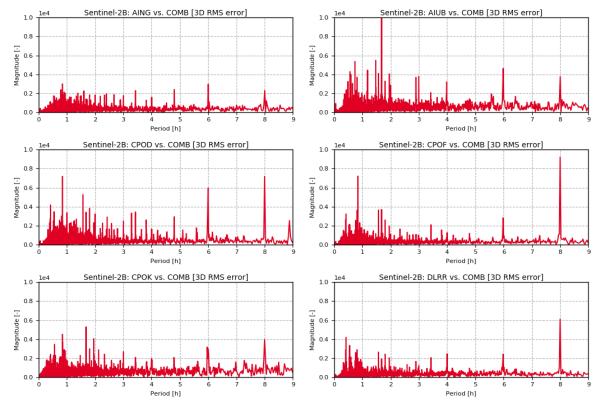


Figure 3-14: Sentinel-2B geographical analysis – Average of the 3D RMS orbit comparisons (All vs. COMB)

# 3.3.4. SPECTRAL ANALYSIS

Figure 3-15 shows the FFT of the 3D RMS orbit comparisons calculated on the previous sub section.







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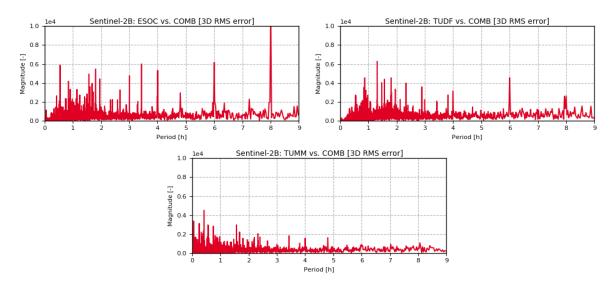


Figure 3-15: Sentinel-2B spectral analysis – 3D RMS orbit comparisons (All vs. COMB)





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#### 3.4. SENTINEL-3A

#### 3.4.1. STATISTICS OF THE GENERATION OF THE SOLUTION COMB

Figure 3-16 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 3-8, 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.

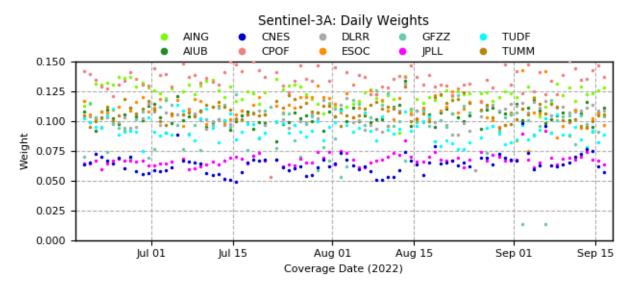


Figure 3-16: Sentinel-3A COMB generation - Daily weights of ALL orbit solutions

Table 3-8: 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	0.10		
CNES	CNES	0.07		
CPOF	CPOD	0.14		
DLRR	DLR	0.10		
ESOC	ESOC	0.11		
GFZZ	GFZ	0.09		
JPLL	JPL	0.07		
TUDF	TUD	0.10		
TUMM	TUM	0.11		

#### 3.4.2. TEMPORAL EVOLUTION OF THE ORBITS COMPARISONS

Figure 3-17 and Figure 3-18 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 3-19 and Table 3-9,





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where the mean of the daily RMS is calculated not only for the 3D RMS but also for other satellite components.

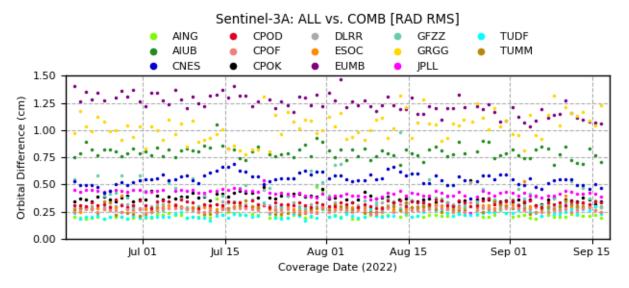


Figure 3-17: Sentinel-3A orbit comparisons – All vs. COMB [radial RMS; cm]

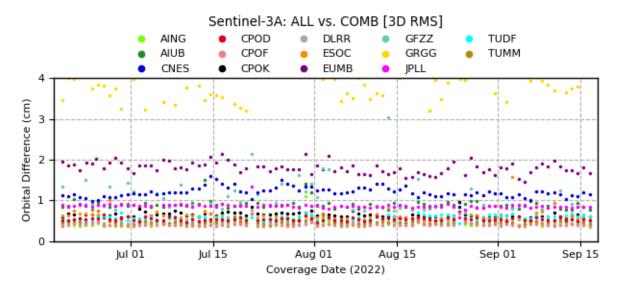


Figure 3-18: Sentinel-3A orbit comparisons - All vs. COMB [3D RMS; cm]





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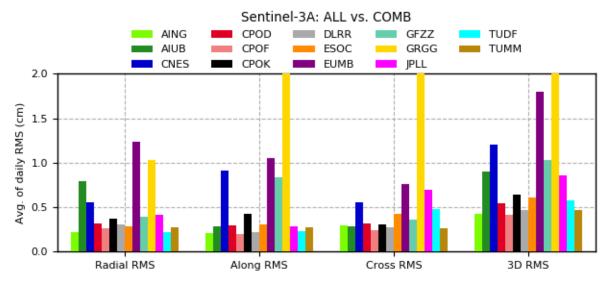


Figure 3-19: Sentinel-3A orbit comparisons – Mean of daily RMS [cm] (All vs. COMB [radial, along, cross and 3D RMS])

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

Orbit Comparisons (Mean of daily RMS [cm])						
Orbit Solution	Combre	Satellite component				
	Centre	Radial	Along-track	Cross-track	3D	Typical
AING	AIUB	0.22	0.21	0.30	0.43	0.25
AIUB	AIUB	0.80	0.28	0.28	0.90	0.52
CNES	CNES	0.55	0.91	0.55	1.20	0.70
CPOD	CPOD	0.32	0.30	0.32	0.54	0.31
CPOF	CPOD	0.26	0.20	0.24	0.41	0.24
СРОК	CPOD	0.37	0.43	0.30	0.65	0.37
DLRR	DLR	0.31	0.22	0.27	0.47	0.27
ESOC	ESOC	0.29	0.31	0.43	0.61	0.35
EUMB	EUMB	1.24	1.05	0.76	1.80	1.04
GFZZ	GFZ	0.40	0.83	0.36	1.03	0.60
GRGG	GRG	1.03	3.12	2.21	4.01	2.32
JPLL	JPL	0.42	0.28	0.69	0.86	0.50
TUDF	TUD	0.22	0.23	0.48	0.57	0.33
TUMM	TUM	0.28	0.27	0.27	0.47	0.27

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

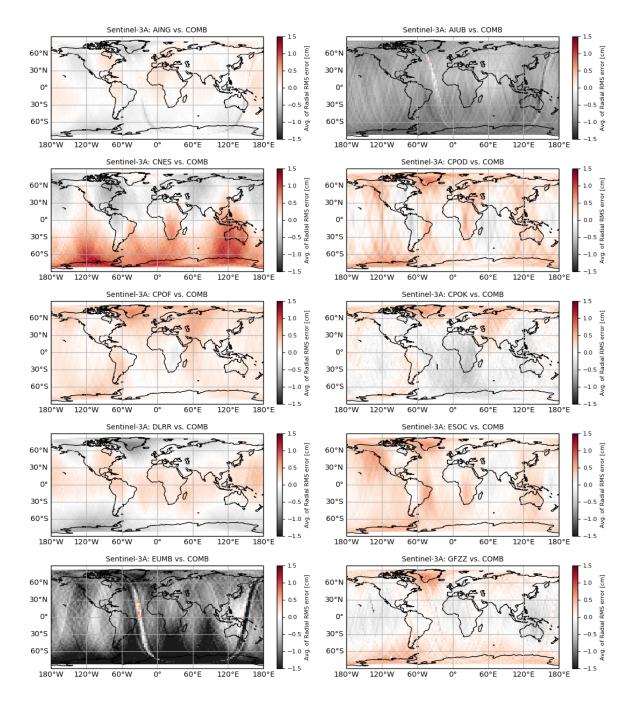
#### 3.4.3. GEOGRAPHICAL ANALYSIS

Figure 3-20 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.





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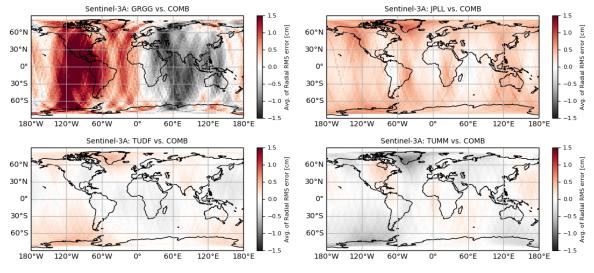
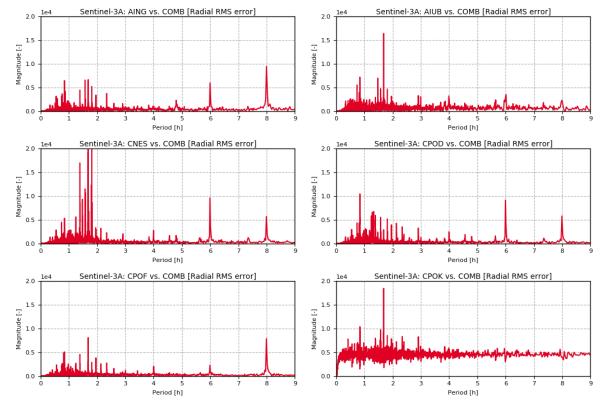


Figure 3-20: Sentinel-3A geographical analysis – Average of the radial RMS orbit comparisons (All vs. COMB)

# 3.4.4. SPECTRAL ANALYSIS

Figure 3-21 shows the FFT of the 3D RMS orbit comparisons calculated on the previous sub section.







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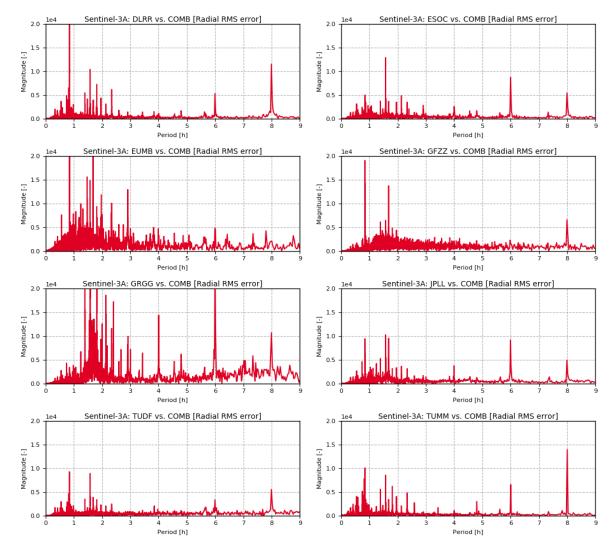


Figure 3-21: Sentinel-3A spectral analysis - Radial RMS orbit comparisons (All vs. COMB)

# 3.4.5. SLR VALIDATION

Figure 3-22 shows the accepted Sentinel-3A observations that the SLR stations have retrieved from the tracking of Sentinel-3A satellite during the reported period.





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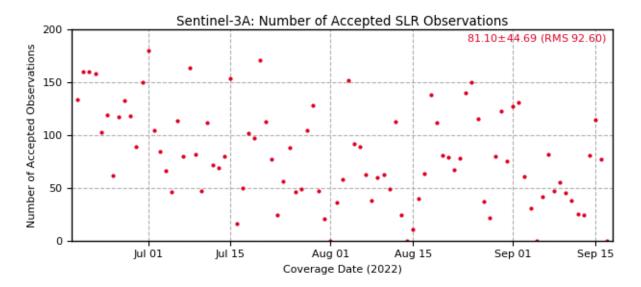


Figure 3-22: Sentinel-3A SLR validation - Number of accepted SLR observations

The SLR residuals showed below have been calculated by removing a constant bias affecting their generation. These biases are computing using the COMB solution, using all elevations, and estimating a single value for the whole period. Table 3-10 summarises the range biases per SLR station that have been considered during the processing of the SLR residuals.

Table 3-10: Sentinel-3A SLR validation – Estimated two-range biases per SLR station

Two-Range Biases				
SLR station		Dina [mm]		
Monument	Code	Bias [mm]		
7090	YARL	12.35		
7105	GODL	-8.47		
7110	MONL	-2.27		
7119	HA4T	18.21		
7501	HARL	14.51		
7810	ZIML	-		

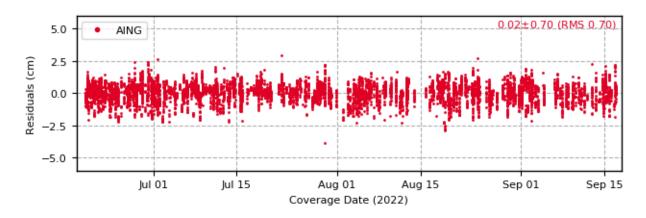
Two-Range Biases					
SLR station		B: []			
Monument	Code	Bias [mm]			
7825	STL3	-			
7839	GRZL	2.45			
7840	HERL	-5.67			
7841	РОТ3	-39.17			
7941	MATM	-16.12			
8834	WETL	-			

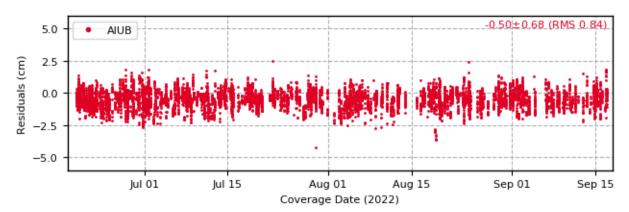
Figure 3-23 presents the temporal evolution of the Sentinel-3A SLR residuals that have been calculated from each orbit solution. The white spaces that can be found in the plots of the figure are due to punctual missing orbit solutions mainly caused by either manoeuvres or large gaps of data. Despite this fact, all SLR residuals of the different orbit solutions have behaved nominally, obtaining similar values as previous RSR documents. 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.

