Prepared by ESA
CGMS Plenary Information Document

STATUS OF THE CURRENT AND FUTURE ESA EARTH OBSERVATION MISSIONS AND PROGRAMMES

CGMS is informed of the current status of the European Space Agency Earth Observation missions currently in-orbit. Two of them, MSG and MetOp are in co-operation with EUMETSAT.

Copernicus represents the major continuing initiative of European efforts in Earth Observation. The first Copernicus dedicated satellite ("Sentinel-1A") was launched on 3 April 2014, followed by Sentinel-2A in June 2015, Sentinel-3A in February 2016, Sentinel-1B in April 2016,Sentinel-2B in April 2017, Sentinel-5P satellite in October 2017, Sentinel-3B in April 2018 and Sentinel-6 Michael Freilich on 21 November 2020; other Sentinels will follow in the coming years. Sentinel operations continued nominally apart from the major Sentinel-1B anomaly that occurred on 23 December 2021affecting the satellite power system. The satellite remains under control, regular orbit control manoeuvres are routinely performed. A long-term unavailability of data provision (several months) is assumed, but it is still too early to consider a permanent unavailability of Sentinel-1B.

Sentinel missions are developed, launched and operated in partnership with the European Union and EUMETSAT. The Sentinel-4 and 5 instruments developed by ESA will fly respectively on the MTG-S and Metop-SG missions also developed by ESA in cooperation with EUMETSAT.

The Earth Explorer missions currently in orbit (SMOS, CryoSat, Swarm, Aeolus) are all performing extremely well and the related data exploitation is based on continuous data of excellent quality. The three missions all feature strong elements of international collaboration and a growing synergy between them. The SMOS satellite was launched on 2 November 2009. The CryoSat-2 satellite was launched on 8 April 2010, the Swarm satellites on 22 November 2013. Aeolus is the last Earth Explorer satellite put into orbit on 21 August 2018 and its Doppler Wind Lidar technique used for measuring wind profiles from space has already been fully demonstrated. The positive impact of Aeolus on the weather forecast has been also seen by multiple Numerical Weather Prediction centres world-wide, in particular by ECMWF.

The Proba-V small satellite was launched on 7 May 2013. Its coarse resolution imager has,

together with Sentinel-3, continued the data acquisition of the Vegetation payload on-board SPOT-4 and 5, during the reporting period. However from July 2020, owing to its orbital drift, Proba-V Vegetation instrument has ended its operations on 31 October 2021 as planned; the satellite continues to be operated for ensuring the operations of the EPT instrument.. The Proba-V Cubesat Companion (PV-CC) development within the GSTP programme now envisages a launch with Vega-C at end 2022 / early 2023.

CGMS is further informed of the current status of the **future** European Space Agency Earth Observation missions. Two of them, MTG and MetOp-SG, are in co-operation with EUMETSAT. The Living Planet Programme has three lines of implementation: Earth Explorer satellites, Earth Watch satellites plus services and applications demonstration.

Progress in the preparation of the forthcoming Explorer missions, EarthCARE, Biomass, FLEX, and FORUM is described. FORUM was selected for implementation as Earth Explorer 9 (EE-9) on 23-25 September 2019. •The Phase B2/C/D/E1 space segment contract for FORUM has been finalised and signed at the beginning of April 2022..

The Phase A studies - two parallel system studies - supporting science studies and campaigns for Harmony have progressed nominally. .

On 25 May 2020, ESA issued a Call for Ideas for Earth Explorer 11 (EE-11). The science requirement consolidation (SciReC) studies have been kicked-off for the four Phase 0 mission candidates CAIRT, Nitrosat, SEASTAR, and WIVERN. The tender evaluation of the System Studies for all four mission candidates have been conducted in the March- April 2022 timeframe and those activities are expected to kick-off by mid-May.

Activities related to Aeolus Follow-On, Arctic Weather Satellite (AWS), TRUTHS, SCOUTs and ALTIUS are ongoing. Each of these missions are planned contribute routine, operational monitoring data to improve our understanding of the Earth system and climate change.

Looking to the future, the six Copernicus Expansion missions are currently in phase B2/C/D/E1, addressing EU policy and gaps in Copernicus user needs, and each expanding the current capabilities of the Copernicus space component: CHIME, CIMR, CO2M, CRISTAL, LSTM, and ROSE-L. The Sentinel development activities, including Copernicus Expansion missions and Next Generation missions, continued in line with Segment 4 of the Copernicus Space Component (CSC) Programme, the FutureEO Programme and the CSC Long Term Scenario. Sentinel development activities, including Copernicus Expansion missions and Next Generation missions, continued in line with Segment 4 of the Copernicus Space Component (CSC) Programme, the FutureEO Programme and the CSC Long Term Scenario.

Develop the prototypes (Phase B2/C/D/E1 of both Sentinel-1 NG and Sentinel-3 Topography NG) including accompanying scientific studies, processor prototype development, and cal/val activities.

CGMS is also informed of the status of the Earth Watch Programme element, Global Monitoring of Essential Climate Variables (also known as the ‘ESA Climate Change Initiative’

or CCI). The CCI has continued to progress very well since its inception in 2008. In 2016, a second phase of the programme, CCI+, was approved by ESA member states which is allowing to study and monitor 23 essential climate variables (ECV) derived from satellite data, fulfilling GCOS objectives. Out of these 23 ECVs, 16 have been handed over to the Copernicus Climate Change Service (C3S) lead by ECMWF, for operational use.

As a general observation, the COVID-19 pandemic has affected several activities related to the procurement of satellites and instruments at different degrees. Thanks to appropriate measures, the impacts on development projects have been mitigated has much as possible, while overall, the operations of ESA satellites currently in orbit and services to users have been kept nominal.

Contents

STATUS OF THE CURRENT AND FUTURE ESA EARTH OBSERVATION MISSIONS AND PROGRAMMES

1 INTRODUCTION

This paper provides information on the status of the current and future European Space Agency Earth Observation missions. ESA's EO Programme comprises a science and research element, which includes the Earth Explorer missions, and an Earth Watch element, which is designed to facilitate the delivery of Earth observation data for use in operational services. Earth Watch includes the well-established meteorological missions developed in coordination with the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT). These missions (MSG, MTG, MetOp and MetOp-SG) are not dealt with in this report.

Current in-flight missions include four R&D satellites missions (6 satellites) from the Earth Explorer series, two small satellites of the Proba series, and eight Sentinel satellites. The status of future Earth Explorer and Earth Watch missions is presented, as well as the progress in the development of the ESA Climate Change Initiative (CCI).

Although the past ESA ERS-1, ERS-2, Envisat and GOCE missions are no longer operating, thousands of users still access the large ESA on-line archives to get products generated from their respective instrument complements.

2 CURRENT ESA SATELLITE SYSTEMS

Satellites	Equator Crossing Time Altitude	Launch date	Access to data or products	Instruments	Status, applications and other information
PROBA-1	7:30 (D) 615 km	22/10/2001	Earthnet on line	CHRIS, SREM	The orbit is drifting from the original 10:30 desc. ECT.
SMOS (with CNES and CDTI)	06:00 (A) 755 km	2/11/2009	SMOS data centres	MIRAS (Microwave Imaging Radiometer using Aperture Synthesis), GPS, STA	L-band radiometer for salinity & soil moisture observation
PROBA-2	06:00 (A) 730 km	2/11/2009	Earthnet on line	SWAP, LYRA, TPMU, DSLP	2nd flight unit of the PROBA programme. Main mission: space weather
CryoSat-2	717 km (92° incl.)	8/04/2010	Earthnet on line	SIRAL (SAR Interferometric Radar Altimeter), DORIS, LRR	Polar ice monitoring

Satellites	Equator Crossing Time Altitude	Launch date	Access to data or products	Instruments	Status, applications and other information
PROBA-V	10:30 (D) 820 km	5/07/2013	Earthnet on line	VEGETATION-P	2nd flight unit of the PROBA programme. Main mission: vegetation monitoring
Swarm A & C (with CNES and CSA)	87.35° 460 km	22/11/2013	Earthnet on line	ACC, SM, EFI (SWARM), GPS (ESA), LRR (DLR), STR (SWARM), VFM	Earth magnetic field
Swarm B	87.75° 530 km	22/11/2013	Earthnet on line		
Aeolus	97° 320 km	22/08/2018	Earthnet on line	ALADIN instrument (Atmospheric Laser Doppler Instrument)	Global observations of wind profiles from space to improve the quality of weather forecasts, and to advance our understanding of atmospheric dynamics and climate processes.
Sentinel-1A (with EC)	06:00 (D) 693 km	03/04/2014	Copernicus Space component data access	SAR-C	Radar imagery
Sentinel-2A (with EC)	10:30 (D) 786 km	22/06/2015	Data available from centres of the Payload Data Ground Segment (PDGS). Real-time availability possible at appointed X-band stations.	MSI (Multispectral imager)	Land and vegetation observation
Sentinel-3A (with EC)	10:00 (D) 814.5 km	16/02/2016	Data available from centres of the Payload Data Ground Segment (PDGS). Real-time availability possible at appointed X-band stations.	DORIS, GPS, LRR, MWR, OLCI, SLSTR, SRAL	Primary mission: ocean observation. Secondary mission: atmosphere and land applications
Sentinel-1B (with EC)	06:00 (D) 693 km	25/04/2016	Data available from centres of the Payload Data Ground Segment (PDGS). Real-time availability possible at appointed X-band stations.	SAR-C	Radar imagery
Sentinel-2B (with EC)	10:30 (D) 786 km	06/03/2017	Data available from centres of the Payload Data Ground Segment (PDGS). Real-time availability possible at appointed X-band stations.	MSI (Multispectral imager)	Land and vegetation observation
Sentinel-5P (with EC and NSO)	13:30 (D) 824 km	13/10/2017	Data available from centres of the Payload Data Ground Segment (PDGS). Real-time availability possible at appointed X-band stations.	TROPOMI	Atmospheric composition and air quality monitoring.
Sentinel-3B (with EC)	10:00 (D) 814.5 km	25/04/2018	Data available from centres of the Payload Data Ground Segment (PDGS). Real-time availability possible at appointed X-band stations.	DORIS, GPS, LRR, MWR, OLCI, SLSTR, SRAL	Primary mission: ocean observation. Secondary mission: atmosphere and land applications

Satellites	Equator Crossing Time Altitude	Launch date	Access to data or products	Instruments	Status, applications and other information
Sentinel-6 Michael Freilich	non-Sun-synchronous orbit 1336 km	21 November 2020	Products are still not accessible to public during the ongoing commissioning phase	AMR-C, DORIS-NG, GNSS POD Receiver, GNSS-RO Receiver, LRA (Sentinel-6), Poseidon-4 Altimeter	Provides continuity of the reference, high-precision ocean topography service after Jason-3

3 STATUS OF CURRENT EARTH EXPLORER SATELLITES

Three ESA Earth Explorer missions are currently in operation, namely SMOS (launched in 2009), CryoSat-2 (launched in 2010) and the Swarm constellation of 3 satellites (launched in 2013). All three missions, as well as GOCE, have provided outstanding results of interest to the meteorological and climate research communities at large. The overall performance of the SMOS, CryoSat, Swarm missions remains excellent. Both ESA DOSTAG and PB-EO have endorsed the extension of the SMOS, CryoSat and Swarm missions until the end of 2025. Final approval will be given at the ESA Council at Ministerial Level (CMIN22).

3.1 GOCE

In orbit from March 2009 to November 2013, the Gravity field and steady-state Ocean Explorer (GOCE) measured the Earth's gravity field with unprecedented detail to advance our understanding of ocean circulation, sea-level change and Earth-interior processes.

3.1.1 Status of spacecraft

GOCE successfully completed its last measurement cycle at an altitude of 223.88 km on 19 October 2013. The satellite re-entered into the Earth atmosphere on 11 November 2013. No damage or casualties due to debris have been reported. The GOCE spacecraft was indeed working very well until just minutes before re-entry.

3.1.2 Performance and results

All Level 1 and Level 2 data up to 1st October 2013, which marks the last instrument calibration activity, have been processed and released to the user community.

The GOCE Level-1b and Level-2 reprocessing campaigns and the related delivery of the Release 6 gravity field products have been completed and the complete set of data released to the user community together with the satellite house-keeping database. The data have been migrated to the new user data access system and rendered accessible at the end of February 2020. The previous user data access system will be available until end of March 2020. The GOCE Gravity Field Model coefficients have been released in the common ICGEM format together with the associated variance-covariance matrices.

The final version of the GOCE User Toolbox (GUT) software package (v3.2) including both the GUI and the updated toolbox documentation and data package has been validated and accepted by ESA. Release to users is planned for Q2 2020.

Programmatic discussions have also been held in March 2020 between ESA and NASA, based on a series of meetings and teleconferences in 2019, to identify the

most suitable scenario for implementation of a joint mass change mission based on a joint constellation of 2 pairs of satellites in an optimum orbit configuration, leveraging on technology developments, and technical and scientific expertise available both in Europe and in the US. The proposed mission architecture responds to user requirements previously established by the Interagency Gravity Science Working Group and builds upon the heritage from CHAMP, GOCE, GRACE, GRACE-FO and on-going pre-developments on laser–ranging interferometry in preparation for the Next Generation Gravity Mission (NGGM), the LISA mission, and in the US Decadal Survey Mass Change Designated Observable (MCDO) study activity.

3.2 SMOS

Launched on 2 November 2009, SMOS is the second Earth Explorer Opportunity mission to be developed as part of ESA's Living Planet Programme. SMOS carries a novel microwave sensor to capture images of brightness temperature, from which information on soil moisture and ocean salinity is derived. The data acquired from the SMOS mission leads to better weather and extreme-event forecasting, and contribute to seasonal-climate forecasting.

3.2.1 Status of spacecraft

The platform is operated under CNES responsibility. No major anomalies or failures have been identified since launch, and the same applies for the interfaces to the payload. Collision Avoidance Manoeuvres (CAM) are performed when necessary as well as Orbit Correction Manoeuvres (OCM) to maintain the mission performances.

3.2.2 Performance and results

Due to strong Space Weather conditions, on 21 December, four consecutive mass memory latch-ups triggered the stop of the on-board science telemetry recording and X-band data downlink. Corresponding contingency recovery procedure was quickly applied performing a manual reset of the instrument. As consequence of this anomaly3 hrs and 30 min of science data were lost. Apart of this major event, the SMOS payload is operating nominally, with the exception of some other minor anomalies impacting on the data availability. In total, all the anomalies in this period caused 3 hrs45 min and 34 sec of on-board data losses and 2 hrs 19 min and 50 sec of on-board degraded data (0.08%), from 1 December 2021 to 1 April 2022. This results in an overall mission performance of 99.79%, which is within the system performance requirement of 98% for generating observation data. The cumulative data lost since 1 May 2010 amounts to 0.082% and the degraded data amounts to 0.44%, resulting in an overall mission performance of 99.48%.

Globally, 99.9% of the dumped passes have been acquired. The acquired data were successfully processed to 99.99% for all product Levels including near-real time (NRT) for the period between 12 December 2021 and 31 March 2022. The timeline of 165 minutes for the NRT products was met in 97.1%.

A monthly report on SMOS data performances is available on https://earth.esa.int/eogateway/instruments/miras.

Since the opening of the ESA SMOS dissemination data service in March 2016, approximately 35 million products have been downloaded by more than 2970 active

accounts (with more than 65 new accesses per month) for a total volume of about 1550 TB (Figure 1) up to 15 March 2022.

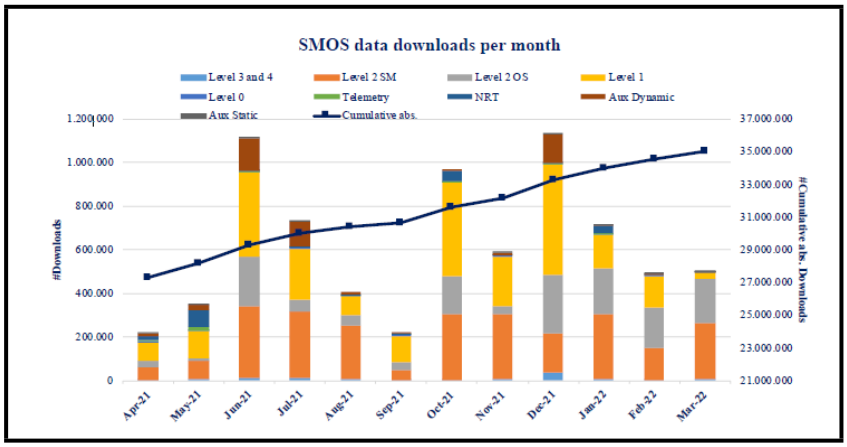

Figure 1: *Performance of ESA SMOS data portal, which is operational since March 2016. Around 35 million products have been downloaded by more than 2970 active accounts, for a total volume of 1550TB*

Reprocessing activities for SMOS sea winds, soil freeze/thaw state and sea-ice thickness dataset based on reprocessed Level-1 V7 were completed. The dataset is under validation. The sea-ice thickness dataset was disseminated in January 2022 (https://earth.esa.int/eogateway/news/smos-sea-ice-thickness-reprocessed-data-available), sea winds and soil freeze/thaw state products are under final validation. Dissemination to the users is planned in Q2 2022.

Radio Frequency Interference and Frequency Coordination:

Currently there are 428 RFI (Radio Frequency Interference) sources worldwide active (status 28 February 2022), of which 34% are strong sources with brightness temperature (BT) between 1000 K and 5000 K and 11% are very strong sources with brightness temperatures higher than 5000 K. The total number of RFI sources has decreased (2 fewer) since the last quarter.

During the reporting period, formal contacts have been established via ANFR (French National Agency for Frequency issues who is acting on behalf of ESA), with the national authorities of Egypt, Croatia, Algeria and China. And regular contacts have continued to be made with the administration of France, USA, Canada in order to update the interference status over their countries.

A new extremely strong RFI came up in the West of China in January this year with a BT of 250 000 K, polluting extensive areas in Central Asia. A report about this RFI was sent to the Chinese Administration in February.

It is worth to mention the preventive action carried out by ANFR to avoid future broadcast services for the Paris 2024 Olympic Games for air-to-ground video transmissions for big events in the SMOS band which finally will not be used.

As part of the effort to raise awareness of the international community about RFI problem an abstract titled “Improved location accuracy of L-band interference sources through multiple observations on L1C products of the SMOS satellite” was submitted to the IGARSS Workshop 2022 and a presentation was given in the “RFI workshop ECMWF 2022” titled “Statistics of Interference Sources in L-Band Observed by SMOS”.

SMAP-SMOS coordination to report together to those administrations affected by RFI, which was agreed last year, is working very well, contacting three National

Administration in this period. This cooperation is considered an important element to keep on getting better the RFI status all around the world.

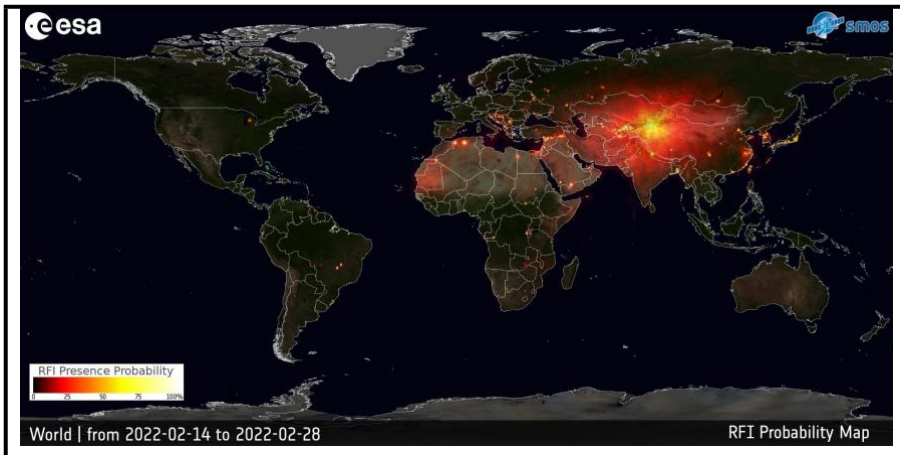

Figure 2:
Global map showing the probability of SMOS persistent RFI occurrences during the period 14 to 28 February 2022 (credits: SMOS RFI team at ESA ESAC)

SMOS Data Quality Evolution, Product Portfolio Evolution and Calibration / Validation

Level 1:

Preliminary feedback on the evaluation of the v750 RFI signal filtering algorithm has been received by the different ESLs. The results show that some improvements are present and more data is available for retrievals, but the quality of the data is still assessed. The feedback also provided suggestions for improvements of the current algorithm to be implemented in future versions.

Level-2

Soil Moisture (SM)

A novel L2SM processor has been finalized and delivered at the end of March.

- An evaluation of the consortium updated proposal for the special reprocessing with homogenous auxiliary data, such as ECMWF Reanalyses (overcoming the inherent operational constraints) has been performed.

Sea Surface Salinity (OS)

The L2OS v7 baseline verification report is completed and online (https://earth.esa.int/eogateway/news/smos-l2-sea-surface-salinity-products-documentation-updates).

A novel L2OS processor is under finalization with an expected delivery in April/May 2022. It will include the implementation of a novel retrieval scheme labelled Debiased-Non Bayesian (DnB).

Sea ice thickness

Sea ice thickness dataset was disseminated in January 2022 (https://earth.esa.int/eogateway/news/smos-sea-ice-thickness-reprocessed-data-available)

Wind

The new processor V300 is delivering SMOS sea winds since 4 August 2021. Operations are nominal. The processor V300 has been used for the entire mission reprocessing, the dataset is under validation.

Soil Freeze/Thaw

Algorithm improvements investigations are on-going. A processor upgrade is envisaged during the period 2022-2024.

Product portfolio evolution

Ice sheets melting and ice sheets temperature prototype products are under validation by the Cryosphere ESL for possible inclusion into SMOS's product portfolio.

The Copernicus Climate Change Service (C3S) and the Copernicus Marine Environment Monitoring Service (CMEMS) use SMOS data sets as input for their services.

3.3 CryoSat-2

ESA's Earth Explorer CryoSat-2 mission, launched on 8 April 2010, is dedicated to the precise monitoring of the changes in the thickness of marine ice floating in the polar oceans and variations in the thickness of the vast ice sheets that overlie Greenland and Antarctica.

3.3.1 Status of spacecraft and mission

The **CryoSat** mission has reached **12 years of operations and exploitation** in early April 2022.

Overall, the space segment performed nominally with no major issues.

The performance of the mission (i.e. 98.61%) is excellent and remains well above the design specifications. Since the start of the exploitation phase, the overall system availability is 99.08%.

No significant changes were observed in the propellant leakage rate: it keeps increasing in line with the predictions. The latest prediction for fuel depletion is November 2024. The current plan foresees a switchover to the backup propulsion branch (RCS-B) at the end of spring 2023, extending the fuel availability into the 2028 time frame.

3.3.2 Performance and results

Overall, the ground segment performed nominally with no major issues.

The SIRAL instrument was programmed according to the current CryoSat Geographical Mode Mask 4.0.

During the reporting period, the end-to-end mission performance, namely the overall mission data return, which takes into account the planned (0.26%) and unplanned unavailability (0.0%) of the space and ground segments, was 99.74%.

Since the start of the mission, the overall availability of the science data has been 98.61% (see Figure 3), well above the design performance of 94.00%. The system availability, which considers only failures, is 99.08%.

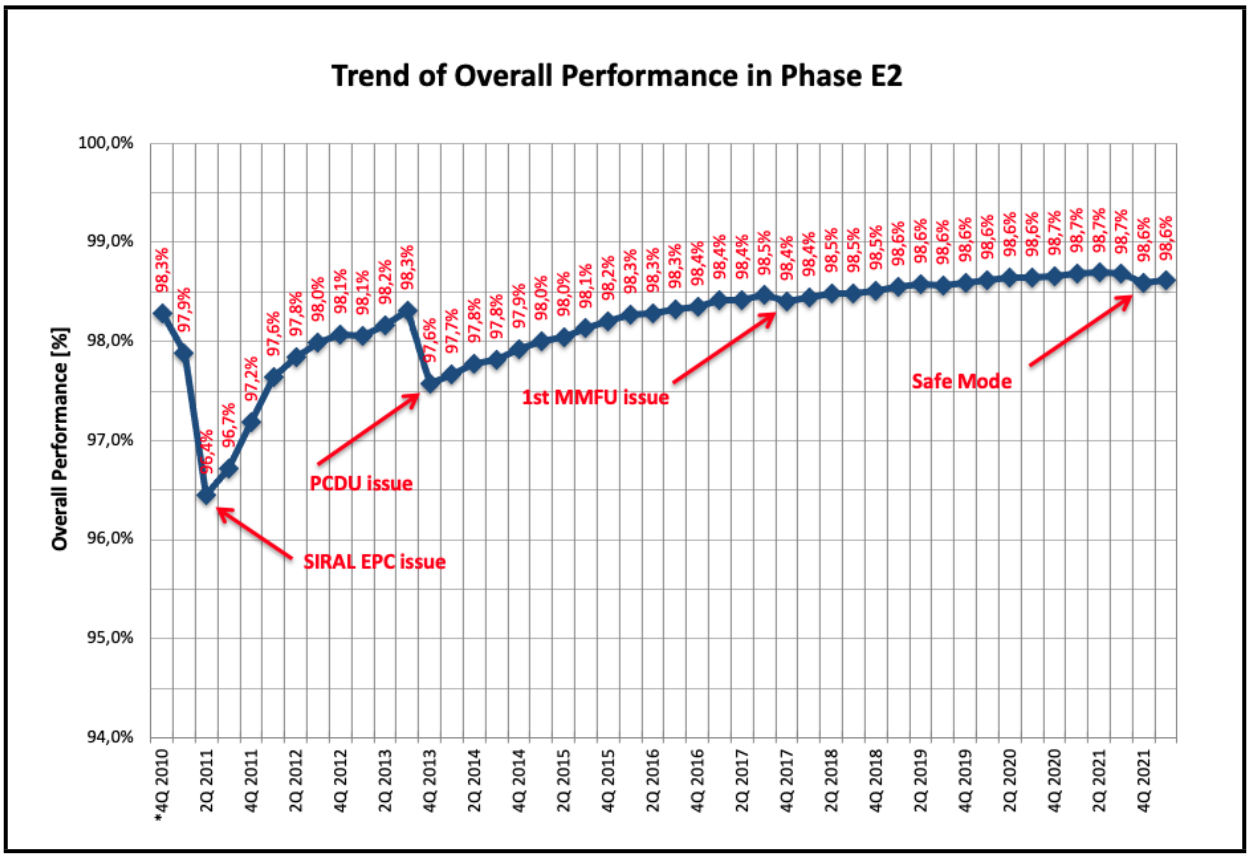

Figure 3: *Historical Mission Performance in Phase E2*

The CryoSat data availability page on the Earth web portal (https://earth.esa.int/web/guest/missions/cryosat/unavailability-periods) provides the entire of all the mission data gap since the start of the mission. This page is constantly updated, adding all the periods where the instrument is unavailable.

Over the reporting period, an aggregate grand total in excess of 29 TB of products were downloaded from the Science Server.

Users can access and discover CryoSat products through the following tools and links:

- FTP at ftp://science-pds.cryosat.esa.int
- HTTPS at https://science-pds.cryosat.esa.int/
- ESA EO-CAT https://eocat.esa.int/sec/#data-services-area
- VtCryoSat https://visioterra.net/VtCryoSat/
- CRYO2ICE https://cryo2ice.org
- CPOM http://www.cpom.ucl.ac.uk/csopr/seaice.php

- CryoTEMPO https://cryotempo-eolis.org
- CEOS https://fedeo-client.ceos.org/#
- EODC - ESA EO Missions Data Hub Relay https://dhr.datahub.eodc.eu/#/home
- App on Apple Store https://apps.apple.com/it/app/esa-cryosat/id484020380
- App on Google Play Store https://bit.ly/3j5lESk

Reprocessing: Activities for the reprocessing of Baseline ice Echo have started with the reprocessing of the full Star Tracker and Calibration mission data completed. The activity will be carried out by the DAMPS service and it is expected to last less than one year (i.e. full dataset completed by spring 2023). Reprocessed products will be published in batches of one month once they are quality checked. Progress will be reported in the next reporting periods.

Quality Control and Monitoring: The overall daily quality and operational control of the ice and ocean CryoSat products are carried by IDEAS+ (UK). Reports are available on QC_Reports.

Detailed quality control of the L2 ice products is carried out by Mullard Space Science Laboratory (MSSL, UK). Reports are available on http://cryosat.mssl.ucl.ac.uk/qa/ .

The Technical University of Delft (TUD, NL) carries out complementary quality control and science validations of the L2 CryoSat Ocean Products (COP). Reports are delivered on a bi-yearly basis and only internally available. During the current reporting period, group has looked into the sea state bias correction of Jason-3, Sentinel-6 and CryoSat and concluded that there is dependency on the re-trackers that are used.

The first results of a swell detection method based on CryoSat-2 Fully Focused-SAR data have been published in a GRL paper (Altiparmaki et al., 2022) and presented during the ESA-TUD progress meeting in March.

The National Oceanography Centre (NOC, UK) produces complementary validation reports on ocean L2 data (NOP, GOP and IOP) including reprocessed datasets. The NOC daily reports are publicly available on NOC_Reports.

Long-term monitoring of the instrument performance is constantly carried out by ARESYS (IT) and periodically reported. The roll manoeuvres campaign commanded in December confirmed that the interferometer is stable and within requirements after more than a decade in space

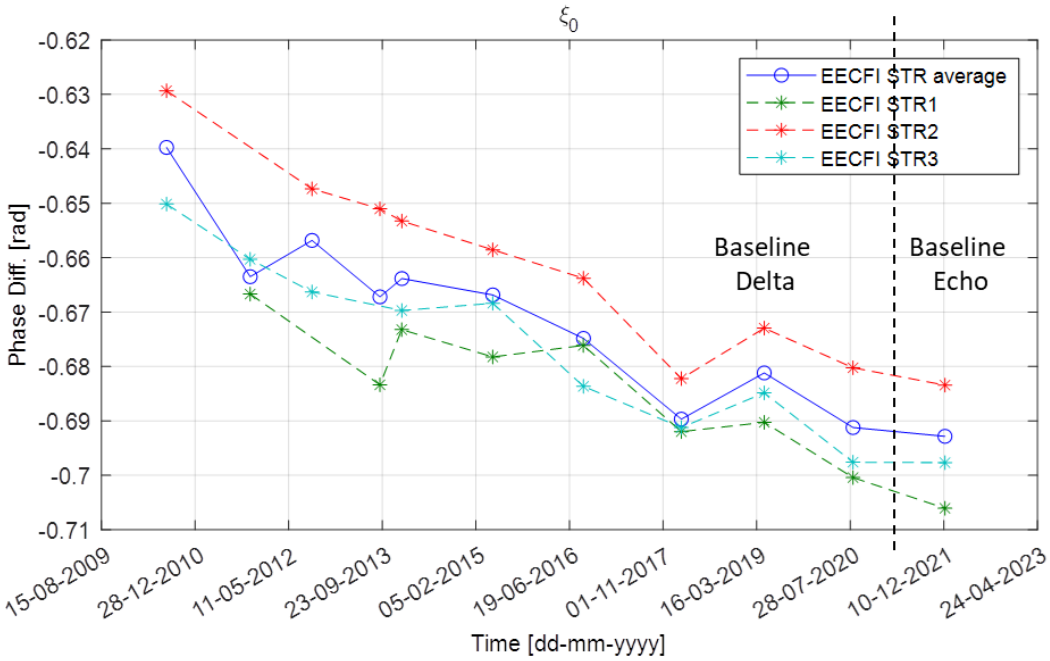

Figure 4: *Historical evolution of the roll bias showing an approximately constantly decreasing rate with no significant differences between Baseline Delta and Baseline Echo.*

An independent quality control of the SIRAL radar parameters is also periodically performed by IsardSAT (ES) throughout the processing of the transponder data over Svalbard and Crete. During the reporting period, no major issues were found, confirming the excellent status of the instrument. The range bias resulting from all available processed passes in more than a decade (2010 - 2022), it is showing excellent long-term stability and agreement between SAR, SARIn and Fully Focussed processed data.

Since the CryoSat-2 (CS2) orbit alignment with ICESat-2 (IS2), several months of winter data are now available to measure sea-ice parameters. A task, led by LEGOS (FR) and QA4EO SERCO team (IT), is focusing on better understanding the freeboard differences between the IS2 laser and CS2 Ku measurements over First Year Ice (FYI) and Multi-Year Ice (MYI), in particular to retrieve key geophysical parameters such as snow depth.

This task is performed in close coordination with the Polar+ Snow on Sea Ice project that aims to produce and validate an experimental dataset of snow thickness over the Arctic. The experimental LaKu dataset has been compared to other snow products and to in situ data showing a very good agreement with the snow depth measured by the OIB snow radar

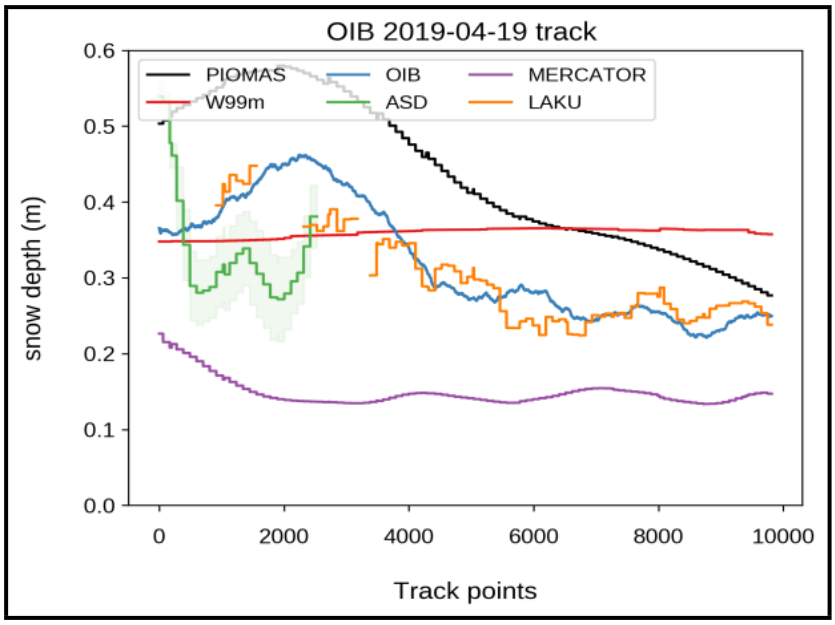

Figure 5.

Comparison of snow depth (SD) from OIB along one transect against various SD gridded products (PIOMAS, W99m, ASD, MERCATOR, LaKu)

Data Quality:

The CryoSat ice and ocean data products are routinely quality-controlled and thoroughly validated:

- Ice Chain: No major issues to report. The quality of the ice products is optimal
- Ocean Chain: No major issues to report. The quality of the ocean products is optimal

Calibration and Validation Campaigns

Transponder calibration over-flights were performed over the Svalbard and Crete transponders according to the annual campaign plan.

After two years of postponement due to COVID, CryoVEx 2022 or Cryo2IceEx 2022 will take place. The plan of Airborne and ground measurements has been consolidated and measurements will span the period of 23 March to 13 April 2022. The main campaign objective is to under fly Cryo2Ice tracks over sea-ice in the Arctic.

For Antarctica, the two national proposals from the UK and Germany have been funded. The UK campaign plans are going ahead and ESA has started the discussions about adding on an ESA component (extra flight hours and ground measurements) to the UK campaign. The main objective will be to validate the Cryo2Ice measurements over the Antarctic sea-ice. Further consolidation of Antarctic plans is expected to be reported in the quarter.

The QA4EO SERCO team (IT) has also kicked off a new activity in collaboration with the Mediterranean Institute of Oceanography (MIO, FR), with a twofold objective: a) to increase the diversity of observations and better understand fine-scale

oceanographic features in the Mediterranean region; b) to provide Cal/Val materials for CryoSat-2.

Planning of a 4-day summer campaign has started, with the identification of potential CryoSat-2 passes over the North-Western Mediterranean Sea in June 2022. This campaign will have as objectives to collect coincident in situ data (e.g., Vertical Velocity Profiler, Julio mooring) and compare them with CryoSat-2, and possibly ICESat-2. The intercomparison will also be beneficial to explore future synergies between CryoSat and SWOT for the observation of coastal and small scale features.

Scientific Results

The highest impacting science paper to make use of CryoSat-2 measurements during the reporting period was that of Braakmann-Folgmann et al. who use ICESat, CryoSat-2 and Sentinel-1 and -3 satellite imagery and altimetry to quantify the area, thickness, and volume change of the massive A68A iceberg from its calving off the Larsen-C Ice Shelf in July 2017 until January 2021, when it disintegrated. A68A thinned from 235 ± 9 to 168 ± 10 m, on average, and lost 802 ± 34 Gt of ice in 3.5 years, 254 ± 17 Gt of which was through basal melting (a lower bound for the immediate freshwater input into the ocean). Basal melting peaked at 7.2 ± 2.3 m/month in the Northern Scotia Sea and an estimated 152 ± 61 Gt of freshwater was released off South Georgia, potentially altering the local ocean properties, plankton occurrence and conditions for predators.