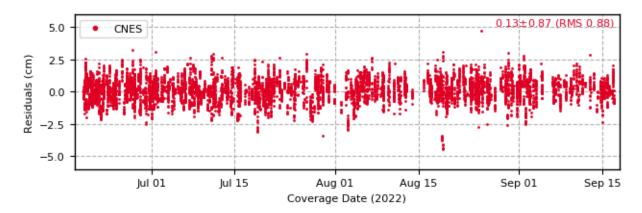


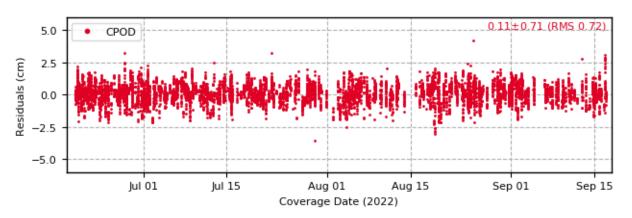


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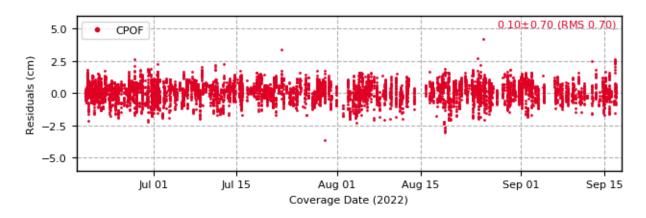


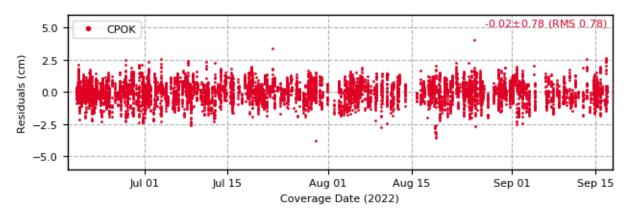


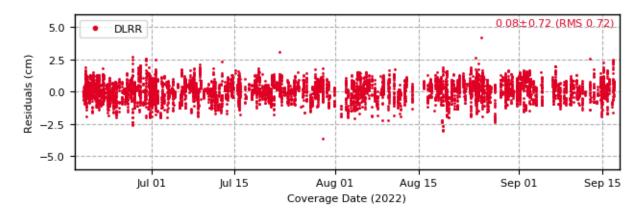


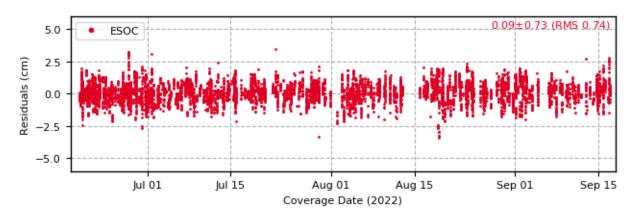


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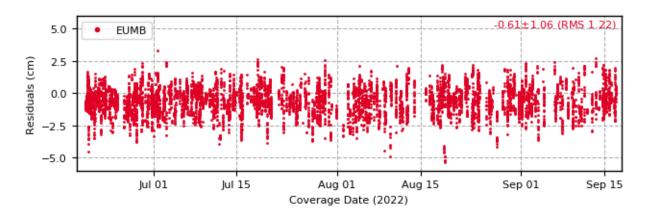


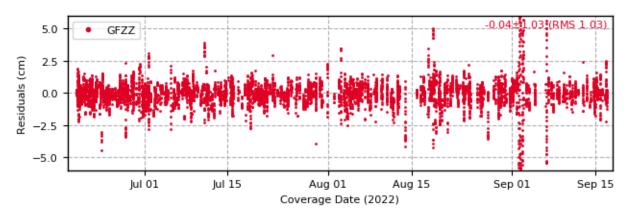


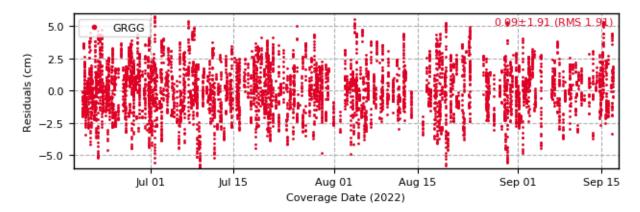


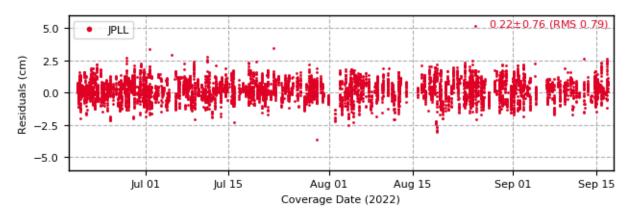


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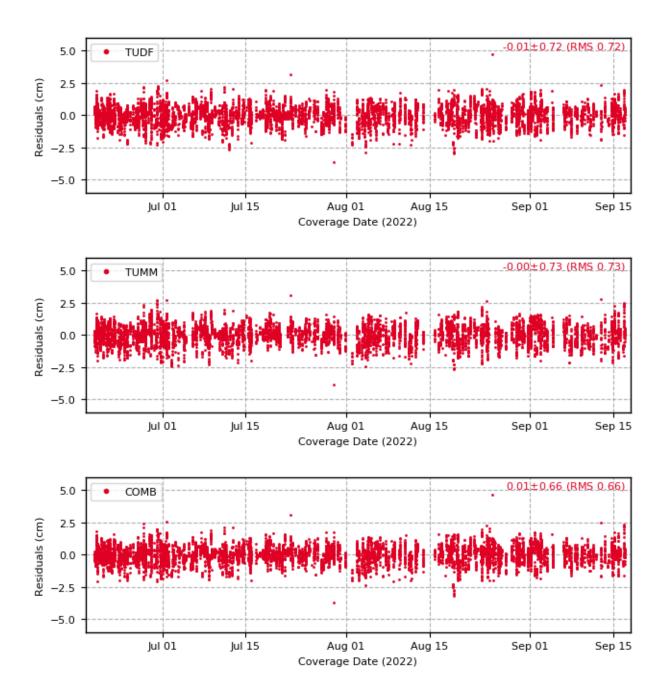


Figure 3-23: Sentinel-3A SLR validation - SLR residuals [cm]

The previous outcome is summarised in Figure 3-24 and Table 3-11 where the mean, standard deviation (STD) and RMS values of the calculated SLR residuals are shown.





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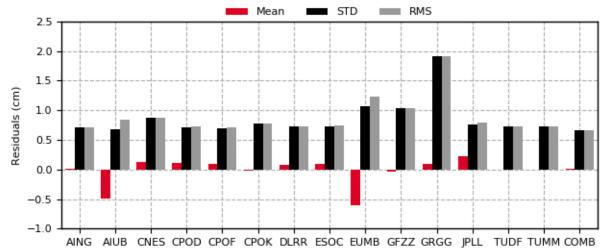


Figure 3-24: Sentinel-3A SLR validation – SLR residuals [cm] (mean, STD and RMS)

Table 3-11: Sentinel-3A SLR validation – SLR residuals [cm] (mean, STD and RMS)

SLR Residuals [cm]					
Orbit Solution	Centre	Mean	Standard Deviation	RMS	
AING	AIUB	0.02	0.70	0.70	
AIUB	AIUB	-0.50	0.68	0.84	
CNES	CNES	0.13	0.87	0.88	
CPOD	CPOD	0.11	0.71	0.72	
CPOF	CPOD	0.10	0.70	0.70	
СРОК	CPOD	-0.02	0.78	0.78	
DLRR	DLR	0.08	0.72	0.72	
ESOC	ESOC	0.09	0.73	0.74	
EUMB	EUMB	-0.61	1.06	1.22	
GFZZ	GFZ	-0.04	1.03	1.03	
GRGG	GRG	0.09	1.91	1.91	
JPLL	JPL	0.22	0.76	0.79	
TUDF	TUD	-0.01	0.72	0.72	
TUMM	TUM	-0.00	0.73	0.73	
СОМВ	-	0.01	0.66	0.66	

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 CPOS), CNES (the MDO solution, which has been labelled as CNER), and two TUD solutions are compared here against the combined solution.





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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 3-25 shows the radial RMS accuracy of the orbit solutions for all the reported time 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.

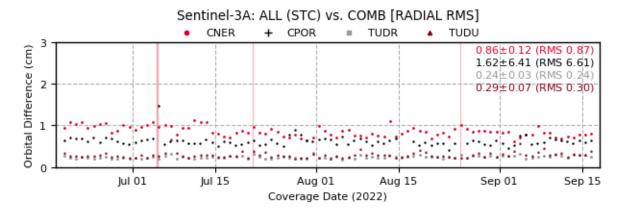


Figure 3-25: Sentinel-3A orbit comparisons – All (STC) vs. COMB [radial RMS; cm]

A more detailed distribution of the obtained accuracy can be found in Table 3-12, where the percentiles of the radial RMS is calculated for different thresholds.

Table 3-12: Sentinel-3A STC (all) solutions – Accuracy percentiles (orbit comparisons against COMB solution [radial RMS], respectively)

	Product Accuracy					
Thursday		Percentage (	of Fulfilment			
Threshold	CNER	CPOR	TUDR	TUDU		
< 1 cm	86.67 %	95.56 %	100.00 %	100.00 %		
< 2 cm	100.00 %	96.67 %	100.00 %	100.00 %		
< 3 cm	100.00 %	96.67 %	100.00 %	100.00 %		
< 4 cm	100.00 %	96.67 %	100.00 %	100.00 %		





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# 3.5. SENTINEL-3B

# 3.5.1. STATISTICS OF THE GENERATION OF THE SOLUTION COMB

Figure 3-26 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 3-13, 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.

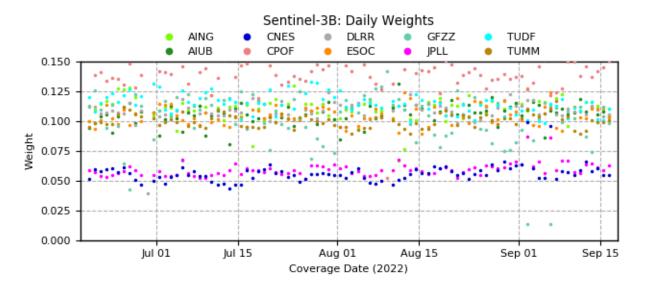


Figure 3-26: Sentinel-3B COMB generation - Daily weights of ALL orbit solutions

Table 3-13: Sentinel-3B COMB generation - Mean of the daily weights of ALL orbit solutions

Daily Weights					
Orbit Solution	Centre	Mean			
AING	AIUB	0.11			
AIUB	AIUB	0.11			
CNES	CNES	0.06			
CPOF	CPOD	0.14			
DLRR	DLR	0.11			
ESOC	ESOC	0.10			
GFZZ	GFZ	0.10			
JPLL	JPL	0.06			
TUDF	TUD	0.12			
TUMM	TUM	0.10			

# 3.5.2. TEMPORAL EVOLUTION OF THE ORBITS COMPARISONS

Figure 3-27 and Figure 3-28 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 3-29 and Table 3-14,





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where the mean of the daily RMS is calculated not only for the 3D RMS but also for other satellite components.

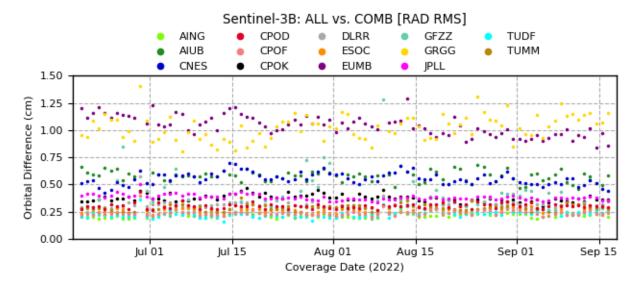


Figure 3-27: Sentinel-3B orbit comparisons – All vs. COMB [radial RMS; cm]

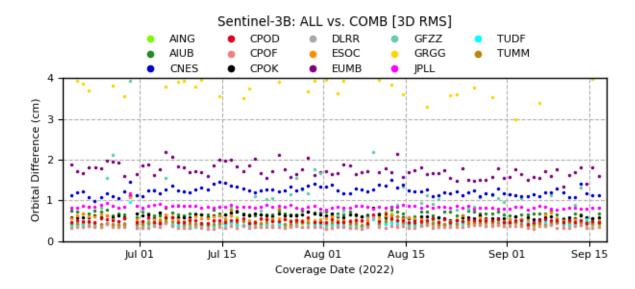


Figure 3-28: Sentinel-3B orbit comparisons – All vs. COMB [3D RMS; cm]





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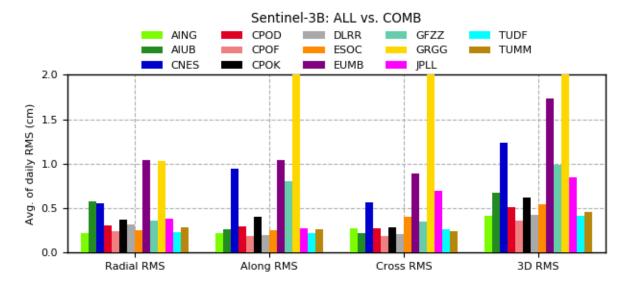


Figure 3-29: Sentinel-3B orbit comparisons – Mean of daily RMS [cm] (All vs. COMB [radial, along, cross and 3D RMS])

Table 3-14: Sentinel-3B orbit comparisons - Mean of daily RMS [cm] (All vs. COMB)

			-		:	
	Orbit Comparisons (Mean of daily RMS [cm])					
Orbit	Combus	Satellite component				
Solution	Centre	Radial	Along-track	Cross-track	3D	Typical
AING	AIUB	0.21	0.22	0.28	0.42	0.24
AIUB	AIUB	0.58	0.26	0.22	0.67	0.39
CNES	CNES	0.55	0.94	0.57	1.23	0.71
CPOD	CPOD	0.30	0.30	0.28	0.51	0.29
CPOF	CPOD	0.24	0.19	0.19	0.36	0.21
СРОК	CPOD	0.37	0.40	0.28	0.62	0.35
DLRR	DLR	0.31	0.20	0.21	0.43	0.25
ESOC	ESOC	0.26	0.25	0.40	0.54	0.31
EUMB	EUMB	1.04	1.04	0.89	1.73	1.00
GFZZ	GFZ	0.36	0.80	0.35	0.98	0.57
GRGG	GRG	1.03	3.37	2.39	4.31	2.49
JPLL	JPL	0.38	0.27	0.70	0.84	0.49
TUDF	TUD	0.23	0.22	0.27	0.42	0.24
TUMM	TUM	0.29	0.27	0.24	0.46	0.27

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

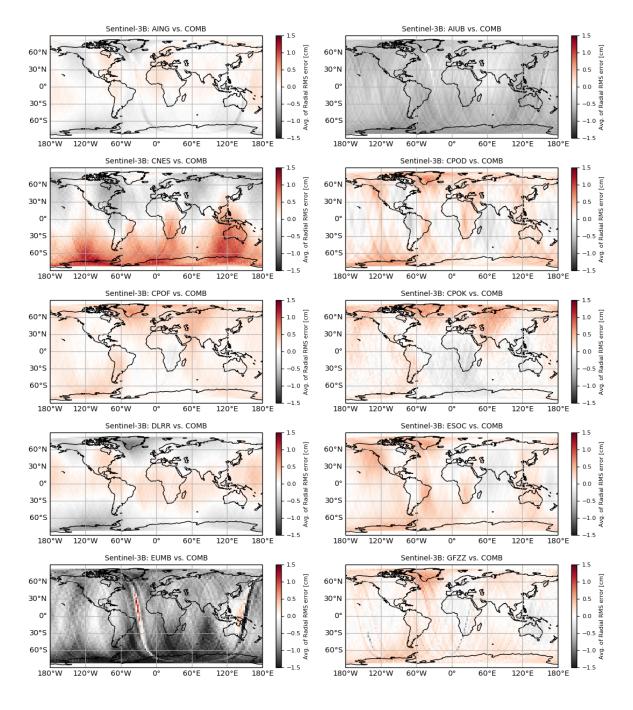
# 3.5.3. GEOGRAPHICAL ANALYSIS

Figure 3-30 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.