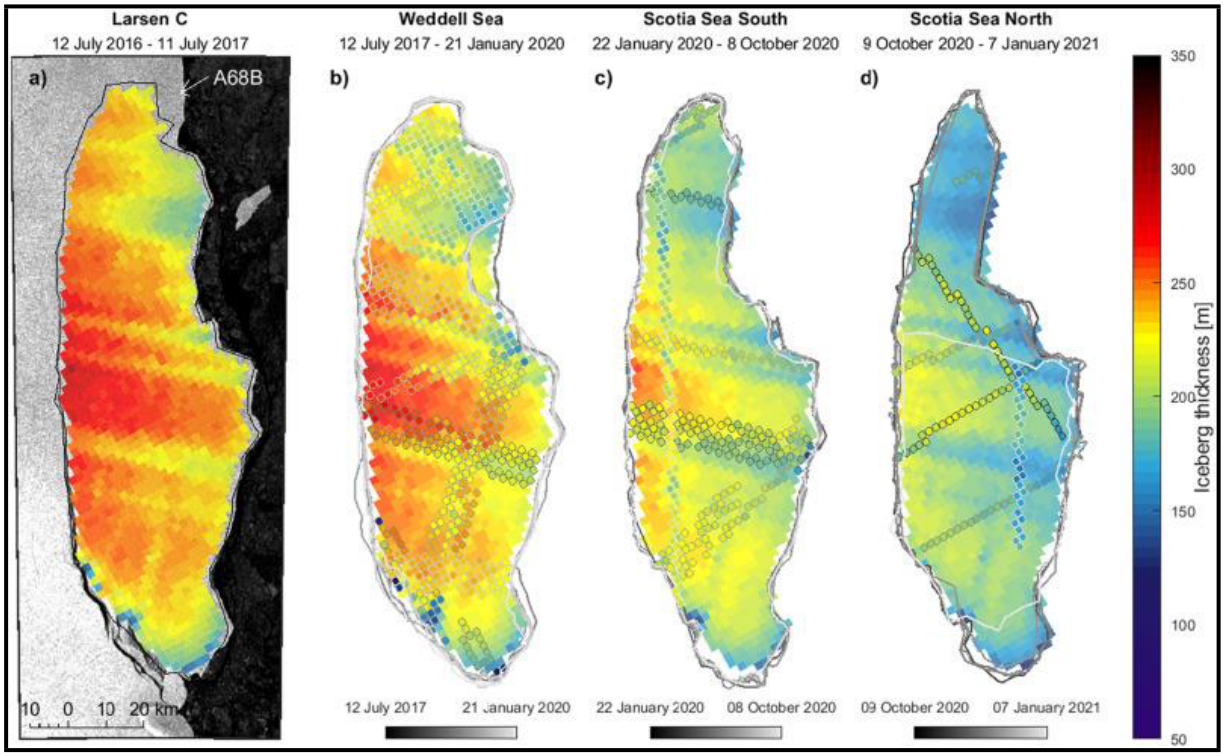

Figure 6: *Maps of the A68A iceberg thickness when it was still part of the Larsen-C Ice Shelf (a) and at later dates as it drifted through the Weddell and Scotia Seas (b-d). The initial thickness is superimposed on a Sentinel-1 image acquired on 10 July 2017, and the region from which A68B was formed is also indicated. On later dates, the iceberg thickness is computed at collocated altimetry overpasses (outlined grid-cells, shaded according to date relative to the interval start) and modelled at the mid-point of each interval elsewhere*.

3.4 SWARM

Swarm is the fourth Earth Explorer Opportunity Mission of ESA's Earth Observation Envelope Programme. This constellation of three satellites is designed to measure the magnetic signals that stem from Earth's core, mantle, crust, oceans, ionosphere and magnetosphere.

3.4.1 Status of spacecraft

Overall, the three spacecraft performed nominally during the reporting period with the exceptions mentioned here below. The platforms have been performing well and are in excellent conditions.

After the so-called "counter-rotating orbits" phase, the lower pair constellation is back to routine with a separation of 4 to 10 seconds between Swarm-A and Swarm-C since 13 January 2022, involving an orbit control manoeuvre on Swarm-A on 13 January 2022.

Due to the ramping-up of the Solar cycle and its effects on the atmospheric drag and ultimately on the orbital decay, the teams started the planning and preparation of an orbit manoeuvre campaign that will be carried out in Q2/2022 to raise the orbits of Swarm-A and Swarm-C between 32km and 44km (TBD), this being the first phase of a step-wise raise of the orbit, whose final target will depend on the evolution of the Solar cycle in the next months and year. In preparation of the campaign, long duration test manoeuvres have been planned with Swarm-B – therefore not impacting the lower pair constellation – to characterise the Cold Gas Propulsion System in view of the upcoming campaign. A first 40 minutes duration manoeuvre did perform nominally on 16 March 2022. Following this successful test, a full single orbit duration orbit raise was tested on 30 March.

The trend of collision warnings received during the period has further increased, especially with respect to satellite constellations, with a total of eight close approach situations analysed, none of them eventually needed to execute a Collision Avoidance Manoeuvre. A first collision warning between Swarm-C and a COSMOS 1408 fragmentation debris, originated by the Russian Anti Satellite Test performed in November, 2021 was notified to happen on 15 January 2022. Also this event was analysed and with the latest updates it did not require an avoidance manoeuvre.

3.4.2 Performance and results

Apart from a few anomalies all Vector Field Magnetometers (VFMs) as well as the Swarm Alpha and Bravo Absolute Scalar Magnetometers (ASMs) continue to perform extremely well, resulting in truly excellent magnetic field data. The extremely high quality of the magnetometer data in combination with high time resolution, from a constellation of three satellites, are the pillars of the Swarm mission success.

All the Accelerometers and the Star Trackers are performing well.
Non-permanent degradation in image quality remains present on all Electric Field Instruments (Thermal Ion Imagers), preventing continuous acquisition of highest-quality science data. The current work-around operational scenario that allows the acquisition of valuable scientific data consists in keeping the instruments in nominal (i.e. high voltage) operation only partially, namely eight consecutive daily orbits on

Swarm-A & -B and two consecutive daily orbits on Swarm-C (eventually reduced to 4 orbits on Swarm-A since 28 March and to 1 orbit on Swarm-C since 17 February due to peripheral anomalies, see below). The rest of the time, sensor surfaces are scrubbed.

All ingestion, Level 1 and Level 2 processing, archiving, and dissemination functions are running nominally and the production is fully current, except for the Level 2 Field-Aligned Current Dual (FAC_AC) processor which was blocked since 7 November 2021 until 2 January 2022 due to the constrains imposed by the Swarm-A and Swarm-C constellation evolution. During the period from 1 December 2021 to mid-March 2021 the performances of the Level 1 processing (computed as the percentage of successful job orders when input data is available) were optimal for all Level 1 processors: ORBATT (100%), ACCELE (100%), MAGNET (100%) and PLASMA (100%). For Level 2, the processing performance was 97.5% mainly due to the lack of FAC_AC combined production during the period mentioned above. The actual data availability (taking also into account spacecraft tests, instrument problems, failures in previous processing steps, and missing auxiliary files) was almost 99.8% for Level 1 data, and 97.2% for Level 2 products mainly due to a EFI switch off on Swarm-A between 14/01/2022 to 18/01/2022.

With regard to the Level 2 Cat-2 processing, the operational pipeline is generating on a daily basis Field Aligned Currents (FAC) derived from single and combined spacecraft measurements, Total Electron Content (TEC), and an Ionospheric Bubble Index (IBI).

All data products are routinely made available to both Cal/Val teams and general users through the Swarm dissemination server. In addition, the Swarm dissemination server also provides to all users some advanced datasets, such as the ASM/VFM residuals dataset, the provisional results of Swarm plasma data for all three spacecraft - including the Langmuir probes extended dataset at 2 Hz, and the 16 Hz ionospheric electron density from faceplate measurements - thanks to a special effort from the Electric Field Instrument teams.

The production of the Level 2 Cat-1 fast-track magnetospheric field model, the precise science orbits and non-gravitational acceleration and thermosphere neutral densities determined solely from GPSR data is current and products are made available to users on a routine basis.

During the January-March 2022 period, more than 11.3 TB of Swarm data products - corresponding to more than more than 785 thousand files - have been distributed to the users. Since March 2019, the ESA Swarm dissemination server is also hosting a mirror of the CASSIOPE/e-POP full data archive (past and current observations) in native format. This improves the e-POP data accessibility, especially for European users.

The data quality team of the Swarm DISC (Data Innovation and Science Cluster) provides essential services to ESA for the verification and validation of all data products, as well as the enhancement of processing algorithms. The next phase of the Swarm DISC- DISC-4 – was kicked off 1 January 2022 and will run until 31 March 2023. In addition to the basic activities, the Swarm DISC-4 will further develop

opportunities for Fast-Track L1b and L2 data processing and Space Weather activities. This will include the identification, implementation, testing, and operation of Fast-track versions of the L1b and L2 data processors to provide Swarm data products that are relevant for Space weather applications on a more rapid and more frequent basis compared to the product baseline.
Swarm DISC is working on an improved model of the dB-Sun correction model to remove, or at least reduce, the observed systematic magnetic field differences of up to 2 nT, which is expected to result in a further improvement of the excellent Swarm data quality. the close proximity of the Swarm Alpha and Charlie satellites during the previous months opened for new exciting opportunities not only for science but also for data quality check and improvements. As an example, the Swarm DISC team found an unexpected difference in the y-component of the VFM magnetometers (roughly corresponding to the magnetic East-West component) between the two satellites. Its dependence on the sun position with regards to the spacecraft suggests that this signature is not of geophysical origin but a result of non-optimal magnetic field correction (see Figure 7).

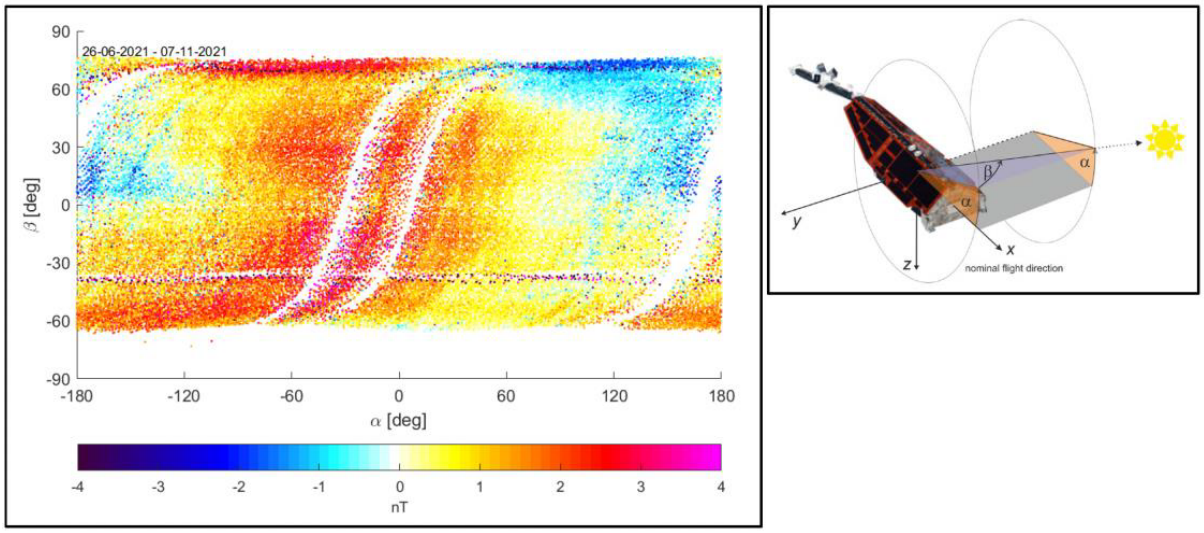

Figure 7: *Difference of simultaneous measurements of the VFM y-components taken by Charlie and Alpha in dependence on the sun position angles (α, β) (defined in the right panel) during the period 26 June to 7 November 2021 when the two satellites were in about the same orbital plane (no longitudinal separation between the two spacecraft).*

3.5 AEOLUS

Launched on 22 August 2018, Aeolus is the first satellite mission to acquire profiles of Earth's wind on a global scale. The primary objective of the Aeolus mission is to demonstrate the Doppler Wind Lidar technique to measure wind profiles from space. The mission sets out to provide observations of global wind profiles along the instrument line of sight (LOS) direction over a minimum lifetime of 3 years. The data will be assimilated into NWP models, to improve the analyses and forecasting of the 3-D vector wind field. A secondary mission objective is to provide data sets suitable for the evaluation of climate models.

3.5.1 Status of spacecraft and mission

The performance of the Aeolus satellite and its payload ALADIN are satisfactory.

The platform consumables (i.e. spacecraft fuel and oxygen for the instrument purging system) are in good conditions and will allow operations well beyond the current funded mission lifetime end of 2022. A general increase in fuel consumption can be observed and is expected as a result of the increase in solar activity.

The Aeolus satellite and its instrument ALADIN has now exceeded their nominal lifetime by 4 months and to date, has accumulated over 5 billion laser shots.
The UV output energy of the current operational FM-B laser was increased during the reporting period and its current output is around a record value of 90mJ. It has been operating since July 2019 without major problems and has been remarkably stable. The laser is now approaching its design lifetime of 3 years which is an important milestone in terms of in-orbit qualification of many instrument components (i.e. Transmitter Laser Electronics) and a significant heritage for Aeolus-2.
The atmospheric return signal is continuing to decrease monotonically with a rate similar to the previous reporting period. The current level of loss since July 2019 is around 40%. Both the Rayleigh and Mie internal paths are showing similar degradation trends to the atmospheric path signal.
Sensitivity tests were performed in March in order to try to move the beam away from the most absorbing regions in the optical path. Unfortunately, these tests were not very successful.
A test on the Master Oscillator (MO) energy was conducted in the Laser Operation Verification Facility (LOVF) utilising the flight spare laser (FM-C). This demonstrated that the Master Oscillator energy could be increased from 4.7 to 6.3mJ. This gives an additional means of increasing the laser energy in space and hence the atmospheric signal levels. However, special attention needs to be paid to the laser fluence, which is becoming harder to evaluate accurately, due to the large optical losses on the instrument reference path where the measurements are taken.
Several trials were conducted to change the number of laser shots accumulated for a single wind measurement, the so-called P/N settings. This gave an unexpectedly large benefit in terms of reduced random error for the Rayleigh and Mie winds of 15% and 17% respectively. This gain comes at the expense of lower horizontal resolution but was judged to be acceptable by ESA and the scientific community. The unexpected gains in performance means that there is probably an additional source of noise in the instrument (i.e. read-out noise), which is becoming more important as the atmospheric return signal decreases. The new P/N settings will become operational in April.
A new analysis of the losses - that were observed on the ALADIN instrument since the beginning - is being carried out by Les Myriades to better understand and reduce the potential roots causes and, more importantly, to ensure that this is avoided for Aeolus-2.The Preliminary outcome is pointing to different radiometric loss for the Mie compared to the Rayleigh, which could be due to a potential issue between the spectrometers, which are operated sequentially. The analysis is ongoing
The Doppler Wind Lidar technique used for measuring wind profiles from space has already been fully demonstrated. The positive impact on the weather forecast has been also seen by multiple NWP centres world-wide, although longer unbiased datasets are still necessary in order to achieve statistically significant results

representing also multiple seasons. A new systematic L2B Quality Management Service was rolled out at ECMWF which extracts the number of winds from L2B products and compares it against pre-defined reference threshold values to determine if the product is in line with quality requirements.

3.5.2 Performance and results

During the reporting period, the Aeolus Ground Segment performed nominally. In total, 99,77% of the scheduled Aeolus passes were successfully acquired during this reporting period and the 99,71% of the systematically processed L1B data products were made available to ECMWF and Aeolus Cal/Val community in far less than 3 hours from sensing, demonstrating the maturity of the L1B NRT service. The overall production completeness of L2A (aerosol/cloud optical products) was 99,94% and 99,71% for the L2B wind products generated at ECMWF and distributed successfully to Aeolus data users in NRT within 3 hours from data sensing.

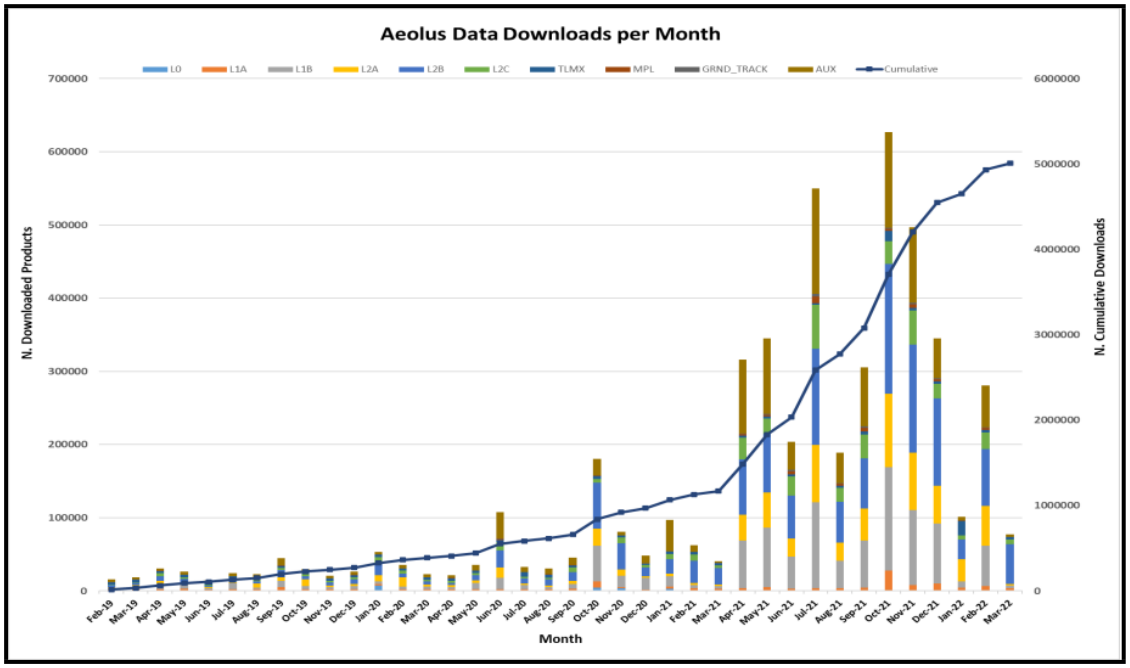

Figure 8: *Aeolus Data Download from ESA Aeolus Online Dissemination Service.* .

Aeolus users can also access wind data through EUMETCast, EUMETSAT's primary dissemination mechanism and through the Global Telecommunications System (GTS) of WMO in BUFR format.

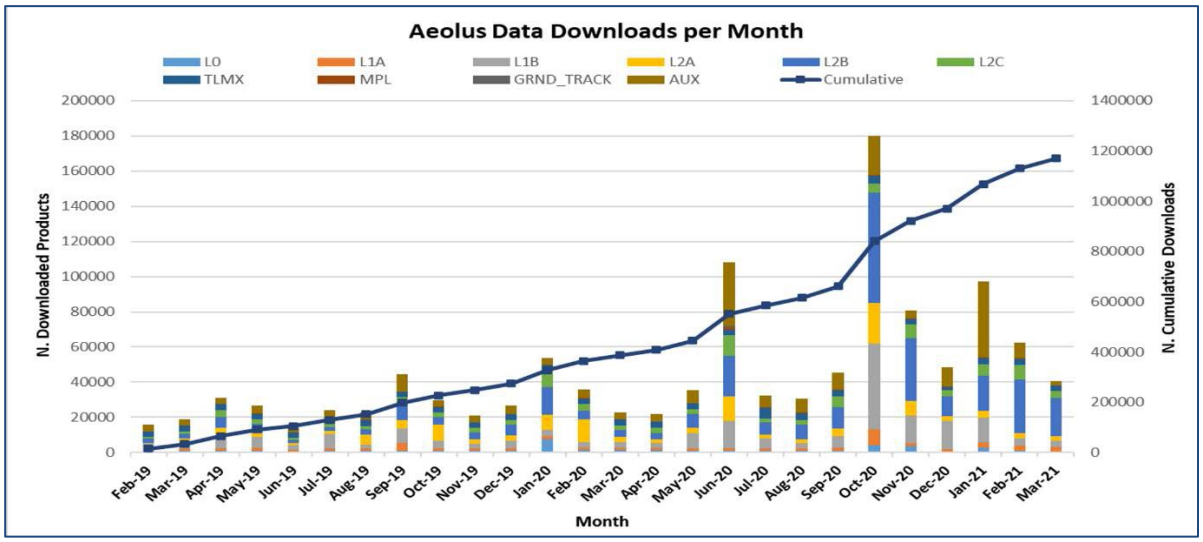

Figure 8: *Aeolus Data Download from ESA Aeolus Online Dissemination Service*

Users can access and discover Aeolus products through the following tools and links:

- Aeolus Online Dissemination http Service http://aeolus-ds.eo.esa.int/oads/access/
- ESA Aeolus Online Dissemination ftp Service ftps:// aeolus-ds.eo.esa.int
- WMO in BUFR format https://acquisition.ecmwf.int/index.html
- VirES https://aeolus.services
- App on Apple Store https://apps.apple.com/it/app/esa-aeolus/id1584780880
- App on Google Play Store https://bit.ly/3LO2FZ2

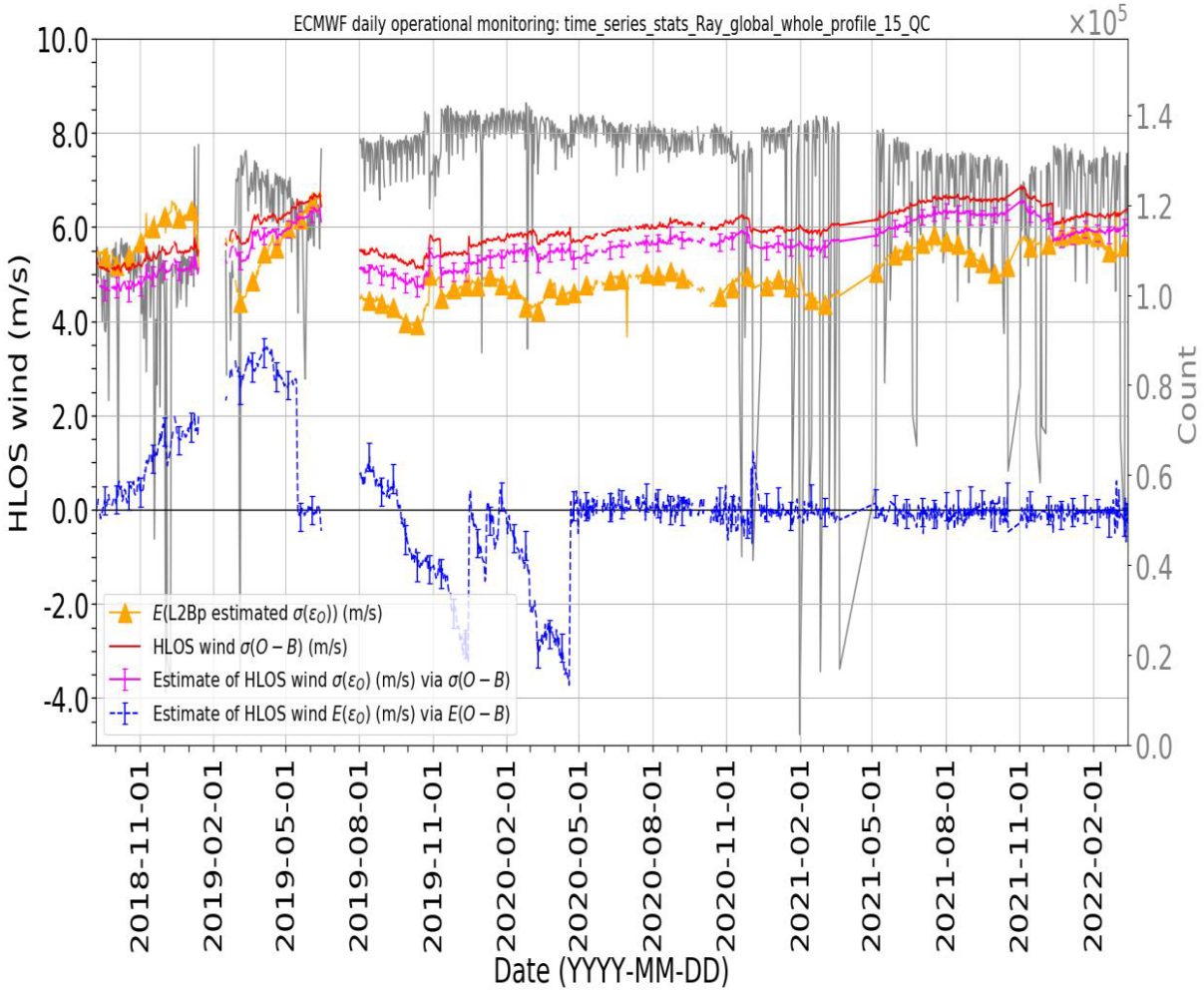

Figure 9: *Evolution of L2B Rayleigh-clear global random error for free troposphere (2-16km). The current random error is around 6.0 m/s*

Calibration and Validation

Based on the latest half yearly Cal/Val reports from all individual Cal/Val teams, the DISC has issued the next iteration of the Cal/Val Synthesis report, summarising Cal/Val results, together with main findings and suggestions for the different scientific products, accompanied with the teams' suggestions for potential future improvements of QC, retrievals and processes.

The Joint Aeolus Tropical Atlantic Campaign (JATAC), deployed on Cabo Verde and the US Virgin Islands in August and September 2021.

The analysis of the data is progressing well and preliminary results were presented at the JATAC Data Workshop on 15-17 February 2022 with around 100 participants and further discussed in the frame of the 3rd years Aeolus Conference (Taormina, Italy).

While the airborne activities were concluded, the ground-based elements of JATAC (i.e. ASKOS), installed at the OSCM facilities in Cape Verde, will remain until autumn 2022 for a campaign with the drones from the Cyprus Institute (CY) focusing on aerosol validation and science in June/July and a potential joint campaign with the NASA DC-8 in the frame of the US CPEX-2022 campaign.

Since the public release of data, all users can explore and analyse Aeolus L1B and L2B NRT data further through VirES (https://aeolus.services) which is a highly interactive data discovery, exploitation and visualisation web-based client application tool for Aeolus products.

4 STATUS OF CURRENT EARTH WATCH SATELLITES

The Earth Watch programme encompasses the development of the series of operational meteorological satellites of EUMETSAT (not covered in this report), the Proba series of small satellites for medium-resolution imagery, and the Copernicus programme of Sentinel satellites designed to provide reliable, timely and accurate services to manage the environment, understand and mitigate the effects of climate change and help respond to crises.

4.1 Proba-V

Launched on 7 May 2013, Proba-V is tasked with a full-scale mission: to map land cover and vegetation growth across the entire planet every two days. Proba-V is flying a lighter but fully functional redesign of the 'Vegetation' imaging instruments previously flown aboard France's full-sized Spot-4 and Spot-5 satellites, which have been observing Earth since 1998. The Spot Vegetation dataset had close to 10,000 registered users around the globe and has contributed to hundreds of scientific papers over 15 years. But with further Spot satellites lacking the capacity to carry Vegetation instruments, Proba-V has been designed to meet the future needs of this group. Proba-V's Vegetation instrument boasts improved spatial resolution from its Spot predecessors: 350 m resolution compared to 1 km for Spot Vegetation, with 100 m resolution available within its central field of view. In fact, at that time the full Sentinel-3 constellation (A+B) is expected to be ready to ensure continuity to the SPOT-VGT and Proba-V long-term archive and to address the needs of the land community, in particular of the Copernicus Global Land Service (CGLS).

Proba-V provides data to the instrument's worldwide user community of scientists and service providers. Uses of Proba-V Vegetation data include day-by-day tracking of extreme weather, alerting authorities to crop failures, monitoring inland water resources and tracing the steady spread of deserts and deforestation.

The Vegetation instrument has ended its operations on 31 October 2021 as planned.

The Proba-V programme element has entered into a period of minimal activities, with regular operations of the Proba-V secondary instruments (e.g. EPT instrument) and with some Vegetation data reprocessing activities.

The Proba-V Cubesat Companion (PV-CC) development within the GSTP programme now envisages a launch with Vega-C at end 2022 / early 2023.

4.1.1 Proba-V Operations

The Proba-V satellite remains very stable during the reporting period and was continuously available except for one 36-hour period during which a manual safe mode recovery was carried out. The ESA Space Debris Office regularly informs the

Proba-V Mission Control Centre at ESA-ESEC (European space Security and Education Centre, Redu, Belgium) about any potential collision risks with space debris (Proba-V does not feature the capability to perform debris avoidance orbit manoeuvres).

The use of the Vegetation Instrument was limited to carrying out lunar calibration observation campaigns during the full moon periods. The secondary instruments remain fully operational, in particular the Energetic Particle Telescope (EPT) which provides near real time and static radiation data products for the SSA Space Weather Service Network. The other instruments, ADS-B, SATRAM and HERMOD, are healthy and in semi-continuous operations. Instrument data, including Vegetation calibration acquisitions, were all downloaded using S-Band passes at Redu (more than 3 per day) as the X-Band ground station support is not required anymore.

4.1.2 Proba-V data products and quality

The **Collection-2 baseline** includes improvements to the cloud and cloud shadows screening methods. The development of Collection-2 (C2) Baseline is completed and the first validation dataset, consisting of 5 days of globally reprocessed data, was generated by VITO. It is currently under evaluation.

The results presented so far were really encouraging, since the full processing chain (from L0 to L3) is functioning as expected, although an increase in computational time is verified. This increase was foreseen and mostly driven by the more sophisticated algorithms being used in C2, notably the advanced atmospheric correction and cloud screening modules. On the other hand, in terms of data quality, the C2 products clearly outperform the C1 products. An example is presented in Figure 11, where the cloud (yellow) and snow/ice (red) mask is presented over a mountainous scene in the Alpine region. The over-detection of clouds, which was a known issue in C1 dataset, is clearly presented over this scene, where clear/land and snow/ice pixels are very often wrongly flagged as cloudy. The C2 machine learning algorithm, developed by University of Valencia (Spain), dramatically improves the cloud detection accuracy, as can be observed in the example scene. Several applications are expected to benefit from such improved accuracy, notably land vegetation monitoring, but also snow mapping applications. Likewise, the new atmospheric correction scheme provides significant improvements in the accuracy of Top-Of-Canopy (TOC) reflectances, in particular by removing the spatial and temporal inconsistencies observed in C1.

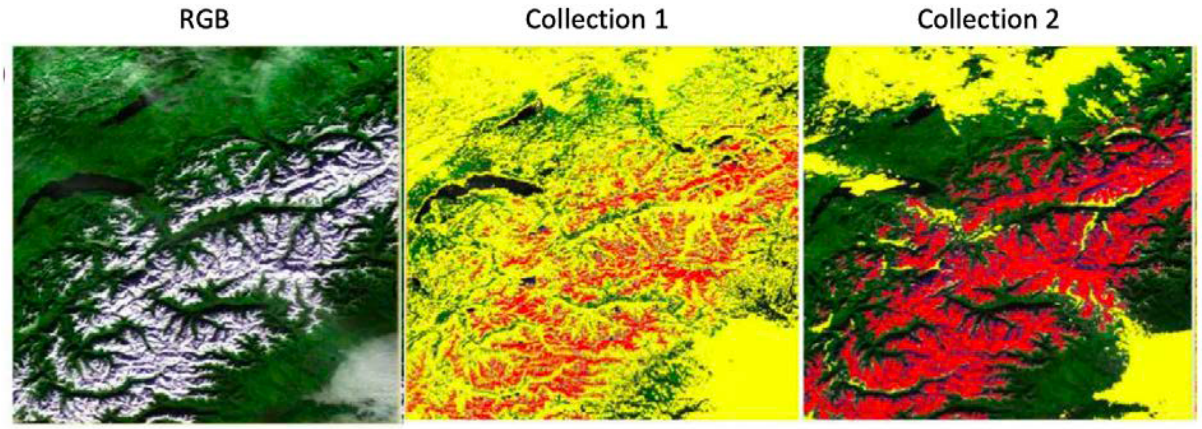

Figure 11: *Cloud mask (yellow) and snow/ice mask (red) for C1 and C2 data.*

Based on these preliminary results, the C2 baseline proves to be a major upgrade in terms of data quality as compared to C1. The go-ahead for the bulk reprocessing will be decided during the forthcoming QWG meeting, after review of the final verification results.

The Collection 2 (C2) reprocessing is on-going at VITO following the schedule agreed during last Quality Working Group (QWG) meeting, with data from 2018-2020 reprocessed first as required by the CGLS. The quality assessment of C2 data is progressing in parallel, notably, an in-depth validation of one full year (2019) was completed and the validation report circulated within the QWG. The validation results clearly demonstrate the improved quality of C2 products, with respect to C1, both in terms of more accurate cloud screening and atmospheric correction. The benchmarking against MODIS NDVI also confirms the C2 improvements with a significant reduction of inter mission biases. Processing of the remaining archive (2014-2017) will start in May and it is expected to be completed by end 2022.

Preparation of Proba-V Companion Smallsat operations

The activities on PV-CC satellite development are proceeding with Aerospacelab. The integration of the optical bench subassembly is finalised (see image). The anti-vibration solution has been selected (Tyvak) and will be ready for the launch.

Aerospacelab has booked the launch with Arianespace flight Vega-C VV23, with a current launch window from 1 Dec. 2022 to 31 Jan. 2023, and a foreseen orbit at 520-550 km altitude.

The radiofrequency coordination agreement with Canada is finally cleared. SSC ground station licensing process for X-band has started on 10 March and it is expected to be ready in September 2022.

Further information about Proba-V products can be found in Earth Online portal[1].

[1] https://earth.esa.int/web/guest/data-access/browse-data-products/-/asset_publisher/y8Qb/content/proba-v-1km-333m-and-100m-products

5 THE COPERNICUS SENTINEL PROGRAMME

Despite the critical situation in Europe due to the COVID-19 crisis, important efforts have been pursued to ensure the continuity of the Sentinel mission operations, which remained nominal during the reporting period. Most of the teams involved in the CSC operations across Europe, both within ESA and in Industry, are tele-working and the access to the operational centres has been minimised, impacting the contingency management and the capability to timely react to potential anomalies. Special non-essential operations have been temporary suspended to focus on the continuity of the routine operations. Routine operations of Sentinel-1A and Sentinel-1B continued nominally during Q4 2021 (Sentinel-1B until 23 December 2021 – see problem areas below), with systematic provision of core products to all users. The mission supported an important number of emergency activations, related to floods in particular, mainly from the International Charter Space and Major Disasters and the Copernicus Emergency Management Service.

Operations of the Sentinel-2 mission continued nominally during the reporting period. The geometric refinement quality of Sentinel-2 products has been performing nominally since the extension to a worldwide coverage that took place during the previous quarter. This improvement provides products with a more accurate absolute geolocation and multi-temporal registration. During the reporting period a lot of attention focused on the preparatory activities for the upcoming upgrade of Sentinel-2 products. This will include improvements both in terms of content/algorithms and format, targeting a transfer to operations during on 25 January 2022. This new processing baseline will be the basis for reprocessing the full Sentinel-2 archive and generate the so-called "Sentinel-2 Collection 1".

Routine operations of Sentinel-3A and Sentinel-3B continued nominally during the reporting period. All instruments, including OLCI, SRAL, SLSTR and MWR, on both satellites, are switched on and performing well. All Sentinel-3A and -3B Level 1 and Level 2 core data products have been released to the user community.

Routine operations of the Sentinel-5 Precursor mission continued nominally during the reporting period producing and disseminating globally Level 1 and Level 2 products. The public release of the Sentinel-5P Ozone Profile product and an improved Methane product (providing also measurements over the sea) took place during November.

5.1 Sentinel-1A and 1B

The Sentinel-1 mission is a polar-orbiting satellite system for the continuation of Synthetic Aperture Radar (SAR) operational applications. Sentinel-1 is a C-band imaging radar mission to provide an all-weather day-and-night supply of imagery for GMES user services. The SAR will operate in two main modes: Interferometric Wide Swath and Wave. The first has a swath width of 250 km and a ground resolution of 5×20 m.

The first Sentinel-1A satellite was successfully launched on 3 April 2014 and commissioned in September 2014. The second Sentinel-1 B was launched on 25 April 2016 and commissioned in September of the same year.

The Sentinel-1A and Sentinel-1B routine operations continued and the overall mission performance was nominal during the quarter, up to the occurrence of the Sentinel-1B major anomaly on 23 December 2021.

The Sentinel-1A routine operations continued and the overall performance was steady during Q1 2022.

Regarding the Sentinel-1B anomaly that occurred on 23 December 2021, very detailed investigations related to the satellite power system's affected unit have been performed and are still on-going. 18 scenarios were studied in order to identify the root cause of the anomaly and possible impacts on the operations of Sentinel-1A, and potential necessary modifications of Sentinel-1C and 1D. New recovery efforts are being made. Conclusion of the board is planned by end of this month. A de-orbiting plan would be devised in the course of next year in case recovery efforts are not successful. Efforts are being made in order to substitute, if at all possible, a small fraction of Sentinel-1B data acquisitions with Copernicus Contributing Missions data to support some parts of the most critical Copernicus Services that are affected and perform relevant adjustments on the Sentinel-1A observation plan.

The Sentinel-1 mission is in routine operations, performing global and systematic observations. The occurrence of satellite anomalies and mission unavailability periods remained very limited during the reporting period, up to the occurrence of the Sentinel-1B major anomaly on 23 December 2021. Important efforts were made to ensure the continuity of the Sentinel-1 mission operations despite the COVID-19 crisis.

The specific support in case of emergency activations was maintained despite the COVID-19 related situation, in particular for CEMS and for the International Charter.