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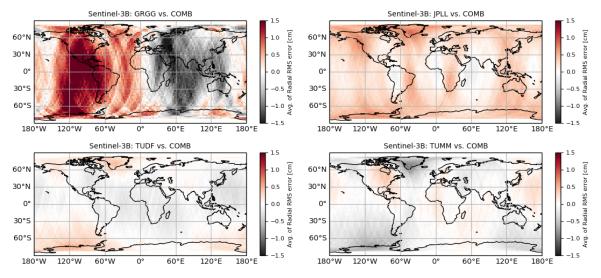
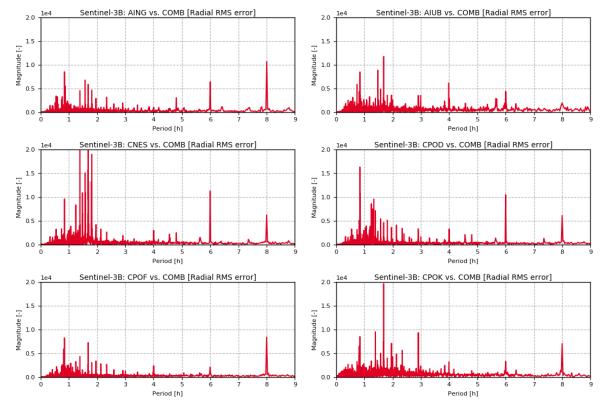


Figure 3-30: Sentinel-3B geographical analysis – Average of the radial RMS orbit comparisons (All vs. COMB)

# 3.5.4. SPECTRAL ANALYSIS

Figure 3-31 shows the FFT of the 3D RMS orbit comparisons calculated on the previous sub section.







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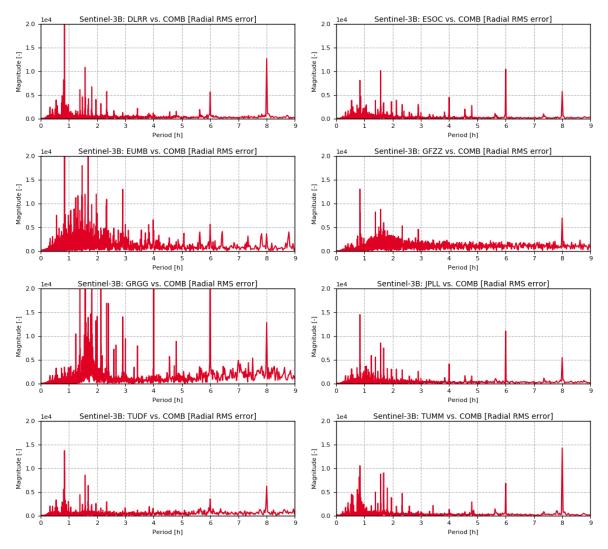


Figure 3-31: Sentinel-3B spectral analysis - Radial RMS orbit comparisons (All vs. COMB)

# 3.5.5. SLR VALIDATION

Figure 3-32 shows the accepted Sentinel-3B observations that the SLR stations have retrieved from the tracking of Sentinel-3B satellite during the reported period.





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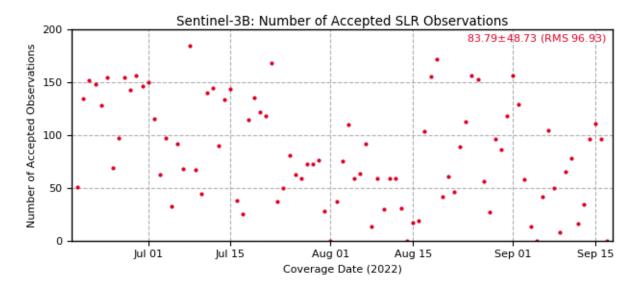


Figure 3-32: Sentinel-3B SLR validation - Number of accepted SLR observations

The SLR residuals showed below have been calculated by removing a constant bias affecting their generation. These biases are computing using the COMB solution, using all elevations, and estimating a single value for the whole period. Table 3-15 summarises the range biases per SLR station that have been considered during the processing of the SLR residuals.

Table 3-15: Sentinel-3B SLR validation – Estimated two-range biases per SLR station

Two-Range Biases				
SLR s	tation	Dina Imma		
Monument	Code	Bias [mm]		
7090	YARL	11.13		
7105	GODL	-9.52		
7110	MONL	0.22		
7119	HA4T	17.59		
7501	HARL	12.75		
7810	ZIML	-		

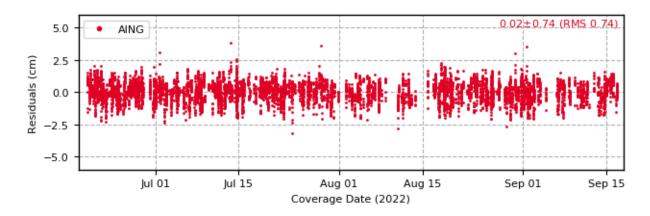
Two-Range Biases				
SLR s	tation	Bias [mm]		
Monument	Monument Code			
7825	STL3	-		
7839	GRZL	5.14		
7840	HERL	-5.31		
7841	РОТ3	-42.23		
7941	MATM	-14.20		
8834	WETL	-		

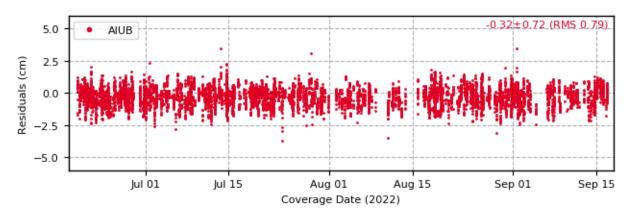
Figure 3-33 presents the temporal evolution of the Sentinel-3B SLR residuals that have been calculated from each orbit solution. The white spaces that can be found in the plots of the figure are due to punctual missing orbit solutions mainly caused by either manoeuvres or large gaps of data. Despite this fact, all SLR residuals of the different orbit solutions have behaved nominally, obtaining similar values as previous RSR documents. 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.

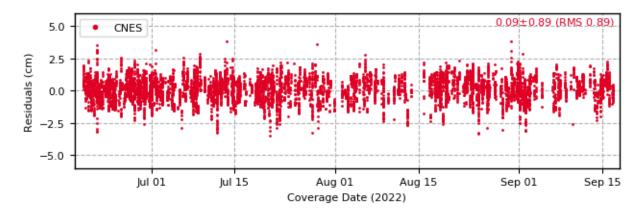


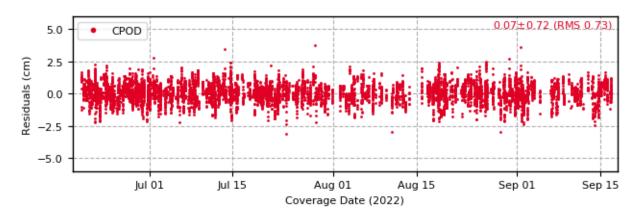


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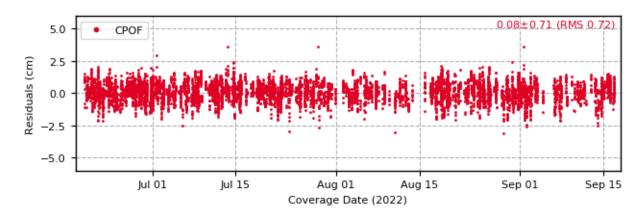


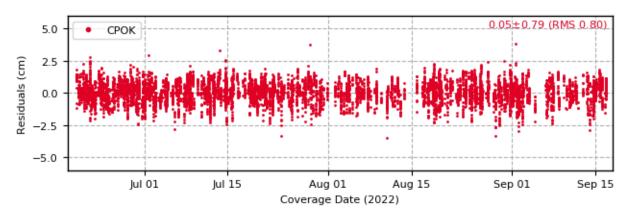


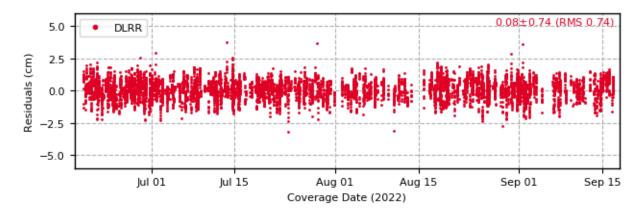


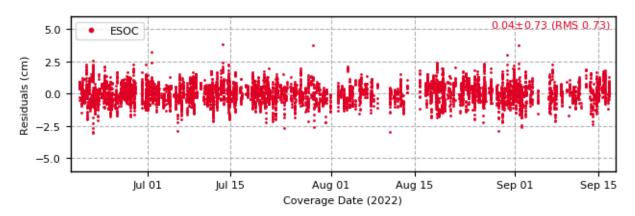


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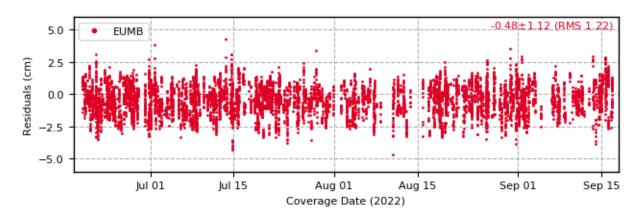


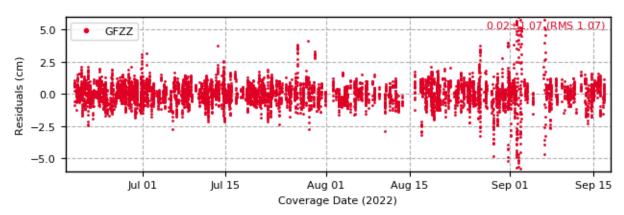


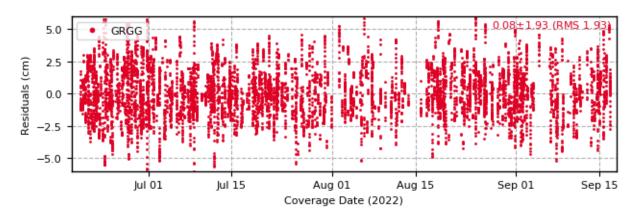


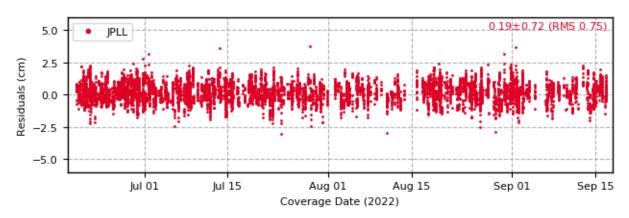


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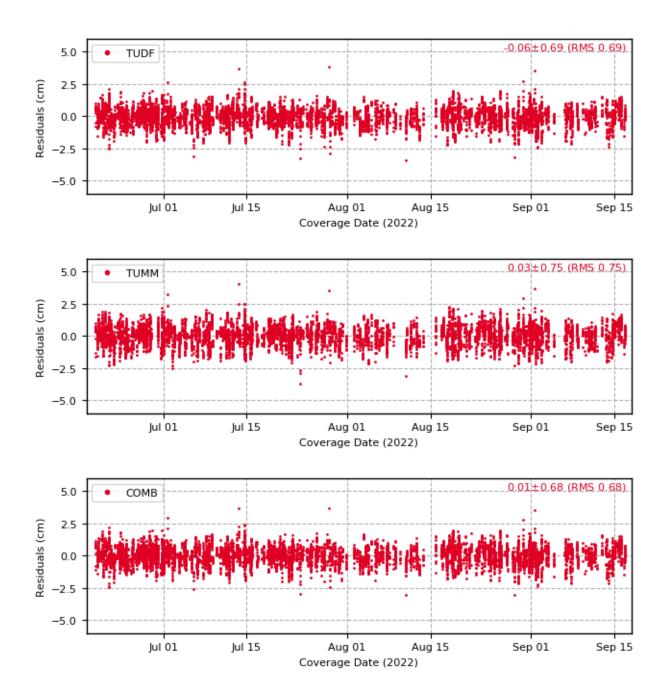


Figure 3-33: Sentinel-3B SLR validation - SLR residuals [cm]

The previous outcome is summarised in Figure 3-34 and Table 3-16 where the mean, standard deviation (STD) and RMS values of the calculated SLR residuals are shown.





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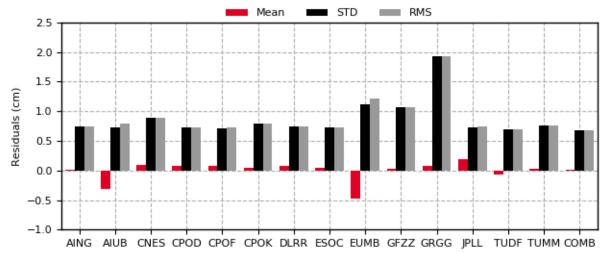


Figure 3-34: Sentinel-3B SLR validation – SLR residuals [cm] (mean, STD and RMS)

Table 3-16: Sentinel-3B SLR validation – SLR residuals [cm] (mean, STD and RMS)

SLR Residuals [cm]					
Orbit Solution	Centre	Mean	Standard Deviation	RMS	
AING	AIUB	0.02	0.74	0.74	
AIUB	AIUB	-0.32	0.72	0.79	
CNES	CNES	0.09	0.89	0.89	
CPOD	CPOD	0.07	0.72	0.73	
CPOF	CPOD	0.08	0.71	0.72	
СРОК	CPOD	0.05	0.79	0.80	
DLRR	DLR	0.08	0.74	0.74	
ESOC	ESOC	0.04	0.73	0.73	
EUMB	EUMB	-0.48	1.12	1.22	
GFZZ	GFZ	0.02	1.07	1.07	
GRGG	GRG	0.08	1.93	1.93	
JPLL	JPL	0.19	0.72	0.75	
TUDF	TUD	-0.06	0.69	0.69	
TUMM	TUM	0.03	0.75	0.75	
СОМВ	-	0.01	0.68	0.68	

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 CPOS), CNES (the MDO solution, which has been labelled as CNER), and two TUD solutions are compared here against the combined solution.





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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 3-35 shows the radial RMS accuracy of the orbit solutions for all the reported time 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.

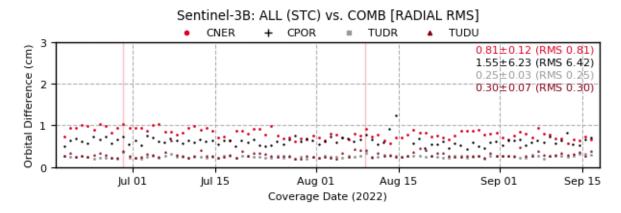


Figure 3-35: Sentinel-3B orbit comparisons - All (STC) vs. COMB [radial RMS; cm]

A more detailed distribution of the obtained accuracy can be found in Table 3-17, where the percentiles of the radial RMS is calculated for different thresholds.

Table 3-17: Sentinel-3B STC (all) solutions - Accuracy percentiles (orbit comparisons against COMB solution [radial RMS], respectively)

	Product Accuracy					
Thurshald		Percentage (	of Fulfilment			
Threshold	CNER	CNER CPOR TUDR TUDU				
< 1 cm	94.44 %	96.67 %	100.00 %	100.00 %		
< 2 cm	100.00 %	97.78 %	100.00 %	100.00 %		
< 3 cm	100.00 %	97.78 %	100.00 %	100.00 %		
< 4 cm	100.00 %	97.78 %	100.00 %	100.00 %		





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# 3.6. SENTINEL-6A

#### 3.6.1. STATISTICS OF THE GENERATION OF THE SOLUTION COMB

Figure 3-36 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 3-18 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.

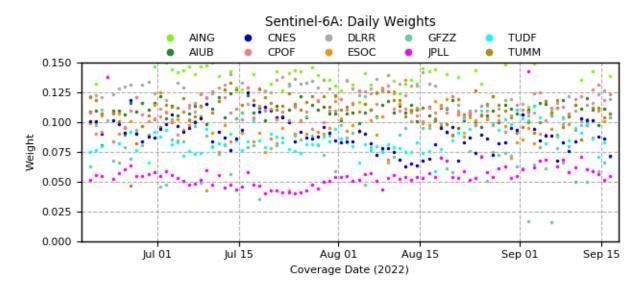


Figure 3-36: Sentinel-6A COMB generation - Daily weights of ALL orbit solutions

Table 3-18: 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	0.11			
CNES	CNES	0.09			
CPOF	CPOD	0.11			
DLRR	DLR	0.12			
ESOC	ESOC	0.10			
GFZZ	GFZ	0.08			
JPLL	JPL	0.06			
TUDF	TUD	0.09			
TUMM	TUM	0.11			

# 3.6.2. TEMPORAL EVOLUTION OF THE ORBITS COMPARISONS

Figure 3-37 and Figure 3-38 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 3-39 and Table 3-19,





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where the mean of the daily RMS is calculated not only for the 3D RMS but also for other satellite components.

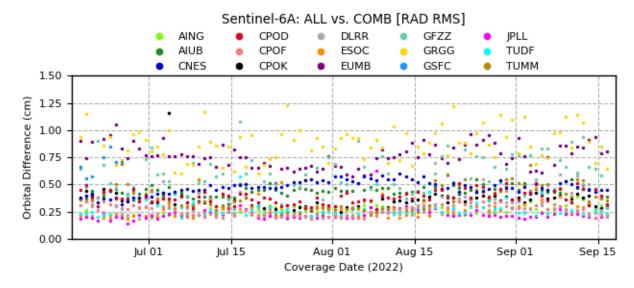


Figure 3-37: Sentinel-6A orbit comparisons – All vs. COMB [radial RMS; cm]

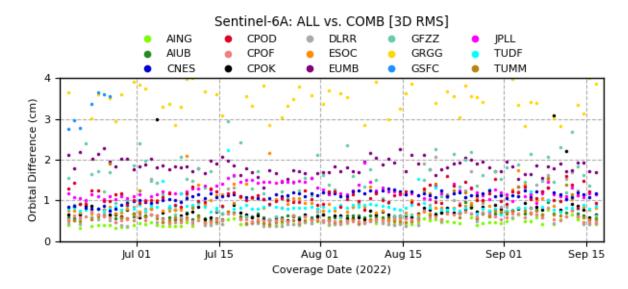


Figure 3-38: Sentinel-6A orbit comparisons - All vs. COMB [3D RMS; cm]





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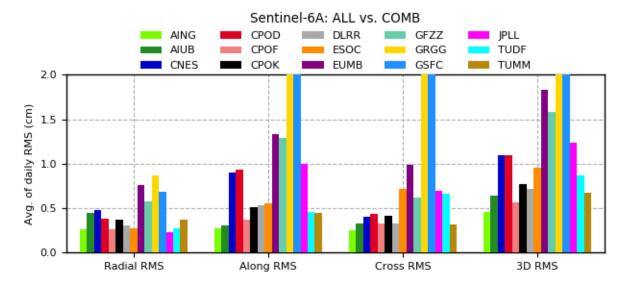


Figure 3-39: Sentinel-6A orbit comparisons – Mean of daily RMS [cm] (All vs. COMB [radial, along, cross and 3D RMS])

Table 3-19: Sentinel-6A orbit comparisons - Mean of daily RMS [cm] (All vs. COMB)

	Orbit Comparisons (Mean of daily RMS [cm])						
Orbit		Satellite component					
Solution	Centre	Radial	Along-track	Cross-track	3D	Typical	
AING	AIUB	0.26	0.28	0.25	0.46	0.27	
AIUB	AIUB	0.44	0.31	0.33	0.64	0.37	
CNES	CNES	0.47	0.90	0.41	1.09	0.63	
CPOD	CPOD	0.38	0.93	0.44	1.10	0.64	
CPOF	CPOD	0.26	0.37	0.33	0.56	0.33	
СРОК	CPOD	0.37	0.52	0.41	0.77	0.44	
DLRR	DLR	0.30	0.53	0.33	0.72	0.42	
ESOC	ESOC	0.27	0.55	0.72	0.96	0.55	
EUMB	EUMB	0.76	1.34	0.98	1.83	1.06	
GFZZ	GFZ	0.58	1.29	0.62	1.58	0.91	
GRGG	GRG	0.87	2.65	2.63	3.90	2.25	
GSFC	GSFC	0.69	2.33	2.09	3.24	1.87	
JPLL	JPL	0.23	1.00	0.69	1.24	0.72	
TUDF	TUD	0.27	0.46	0.66	0.86	0.50	
TUMM	TUM	0.37	0.45	0.31	0.67	0.39	

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

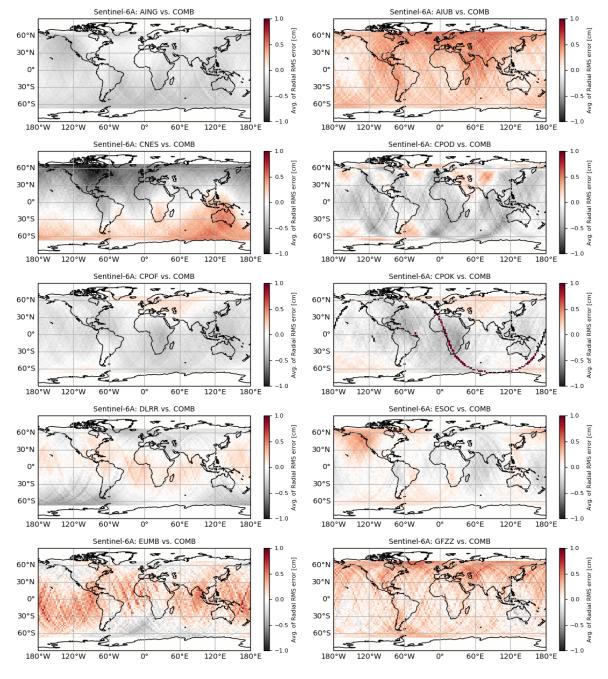




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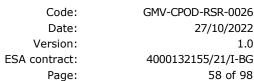
# 3.6.3. GEOGRAPHICAL ANALYSIS

Figure 3-20 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.









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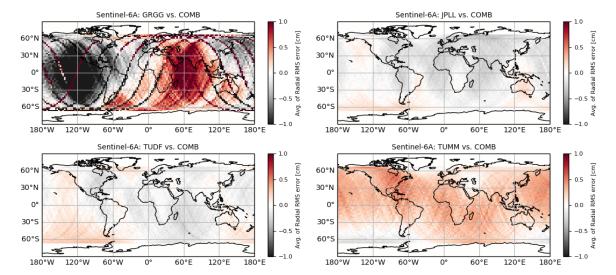
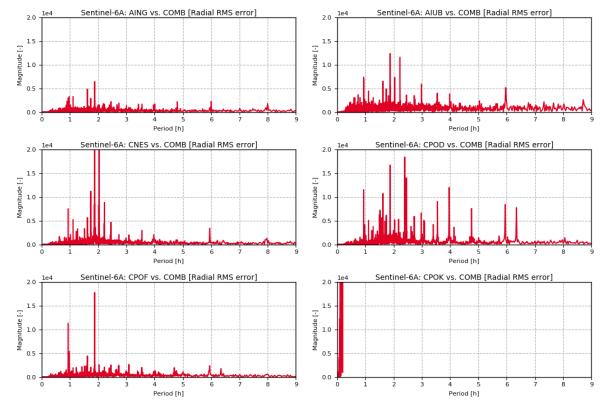


Figure 3-40: Sentinel-3A geographical analysis - Average of the radial RMS orbit comparisons (All vs. COMB)

# 3.6.4. SPECTRAL ANALYSIS

Figure 3-41 shows the FFT of the 3D RMS orbit comparisons calculated on the previous sub section.







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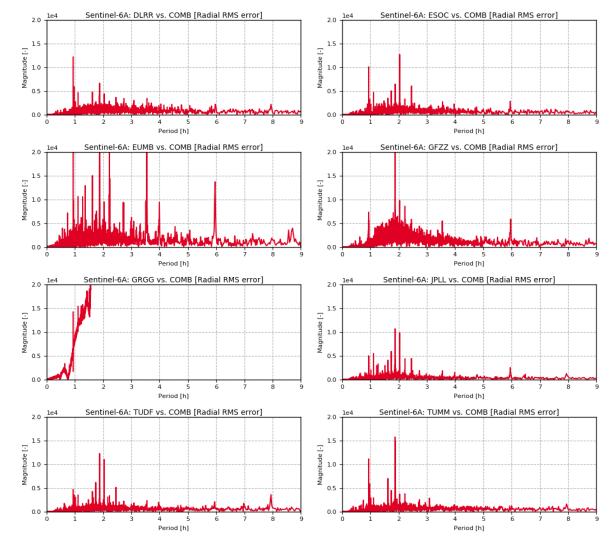


Figure 3-41: Sentinel-6A spectral analysis - Radial RMS orbit comparisons (All vs. COMB)

# 3.6.5. SLR VALIDATION

Figure 3-42 shows the accepted Sentinel-6A observations that the SLR stations have retrieved from the tracking of Sentinel-6A satellite during the reported period.





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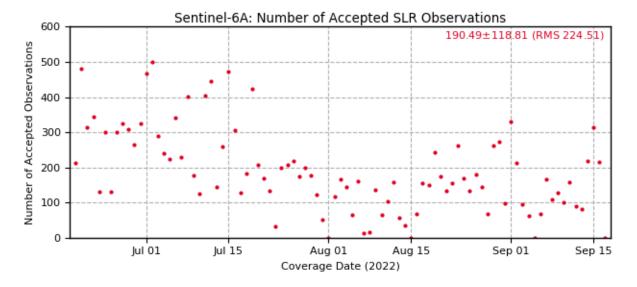


Figure 3-42: Sentinel-6A SLR validation - Number of accepted SLR observations

The SLR residuals showed below have been calculated by removing a constant bias affecting their generation. These biases are computing using the COMB solution, using all elevations, and estimating a single value for the whole period. Table 3-20 summarises the range biases per SLR station that have been considered during the processing of the SLR residuals.

Table 3-20: Sentinel-6A SLR validation – Estimated two-range biases per SLR station

Two-Range Biases					
SLR s	SLR station				
Monument	Code	Bias [mm]			
7090	YARL	14.29			
7105	GODL	-7.22			
7110	MONL	4.58			
7119	HA4T	20.35			
7501	HARL	18.72			
7810	ZIML	-			

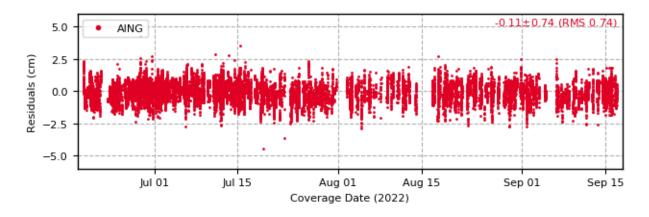
Two-Range Biases				
SLR s	tation	Bina Imma		
Monument	Code	Bias [mm]		
7825	STL3	23.68		
7839	GRZL	5.03		
7840	HERL	-4.06		
7841	РОТ3	-46.27		
7941	MATM	-15.01		
8834	WETL	-0.88		

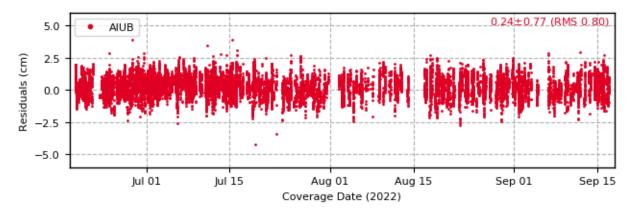
Figure 3-43 presents the temporal evolution of the Sentinel-6A SLR residuals that have been calculated from each orbit solution. The white spaces that can be found in the plots of the figure are due to punctual missing orbit solutions mainly caused by either manoeuvres or large gaps of data. Despite this fact, all SLR residuals of the different orbit solutions have behaved nominally, obtaining similar values as previous RSR documents. 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.

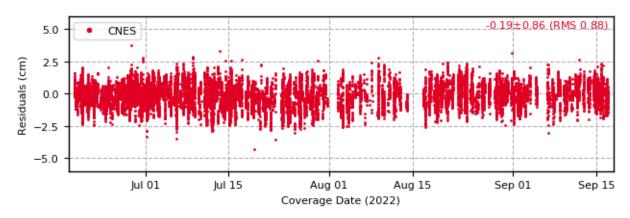


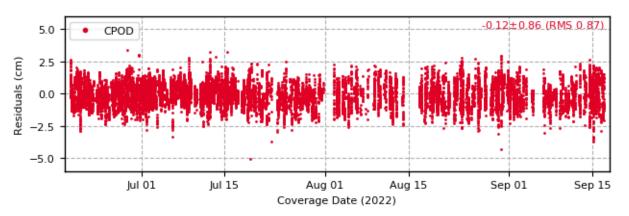


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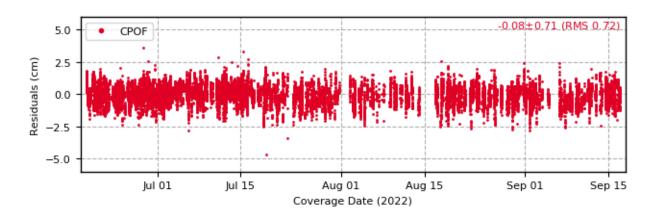


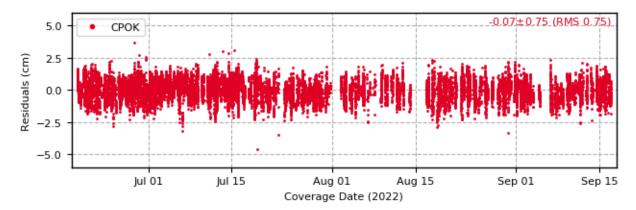


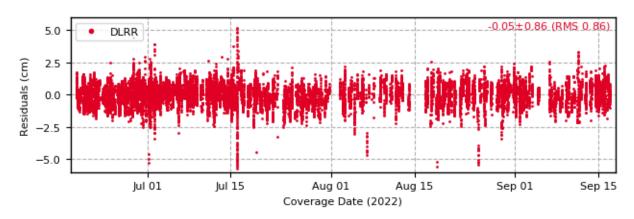


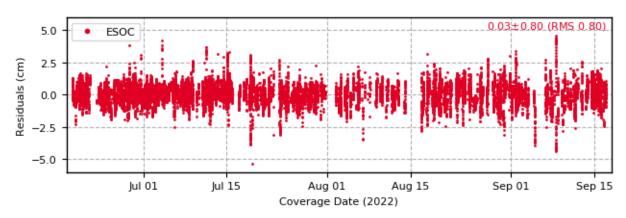


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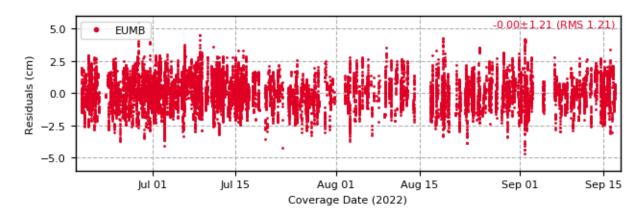