The Sentinel-1 observation scenario for the routine phase supports the systematic coverage of areas of interest for the Copernicus Services, European land and coastal waters, global tectonic and active volcanic areas, and other specific areas worldwide for various applications. In addition, the observation plan includes regular mapping of all land areas worldwide, and a number of specific acquisitions in various SAR operational modes over a limited number of calibration and validation sites, to support the operational activities of the Mission Performance Centre (including cal/val, routine product quality control, etc). Since 26 September 2016, the Sentinel-1 observation plan is implemented with the combined use of Sentinel-1A and Sentinel-1B.

The operations of Sentinel-1A and Sentinel-1B allow for a full mapping of global land areas every 12 days at least (except the inner part of Antarctica which is subject to specific campaigns). Over Europe (EEA-39), the constellation provides a full coverage at least every 6 days, both in ascending and descending geometry (with few exceptions during winter period regarding the Baltic Sea surrounded land areas, due to specific needs from CMEMS).

The Sentinel-1 constellation observation scenario is available for consultation online and in the last version (3.1) of the Sentinel HLOP, published on the website. World maps provide a high-level description of the overall Sentinel-1 constellation observation scenario, in terms of SAR modes, polarisation, observation geometry, revisit and coverage frequency. These new maps are available at:

https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-1/observation-scenario.

The detailed observation plan in the form of acquisition segments (which are generated by the operational mission planning system) is published at:

https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-1/observationscenario/acquisition-segments

The delivery of Sentinel-1 data to the Copernicus Marine Environment Monitoring Service (CMEMS), for sea-ice and iceberg monitoring activities, proceeded smoothly. CMEMS largely relies today on the Sentinel-1 constellation data, which provide an unprecedented coverage of the sea-ice areas of the Earth.

Sentinel-1 contributed during the reporting period to a high number of emergency situations (floods in particular, but not only) from CEMS and the International Charter Space and Major Disasters. The CEMS Rapid Mapping service often does not trigger any Sentinel-1 related action as the relevant acquisitions located in Europe are already part of the routine observation plan and already flagged in NRT (CEMS autonomously download the products from the Copernicus Service data hub).

Specific observations of tropical cyclones overseas / oceans were planned to support the

ESA project CYMS (Scaling-up Cyclone Monitoring Service with Sentinel-1), funded through EOEP-5 Block 4 and managed by the “Science, Applications and Climate" Department. This campaign is performed in agreement with COM. The following cyclones were subject to specific Sentinel-1 planning or adjustment during the reporting period: Pamela (Eastern Pacific Ocean, near Mexico), Malou (Western Pacific Ocean, near Japan), Ruby (South Pacific Ocean), Rai (29W) (South Pacific Ocean).

On this specific activity, following the dedicated meeting of 7 October 2020 organised by COM and potential interested Copernicus Services, CMEMS has expressed interest of possibly gradually integrating this new activity as part of the CMEMS portfolio during the coming MFF period depending on available budget. On ESA side, an extension of the CYMS project should provide a bridging period tentatively until the take-over is potentially made by CMEMS. It is therefore planned to pursue the specific tasking of Sentinel-1 acquisitions at least for the 2021-2022 winter season, and possibly on the 2022 summer season. It is recalled that these few specific acquisitions are planned so that they do not impact the standard Sentinel-1 observation scenario.

The European Maritime Safety Agency (EMSA) operationally uses Sentinel-1 imagery in its CleanSeaNet service. Operations with the EMSA X-Band local stations continued, including both Sentinel-1A and Sentinel-1B X-Band downlinks in pass-through. Since the constellation is in operations, Sentinel-1 has become the main source of radar data for supporting the CleanSeaNet service.

The downlink of Sentinel-1A and Sentinel-1B data is transparently shared between X-Band core stations and the EDRS-A service (i.e. EDRS-A is an additional downlink resource supporting Sentinel-1A and Sentinel-1B operations).

The end-to-end EDRS service availability for Sentinel-1 during the reporting period was 94% (with 1678 optical links successfully executed over a total of 1785 optical links planned).

During Q1 2022a total of 943 optical links were planned as part of the Sentinel-1A routine operations; 894 of them, corresponding to 94.8% of the optical links, were executed without hitch.

5.2 Sentinel-2A and 2B

A pair of Sentinel-2 satellites routinely deliver high-resolution optical images globally, with 5-day revisit, providing enhanced continuity of SPOT- and Landsat-type data. Sentinel-2 carries an optical payload with visible, near infrared and shortwave infrared sensors comprising 13 spectral bands: 4 bands at 10 m, 6 bands at 20 m and 3 bands at 60 m spatial resolution (the latter is dedicated to atmospheric corrections and cloud screening), with a swath width of 290 km.

The Sentinel-2A satellite was successfully launched by VEGA (VV05) on 22 June 2015 and the Sentinel-2B also by VEGA (VV09) on 6 March 2017.

In accordance with the Copernicus data policy, Sentinel-2 data products are made available systematically and free of charge to all data users including the general public, scientific and commercial users. Sentinel-2 products are in Sentinel Standard Archive Format for Europe (SAFE) format, including image data in JPEG2000 format, quality indicators, auxiliary data and metadata.

The Sentinel-2 mission operated nominally, performing systematic acquisitions and distributing good-quality data to users. The occurrence of satellite anomalies and mission unavailability periods remained limited during the reporting period. Important efforts were made to ensure the continuity of the Sentinel-2 mission operations despite the COVID-19 crisis.

The improvement of the image’s geometry, extended worldwide since 23 August 2021, has been performing nominally. Level-1C and Level-2A products have now a more accurate absolute geolocation and multi-temporal registration.

Further to the improvement above, a major upgrade of Sentinel-2 products, both in terms of content and format, is under preparation for a transfer into operations on 25 January2022.

Regarding Level-1C products, the following evolutions will be included:

- o Correction of the radiometric bias between Sentinel-2A and Sentinel-2B;
- o Provision of Level-1C quality masks in raster format;
- o Addition of ECMWF (European Centre for Medium-Range Weather Forecasts) parameters;
- o Addition of CAMS (Copernicus Atmosphere Monitoring Service) parameters;
- o Addition of Level-1C snow/ice mask;
- o Provision of negative radiometric values (implementing an offset);
- o Addition of a DOI (Digital Object Identifier).

Regarding the Sentinel-2 Level-2A products, the first five above-mentioned evolutions are directly inherited from Level-1C product and additional evolutions include:

- o Provision of negative radiometric values (implementing an offset);
- o Provision of Band 01 sampled at 20 m spatial resolution;
- o Addition of Level-2A Quality Indicators;
- o Aerosol correction using CAMS auxiliary data;
- o Improvement of clouds and cloud shadows detection;
- o Improvement of the topographic and casted shadows;
- o Improvement of the bright target classification over coastal areas;
- o Addition of a DOI.

The evolutions above constitute the baseline for the reprocessing of the full archive which is planned to start during the first half of 2022 and will provide to users the so-called Sentinel-2 Collection 1.

An extended observation scenario beyond the HLOP version 3.0 is being operated.

Additional acquisitions include Northern Europe and some additional Arctic Areas in low illumination conditions, additional Pacific Ocean islands (Tuamotu, Austral Islands, Kiribati), Bermuda Islands, Juan Fernandez Archipelago (Chile) and Sargasso Sea.

During Q1 2022, the acquisitions over the Maldives islands were optimised now including all small islands and atolls while not acquiring anymore a segment extending exclusively over water. The ad-hoc acquisition campaign over the Seychelles was started in April 2021 is on-going and will last till March 2022. This campaign was requested by DLR and University of Oxford for the purpose of estimating in-situ carbon stocks in seagrass soils.

The detailed observation plan, under the form of acquisition datastrips, is regularly published online at: https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-2/acquisition-plans

During the reporting period, the configuration of the geometric refinement processor with the Global Reference Image (GRI) and the Copernicus DEM at 90m was operating nominally over Europe/Africa. Given the good performances, this initial deployment was extended to a worldwide coverage on 23 August. The geometric refinement implemented constitutes a major step for the improvement of the geometric performance of Sentinel-2 Level-1C and Level-2A products.

Activities related to CEOS ACIX-II and CMIX exercise, co-organised by ESA and NASA, continued during the reporting period. A first publication with the results from ACIX-II Aqua exercise has been published and is available at:

https://www.sciencedirect.com/science/article/pii/S0034425721000845 . Further details on ACIX II and CMIX exercises can be found on the following website:

https://earth.esa.int/web/sppa/meetings-workshops/hosted-and-co-sponsoredmeetings/acix-ii-cmix-2nd-ws

ACIX III and CMIX II inter-comparison organisation is advancing noting the advent of the first workshop in June 2022 targeted at defining the experimental setup and the intercomparison metrics.

Regarding the downstream usage of Sentinel-2 data products, it is highlighted the fact that Sentinel-2 stayed during 2020 as the top European mission in terms of published peer-reviewed scientific publications (1200 publications). Sentinel-2 remained as well as the top European mission in terms of data volume distributed to users.

Regular Sentinel-2 mission status public reports are released on Sentinel Online at:

https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-2/mission-status

5.3 Sentinel-3A and 3B

The main objective of the Sentinel-3 mission is to measure sea surface topography, sea and land surface temperature, and ocean and land surface colour with high accuracy and reliability to support ocean forecasting systems, environmental monitoring and climate monitoring. The mission definition is driven by the need for continuity in provision of ERS, Envisat and SPOT-Vegetation data, with improvements in instrument performance and coverage. Sentinel-3A was successfully launched on 16 February 2016 and the commissioning phase was terminated in August 2016. Sentinel-3A passed its Routine Operations Readiness Review on 16 October 2017 and is now officially in routine operations, having reached full operational capacity already in July 2017.

Both Sentinel-3A and Sentinel-3B are in routine operations and the overall performance were good during the reporting period. There were no major anomalies during the reporting period. Important efforts are made to ensure the continuity of the Sentinel-3 mission operations during the ongoing COVID-19 pandemic. Currently all instruments, including OLCI, SRAL, SLSTR and MWR, on both satellites are switched on and performing well. All Sentinel-3A and -3B Level 1 and Level 2 core data products have been released to the user community.

Important efforts are made to ensure the continuity of the Sentinel-3 mission operation during the on-going Covid-19 crisis. Currently all instruments, including OLCI, SRAL, SLSTR and MWR, on board both satellites, are switched on and performing well.

All Sentinel-3A and -3B Level 1 and Level 2 core data products are operationally released to the user community and made available via the Open Data Hub. Efforts are continuing to further improve the data quality, based on the results of the validation activities performed by the Sentinel-3 Mission Performance Centre (MPC), the feedback from the Quality Working Groups and the feedback from past Sentinel-3 Validation Team (S3VT) meetings. The performance of the Sentinel-3 core products is nominal.

The Sentinel-3B Level 1 and Level 2 SLSTR data acquired during the commissioning period have been reprocessed with the latest processing baseline and all output products have been made available to users on the Open Hub. Reprocessing of Sentinel-3A SLSTR is completed, and the data will be distributed through the hubs in Q1 2022. SRAL ice margin re-processing is completed and the data is distributed.

All Sentinel-3 PDGS components are currently running in the cloud infrastructure with performance indicators within the expected values. The Land production services are all hosted on OVH cloud.

The circulation of pre-processed data stream to Marine Centre provided over Internet VPN is performing well, with nominal data provision timeliness completeness and availability from both Sentinel-3A and 3B.

The phase-in of the new production services for Sentinel-3A and -3B have started in October and are proceeding nominally.

The Africa Cast service for the dissemination of Sentinel-3 Level-2 Land products over Africa to EUMETSAT, in the frame of the ESA-EUMETSAT “AFRICAcast” joint activity, is operationally working with both Sentinel-3A and -3B Land Level-2 production being available according to the foreseen timeliness.

Reprocessing of Sentinel-3A SLSTR from May 2018 has been completed in the reporting period with data distribution through the hubs started. Corresponding products from Sentinel-3B already released in 2021.

The next Sentinel-3 Mission Constellation operations Review, jointly conducted with EUMETSAT is planned on 12 January 2022.

The quality of the Sentinel-3 products content is routinely monitored by the Sentinel-3 MPC and cyclic reports are published on the ESA Sentinel online web site. The performance of the Sentinel-3 core products content is currently nominal.

The Sentinel-3A/3B STM LAND products are fulfilling the Sentinel-3 mission requirements over all surfaces (e.g. Inland Waters, Sea-Ice & Land Ice).

Following COM authorisation (3 April 2020) to the Sentinel-3 STM L1 processor split between ESA and EUMETSAT, the Sentinel-3 MPC Altimetry team is completing today the implementation of the dedicated Sentinel-3 LAND STM processing chains per surface type, i.e. for inland waters, sea-ice and land ice. The so-called Thematic Instrument Processor Facilities (T-IPF) will be delivered to ESA by end January for the Inland water and Sea-ICE T-IPF and by end February for the Land Ice T-IPF.

Regular progress meetings are held to follow the work done and ensure a successful delivery and deployment of the NEW Sentinel-3 Land Altimetry processors and associated products in early 2022. A full review of the L2 Land Sentinel-3 STM products content has been completed with the support of the Sentinel-3 Altimetry QWG members, to tailor the products content to the user needs.

In parallel of the above Sentinel-3 STM Land activities, a new Sentinel-3 STM L1 Processing Baseline (PB) was delivered to EUMETSAT for the Sentinel-3 Marine Ground Segment. This PB includes in particular an essential fix of the Sentinel-3 SAR Sea Level drift.

The Sentinel-3 Land Altimetry Fiducial Reference Measurement (FRM) activity, so-called ‘St3TART’ for "Sentinel-3 Topography mission Assessment through Reference Techniques" was successfully kicked off on 27 July 2021. The contract will last 18 months. The St3TART activity will provide an operational provision of Fiducial Reference Measurement (FRM) to support the Validation activities and enhance the exploitation of the High Resolution (HR) measurements of the Sentinel-3 SAR

altimeter Land data products during the Routine Operational Phase of the Sentinel-3 mission.

The operations of the range transponder calibration site in Crete are nominal for both Sentinel-3A and -3B SRAL sensors. The Cal/Val infrastructure at the Crete calibration site has been completed with a ground MWR sensor in September 2019. This activity will be covered from Jan 2022 onward through the new Sentinel-3 Land SM MPC Service contract.

An opportunity to perform transponder absolute calibration of the Sentinel-3 STM range and backscatter coefficient is also under discussion with the US JPL Sentinel-6 Cal/Val team. The Sentinel-6 Cal/Val team in JPL built a transponder for the Sentinel-6 mission for deployment on the Catalina island. Operating this transponder for Sentinel-3 STM will allow inter-calibration of the two missions. A mutual benefit to both missions. A Request for Instrument Operation (RIO) is under preparation. Acquisition of the European S6 Range Transponder deployed on the Gavdos island, Greece is also considered for the Sentinel-3A satellite. A RIO was implemented for that purpose in Q4 2021.

5.4 Sentinel-5P

The Sentinel-5 Precursor mission will be a gap-filler, within the 2016-2023 timeframe, between the end-of-life of the current atmospheric chemistry mission (OMI on EOS/Aura) and the operational availability of Sentinel-5. As a joint initiative between ESA and the Netherlands, the mission will comprise a satellite and a UVNS instrument called TROPOMI.

The Sentinel-5P satellite has been launched by Rockot on 13 October 2017.

The TROPOMI instrument continues measuring in nominal baseline with a 360 orbit repeat cycle and is operated since 6 August 2019 with a spatial along-track resolution of 5.5 km (instead 7 km) providing since then ~20% more science data to the user community.

Since March 2019 Sentinel-5P is in routine operations and the TROPOMI instrument continues measuring in nominal baseline with a 360-orbit repeat cycle and since 6 August2019 with a spatial resolution of 5.5 x 3.5 km for most measurements.

The Sentinel-5P mission status is reported at:

https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-5p/mission-status

Sentinel-5P has been flying in loose formation with SUOMI-NPP since December 2017 and VIIRS cloud information is used operationally in the Methane retrieval algorithm.

The products Level 1B Radiance/Irradiance, Tropospheric Ozone, Methane (Offline), Carbon Monoxide, Formaldehyde, Nitrogen Dioxide, Sulphur Dioxide, Total Ozone, Aerosol Absorbing Index, Aerosol Layer Height and Cloud products (Offline and NRT) are available to the public via the Copernicus Sentinel-5 Precursor Data Hub (s5phub.copernicus.eu).

The public release of the Sentinel-5P Ozone Profile product and an improved Methane product (providing also measurements over the sea) took place during November 2021.

The Sentinel-5P PDGS operations have continued nominally during the quarter.

The Sentinel-5P TROPOMI instrument planning is performed by the TROPOMI Operations Support Facility (KNMI) based on a systematic schedule of atmospheric scene measurements on the day side of the orbit and calibration activities on the eclipse period, routinely planned within the repeat cycle of the satellite. Planning operations for the routine X- and S-Band downlink is also performed systematically within the Sentinel-5P acquisition service (KSAT/DLR) to provide full orbit downlink at either Svalbard or Inuvik. The operations of the Sentinel-5P acquisition service were provided smoothly during the reporting period.

The routine production and dissemination of the core products has started in July 2018 within the PDGS operated by DLR in Oberpfaffenhofen. Level-2 products have been made available to the Copernicus Atmospheric Monitoring Service (CAMS), via a dedicated interface (ftp pick-up) point within the PDGS.

The long term archive service operated according to plan. Interfacing with the Instrument Data Analysis Facility (IDAF) at KNMI, for the delivery of subsets of Level-1B and Level-2 data for calibration, TM5 profile data and Level-2 off-line (nitrogen dioxide) data sets have operated nominally.

A new version of the KNMI L1 processor (taking into account radiometric corrections in the irradiance measurements) has been implemented on July 06 into the Sentinel-5P ground segment (including also upgraded L2 processors for all products).

During the reporting period the public release of the Sentinel-5P Ozone Profile product and an improved Methane product (providing also measurements over the sea) has been done.

The Sentinel-5P Product Algorithm Laboratory (PAL) mapping facility has been extended by the inclusion of the provision of daily global Sulphur Dioxide maps to enable users to follow the emission of volcanic eruptions at https://maps.s5p-pal.com

The PAL system has been used to generate a consistent (processed with the same software version) Nitrogen Dioxide (NO2) product covering the time period May 01 2018 until mid Nov. 2021 to enable users to perform trend monitoring especially on the impact of COVID-19 restrictions on air pollution worldwide - https://data-portal.s5ppal.com/products/no2.html .

This dataset has been generated due to a switch in the processor version of the NO2 processor during early December 2020 introducing a discontinuity in the time series of the Sentinel-5P NO2 data. To harmonise this data record the latest operational processor (version 02.03.01) was used to reprocess the data from the beginning of the mission until end of September 2021.

Note that this reprocessing activity is independent of the full mission reprocessing that is planned during 2022, which will use a new radiance calibrated L1B dataset and will be performed by the Sentinel-5P PDGS.