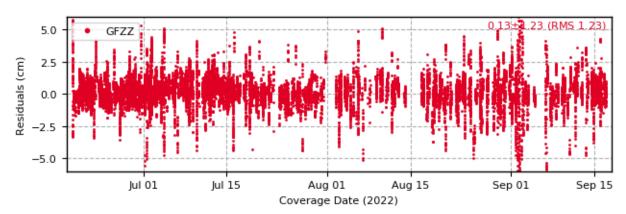


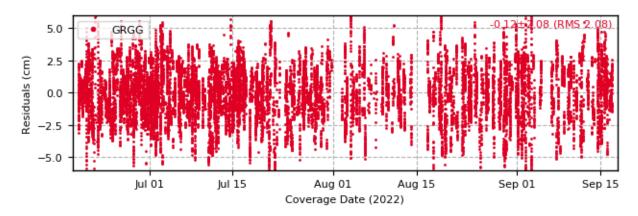


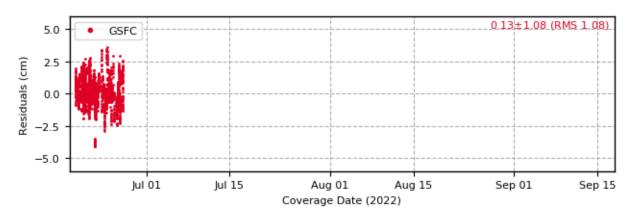


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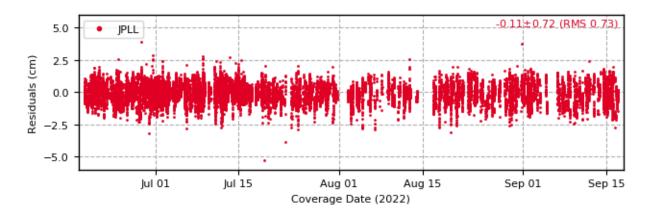


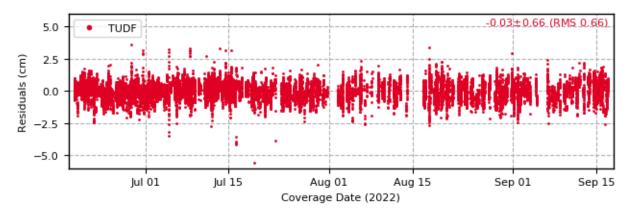


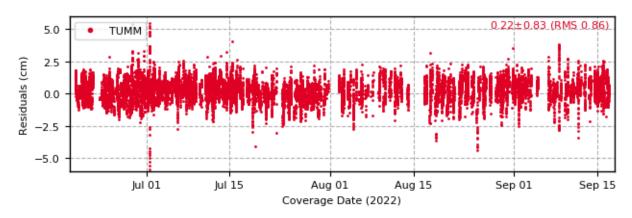




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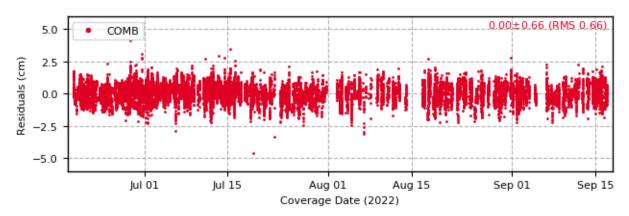


Figure 3-43: Sentinel-6A SLR validation - SLR residuals [cm]





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The previous outcome is summarised in Figure 3-44 and Table 3-21 where the mean, standard deviation (STD) and RMS values of the calculated SLR residuals are shown.

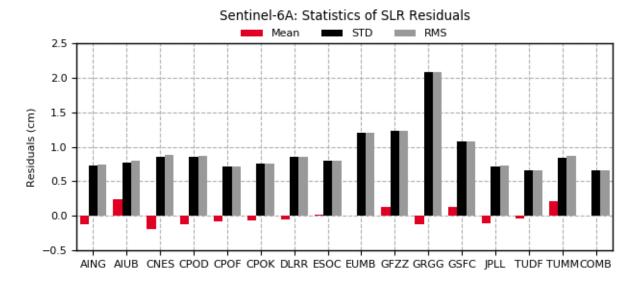


Figure 3-44: Sentinel-6A SLR validation – SLR residuals [cm] (mean, STD and RMS)

Table 3-21: Sentinel-6A SLR validation – SLR residuals [cm] (mean, STD and RMS)

SLR Residuals [cm]					
Orbit Solution	Centre	Mean	Standard Deviation	RMS	
AING	AIUB	-0.11	0.74	0.74	
AIUB	AIUB	0.24	0.77	0.80	
CNES	CNES	-0.19	0.86	0.88	
CPOD	CPOD	-0.12	0.86	0.87	
CPOF	CPOD	-0.08	0.71	0.72	
СРОК	CPOD	-0.07	0.75	0.75	
DLRR	DLR	-0.05	0.86	0.86	
ESOC	ESOC	0.03	0.80	0.80	
EUMB	EUMB	-0.00	1.21	1.21	
GFZZ	GFZ	0.13	1.23	1.23	
GRGG	GRG	-0.12	2.08	2.08	
GSFC	GSFC	0.13	1.08	1.08	
JPLL	JPL	-0.11	0.72	0.73	
TUDF	TUD	-0.03	0.66	0.66	
TUMM	TUM	0.22	0.83	0.86	
СОМВ	-	0.00	0.66	0.66	

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





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

The operational S-6 STC solutions from the CPOD Service (labelled as CPOS), 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 3-35 shows the radial RMS accuracy of the orbit solutions for all the reported time 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.

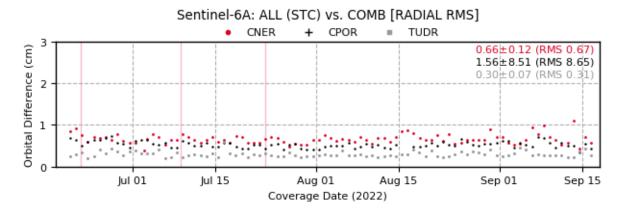


Figure 3-45: Sentinel-6A orbit comparisons - All (STC) vs. COMB [radial RMS; cm]

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

Table 3-22: 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	98.88 %	97.75 %	100.00 %		
< 2 cm	100.00 %	97.75 %	100.00 %		
< 3 cm	100.00 %	97.75 %	100.00 %		
< 4 cm	100.00 %	97.75 %	100.00 %		





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# 4. GNSS SENSOR PERFORMANCE ANALYSIS

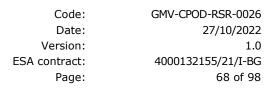
The proper operation of the GNSS receiver is paramount in the POD processing, as it is based on GNSS measurements. Thus, this section is intended to analyse the GNSS sensor performance of each Sentinel. A very detailed analysis, taking the observations corresponding to every single day of the reported 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, **2022/09/01**, 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 90° (zenith) to 0° 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 7°-10°. 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.







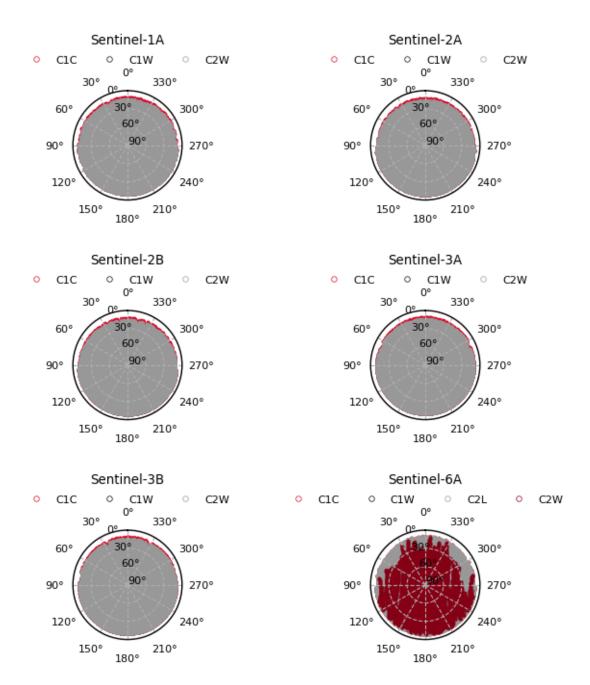


Figure 4-1: Projection of GPS observations onto the antenna frame (on 2022/09/01)





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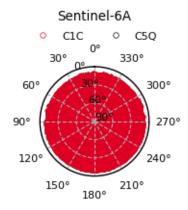
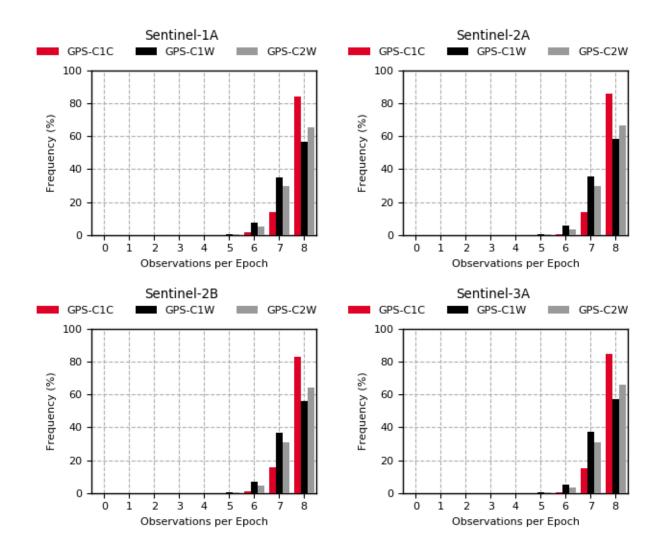


Figure 4-2: Projection of GAL observations onto the antenna frame (on 2022/09/01)







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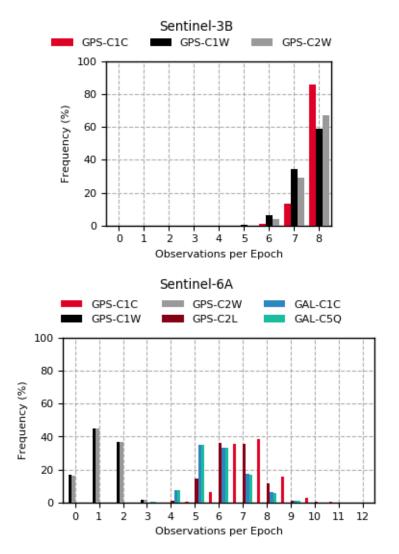


Figure 4-3: Histogram of GNSS observations (on 2022/09/01)

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 and S-1B satellites (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 unveils a near-optimal performance of the GNSS receivers on board.





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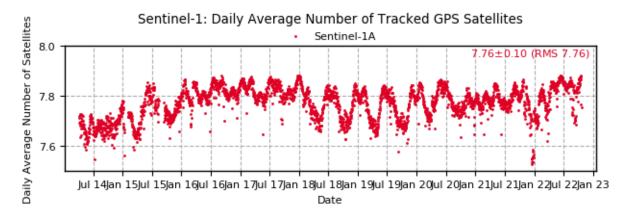


Figure 4-4: Daily average number of GPS satellites tracked by the S-1A and S-1B satellites since the beginning of the missions

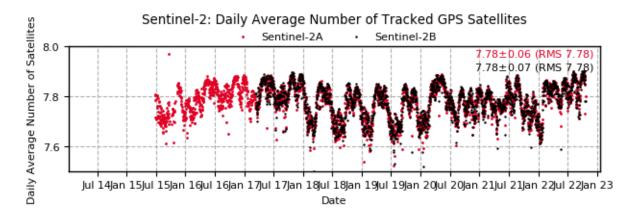


Figure 4-5: Daily average number of GPS satellites tracked by the S-2A and S-2B satellites since the beginning of the missions

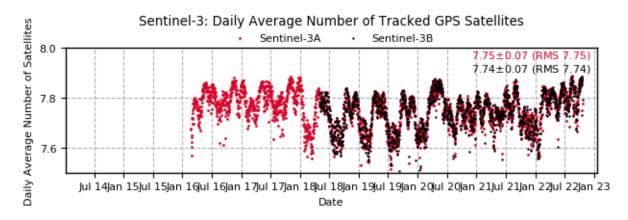


Figure 4-6: Daily average number of GPS satellites tracked by the S-3A and S-3B satellites since the beginning of the missions





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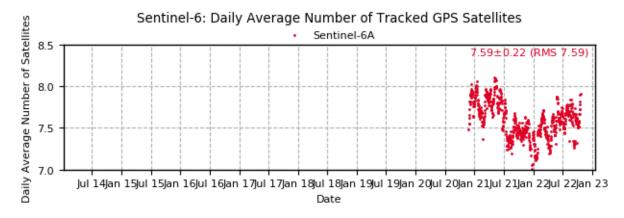


Figure 4-7: Daily average number of GPS satellites tracked by the S-6A satellite since the beginning of the missions

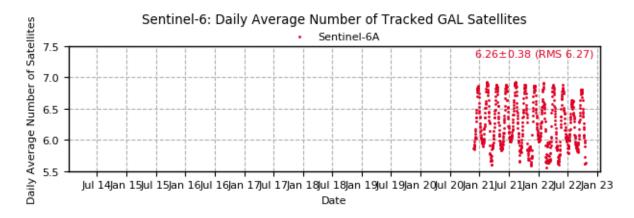


Figure 4-8: Daily average number of GAL satellites tracked by the S-6A satellite since the beginning of the missions

# 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/N₀ 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<sub>0</sub> 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.





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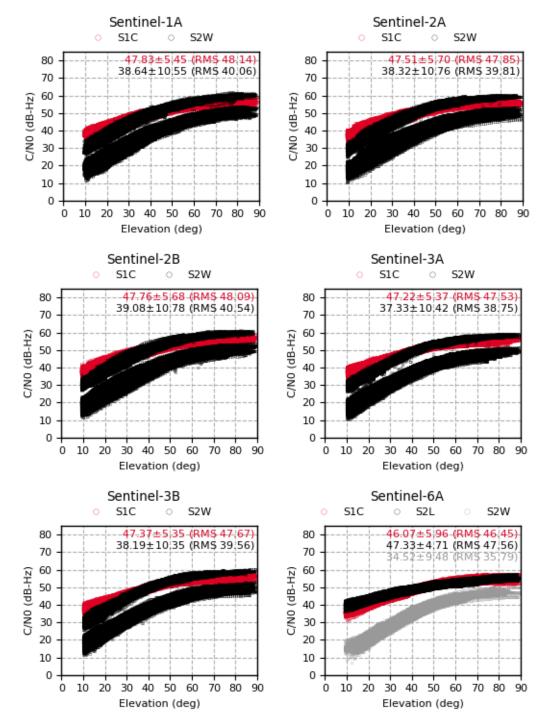


Figure 4-9: Signal strength of GPS observations (on 2022/09/01)





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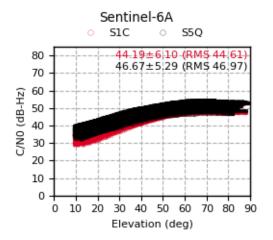


Figure 4-10: Signal strength of GAL observations (on 2022/09/01)

### 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 2022/09/01) 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.