5.5 Sentinel-6 Michael Freilich (Jason-CS)

The Jason-CS satellites form the space component of the Jason Continuity of Service mission, within the Copernicus Space Component Segment 3. Jason-CS will extend high-accuracy ocean topography measurements well into the 2020s, thanks to the participation of all partners (EUMETSAT, ESA, CNES, NOAA and NASA/JPL).

The Poseidon-4 altimeter employs digital architecture and the simultaneous measurement in the advanced SAR mode as well as in the conventional pulse-width limited mode. The Advanced Microwave Radiometer, Climate Quality (AMR-C) will be an enhanced version of JPL's instrument used on Jason-2 and Jason-3. A major programmatic decision has been the abandonment of the High Resolution Microwave Radiometer (HRMR) studies.

The GNSS receiver optimised for Precise Orbit Determination will be an instrument derived from the Sentinel-3b GNSS receiver, while Radio Occultation (RO) capability will be satisfied by a NASA-provided GNSS-RO. Additionally a DORIS Receiver and a NASA-provided Laser Retro-Reflector Array will be embarked.

The **Sentinel-6A Michael Freilich** (Sentinel-6MF) has been launched from the Vandenberg Air Force Base, California, on 21 November 2020.NASA and NOAA jointly acting as the US party are responsible for providing the launch services for both Sentinel-6 A and B satellites, US payload instruments and ground segment support, and will contribute to the operations. The Commissioning phase is still ongoing. The Sentinel-6MF Poseidon-4 altimeter instrument High Power Amplifiers (HPA) shows a decreasing trend in signal power similar to the trends observed on Sentinel-3A and Sentinel-3B. The S6-MF HPAs are in fact spares of the Sentinel-3 batch. The Poseidon-4 altimeter instrument is already showing exceptional end-to-end performance, validating the technology step realized with the completely digital architecture.

The GNSS-POD receiver, tracking Galileo and GPS constellations for the first time in space, is showing excellent results, significantly improved by Galileo.

6 FUTURE ESA SATELLITE SYSTEMS

Important note: all the dates provided in this chapter 6 for launches and other activities in the future are indicative. They reflect the situation as of May 2022.

6.1 Future Earth Explorer and Earth Watch missions

The Earth Explorers are research missions designed to address key scientific challenges identified by the science community while demonstrating breakthrough technology in observing techniques. Involving the science community right from the beginning in the definition of new missions and a peer-reviewed selection process ensures that a resulting mission is developed efficiently and provides the exact data required by the user.

6.1.1 EarthCARE

ESA's EarthCARE (Cloud, Aerosol and Radiation Explorer) mission is the largest and most complex Earth Explorer to date, and will advance our understanding of the role that clouds and aerosols play in reflecting incident solar radiation back into space and trapping infrared radiation emitted from Earth's surface. EarthCARE is a joint venture between ESA and JAXA (Japan Aerospace Exploration Agency).

EarthCARE will advance our understanding of the role that clouds and aerosols play in reflecting incident solar radiation back into space and trapping infrared radiation emitted from Earth’s surface. By acquiring vertical profiles of clouds and aerosols, as well as the radiances at the top of the atmosphere, EarthCARE aims to address these issues. The mission will employ high-performance lidar and radar technology that has never been flown in space before.

The mission has a design lifetime of three years, including a six-months commissioning phase. Launch is planned to take place in the in the first months of 2023.

ATLID was successfully repaired and re-installed in the satellite, in line with the schedule baseline agreed in the previous reporting period.

Preparations for the satellite test campaign after ATLID tests are progressing nominally, with conducted EMC, System Validation Tests-2(SVT-2) and transport to ESTEC environmental test facilities planned to go-ahead as scheduled.

ATLID PLH Flight Spare 4-month duration test completed successfully with stable laser output energy over the full test duration confirmed. Post-test activities completed and refurbishment of the module into the final flight spare is starting.

CPR High Power Transmitter-A integration and testing progressing with some delays, but still in line with satellite level needs. Intermediate EPC level testing completed with some observations, but EPC finally released for integration into the HPT-A. This integration was completed and HPT-A test campaign planned to start early April towards delivery end of May 2022. Based on this progress, the baseline to perform the CPR retrofit in July/August, before satellite environmental test campaign was confirmed.

The activities for the CPR back-up plan, with manufacturing of a Spare HPT is progressing, although also with some delays.

The EarthCARE Overall Ground Segment Verification, Integration Phase was successfully kicked off as planned.

•As a result of the geo-political situation in Ukraine, all activities related to Soyuz launch are suspended and “Force Majeure” was declared by Arianespace. As such, the ongoing PMAR review has been put on hold. The way forward, and potentially huge consequences on the project are under discussion. Satellite level and ground segment activities are planned to progress unaffected until satellite and ground segment qualification/acceptance review, while in parallel the technical and programmatic aspects of a potential switch to an alternative launcher are under investigation.

L1 and L2 Algorithm development activities for the PDGS are reported in section 3.3 below. The Ground Segment compatibility verification campaign is completed and the formal PDGS integration phase was kicked-off on March 10 for a period of ½ year, after which the overall ground segment verification phase will start.

Generation of a test data set covering 2.5 continuous days was performed and the data is currently being used for different ongoing ground segment tests.

Regular coordination with the JAXA ground segment team continued during the reporting period and as well as regular coordination meetings with ECMWF.

6.1.2 Biomass

The Biomass mission was selected in May 2013 as the 7th Earth Explorer mission of its Living Planet programme. The satellite will be designed to provide, for the first time from space, P-band radar measurements optimised to determine the amount of Biomass and carbon stored in the world's forests with greater accuracy than ever before. This information, which is poorly known in the tropics, is essential to understanding the role of forests in Earth's carbon cycle and in climate change. These objectives will be achieved by measuring Biomass and forest height at a resolution of 200 m and forest disturbances at a resolution of 50 m.

Reliable knowledge of tropical forest Biomass also underpins the implementation of the UN Reducing Emissions from Deforestation and forest Degradation (REDD+) initiative – an international effort to reduce carbon emissions from deforestation and land degradation in developing countries. In addition, the measurements made by Biomass offer the opportunity to map the elevation of Earth's terrain under dense vegetation, yielding information on subsurface geology and allowing the estimation of glacier and ice-sheet velocities, critical to our understanding of ice-sheet mass loss in a warming Earth. Biomass also has the potential to evolve into an operational system, providing long-term monitoring of forests – one of Earth's most important natural resources.

The build-up of the satellite platform in Stevenage and the instrument PFM Friedrichshafen are progressing well. These parallel activities will merge into one in July when the instrument will be delivered to STV. The satellite platform is completely assembled with only the reflector and the solar array to be mounted later. All essential flight units to start the instrument PFM tests have been delivered. Work-arounds for the late availability of the PAS PFM and the two Digital Control Units (DCU) are in place.

Satellite integration activities have continued in the last period with all avionics units now being installed. The PDHU PFM was the last unit to be delivered to Airbus UK. The electrical and functional testing of the units and subsystems is ongoing and progressing nominally. Preparations for a system validation test in which the satellite will be commanded from ESOC for the first time are well underway. This one-week interface test will be executed in May.

The first batch of MLI has been installed on the platform by the RUAG team in preparation for the integration of the Large Deployable Reflector (LDR). Its shipment from Florida to the UK had to be put on hold due to concerns over load margins in the motor that drives the deployment. These margins were found insufficient in a

simulation of a worst-case cold environment. The validity of these worst-case assumptions is challenged and the applied margin philosophy is currently being looked at. The slot for the LDR integration into the satellite has been moved from April to end June without impacting the overall schedule thanks to swap of activities.

The Solar Array activities have progressed during the reporting period and the Photovoltaic Assembly (PVA) thermal tests have been completed. The PVA is planned to be integrated into the solar array wing in April. Some delays have been incurred but the need date in early October is expected to be met.

The potential impact of the war in the Ukraine on the availability of the VEGA launcher for Biomass is taken care of outside of the Project. Latest information from Arianespace is however that Biomass should not be impacted.

Communications with ISRO to coordinate the Biomass radar operations with ISRO at times of their launches have resumed. A Joint Working Group has been established with the mandate to find a solution that maximizes Biomass' science return over India.

The current planning calls for a launch in December 2023.

Two years of negotiations with the Namibian Counterparts in order to agree on the content of the MoA, requested by the former as a basis for the implementation of the DesertSAR campaign, have come to end with no agreement reached. ESA tried everything within its reach to comply to the Namibian requests (including going to Council for a second time) and clearly communicated the deadlines to reach the MoA agreement to which the Namibian counterparts were unresponsive. Therefore, a decision was taken to terminate the activity and together with the MAG, new options will be pursued.

All airborne and field data acquisitions for the BelSAR-P campaign have been finalised. The data is prepared for an integration in the MAAP.

The Biomass Level-2 algorithm development CCN is progressing nominally, a Critical Design Review was held on 28 February 2022 with the objective to review the state of the AGB processor and to accept the forest height (FH) and forest disturbance (FD) processor for implementation. All processors are available on https://github.com/BioPAL.

The science team continues to participate to telecons with the NASA GEDI and NISAR teams and the JAXA MOLI and ALOS teams.

The GEO-TREES initiative, which is anticipated to support the funding and collection of ground-based validation data has been started.

6.1.3 FLEX

On 19 November 2015, ESA's Member States selected FLEX as the 8th Earth Explorer mission (also known as the 4th Opportunity Earth Explorer Mission of the EOEP), upon recommendation from the Earth Science Advisory Committee. The Fluorescence Explorer (FLEX) mission will map vegetation fluorescence to quantify photosynthetic activity.

The conversion of atmospheric carbon dioxide and sunlight into energy-rich carbohydrates through photosynthesis is one of the most fundamental processes on Earth – and one on which we all depend. Information from FLEX will improve our understanding of the way carbon moves between plants and the atmosphere and how photosynthesis affects the carbon and water cycles. In addition, information from FLEX will lead to better insight into plant health and stress. This is of particular relevance since the growing global population is placing increasing demands on the production of food and animal feed.

So far, it has not been possible to measure photosynthetic activity from space, but FLEX's novel fluorescence imaging spectrometer will observe this faint glow, which serves as an indicator of photosynthesis. The FLEX satellite will orbit in tandem with one of the Copernicus Sentinel-3 satellites, taking advantage of its optical and thermal sensors to provide an integrated package of measurements. Launch is currently planned for Q3 2025.

A FLEX - Sentinel-3 convoy flight concept meeting was recently held with representatives from EUMETSAT (S3 operator) and flight dynamics experts from ESOC and ESTEC. The FLEX project presented the results of the orbit control strategy analyses, demonstrating that the strategy is safe and that the required operations coordination is reduced to a minimum not disturbing or endangering the S3 operations. In the next step ESA and EUMETSAT will together present this convoy flight concept the European Commission.

The FLORIS instrument CDR Board has been held and concluded that no instrument design showstoppers are identified and that adequate actions by end April are in place to close the review. The main open point of the I-CDR is the L0 and L1b Straylight performance non-compliance. Following the instrument EQM (OMR) tests run end 2021, there were effects on the measurements that impacted the consolidation of the SL budget and model correlation. A taskforce has since been addressing this detector blooming effect and found additional measurement approaches and analysis methods that would eliminate the blooming effect. End of March these activities were almost completed. The consolidated SL budget shows correctable terms that are within specification and performance compliant, however by also considering the non-correctable terms, e.g. residual contamination contributing to SL, the overall budget is in some frequency regions of the O2A and O2B bands off by a factor of 2.

The approach is to involve the scientists (MAG) in assessing the impact on the mission performances. This will require analyses and input to be defined for the End-to-End Simulator and will take several months to establish.

As there is no clear instrument design improvement identifiable that could render the SL budget compliant, the project decision is to continue with the existing instrument and subsystems design. In parallel all effort will be made to further elaborate on EQM campaign lessons learned to improve the instrument PFM on-ground calibration end-2023, to involve the MAG in assessing mission performance impact and to re-assess possibilities for in-orbit improved SL characterisation.

Campaigns and Cal/Val

DEFLOX (JB Hyperspectral, DE):

Through this activity four ground-based instruments (“FloxBoxes”) measuring radiation at a high spectral resolution were procured in 2017. The future calibration/ validation strategy will rely on this type of measurements performed at different heights to bridge the spatial scales from 1 m2 to the size of a satellite footprint. Throughout the last years, the instruments were successfully deployed and operated within the framework of the various campaigns at ground level and on towers.

A new CCN was discussed at the recent MAG meeting and is currently prepared to further advance the understanding of potential height correction methods for deployments on high towers based on discussion with the relevant teams from Germany, Italy and Spain. The current plans foresee to evaluate FloxBox performance focussing on deployment at greater heights in combination with reference targets on ground for different time scales. Measurements are scheduled to start in spring 2022. The activity will be key for finalising the FLEX validation concept.

FLEXSense:

The commissioning phase of Sentinel-3B provided the opportunity for a dedicated campaign making use of reprogrammed OLCI bands to simulate the FLEX convoy mission concept. With Sentinel-3B launched in April 2018, the convoy phase campaign focused on the summer months and five regions in Europe, and with one site in the US. The final presentation for the campaign 2019 took place in Q1 2022.

SF-TAPE (FU-Berlin, DE):

This activity is dedicated to a detailed exploitation of FLEX & Sentinel-3 (S3) tandem concept for fluorescence retrieval by means of utilising S3 tandem data as well as FloxBox measurements in combination with radiative transfer modelling and collocated atmospheric data. The team explored the sensitivity to different sources of uncertainty namely Spectral characterisation, Radiometric uncertainty, and Straylight, with the main aim to develop accurate uncertainty estimates. Ongoing work is dedicated to including existing measurements from the ground-based FLOX instruments to review the consistency between ground-based and satellite data.

6.1.4 FORUM

FORUM was selected on 23-25 September 2019 as Earth Explorer 9.
The Far-infrared Outgoing Radiation Understanding and Monitoring (FORUM) mission will provide new insight into the planet’s radiation budget and how it is controlled, and therefore improve climate models. More than half of Earth’s outgoing longwave energy is in the far-infrared part of the electromagnetic spectrum, which has not been measured. FORUM will fill this gap.

Thanks to new technical developments, the Far-infrared Outgoing Radiation Understanding and Monitoring (FORUM) mission would measure radiation emitted from Earth across the entire far-infrared part of the electromagnetic spectrum. Significantly, it measures in the 15–100 micron range, which has never been done from space before.

These observations are important because Earth emits infrared radiation to space, which is affected by water vapour and cirrus clouds, which, in turn, play key roles in Earth's temperature.

FORUM's benchmark measurements would improve our understanding of the greenhouse effect and, importantly, contribute to the accuracy of climate change assessments that form the basis for policy decisions.

Following the successful Delta TEB for the FORUM Space Segment Phase B2/CD/E1 ITT the main technical activities of this reporting period have been the negotiation with the industrial consortium of all the points identified through the two stages TEB process. The contractual and technical documentation were updated accordingly and are finalised for the signature of the contract.

The Phase B1 pre-development with TAS (UK) and OHB (DE) achieved an important milestone with the Manufacturing Readiness Review for the procurement of the Interferometer Assembly (IA) EM to complete the test programme. The procurement activities are progressing, but small delays occurred in the manufacturing of the Beam Splitter in IOF. The test activities these are planned to be completed in Q3 2022, which remains compatible with the overall schedule.

The schedule has been consolidated during the negotiation phase. Launch date is currently planned in Q3 2027, including 4 months margin at the instrument delivery, 2 months margin at the end of the environmental campaign and 3 months margin between QAR and Pre-Shipment Review.

6.1.5 Earth Explorer 10

Phase A is ongoing for the Earth Explorer 10 (EE-10) candidate mission, Harmony, with two parallel system studies. The Preliminary Requirement Review (PRR) has been kicked off with both TAS/OHB consortium and ADS consortium. The PRR is the final technical and programmatic review of Phase A system studies and will assess the maturity of each system design. The close out of he PRR is planned at the end of May, enabling completion of the Report for Mission Selection in June. The Earth Explorer 10 User Consultation Meeting will take place on5 July 2022 at ESTEC.

6.1.6 Earth Explorer 11

Negotiations for the science requirement consolidation (SciReC) studies have been completed and the studies kicked off for the four Phase 0 mission candidates: CAIRT, Nitrosat, SEASTAR, and WIVERN. Draft versions of the MATER(Mission Assumptions and Technical Requirements Document) prepared by ESA have been discussed with the MAG and iterative updates proposed for each mission, with consolidation of requirements through the accompanying SciReC studies in preparation for the Kick-off of the System Studies. Following the approval of the Phase 0/A/B1 procurement proposal by IPC on 30 September 2021, the Executive has prepared the Phase 0/A ITT packages. A Mission Information Day for industry aiming to increase awareness of EE11 Mission Candidates prior to the Phase 0/A ITT release was also held on 21 October 2021 and widely attended. The Phase 0/A ITTs were released on 25 November for CAIRT, 2 December for Nitrosat, 7 December for SEASTAR and 13 December for WIVERN. Tender Evaluation Board

(TEB's) of the System Studies for all four mission candidates have been conducted within March and the first week of April. Negotiations with the selected consortia are taking place in April. Kick-off of all four activities are expected between mid April and mid May. Preparations for the End-to-End Performance simulator activities to issue the ITT's in Q2 2022 are on-going.

6.1.7 Aeolus Follow-on

Following the successful launch and in-orbit operation of the Aeolus mission, significant progress has been obtained in the assimilation and processing of the Aeolus wind measurements. Recent results have demonstrated the value of Aeolus and its robust and complementary contribution to Numerical Weather Predictions and the direct monitoring of atmospheric dynamics and circulation.

The EUMETSAT Council has expressed its interest for a future operational Doppler Wind Lidar mission and proposed to ESA to prepare for a joint preparatory roadmap for a potential future operational mission.

As such ESA started with drawing lessons learnt, from the Aeolus development and in-orbit operations highlighting the need for preparatory activities such as potential enhancements of the existing technologies used in the instrument and satellite optimisations aimed at resolving the issues encountered during the in-orbit operations with the goal of improving performances and maximising robustness and lifetime, whilst retaining the key Aeolus heritage as far as possible. These improvements are regarded to be mandatory in view of a potential operational mission and of minimising recurrent costs for an affordable multi-satellite programme. ESA will liaise with EUMETSAT to consolidate the mission requirements and programmatic framework in preparation for a potential Aeolus FO mission, which would become the scope of a dedicated operational meteorological programme.

Activities are addressing the development and improvement of the Aeolus technologies and performances. Two phase A2/B1studies are conducted in parallel.