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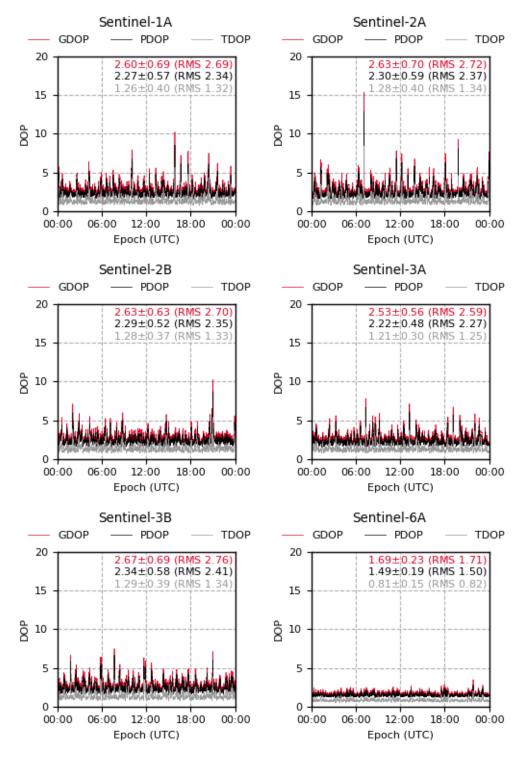


Figure 4-11: Evolution of Dilution of Precision (DOP) Parameters (on 2022/09/01)

### 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).





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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.

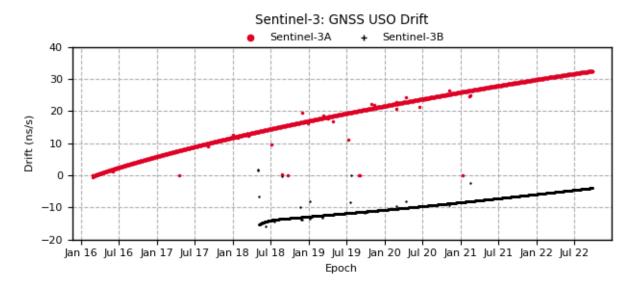


Figure 4-12: Sentinel-3 GNSS USO drift (ns/s)

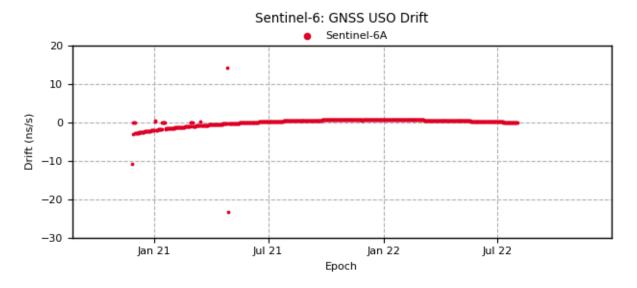


Figure 4-13: Sentinel-6 GNSS USO drift (ns/s)





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### 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 <sup>(*)</sup>
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)	Х		
7090	YARL	Yarragadee (Australia)		Х	Х
7105	GODL	Greenbelt, MD (USA)		X	X
7110	MONL	Monument Peak, CA (USA)		Х	X
7119	HA4T	Haleakala, Hawaii (USA)		Х	Х
7124	THTL	Tahiti (French Polynesia)		Х	
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	Х
7840	HERL	Herstmonceux (UK)		X	Х
7841	РОТ3	Potsdam (Germany)		X	X
7845	GRSM	Grasse, (France)			
7941	MATM	Matera (Italy)		X	X
8834	WETL	Wettzell (Germany)			X
(*) Group of SLR	stations t	that is used for SLR validation of Section 3	.4.5, Section 3	.5.5 and Section 3.6.5.	



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### 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								
Davameter/Medel	Analysis Centre (Orbit Solution)							
Parameter/Model	AING (AIUB)	AIUB (AIUB)	CNES (CNES)	CPOD (GMV)	CPOF (GMV)			
Contact	Adrian Jäggi (adrian.jaeggi@aiub.unibe.ch)	Adrian Jäggi (adrian.jaeggi@aiub.unibe.ch)	Flavien Mercier (flavien.mercier@cnes.fr)	Jaime Fernández (jfernandez@gmv.com)	Jaime Fernández (jfernandez@gmv.com)			
Additional contacts	Daniel Arnold (daniel.arnold@aiub.unibe.ch)	Daniel Arnold (daniel.arnold@aiub.unibe.ch)	Alexandre Couhert (alexandre.couhert@cnes.fr)	copernicuspod@gmv.com	copernicuspod@gmv.com			
Software								
Name and version	Bernese GNSS Software v5.3	Bernese GNSS Software v5.3	ZOOM 6.0	NAPEOS	NAPEOS			
Arc Cut								
Arc lengths	24 h	24 h	36 h	32 h	32 h			
Handle of manoeuvres	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	Manoeuvres are calibrated in the POD process			
Handle of data gaps	No	No	Yes	Yes	Yes			
Reference System								
Polar motion and UT1	CODE final (rapid) products for S1, S2, S3 (for S6)	CODE final (rapid) products for S1, S2, S3 (for S6)	IERS14-C04	IERS finals2000A.data	IERS finals2000A.data			
Pole model	IERS 2010 Conventions	IERS 2010 Conventions	IERS 2010 Conventions (linear pole model)	IERS 2010 Conventions	IERS 2010 Conventions			
Precession/Nutation	IERS 2010 Conventions	IERS 2010 Conventions	IAU 2006/2000A	IERS 2010 Conventions	IERS 2010 Conventions			
Geocenter	n/a	n/a	n/a	n/a	n/a			
Satellite Reference	Satellite Reference							
Mass and centre of gravity	Variable with input from FOS	Variable with input from FOS	Variable with input from FOS	Variable with input from FOS	Variable with input from FOS			





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		Data Proc	essing Summary		
			Analysis Centre (Orbit Solution	)	
Parameter/Model	AING (AIUB)	AIUB (AIUB)	CNES (CNES)	CPOD (GMV)	CPOF (GMV)
Attitude model	S1: Quaternions S2: Quaternions S3: Quaternions S6: Quaternions	S1: Quaternions S2: Quaternions S3: Quaternions S6: Quaternions	S3: Nominal attitude law S6: Quaternions	S1: Quaternions S2: Quaternions S3: Quaternions S6: Quaternions	S1: Quaternions S2: Quaternions S3: Quaternions S6: Quaternions
GNSS antenna reference point (X,Y,Z)	S-1: [RD.1] S-2: [RD.2] S-3: [RD.3] S-6: [RD.4]	S-1: [RD.1] S-2: [RD.2] S-3: [RD.3] S-6: [RD.4]	Adjusted	S-1: [RD.1] S-2: [RD.2] S-3: [RD.3] S-6: [RD.4]	S-1: [RD.1] S-2: [RD.2] S-3: [RD.3] S-6: [RD.4]
GNSS antenna orientation (Euler angles, Z,Y,X)	S-1: [RD.1] S-2: [RD.2] S-3: [RD.3] S-6: [RD.4]	S-1: [RD.1] S-2: [RD.2] S-3: [RD.3] S-6: [RD.4]	Nadir pointing	S-1: [RD.1] S-2: [RD.2] S-3: [RD.3] S-6: [RD.4]	S-1: [RD.1] S-2: [RD.2] S-3: [RD.3] S-6: [RD.4]
DORIS Reference Point (X,Y,Z)	n/a	n/a	n/a	n/a	n/a
SLR Reference Point (X,Y,Z)	n/a	n/a	n/a	n/a	n/a
Gravity					
Gravity field (static)	GOCO05s (120x120)	GOCO05s (120x120)	GRACE+SLR CNES/GRGS RL04 [EIGEN.GRGS.RL04.v1 (90x90)]	EIGEN.GRGS.RL04 TVG (120x120)	GSM-2_MODEL_GRFO_COSTG_ BF01_01op.qmp.coef_2203 (90x90)
Gravity field (time varying)	IERS 2010 Conventions	IERS 2010 Conventions	Drift/annual/semi-annual/bias piece wise linear terms up to degree/order 90	Drift/annual/semi-annual piece wise linear terms up to degree/order 90	Drift/annual/semi-annual piece wise linear terms up to degree/order 90
Solid Earth tides	Applied (IERS 2010)	Applied (IERS 2010)	Applied (IERS 2010)	Applied (IERS 2010)	Applied (IERS 2010)
Ocean tides	EOT11A (50x50)	EOT11A (50x50)	FES2014	FES2014 (100x100, 142 tidal constituents)	FES2014 (100x100, 142 tidal constituents)
Atmospheric gravity	None	None	AOD1B RL06 (100×100)	GFZ AOD L1B RL06 (100x100)	GFZ AOD L1B (100×100)
Atmospheric tides	None	None	AOD1B RL06 (100x100)	GFZ AOD L1B RL06 (100x100)	GFZ AOD L1B (100×100)
Earth pole tide	IERS 2010	IERS 2010	IERS 2010	IERS 2010	IERS 2010
Ocean pole tide	IERS 2010	IERS 2010	IERS 2010	IERS 2010	IERS 2010
Third bodies	Sun, Moon, Planets DE421	Sun, Moon, Planets DE421	Sun, Moon, Planets INPOP08	Sun, Moon, Planets DE-421	Sun, Moon, Planets DE-421
Relativity	n/a	n/a	n/a	n/a	n/a





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	Data Processing Summary							
			Analysis Centre (Orbit Solution	)				
Parameter/Model	AING (AIUB)	AIUB (AIUB)	CNES (CNES)	CPOD (GMV)	CPOF (GMV)			
Surface Forces and Empiricals								
Radiation pressure model	Macro model	No explicit modelling	Box-wing model	Box-wing model (with re-radiation)	Box-wing model (with re-radiation)			
Earth radiation	Albedo and infrared	No explicit modelling	Albedo and Infra-red applied (Knocke et al. 1988)	Albedo and Infra-red applied	Albedo and Infra-red applied			
Total Solar Irradiance (TSI)	n/a	n/a	n/a	n/a	n/a			
Atmospheric density model	DTM2013	No explicit modelling	NRLMSISE-00	msise00	msise00			
Radiation pressure coefficient	1/day	No explicit modelling	Fixed (1.0)	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)			
Drag coefficients	1/day	No explicit modelling	Fixed (1.0)	Estimated 1 coefficient per arc (constrained with 0.3)	Estimated 1 coefficient per arc (constrained with 0.3)			
1/rev empiricals	n/a	n/a	1/rev along track and cross track per orbit, constrained (5E-10, 2E-9)	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)			
Other empiricals	Piecewise constant empiricals in R,S,W, every 6', constrained to zero with 5E-10 m/s^2	Piecewise constant empiricals in R,S,W, every 6' (constrained)	Constant empirical accelerations along track at 30 min intervals constrained (1E-9 m/s2)	n/a	n/a			
GNSS Measurements								
Relativity	Applied	Applied	Applied (IGS conventions, Shapiro)	Applied (IERS 2010)	Applied (IERS 2010)			
Sampling	10 s	10 s	30 s	10 s	10 s			
Observations	Iono-free linear combination of phase measurements	Iono-free linear combination of phase measurements	Iono-free linear combinations of phase and pseudo-range (normal points) measurements	Iono-free linear combinations of phase and pseudo-range measurements	Iono-free linear combinations of phase and pseudo-range measurements			
Weight	n/a	n/a	2 m (pseudo-range) / 20 mm (carrier-phase)	0.8 m (pseudo-range) / 10 mm (carrier-phase)	0.8 m (pseudo-range) / 10 mm (carrier-phase)			
Elevation angle cut-off	0 deg	0 deg	10 deg	7 deg	7 deg			
Down-weighting law	None	None	Applied for DORIS data	None	None			
Antenna phase-centre wind- up correction	Applied	Applied	Applied	Applied	Applied			





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	Data Processing Summary							
Down water / Markel	Analysis Centre (Orbit Solution)							
Parameter/Model	AING (AIUB)	AIUB (AIUB)	CNES (CNES)	CPOD (GMV)	CPOF (GMV)			
Antenna phase-centre variation	Applied (AIUB maps)	Applied (AIUB maps)	Applied (CNES map)	Applied (sen08_2170.atx)	Applied (sen08_2170.atx)			
<b>GNSS/DORIS Parameters</b>								
Receiver clocks	Per epoch, every 10 s	Per epoch, every 10 s	Per epoch, every 30 s	Per epoch, every 10 s	Per epoch, every 10 s			
Receiver ambiguities	Estimated (integer)	Estimated (integer)	Estimated (integer)	Estimated (integer)	Estimated (integer)			
GNSS orbits	Fixed (CODE final products, CODE rapid products for S6A)	Fixed (CODE final products, CODE rapid products for S6A)	Fixed (GRG finals)	Fixed (CODE final, CODE rapid for S6A)	Fixed (CODE final, CODE rapid for S6A)			
GNSS clocks	Fixed (CODE final products, 5 s clocks, CODE rapid products for S6A)	Fixed (CODE final products, 5 s clocks, CODE rapid products for S6A)	Fixed (GRG finals)	Fixed (CODE final, 5 s, CODE rapid for S6A)	Fixed (CODE final, 5 s, CODE rapid for S6A)			
GNSS satellite biases	n/a	n/a	n/a	CODE finals	CODE finals			
DORIS troposphere	n/a	n/a	GPT2/VMF1 + one gradient per station in North & East directions	n/a	n/a			
DORIS coordinates	n/a	n/a	DPOD2014	n/a	n/a			
SLR Coordinates	n/a	n/a	n/a	n/a	n/a			
SLR Troposphere	n/a	n/a	n/a	n/a	n/a			
SLR Mapping Function	n/a	n/a	n/a	n/a	n/a			
SLR Elevation Cutoff Angle	n/a	n/a	n/a	n/a	n/a			
DORIS Ground Antenna Phase Law	n/a	n/a	n/a	n/a	n/a			
DORIS Elevation Cutoff Angle	n/a	n/a	n/a	n/a	n/a			
DORIS Elevation Down- weighting Function	n/a	n/a	n/a	n/a	n/a			



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### Table B-2: Data processing summary (II)