The Aeolus Follow-On Instrument Consolidation Study progressed with a focus on closing MTR actions and implementing updates on the mechanical, thermal and electrical design. A major work has been the continuation of the instrument performance modelling and the related documentation. The proposed design allows meeting the random error performance requirement thanks to the improved throughput in the bistatic configuration. Concerning the wind bias performance requirement, the current instrument budget shows a non-compliance. Further iterations are taking place with the Aeolus Scientific Advisory Group and EUMETSAT to define acceptable corrections of the bias and a possible use of the ECMWF model. Beyond the improved telescope design reducing the contributions linked to thermal gradients, the spectrometer design and the co-alignment loop are being further studied with the objective to reduce further the non-compliance and improve the bias performance. This work will be continued through the extension of the instrument study, recently approved by the Industrial Policy Committee. The instrument interface documentation required for supporting the System Phase A2/B1 studies has been provided as part of the tender package. Continuous support to both system activities

and update of the interface documentation will be provided throughout the instrument study extension.

The Phase A2/B1 system accommodation study ITT has been issued with closing date by end March.

Concerning the laser transmitter developments with Leonardo, latest results of the breadboarding activities related to the four path amplification configuration have shown a significant improvement on the beam quality. Both designs (three versus four paths amplification) will be kept further as the laser accommodation is compatible of both configurations. The manufacturing of the optical bench has been launched.

The ILT/ADS-D laser design has been further iterated with the instrument prime through a series of workshop with the objective to optimise the mass and reduce the thermal design complexity. The nationally funded activity, ALTA, complementing the on-going activity with the objective to develop a full Engineering Model, has been kicked-off.

A few elements are key to EUMETSAT MSs: a longer lifetime, a more robust instrument and a low cost. ESA intends to submit an Aeolus-2 Programme to the ESA Ministerial in 2022 (CMIN22), for a Follow-on programme with EUMETSAT (ESA would procure the first satellite, and EUMETSAT the recurrent ones). The earliest possible target launch date is 2030.

6.1.8 Arctic Weather Satellite (AWS)

Approved at Space19+ (ESA's Council at Ministerial Level), this small satellite (~100 kg) is the prototype for a future constellation of small satellites carrying microwave sounder instruments. The AWS advanced sensors will provide information about humidity, precipitation and ice clouds in the atmosphere. This data offers meteorological institutes excellent opportunities to improve weather forecasts in Arctic and subarctic areas, and helps improve the quality of global forecasts.

EUMETSAT would operate this potential future operational constellation. This prototype will serve for one year as a demo for the future constellation.

The AWS Mission Preliminary Design Review (PDR) was held and was successfully closed in February. The main outcomes were to introduce an additional (pre)-Structural Model to allow an early correlation between the Structural Model design and the test results, and to initiate the procurement of a standard dish antenna for the L-band Ground Station.

The overall AWS system design and interfaces necessary for the development of the different elements (Space Segment, Ground Segment, data distribution, Launchers) are at a good level. The first public Space-to-Ground interface document for the Direct Data Broadcast (DDB) has been released. This allows end users to plan their reception station for the DDB data.

The capability to download all the science data collected in one orbit plus the platform housekeeping telemetry, at every pass over the Ground Station in Svalbard, was a major area of concern at last QSR. A back-up solution was initiated at the

PDR, through the procurement of a standard L-band dish antenna. This will mitigate the identified technical performance risk and also the development schedule risk. The dish antenna provides a much higher performance and will be able to track the Satellite down to 2 degrees above horizon, thereby eliminating any blind orbits, and the associated link budgets will be updated accordingly. KSAT will provide the L-band dish antenna as a service from Svalbard. The DBFN development will continue in parallel, but the DBFN antenna will not become operational and will not be installed in Svalbard.

The mission analysis has also been updated, showing more capability to correct Launcher dispersions to reach the operational orbit in shorter time.

Target date for the launch is Q1 2024.

EUMETSAT participated to the AWS Mission PDR as Panel member and also participated to the Board meeting. The next ESA, industry and EUMETSAT operations coordination meeting is planned in April. EUMETSAT has also been invited to participate to the AWS Progress meetings. EUMETSAT has invited ESA to participate to their Phase A Key Point Review.

EUMETSAT has progressed well with the definition of the future AWS Constellation and selected a baseline of three orbital planes with LTDNs of 03:30, 07:30 and 11:30, with two Satellites in each orbital plane. These orbital planes have been selected to complement the MetOp-SG and NOAA JPSS Satellite observations. EUMETSAT foresees a couple of replenishments of the Satellites in each orbital plane to provide an operational Constellation with over 13 years of operations.

6.1.9 TRUTHS

Also approved at the Space19+, TRUTHS will provide benchmark measurements that improve our ability to estimate the radiative imbalances underlying climate change. Reference datasets from TRUTHS will be used to calibrate other satellite sensors, such as those carried on the Copernicus missions and the emerging constellations of small satellites.

The Phase-B1 of the system study is being completed. The Industrial Team has supported a progress meeting (PM-4, 25-26 January 2021) where the consolidated system architecture, has been further developed, with specific focus on thermal control and mechanical design. A more compact accommodation of the Payload in the CRISTAL recurrent platform has been proposed, which increases volume efficiency and favours manoeuvrability. The work on the performance assessment has been followed up in different meetings to ensure the implementation of the new On-Board calibration system (OBCS) is providing the expected accuracy and stability. The end event of the Phase B1, the ISRR (Intermediate System Requirements Review), has been planned and will start at end April with the delivery of the data package by the Industrial Consortium and carried out in May, with a fast-track Review approach; the Board Meeting is scheduled at mid-June.

The technology pre-developments are continuing, and new results have been presented by the industrial team.

The rapidly progressing TRUTHS activities were supported by two MAG meetings in the reporting period: The 6th TRUTHS MAG Meeting on 2-3 February 2022, and the 7th TRUTHS MAG Meeting on 15 and 21 March 2022, complemented by a dedicated straylight meeting on 4 March 2022. The focus of both MAG meetings was on the consolidation of the system and instrument requirements towards the Intermediate System Requirements Review (ISRR), with a particular focus on the spectral and spatial straylight, ISRF and SNR requirements.

The work of the TRUTHS Mission Accompanying Consolidation Study (TMAC) team led by NPL (UK) is continuing to provide important support the TRUTHS industry and science activities. A second Contract Change note is currently being placed to consolidate the Sensor-to-Sensor cross-calibration approach and the transfer of the TRUTHS radiometric accuracy to different sensors. Furthermore, the impact of observational data gaps in climate benchmark will be investigated as part of the additional activities.

6.1.10 ALTIUS

ALTIUS (Atmospheric Limb Tracker for Investigation of the Upcoming Stratosphere) is a satellite mission proposed by the Belgian Institute for Space Aeronomy and currently under development by ESA. Its main objective is to monitor the distribution and evolution of stratospheric ozone in the Earth's atmosphere. The industrial consortium is led by QinetiQ Space, acting as mission prime. The satellite design is based on the PROBA small satellite bus. The payload, developed by OIP Sensor Systems, is an innovative UV, visible and NIR instrument.

Technical progress on the ALTIUS project was made to progress on Phase C activities for all subsystems. Fortunately, the COVID restrictions were eased in most EU countries so ESA and industrial teams are mostly back nominal working at the office and several face to face meetings with industry could take place.

The Instrument schedule remains on the critical path towards the launch date, there is still a comfortable slack between the platform acceptance and the Instrument delivery.

The Instrument delivery has no margin with respect the contractual date of August 2024. First critical path is the optical modules delivery from AMOS which has been delayed due to STM and QM longer campaigns. Second critical path is the electronics CCU where no solution on the needed resources for the heavy parallel test campaign has been found yet. Overall EEE parts lead time and PCB manufacturing time is a concern and early procurement is being initiated for all Instrument electronics. Fabry-Perot has now some slack with respect to the critical path but the recent delay on the EM reduced the slack. Because of these recent delays, it was decided to move the CDR from September 2022 to November 2022 to make sure all the necessary inputs to this important milestone are the right maturity and STM/EM instrument campaigns are complete.

Platform acceptance date is being delayed to early autumn 2023 due to the delay of the propulsion subsystem and the syrlinks units. The MMU is also close to the critical

path. However, there is still a significant slack between the platform and the Instrument.

Launch date is maintained to mid-May 2025 from Kourou but there is no margin anymore.

6.2 Future Sentinel missions (planned and potential)

In addition to meteorological satellites, the Copernicus missions, which form part of the Copernicus Space Component, will collect robust, long-term climate-relevant datasets. Most of the development activities have been impacted by the Covid-19 sanitary situation with schedule delays of few months.

The last part of that section 6.2 gathers information related to the “Radio Frequency Interference Issues and Spectrum Management” for some Copernicus Sentinel missions.

6.2.1 Sentinel-1 C and D

During the reporting period the activities focused on resuming the Sentinel-1C Assembly, Integration and Tests (AIT) campaign, once the Sentinel-1D initiated the storage activities after the successful Pre-Storage Review closeout on 4 October. The PSR Board took place on 30 September 2021.
Under the activities to demonstrate Sentinel-1C/D compatibility with VEGA-C:
- At spacecraft-level the design and the subsystem-level qualification shows nominally compatible with the current VEGA-C levels and dimensions.
- At launcher-level, the Preliminary Mission Analysis phase of the compatibility study with Arianespace is in progress.

With respect to the Sentinel-1C launcher procurement, it has been agreed with the Commission to issue an ad-hoc ITT for Arianespace while the Framework Contract for Copernicus and Galileo is being negotiated between the Commission and Arianespace.

The ITT was issued in December. The Arianespace proposal was received on 14 January 2022 and is presently reviewed by ESA. In principle, the definition of the Sentinel-1C Launch Period is expected from 1 December 2022 to 31 May 2023.

The Sentinel-1D is in storage after the Pre-Storage Review (PSR) Board that took place on 30 September 2021.

The Sentinel-1C QAR close-out date is also confirmed on 31 October 2022. This date is consistent with the potential Sentinel-1C Launch as from December 2022.

6.2.2 Sentinel-2 C and D

During Q4 2021, the AIT activities on both satellites at the Prime’s premises in

Friedrichshafen, at IABG test facilities in Ottobrunn, and at subcontractor's facilities, continued nominally, in spite of COVID-19 restrictions becoming more constraining and refraining cross-border travels.
In particular, Sentinel-2C Satellite AIT activities in IABG progressed again perfectly in line with the plan. After mass property measurements, the sine vibration tests were completed successfully and were followed by acoustic tests which completed the mechanical test sequence. The Solar Array was then deployed with exercising the flight sequence, before being dismounted from the satellite. Once deployed on its own test rig, the Solar Array was tested and inspected for any potential damage, none was found. It was then stowed again and moved into its container, where it will remain during the storage period. The Satellite is now completing the final verifications following the environment campaign.
These include in particular alignment checks and verifications of the propulsion system that were completed before Christmas. The shipment of the Satellite back to the Prime facilities in Friedrichshafen took place on 20 December.

On Sentinel-2D, the Satellite AIT activities restarted as planned after the delivery of OCPD to the Prime. The terminal has been mechanically and electrically integrated on the Satellite and the OCP Sub-System Integration tests (IST) are currently in preparation. The next important milestone on Sentinel-2D will be the delivery and integration of MSI-D unit in Q2 2022.

ESA and the Prime have started preparing the next major milestones of the project, namely the Flight Acceptance Review (FAR) of Sentinel-2C and the Pre-Storage Review (PSR) of Sentinel-2D, planned in Q1 and Q2 2022 respectively. At System level, several activities are progressing as planned in preparation for the FAR of Sentinel-2C.

The Ground Segment Validation plan and the In-Orbit Commissioning Phase plan are being finalised. In addition, a mission analysis assessment is being performed and documented, taking into account a consolidated launch strategy.

Sentinel-2C schedule remains stable. The EVT campaign in IABG was completed on 20 December. At this point, the Satellite was shipped back to Friedrichshafen where post-environmental System tests will be executed, leading to a FAR Board by end of March 2022.

Sentinel-2D schedule is driven by MSI-D AIT and remains stable. The delivery of MSI-D to the Prime is planned end of March 2022, leading to a PSR 2 months later, end of May 2022.

Both the FAR and PSR dates remain fully compatible with the target launch dates of Sentinel-2C (Q1-Q2 2024) and Sentinel-2D (2025-2028).

6.2.3 Sentinel-3 C and D

The industrial team activities continued mostly nominally although on-going restrictions due to COVID-19 continued to impact movement of hardware and people, including a further delay on SLSTR-D activities.

The Sentinel-3C system AIT activities progressed and are almost fully completed. System functional tests continued including IST-2, OST, EMC/RFC, Mass/Centring/ Inertia (MCI) campaign and UPS mass flow tests. The battery state of charge measurement, launch configuration (EMC) and mission profile tests are planned to be executed in early January.

During the IST-2 testing a loss of power was detected on SRAL. Investigations and retests in both conducted and radiated modes were performed, and it was found to be due to a problem with the anechoic wall set-up. Following the fix and repair of the wall a retest will be performed in January, to confirm there is no instrument problem, and also to have a consolidated reference measurement before storage.

Due to the delay caused by the SRAL investigations the remaining activities had to be reorganised resulting in the few tests plus the SVT being rescheduled to early January.

The Sentinel-3C FAR/PSR was kicked off as scheduled on 15 December, with the planning for the late delivery of the documents linked to the few outstanding tests agreed.
The Sentinel-3D remaining AIT activities continued with the GNSS and SRAL datation tests and close out of NCR investigations. The updated central on-board software was loaded and tested.

During the initial alignment measurement on the SRAL antenna a misalignment was detected. Following investigations with the antenna manufacturer (MDA) and additional measurements performed with the SRAL antenna dismounted, new shims were defined and the antenna will be remounted in January.

The Sentinel-3D “PF/Topo” Pre-Storage Review (PSR) was held in November. This project level review addressed the integrated satellite (Platform, SRAL, MWR, DORIS, GNSS, LRR) with respect to the testing and verification for this build, plus the storage aspects. Although the majority of the objectives were fully met, the Board requested two items to be reported in a close-out meeting in January, i.e. SRAL misalignment (see above) and completion of planned open work prior to storage. Once confirmation of these items has been provided the S-3D PF/Topo integrated satellite will be placed into storage conditions.

Vega-C PMAR part 2 is pending the Vega-C maiden flight and will be planned accordingly.

6.2.4 Sentinels-4/-5

The Sentinel-4 and Sentinel-5 missions are dedicated to monitoring the composition of the atmosphere for GMES Atmosphere Services. Both missions will be carried on meteorological satellites operated by EUMETSAT. The Sentinel-4 and -5 missions will provide information on atmospheric variables in support of European policies. Services will include the monitoring of air quality, stratospheric ozone and solar radiation, and climate monitoring.

6.2.4.1 Sentinel-4

Sentinel-4 is dedicated to air quality monitoring. To be carried on the geostationary Meteosat Third Generation satellites, the Sentinel-4 mission aims to provide continuous monitoring of the composition of the Earth's atmosphere at high temporal and spatial resolution and the data will be used to support monitoring and forecasting over Europe. It comprises an Ultraviolet Visible Near-infrared (UVN) spectrometer and data from EUMETSAT's thermal InfraRed Sounder (IRS), both embarked on the MTG-Sounder (MTG-S) satellite. After the MTG-S satellite is in orbit, the Sentinel-4 mission also includes data from EUMETSAT's Flexible Combined Imager (FCI) embarked on the MTG-Imager (MTG-I) satellite. The Sentinel-4 instrument data, jointly with other data from future meteorological missions, will cover the need for continuous monitoring of atmospheric composition and air quality over Europe with a revisit time of about one hour. The main data products will be O3 (Ozone), NO2 (Nitrogen dioxide), SO2 (Sulphur dioxide), HCHO (Formaldehyde), CHOCHO (Glyoxal) and the aerosol optical depth.

The Sentinel-4/UVN instrument is a high resolution spectrometer system operating with three designated bands in the solar reflectance spectrum, covering the ultraviolet (305-400 nm), visible (400-500 nm) and near-infrared (750-775 nm) bands. The central Sentinel-4/UVN instrument parameters are a spatial sampling of 8 km over Europe and a fast repeat cycle over Europe and North Africa (Sahara) of 60 minutes. The respective spectral resolution is 0.5 nm in the ultraviolet and visible bands, with the goal of 0.12 nm in near infra-red.

The PFM instrument AIT activities progressed in a satisfactory manner during the last months:

- Prime Contractor preparatory activities at RAL (UK): during this reporting period the Prime contractor has completed all the possible preparatory activities to ensure the readiness of their mechanical and electrical GSEs needed for the manipulation and control of the PFM instrument once inside the vacuum chamber. Few remaining activities will be completed ahead of the start of the TV/TB & calibration campaign only when the full STC-2 TV chamber readiness will be achieved by RAL
- Preparation of the PFM Thermal Balance / Thermal Vacuum (TB/TV) Test: during this reporting period, the Prime Contractor team have delivered the relevant thermal documentation: the internal Project review have so far not identified any major problem thanks especially to the very considerable experience gained by the Prime Contractor during the 2019 TV/TB campaign performed at RAL (UK) with the instrument Engineering Model fully representative of the PFM from a thermal point of view. Some product assurance related documentation is outstanding.
- Calibration & Characterisation (C&C) OGSEs: in parallel to the Airbus team activities, during this reporting period the Durham University staff completed the final commissioning of the set of optical GSEs under their responsibility. The radiometric calibration of the optical GSEs under the MSSL responsibility is progressing well: the diffuser panels calibration has been completed while the

FEL lamp and the Integrating Sphere will be completed in April ahead of the start of the C&C campaign.

Current schedule/Deliverable):

The Sentinel-4A delivery to MTG is planned for Q3 2022.

The Sentinel-4B delivery to MTG is planned for Q1 2024

6.2.4.2 Sentinel-5

To be carried on the polar-orbiting MetOp Second Generation satellite, the Sentinel-5 mission comprises an Ultraviolet Visible Near-infrared Shortwave (UVNS) spectrometer and data from EUMETSAT's IRS, the Visible Infrared Imager (VII) and the Multi-viewing Multi-channel Multi-polarization Imager (3MI).

Given the overall delays incurred on the project, it was decided, in agreement with MetOp-SG, to implement a revised model philosophy. In order to allow the spacecraft assembly and qualification tests to proceed as planned, we will deliver first an Intermediate Integration Model (IIM), which is fully flight representative in terms of mechanical, thermal and electrical interfaces. The IIM is based on the refurbishment of the instrument STM and is populated with mass dummies for the optical units. The instrument PFM can then be delivered and exchanged at a later point in time. The refurbishment of the STM into the IIM optical module (IOM) is completed and the unit successfully passed vibration tests. Electrical functional tests are ongoing with the engineering models of the electronic boxes. ESD tests are planned at the end of March. The assembly will finally be delivered together with the Instrument Control Subsystem (ICS) and Detector Support Electronics (DSE) Proto-Flight units (PFM). The schedule for the IIM is now driven by the timely availability and integration of the ICS and DSE PFMs and final thermal vacuum tests.