	Data Processing Summary						
Dava washaw / Mardal	Analysis Centre (Orbit Solution)						
Parameter/Model	CPOK (GMV)	DLR (DLR)	EUMB (EUMETSAT)	ESOC (ESOC)	GFZ (GFZ)		
Contact	Jaime Fernández (jfernandez@gmv.com)	Martin Wermuth (martin.wermuth@dlr.de)	Francisco Sancho (francisco.sancho@eumetsat.int)	Francesco Gini (francesco.gini@esa.int)	Patrick Schreiner (patrick.schreiner@gfz-potsdam.de)		
Additional contacts	copernicuspod@gmv.com	Oliver Montenbruck (oliver.montenbruck@dlr.de) Stefan Hackel (stefan.hackel@dlr.de)	Sebastiano Padovan (sebastiano.padovan@ external.eumetsat.int)	Erik Schoenemann (Erik.Schoenemann@esa.int)	Anton Reinhold (reinh_a@gfz-potsdam.de) Frank Flechtner (frank.flechtner@gfz-potsdam.de)		
Software							
Name and version	NAPEOS	GHOST 2276	Bernese GNSS Software v5.3	NAPEOS 4.7	EPOS-OC (v6.74)		
Arc Cut							
Arc lengths	24 h	30 h	24 h	30 h	28 h (beginning and end cut to 24 h)		
Handle of manoeuvres	Manoeuvres are calibrated in the POD process	Manoeuvres are calibrated in the POD process	Only days processed w/o manoeuvres	Only days processed w/o manoeuvres and observation gaps<=1h	Only days processed w/o manoeuvres		
Handle of data gaps	Yes	Yes	No	Yes	Yes		
Reference System							
Polar motion and UT1	IERS finals2000A.data	igs96p02.erp	CODE final products	IERS Bulletin A (IERS rapids)	IERS Bulletin A/B		
Pole model	IERS 2010 Conventions	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	IERS 2010 Conventions		
Geocenter	n/a	n/a	n/a	n/a	n/a		
Satellite Reference							
Mass and centre of gravity	Variable with input from FOS	Variable with input from FOS	Variable with input from FOS	Variable with input from FOS	Variable with input from FOS		
Attitude model	S-1: Quaternions S-2: Quaternions S-3: Quaternions S-6: Quaternions	S1: Nominal attitude law S2: Quaternions S3: Quaternions S6: Quaternions	S-3: Quaternions S6A: Quaternions	Nominal attitude law S6A: Quaternions	S-3: Quaternions S6A: Quaternions		





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		Data Proces	ssing Summary					
Parameter/Model	Analysis Centre (Orbit Solution)							
Parameter/ Model	CPOK (GMV)	DLR (DLR)	EUMB (EUMETSAT)	ESOC (ESOC)	GFZ (GFZ)			
GNSS antenna reference point (X,Y,Z)	S-1: [RD.1] S-2: [RD.2] S-3: [RD.3] S-6: [RD.4]	S-1: [RD.1] S-2: [RD.2] S-3: [RD.3] S-6: [RD.4]	S-3: [RD.3] S-6: [RD.4]	S-1: [RD.1] S-2: [RD.2] S-3: [RD.3] S-6: [RD.4]	S3A-GPSA: +2.8810 / -0.1900 / -0.7940 m S3B-GPSA: +2.8810 / -0.2000 / -0.7940 m S6A-GPS-N: +2.474830 / +0.000120 / - 1.080310 m S6A-GPS-R: +2.874860 / +0.000160 / - 1.080310 m			
GNSS antenna orientation (Euler angles, Z,Y,X)	S-1: [RD.1] S-2: [RD.2] S-3: [RD.3] S-6: [RD.4]	S-1: [RD.1] S-2: [RD.2] S-3: [RD.3] S-6: [RD.4]	S-3: [RD.3] S-6: [RD.4]	S-1: [RD.1] S-2: [RD.2] S-3: [RD.3] S-6: [RD.4]	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-GPS-N: Boresight: -0.0002360 / +0.0000000 / -1.0000000  Azimuth: +1.0000000 / - 0.0007070 / -0.0002360  S6A-GPS-R: Boresight: +0.0004700 / - 0.0001180 / -0.9999990  Azimuth: -1.0000000 / +0.0004700 / -			
DORIS Reference Point (X,Y,Z)	n/a	n/a	n/a	n/a	n/a			
SLR Reference Point (X,Y,Z)	n/a	n/a	n/a	n/a	S3A:1.13403/0.647905/0.80118 S3B:1.13403/0.637905/0.80118 S6A:1.624841/- 0.400638/0.664777			





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	Data Processing Summary							
Davana kay / Madal	Analysis Centre (Orbit Solution)							
Parameter/Model	CPOK (GMV)	DLR (DLR)	EUMB (EUMETSAT)	ESOC (ESOC)	GFZ (GFZ)			
Gravity								
Gravity field (static)	n/a	GOCO03S (100x100)	EGM2008 (120x120)	EIGEN.GRGS.RL04.MEAN-FIELD with quadratic_mean_pole	GOCO06s (120x120)			
Gravity field (time varying)	n/a	n/a	IERS 2010 Conventions	Drift/annual/semi-annual piece wise linear terms up to degree/order 80	GOCO06s (120x120)			
Solid Earth tides	n/a	Applied	Applied (IERS 2010)	Applied (IERS 2010)	IERS 2010			
Ocean tides	n/a	Applied (FES 2004)	FES 2004 (50x50)	EOT11a (50x50)	FES2014 (100×100)			
Atmospheric gravity	n/a	n/a	None	AOD1B RL06 (100×100)	AOD1B RL06 (180x180)			
Atmospheric tides	n/a	n/a	None	Ray-Ponte 2003	BB2003			
Earth pole tide	n/a	n/a	IERS 2010	IERS 2010	IERS 2010			
Ocean pole tide	n/a	n/a	IERS 2010	IERS 2010	Desai (30x30)			
Third bodies	n/a	Sun, Moon (analytical series)	Sun, Moon, Planets DE405	Sun, Moon, Planets DE405	FERRARI77, DE430			
Relativity	n/a	n/a	n/a	n/a	Applied			
<b>Surface Forces and Empiricals</b>								
Radiation pressure model	n/a	Macro-model	No explicit modelling	S1,2,3: QWG Box-wing model S6: ESOC Box-wing model	Macro model			
Earth radiation	n/a	Albedo and Infra-red	No explicit modelling	Albedo and Infra-red applied	Heurtel			
Total Solar Irradiance (TSI)	n/a	n/a	n/a	n/a	Analytically variable			
Atmospheric density model	n/a	NRLMSISE-00, macro model, drag, lift	No explicit modelling	Fixed	MSISE-90			
Radiation pressure coefficient	n/a	1 per arc (estimated)	No explicit modelling	1 per day	S3: 1 per arc (estimated) S6: 1 set per arc (estimated)			
Drag coefficients	n/a	1 per arc (estimated)	No explicit modelling	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)	5 per arc (estimated)			





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	Data Processing Summary						
B /M. J. J	Analysis Centre (Orbit Solution)						
Parameter/Model	CPOK (GMV)	DLR (DLR)	EUMB (EUMETSAT)	ESOC (ESOC)	GFZ (GFZ)		
1/rev empiricals	n/a	n/a	n/a	n/a	1/rev (sin/cos) along- and cross- track direction every 75', polygonal amplitude modelling, constrained		
Other empiricals	n/a	Constant empirical accelerations in RTN at 10 min intervals (constrained to zero)	Piecewise constant empiricals in R,S,W, every 6' (constrained)	Fixed	n/a		
GNSS Measurements							
Relativity	Applied (IERS 2010)	Applied	Applied	Applied (IERS 2010)	Applied		
Sampling	10 s	30 s	10 s	10 s	30 s		
Observations	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 measurements (pseudorange measurements only used for clock synchronisation)	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 and pseudo-range measurements (zero differenced)		
Weight	0.8 m (pseudo-range) / 10 mm (carrier-phase)	1 m (pseudo-ranges), 10 mm (carrier-phase)	n/a	1.0 m (pseudo-range) / 10 mm (carrier-phase)	S3A: 0.47 m (pseudo-ranges), 3.8 mm (carrier-phase) S3B: 0.45 m (pseudo-ranges), 3.8 mm (carrier-phase) S6A: 0.88 m (pseudo-ranges), 4.9 mm (carrier-phase)		
Elevation angle cut-off	7 deg	0 deg	10 deg	7 deg	0 deg		
Down-weighting law	None	None	None	None	None		
Antenna phase-centre wind- up correction	Applied	Applied	Applied	Applied	Applied		
Antenna phase-centre variation	Applied (sen08_2170.atx)	Applied (DLR maps)	S3A/B: Applied (AIUB maps) S6A: Applied (In-flight calibrated AIUB maps)	Applied S1,2,3: sen08_2025_S1_mod.atx S6: s6a_PCVB3_wtNOAZI.atx	Applied (GFZ inflight calibration)		
GNSS/DORIS Parameters							
Receiver clocks	Per epoch, every 10 s	Per epoch, every 10 s	Per epoch, every 10 s	Per epoch, every 10 s	Per epoch, every 30 s		





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Data Processing Summary								
Down water / Market	Analysis Centre (Orbit Solution)							
Parameter/Model	CPOK (GMV)	DLR (DLR)	EUMB (EUMETSAT)	ESOC (ESOC)	GFZ (GFZ)			
Receiver ambiguities	Estimated (fixed)	Estimated (integer)	Estimated (float)	Estimated (integer)	Estimated (CS fixed)			
GNSS orbits	Fixed (CODE final, CODE rapid for S6A)	Fixed (CODE final)	Fixed (CODE finals)	Fixed (ESOC COP Final GPS and Galileo)	Fixed (consistent model constellation, 30s)			
GNSS clocks	Fixed (CODE final, 5 s, CODE rapid for S6A)	Fixed (CODE final, 5 s)	Fixed (CODE finals, 5 s clocks)	Fixed (ESOC COP Final GPS and Galileo)	Fixed (consistent model constellation, 30s)			
GNSS satellite biases	CODE finals	CODE final	n/a	ESOC final	n/a			
DORIS troposphere	n/a	n/a	n/a	n/a	n/a			
DORIS coordinates	n/a	n/a	n/a	n/a	n/a			
SLR Coordinates	n/a	n/a	n/a	n/a	n/a			
SLR Troposphere	n/a	n/a	n/a	n/a	n/a			
SLR Mapping Function	n/a	n/a	n/a	n/a	n/a			
SLR Elevation Cutoff Angle	n/a	n/a	n/a	n/a	n/a			
DORIS Ground Antenna Phase Law	n/a	n/a	n/a	n/a	n/a			
<b>DORIS Elevation Cutoff Angle</b>	n/a	n/a	n/a	n/a	n/a			
DORIS Elevation Down- weighting Function	n/a	n/a	n/a	n/a	n/a			

### Table B-3: Data processing summary (III)

Data Processing Summary							
		Analysis Centre (Orbit Solution)					
Parameter/Model	GRG (CLS)	GSC (GSFC)	JPL (JPLL)	TUDF (TU Delft)	TUM (TUM)		
Contact	Capdeville Hugues (hcapdeville@groupcls.com)	Nikita Zelensky (nzelensk@umd.edu)			Bingbing Duan (bingbing.duan@tum.de)		
Additional contacts	Lemoine Jean-Michel (Jean-Michel.Lemoine@cnes.fr)	Frank Lemoine (Frank.G.Lemoine@nasa.gov)		Pieter Visser (P.N.A.M.Visser@tudelft.nl)	Urs Hugentobler (urs.hugentobler@bv.tum.de)		





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		Data Proce	ssing Summary				
	Analysis Centre (Orbit Solution)						
Parameter/Model	GRG (CLS)	GSC (GSFC)	JPL (JPLL)	TUDF (TU Delft)	TUM (TUM)		
Software							
Name and version	GINS/DYNAMO	GEODYN version 2002	GIPSY-OASIS (v6.4)	GIPSY-X (v1.7)	Bernese GNSS Software v5.3 (mod)		
Arc Cut							
Arc lengths	84 h	~10 days (1 cycle)	30 h	30 h	30 h		
Handle of manoeuvres	Manoeuvres are calibrated in the POD process	Truncate arcs at manoeuvres	Manoeuvres are detected and handled in the POD process	Manoeuvres are calibrated in the POD process	Only days processed w/o manoeuvres		
Handle of data gaps	Yes	No	Yes	Yes	No		
Reference System							
Polar motion and UT1	IERS14-C04	IERS Bulletin A daily	JPL Final products	JPL Final / Rapid_GE (S6A) products	IERS finals2000A.data		
Pole model	IERS 2010 Conventions (linear pole model)	IERS 2017 (linear mean pole)	IERS 2010 Conventions (linear mean pole)	IERS 2010 Conventions	IERS 2010 Conventions		
Precession/Nutation	IERS 2010 Conventions	IAU2000A	IERS 2010 Conventions	IERS 2010 Conventions	IERS 2010 Conventions		
Geocenter	n/a	Altamimi et al. (2016) (annual model)	n/a	n/a	n/a		
Satellite Reference							
Mass and centre of gravity	Variable with input from FOS	Variable with input from FOS	Variable with input from FOS	Variable with input from FOS	Variable with input from FOS		
Attitude model	S-3: Nominal attitude law	S6: Quaternions	S-3: Quaternions S-6: Quaternions	S-1: Quaternions S-2: Quaternions S-3: Quaternions S-6: Quaternions	S-1: Nominal attitude law S-2: Quaternions S-3: Quaternions S-6: Quaternions		
GNSS antenna reference point (X,Y,Z)	S-3: [RD.3] S-6: [RD.4]	S-6: [RD.4]	S-3: [RD.3] S-6: [RD.4]	S-1: [RD.1] S-2: [RD.2] S-3: [RD.3] S-6: [RD.4]	S-1: [RD.1] S-2: [RD.2] S-3: [RD.3] S-6: [RD.4]		
GNSS antenna orientation (Euler angles, Z,Y,X)	S-3: [RD.3] S-6: [RD.4]	S-6: [RD.4]	S-3: [RD.3] S-6: [RD.4]	S-1: [RD.1] S-2: [RD.2] S-3: [RD.3] S-6: [RD.4]	S-1: [RD.1] S-2: [RD.2] S-3: [RD.3] S-6: [RD.4]		





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	Data Processing Summary					
	Analysis Centre (Orbit Solution)					
Parameter/Model	GRG (CLS)	GSC (GSFC)	JPL (JPLL)	TUDF (TU Delft)	TUM (TUM)	
DORIS Reference Point (X,Y,Z)	n/a	S6 (iono-free)	n/a	n/a	n/a	
SLR Reference Point (X,Y,Z)	n/a	n/a	n/a	n/a	n/a	
Gravity						
Gravity field (static)	EIGEN-GRGS.RL04-v2.MEAN-FIELD (95x95)	GOCO05s	EIGEN.GRGS.RL04.MEAN-FIELD with linear mean pole (200x200)	EIGEN.GRGS.RL04.MEAN-FIELD with quadratic_mean_pole (200X200)	EIGEN GL04C (120x120)	
Gravity field (time varying)	Drift/annual/semi-annual piece wise linear terms up to degree/order 95	L >= 6. GOCO05s. L = 2 to 5. derived from SLR/DORIS low degree solutions.	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	Drift of 20, 30, 40	
Solid Earth tides	Applied (IERS 2010)	IERS2010	Applied (IERS2010)	Applied (IERS 2010)	Applied (IERS 2010)	
Ocean tides	FES2014	GOT4.10c	GOT4.8AC (50x50)	Applied (FES2004)	FES2004 (50x50)	
Atmospheric gravity	AOD1B RL06 (100x100)	AOD1B RL06 (99x99)	AOD1B RL06 (100x100)	AOD1B RL06 (180x180)	None	
Atmospheric tides	AOD1B RL06 (100x100)	Dobslaw et al (2017)	None	n/a	None	
Earth pole tide	IERS 2010	IERS 2010	IERS 2010	IERS 2010	IERS 2010	
Ocean pole tide	IERS 2010	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	Sun, Moon, Planets DE405	
Relativity	n/a	Schwarzchild, Lense-Thirring, DeSitter applied	n/a	n/a	n/a	
Surface Forces and Empiricals						
Radiation pressure model	Box-wing model	Bow-wing modlel	Box-wing model	Box-wing model	Box-wing model	
Earth radiation	Albedo and Infra-red applied	Knocke et al. (1988)	Albedo	Albedo	Box-wing for Albedo and Infra-red	
Total Solar Irradiance (TSI)	n/a	1360.45 W/m**2 (Kopp and Lean, 2011)	n/a	n/a	n/a	
Atmospheric density model	DTM2000	MSIS-86 (Hedin, 1987)	DTM2000	DTM2000	MSISE-90	
Radiation pressure coefficient	1 per day but strongly constrained	1 per arc (pre-estimated)	Fixed to 1.0	S123: 1 per arc (estimated) S6: Fixed to 1.020506	1 per arc (estimated)	
Drag coefficients	1 per 4 h (estimated)	3 /day (estimated)	1 per arc (estimated)	1 per arc (estimated) S6A: Fixed (1.0)	1 per arc (estimated)	





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	Data Processing Summary					
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Parameter/Model	GRG (CLS)	GSC (GSFC)	JPL (JPLL)	TUDF (TU Delft)	TUM (TUM)	
1/rev empiricals	2 sets per arc in along-track and cross-track direction (sin/cos)	Along-track & Cross-track OPR/day	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	2 sets in along-track and cross- track direction (with sin/cos signals)	
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.	Stoch. velocity changes every 15 min (constr. 5e-7m/s2)	
GNSS Measurements						
Relativity	Applied		Applied	Applied	Applied	
Sampling	10 s		S3: 30 s S6: 300 s	30 s	30 s for S6A, 10 s for others	
Observations	Iono-free linear combination		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)	Iono-free linear combinations of phase and pseudo-range measurements	
Weight	n/a		1.0 m (pseudo-range) / 10 mm (carrier-phase)	1.0 m (pseudo range) / 10 mm (carrier-phase)	n/a	
Elevation angle cut-off	10 deg		0 deg	0 deg	0 deg	
Down-weighting law	For elevation 620_; weight of the observation is multiplied by the square of the elevation divided by 400 with elevation in degrees		S3: 1/sin(elev) S6: None	None	None	
Antenna phase-centre wind- up correction	Applied		Applied	Applied (IGS model)	Applied (IGS model)	
Antenna phase-centre variation	n/a		Applied (JPL inflight calibration)	Applied (sen08_2170.atx)	Applied (sen08_2170.atx)	
GNSS/DORIS Parameters	GNSS/DORIS Parameters					





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B /M. J. I	Analysis Centre (Orbit Solution)					
Parameter/Model	GRG (CLS)	GSC (GSFC)	JPL (JPLL)	TUDF (TU Delft)	TUM (TUM)	
Receiver clocks	n/a		S3: Per epoch, every 30 s S6: Per epoch, every 300 s	Per epoch, every 30 s (no relativistic corrections applied)	Per epoch, every 10 s	
Receiver ambiguities	n/a		Estimated (integer)	Estimated (resolved, typically 80% (S1,S2,S3) and 90% (S6A G(1W_2W)+E(1C_5Q)	Estimated (resolved, typically more than 95%)	
GNSS orbits	n/a		Fixed (JPL Final / IGS14)	Fixed (JPL GPS Final / IGb14) S6A: Fixed (JPL GNSS Rapid_GE / IGb14)	Fixed (CODE final, CODE rapid for S6A)	
GNSS clocks	n/a		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 / IGb14, 300 s clocks)	Fixed (CODE final, 5 s, CODE rapid for S6A)	
GNSS satellite biases	n/a		n/a	S6A: Constellation bias estimated (GPS Legacy (1W_2W) comes from AGGA 2)	n/a	
DORIS troposphere	GPT2+VMF1 + one gradient per station in North East directions	GPT/VMF-1	n/a	n/a	n/a	
DORIS coordinates	ITRF2014 (DPOD2014)	DPOD2014v5	n/a	n/a	n/a	
SLR Coordinates	n/a	SLRF2014/v200428	n/a	n/a	n/a	
SLR Troposphere	n/a	Sastamoinen (1972)	n/a	n/a	n/a	
SLR Mapping Function	n/a	Mendes et al. (2005)	n/a	n/a	n/a	
SLR Elevation Cutoff Angle	n/a	15 deg	n/a	n/a	n/a	
DORIS Ground Antenna Phase Law	n/a	Applied. Tourain et al. (2016)	n/a	n/a	n/a	
<b>DORIS Elevation Cutoff Angle</b>	n/a	10 deg	n/a	n/a	n/a	
DORIS Elevation Down- weighting Function	n/a	1/sin(elev)**(1/2)	n/a	n/a	n/a	





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## 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,  $r_0$ , and the position of the solution for institution j,  $r_j$ , at time  $t^*$ . This is:

$$d_i(t^*) = |\boldsymbol{r}_0(t^*) - \boldsymbol{r}_i(t^*)|$$

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.





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# 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.

### F.1. SENTINEL-1A

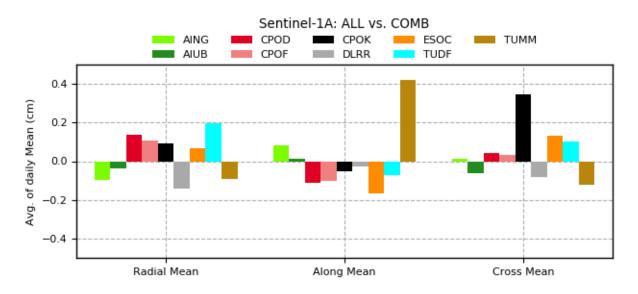


Figure D-1: Sentinel-1A orbit comparisons – Mean of daily average [cm] (All vs. COMB [radial, along, cross and 3D RMS])

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

Orbit Comparisons (Mean of daily average [cm])					
Orbit	Centre	Satellite component			
Solution	Centre	Radial	Along-track	Cross-track	
AING	AIUB	-0.10	0.08	0.01	
AIUB	AIUB	-0.04	0.01	-0.06	
CPOD	CPOD	0.14	-0.11	0.04	
CPOF	CPOD	0.10	-0.10	0.03	
СРОК	CPOD	0.09	-0.05	0.35	
DLRR	DLR	-0.14	-0.03	-0.08	
ESOC	ESOC	0.07	-0.17	0.13	
TUDF	TUD	0.19	-0.07	0.10	
TUMM	TUM	-0.09	0.42	-0.12	





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### F.2. SENTINEL-2A

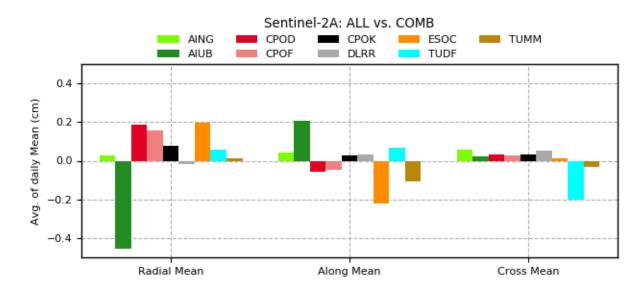


Figure D-2: Sentinel-2A orbit comparisons – Mean of daily average [cm] (All vs. COMB [radial, along, cross and 3D RMS])

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

Orbit Comparisons (Mean of daily average [cm])					
Orbit		Satellite component			
Solution	Centre	Radial	Along-track	Cross-track	
AING	AIUB	0.03	0.04	0.06	
AIUB	AIUB	-0.45	0.21	0.02	
CPOD	CPOD	0.18	-0.06	0.03	
CPOF	CPOD	0.15	-0.05	0.03	
СРОК	CPOD	0.08	0.03	0.03	
DLRR	DLR	-0.01	0.03	0.05	
ESOC	ESOC	0.20	-0.22	0.01	
TUDF	TUD	0.06	0.07	-0.20	
TUMM	TUM	0.01	-0.11	-0.03	





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### F.3. SENTINEL-2B

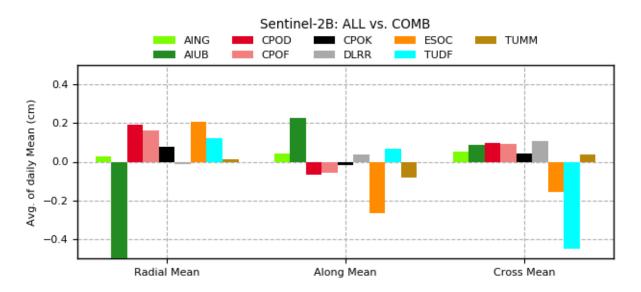


Figure D-3: Sentinel-2B orbit comparisons – Mean of daily average [cm] (All vs. COMB [radial, along, cross and 3D RMS])

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

Orbit Comparisons (Mean of daily average [cm])					
Orbit		Satellite component			
Solution	Centre	Radial	Along-track	Cross-track	
AING	AIUB	0.03	0.04	0.05	
AIUB	AIUB	-0.53	0.23	0.09	
CPOD	CPOD	0.19	-0.07	0.10	
CPOF	CPOD	0.16	-0.06	0.09	
СРОК	CPOD	0.07	-0.02	0.04	
DLRR	DLR	-0.01	0.04	0.10	
ESOC	ESOC	0.21	-0.27	-0.16	
TUDF	TUD	0.12	0.07	-0.45	
TUMM	TUM	0.01	-0.08	0.04	





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### F.4. SENTINEL-3A

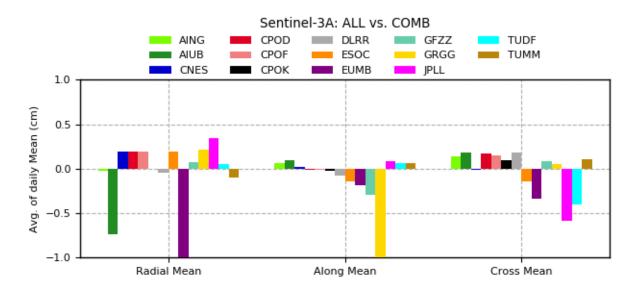


Figure D-4: Sentinel-3A orbit comparisons – Mean of daily average [cm] (All vs. COMB [radial, along, cross and 3D RMS])

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

Orbit Comparisons (Mean of daily average [cm])					
Orbit	Combine	Satellite component			
Solution	Centre	Radial	Along-track	Cross-track	
AING	AIUB	-0.03	0.06	0.14	
AIUB	AIUB	-0.74	0.09	0.18	
CNES	CNES	0.19	0.02	-0.02	
CPOD	CPOD	0.19	-0.02	0.17	
CPOF	CPOD	0.19	-0.01	0.15	
СРОК	CPOD	-0.00	-0.02	0.09	
DLRR	DLR	-0.04	-0.08	0.19	
ESOC	ESOC	0.20	-0.14	-0.14	
EUMB	EUMB	-1.01	-0.19	-0.34	
GFZZ	GFZ	0.07	-0.30	0.08	
GRGG	GRG	0.22	-1.13	0.05	
JPLL	JPL	0.34	0.09	-0.59	
TUDF	TUD	0.05	0.06	-0.40	
TUMM	TUM	-0.10	0.06	0.11	





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### F.5. SENTINEL-3B

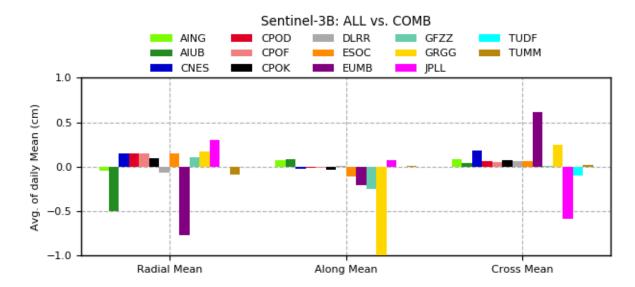


Figure D-5: Sentinel-3B orbit comparisons – Mean of daily average [cm] (All vs. COMB [radial, along, cross and 3D RMS])

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

Orbit Comparisons (Mean of daily average [cm])					
Orbit	Centre	Satellite component			
Solution	Centre	Radial	Along-track	Cross-track	
AING	AIUB	-0.04	0.07	0.09	
AIUB	AIUB	-0.50	0.08	0.05	
CNES	CNES	0.15	-0.02	0.18	
CPOD	CPOD	0.15	-0.01	0.07	
CPOF	CPOD	0.15	-0.01	0.05	
СРОК	CPOD	0.10	-0.04	0.07	
DLRR	DLR	-0.07	0.01	0.06	
ESOC	ESOC	0.15	-0.11	0.06	
EUMB	EUMB	-0.77	-0.20	0.61	
GFZZ	GFZ	0.10	-0.25	0.01	
GRGG	GRG	0.17	-1.63	0.25	
JPLL	JPL	0.30	0.07	-0.59	
TUDF	TUD	-0.00	-0.00	-0.10	
TUMM	TUM	-0.09	0.01	0.02	





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### F.6. SENTINEL-6A

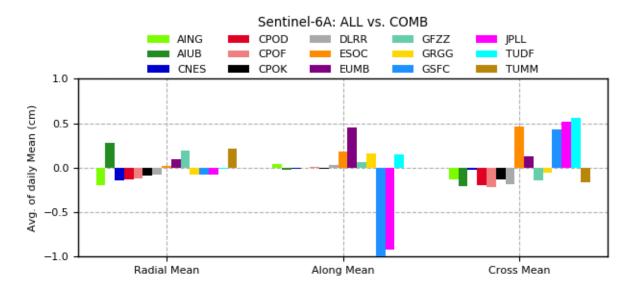


Figure D-6: Sentinel-6A orbit comparisons – Mean of daily average [cm] (All vs. COMB [radial, along, cross and 3D RMS])

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

Orbit Comparisons (Mean of daily average [cm])					
Orbit		Satellite component			
Solution	Centre	Radial	Along-track	Cross-track	
AING	AIUB	-0.20	0.04	-0.13	
AIUB	AIUB	0.28	-0.02	-0.21	
CNES	CNES	-0.14	-0.01	-0.02	
CPOD	CPOD	-0.13	0.00	-0.20	
CPOF	CPOD	-0.12	0.01	-0.21	
СРОК	CPOD	-0.09	-0.01	-0.13	
DLRR	DLR	-0.07	0.03	-0.18	
ESOC	ESOC	0.02	0.18	0.46	
EUMB	EUMB	0.10	0.45	0.13	
GFZZ	GFZ	0.19	0.07	-0.14	
GRGG	GRG	-0.08	0.16	-0.05	
GSFC	GSFC	-0.07	-1.24	0.43	
JPLL	JPL	-0.08	-0.92	0.52	
TUDF	TUD	-0.02	0.15	0.56	
TUMM	TUM	0.21	0.00	-0.16	





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