With the objective of further consolidating satellite instrument operations procedures, MetOp-SG industry has requested the Sentinel-5 project to integrate the IIM to the satellite Simulator-EFM prior to integration on the satellite PFM. A change request was issued to the Sentinel-5 Prime for the incorporation of this activity into the instrument baseline. These include procurement of some additional elements (harness, PEB table, etc.) and incorporation of AIT support to the SimEFM activities performed at satellite integrator facilities. The related contract change has been approved. The new harness is manufactured and undergoing testing.

System level activities were focussed on support to the Intermediate Integration Model (IIM) integration activities on the satellite PFM, progress on the remaining sub-system PFM testing, follow-up of the RAL recovery actions and instrument PFM integration activities.

Given the overall delays incurred on the project, and in order to allow the spacecraft assembly and qualification tests to proceed as planned, it was decided to implement an Intermediate Integration Model (IIM), which is fully flight representative in terms of mechanical, thermal and electrical interfaces. The IIM is based on the refurbishment of the instrument STM and is populated with mass dummies for the optical units and complemented by the Instrument Control Subsystem (ICS) and Detector Support

Electronics (DSE) Proto-Flight units (PFM). The instrument PFM can then be delivered and exchanged at a later point in time.

The IIM integration on the PFM spacecraft has been completed successfully. Functional tests are foreseen in April-May 2022.

All the flight model (PFM, FM2 and FM3) structures are at Airbus. The FM3 structure has also completed its final bake-out. Integration of the PFM instrument with the optical sub-systems has started (see optics section).

Besides all thermal hardware, also all the flight model harnesses have been completed and delivered.

Some SWIR detectors presented a leak and cracks at the window seal. A first brazing process improvement has been applied to the new PFM detectors. While this process does not guarantee full hermeticity, the windows present no cracks any longer. Two of these devices are integrated in the SWIR PFM subsystem. In order to further improve the hermeticity, Lynred and Airbus have revisited and improved the design of the window holder and the window metallisation. New parts have subsequently been ordered and will be used for the FM2 and FM3, however the supplier of the windows has encountered some problems in its manufacturing and the deliveries will be delayed. In parallel, Lynred continues with the validation of the new design.

The SWIR sub-system PFM has completed all its environmental and performance tests. During cryogenic tests, it was found that the internal LED illumination system is partly vignetted due to the thermal and straylight shield situated right in front of the detectors. While it does not affect the regular light path, it slightly intercepts the LED light path. This will be corrected in the FM2 and FM3, but has been agreed to use as is in the PFM. Work-around operational procedure is being elaborated. On overall instrument performances, the slight decrease in UV1 responsivity of the related focal plane assembly has been assessed and does not affect the compliance to the system requirements.

The major non-compliances are still directly coupled with the stray-light performance of the instrument at Level-0, affecting all spectral channels, but particularly the SWIR-3 band. The efficiency of the stray-light correction will be better known after straylight measurements are performed during the calibration campaign.

The impact of the synthetic residual stray-light appears to be critical for the CH4 and HCHO products, for which the error contribution due to stray-light alone exceeds the allowed L2 uncertainty. The straylight contribution consumes a significant fraction of the uncertainty requirement for the O3 profile, total O3, and SO2 products. The impact appears to be small for NO2, CHOCHO, aerosol, clouds, and CO. However, the representativity of the synthetic stray-light data is of course still limited. Straylight contribution will be included in the budgets once the straylight data from the PFM campaign become available.

Additional impact assessments of different limiting features in the instrument such as the SWIR detector lag affect and residual errors in the knowledge of the Instrument Spectral Response Function (ISRF) are currently under evaluation by the Level-2 development team.

The Sentinel-5A delivery to MetOp-SG is planned for July 2023.

6.2.5 Sentinel-6 (Jason-CS)

The satellite-B moved from Friedrichshafen to Ottobrunn, at the IABG environmental test facility. The late availability of the thermal chamber due to previous users, made the schedule very tight, in particular with the aggravated measures necessary due to the COVID-19 pandemic situation. Nevertheless, with the agreed shorter sequence, the thermal vacuum test was completed on time before Christmas. As planned, the complete test will be repeated after de-storage for the launch campaign preparation in 2025.

The acoustic vibration test is in preparation as the next step in the environmental test sequence, which will continue with Electro Magnetic Compatibility and complete in March 2022.

Discussions are on-going about contracting the storage activities, in particular about the necessary insurance coverage during storage and during the yearly verification activities.

The Pre-Storage Review (PSR) is still planned early June 2022.

6.2.6 Copernicus Expansion Missions

Data from the Copernicus Sentinels developed by ESA, feed into the Copernicus Services, which help address challenges such as urbanisation, food security, rising sea levels, diminishing polar ice, natural disasters and, of course, climate change.

Looking to the future, the following six Copernicus Expansion are being studied to address EU policy and gaps in Copernicus user needs, and to expand the current capabilities of the Copernicus space component.

On 20 January 2022, COM and ESA presented a joint proposal on the way forward at the occasion of the 6th Joint Informal PB-EO/Space Programme Committee in Copernicus Configuration on Copernicus. The proposal foresees: an increase of the allocated budget delegated to ESA from 3365 M€ to 3394 M€; the introduction of a new programmatic milestone called ‘Funding Gate Milestone (FGM) no later than 30 June 2024; an implementation scheme based on the postponement of a series of industrial commitments. This joint proposal allows for additional budget up to FGM and to continue the implementation according to the User Requirements and the goals of EU policies while securing the missing funding.

Sentinel development activities, including Copernicus Expansion missions and Next Generation missions, continued in line with Segment 4 of the Copernicus Space Component (CSC) Programme, the FutureEO Programme and the CSC Long Term Scenario.

The System Requirements Reviews for the 6 Copernicus Expansion missions have been completed.

Sentinel-1 NG:

Phase A/B1 activities are progressing as planned. The Preliminary Requirements Reviews for the two consortia are on going. The PRR kick-off for the ADS contract took place on 31 January 2022 and for the TAS-I contract on 23 February. The PRR Board meeting (with ADS) was held on 29 March and the one with TAS-I is planned on 7 April. As reported in the last QSR, the Mission Concepts to develop in both Phase B1 will be based on planar array antennas, following the Mid-Term Check Point (MTCP) conclusions. In parallel, ITTs for technology pre-development contracts are being published.

Sentinel-2 NG and Sentinel-3 Optical NG:

The Sentinel-2 NG and Sentinel-3 Optical NG Phase 0 activities are progressing nominally with Ad-Hoc Expert Group held during the reporting period for both missions.

Mid Term Review meetings for S-2 NG and S-3 Optical NG took place in Nov and Dec 2021, respectively, and declared successful.

The Mission Architecture Review (MAR) of S-2 NG is planned on 16-17 May 2022 for the ADS led consortium and on 30 June/1 July for the OHB led consortium.

The MAR meetings of both S-3 Optical NG consortia are expected to be held in Q3 2022.

Sentinel-3 Topo NG and Sentinel-6 NG:

Regarding Sentinel-3 Topo NG and Sentinel-6 NG activities, the third S-3 Topo NG MAG meeting was held on 3-4 March including a critical review and assessment of S-3 Topo NG mission requirements in preparation for the PCR. A revised version of the MRD has been prepared following inputs from Industry and the S-3 Topo NG MAG.

The Assessment SEa Level rise Stability Uncertainty (ASELSU) study is developing a detailed uncertainty budget in support of the S-6 NG mission development. The approach, starting at the Radar Equation, was reviewed at Progress meeting#2 and is making good progress.

CHIME: Copernicus Hyperspectral Imaging Mission

The CHIME mission, which includes a constellation of two satellites, aims at augmenting the CSC with precise spectroscopic measurements to derive quantitative surface characteristics supporting the monitoring, implementation and improvement of a range of policies in the domain of raw materials, agriculture, soils, food security, biodiversity, environmental degradation and hazards, inland and coastal waters, snow, forestry and the urban environment.

The mission would complement Copernicus Sentinel-2 for applications such as land-cover mapping.

The CHIME Qualification Acceptance Review (QAR) is currently planned for Q3 2028.

CIMR: Copernicus Imaging Microwave Radiometer

The aim of the Copernicus Imaging Microwave Radiometer (CIMR) mission, which includes a constellation of two satellites, is to provide high-spatial resolution microwave imaging radiometry measurements and derived products with continuous global coverage (~95% daily, no gap at the poles) and sub-daily (6 hours average) revisit in the polar regions and adjacent seas, to address Copernicus user needs. The primary mission requirements are to acquire global observations to address Sea Ice Concentration (SIC) and Sea Surface Temperature (SST) with secondary requirements covering a very wide number of parameters related to COM Arctic Policy including: ice-type, sea-ice drift, thin sea-ice thickness, terrestrial snow extent, sea surface salinity, ice surface temperature, wind speed over the ocean, soil moisture, and vegetation indices. CIMR satellites will operate in synergy with MetOp-SG(B), providing collocated and contemporaneous measurements in the polar regions with MWI/ICI and SCA instruments.

CIMR will be operated by ESA and EUM will generate and deliver the global ocean L2 products

The CIMR QAR is currently planned for Q2 2028.

CO2M: Copernicus Anthropogenic Carbon Dioxide Monitoring

This mission, which includes a constellation of three satellites, aims to provide Copernicus with a CO2 monitoring and verification support capacity, capable of estimating anthropogenic CO2 emissions at country and megacity scales. This operational capacity shall allow evaluating the implementation and effectiveness of the CO2 emission reduction strategies proposed in the Paris Agreement. Such a system needs to provide accurate and consistent quantification of anthropogenic CO2 emissions and their trends. As part of the product portfolio and in support of the main mission objective, there will be also CH4, NO2, aerosol and solar-induced fluorescence of vegetation operationally retrieved at similarly high spatial resolution. Although this includes air quality relevant information, these products are not necessarily retrieved in near-real time.

CO2M will be operated by EUMETSAT

The CO2M QAR is currently planned for end Q3 2025.

CRISTAL: Copernicus Polar Ice and Snow Topography Altimeter

The Copernicus polaR Ice and Snow Topography ALtimeter (CRISTAL) Mission, which includes a constellation of two satellites, shall provide enhanced retrieval of land ice sheet/glacier elevation, sea ice thickness and freeboard and ocean surface elevation, wave-height and wind speed by measurements implementing higher spatial resolution. The primary high level objectives are to monitor critical climate signals: ice sheet, ice cap melting and sea level, as well as to monitor variability of

Arctic and Southern Ocean sea-ice and its snow loading to support Copernicus operational products and services concerning the polar regions. Other objectives are to support applications related to coastal and inland waters and contribute to the observation of ocean topography. CRISTAL will carry a multi-frequency radar altimeter and a microwave radiometer.

CRISTAL will be operated by ESA and EUM will generate and deliver the global ocean L1 and L2 products.

The CRISTAL QAR is currently planned for June 2027.

LSTM: Copernicus Land Surface Temperature Monitoring

Surface temperature is already being observed from space with thermal infrared (TIR) sensors, however at spatio-temporal resolutions insufficient for many applications and services, including agriculture. The LSTM mission, which includes a constellation of two satellites, will increase the spatial resolution of the TIR observations currently provided by Copernicus by a factor 400, bringing them to field scale. This mission shall be able to complement the current visible (VIS) and near-infrared (NIR) Copernicus observations with high spatio-temporal resolution TIR observations over land and coastal regions in support of agriculture management services and possibly a range of additional services.

The LSTM QAR is currently planned for October 2028.

ROSE-L: L-band Synthetic Aperture Radar

As part of the Copernicus expansion, ESA has undertaken the development of the L-band Synthetic Aperture Radar (SAR) Mission, referred to as Radar Observing System for Europe (ROSE-L). This mission, which includes a constellation of two satellites, will acquire systematically and provide routinely data and information products for the Copernicus Marine, Land, Climate Change and Emergency services, as well as to the recently proposed Copernicus Land Motion service.

Its target applications are the measurement of surface deformation of vegetated terrain, soil moisture, land cover classification, crop type discrimination and its temporal analysis. Furthermore, the mission will monitor Polar ice sheets and ice caps, and the sea-ice conditions (i.e. type, drift, deformation, concentration, lead fraction), as well as contribute to the European maritime situational awareness. The envisioned acquisition of co-located ROSE-L and C-band Sentinel-1 SAR data within a short time interval, providing quasi multi-frequency imagery, will improve the classification of sea-ice types and the estimation of sea-ice drift, respectively. The ROSE-L mission will provide repeat-pass SAR interferometry (InSAR) capability for each ROSE-L satellite.

The ROSE-L QAR is currently planned for Q1 2028.

Radio Frequency Interference Issues and Spectrum Management

These are the activities carried out and main updates during the reporting period on radio frequency interference issues:

• Frequency bands under RR No. 5.340: RR No. 5.340 states that all emissions are prohibited in a number of frequency bands. Discussions are ongoing in CEPT on the possible identification of criteria under which active services could be authorised to operate in bands subject to RR No. 5.340.

To protect several Copernicus missions, it is important that no active services are allowed to operate within these bands. This may affect CIMR, CRISTAL,Sentinel-3, Sentinel-6 and the Sentinel-3 NG Topography missions. Support from the National Regulatory Authorities of Member States on this topic would be helpful.

• CIMR and 5G: agenda item 1.2 of WRC-23 may result in new 5G systems near7 GHz. A preliminary study from ANFR/France showed that this would have a very detrimental impact on CIMR channel at 6.9 GHz. There is no allocation to EO sensors in this frequency range, so this study will not be formally taken into account for WRC-23. However, Working Party 7C of the ITU-R is developing anew ITU-R Report where the work done on EO sensors and 5G can be gathered and used as future reference.

The issue of new transmitters trying to occupy bands needed for radiometry is ever present, and a variety of mitigating steps are being studied by ESA project Teams (particularly CIMR and Sentinel-3 Next Generation Topography). The issue of new 5G systems under WRC-23 agenda item 1.2 is however particularly worrisome.

• CRISTAL radiometer: the radiometer supporting the IRIS altimeter will be provided by NASA/JPL as done for Sentinel-6. This radiometer (AMR-CR)includes one frequency channel centred at 34 GHz, which is outside the frequencies allocated to EO sensors, and corresponds to a frequency used by powerful military radars (in the 33.4-36 GHz band). One of these radar systems, the KREMS from the USA military, is known and ESA (via NOAA) has established a procedure to ask the KREMS American operators to avoid tracking Sentinel-3and Sentinel-6. The same procedure can be applied to CRISTAL. However, this frequency allocation is also used by other Earth-to-Space military radars more powerful than KREMS, at unknown locations in Russia and China. It is very unlikely that the collaborative approach used for KREMS can be applied to these Russian and Chinese radars. Also, operating in-band with respect to these radars does not provide out-of-band attenuation.

The CRISTAL project highlighted that NASA has reported that the same mitigation measures applied to Sentinel-6 MF will be applied to CRISTAL, i.e. to add CRISTAL to the “exclusion list” of KREMS (i.e. list of objects they will not track) and the implementation of an internal protection circuit which triggers when the RF input power reaches a critical threshold.

6.3 ESA Climate Change Initiative (CCI)

6.3.1 Background

Combined satellite and *in situ* data archives can be used to produce data products for climate monitoring, modelling and prediction. To this end, the ESA Climate Change Initiative (CCI) was launched in 2009. The CCI has been created to address the GCOS Essential Climate Variable (ECV) requirements for satellite datasets and derived products. Its principal objective is “*to realize the full potential of the long-term*

global Earth Observation archives that ESA together with its Member states have established over the last thirty years, as a significant and timely contribution to the ECV databases required by the UNFCCC". The CCI focuses on the exploitation of data records primarily, but not exclusively, from past ESA satellite missions, for the benefit of climate monitoring and climate research. It complements existing efforts in Europe (e.g. led by EUMETSAT through the CM SAF) and internationally which focus on datasets characterizing meteorological aspects of the climate system.

6.3.2 CCI Phase 1

A competitive tender for proposals to generate climate-quality products addressing a first set of ECVs was released by ESA in the last quarter of 2009. As part of CCI phase 1, between August and December 2010, ten *ECV_cci* projects were launched. In addition to the ten *ECV_cci* teams, a CCI Climate Modelling User Group (CMUG) consisting of major European climate modelling centres was set up. At all stages of the program, its task was to provide a climate modelling perspective on the CCI, and to test datasets generated in the CCI within their models. CMUG also aims to provide an interface between the CCI and the international climate modelling community. Finally, a CCI project on sea ice was launched in January 2012, together with two other projects dedicated to ice sheets and soil moisture, though funded under a different scheme. All CCI projects have reached the end of Phase 1 of the programme and generated ECV data products. The CMUG project Phase 1 was also completed by its deadline at the end of March 2014. In 2014 the *Ice_Sheets_cci* was split into two parallel contractual activities, covering respectively the Greenland and the Antarctic Ice Sheets.

6.3.3 CCI Phase 2

The last project to complete Phase 1 was the *Ice_Sheets_cci* at the end of March 2015. The kick-off meeting for Phase 2 of its two parts were held at the end of April 2015.

As the ECV products matured, the focus of project teams expanded from the specifications of the data sets to looking at how the data can be used, both across the CCI programme and in broader climate and environmental research questions.

The CCI project teams continued to make scientific publications in high impact scientific journals. The projects have also had time to promote their data sets more widely within their research communities. This means that some products have been downloaded extensively. There are variations between the projects depending on the product maturity, competition from other products, size of the research community, and how international it is but all are seeing a sea increase in users of their data.

6.3.4 Current status

The implementation of the CCI programme continues nominally with the following highlights to be noted:

- The Intergovernmental Panel on Climate Change (IPCC) released its Assessment Report for Working Group II on impacts, adaptation and vulnerability in February 2022. Papers from the CCI were cited 70 times.

- ESA submitted on behalf of the Systematic Observation community a synthesis report on "The role of Systematic Earth Observations in the Global Stocktake" to UNFCCC. The report can be downloaded from UNFCCC Submission Portal: https://www4.unfccc.int/sites/SubmissionsStaging/Documents/202203012343---SO-in-GST-2022-final.pdf
- Following the successful selection of ESA's proposal to host the WCRP's Coupled Model Intercomparison Project International Project Office (CMIP-IPO) at ESA-ECSAT, the office has now started working as of 1 March 2022, https://climate.esa.int/en/news-events/esa-to-host-new-cmip-international-project-office/
- The 12th CCI and Climate Modelling User Group colocation meeting will be held 24-27 October 2022 in ESRIN, Frascati, Italy.
- The implementation of phase 2 is on-going, with extensions to existing ECV projects under theme i) and theme ii) being placed. The ITT on vegetation parameters has been placed. The ITT for precursor for ozone and aerosol to extend the portfolio of ECVs is under assessment. The ITTs for the 2nd slice of the sea-level budget closure and the long-lived greenhouse gases are planned for Q2/Q3 2022.
- A new ECV project, Vegetation Parameters project kicked off in March 2022.

6.3.5 Scientific highlights

• **Lakes**: A global analysis of the effect of climate on lakes (Woolway et al, Nature, 2021), drawing on data from the CCI Lakes project, was included in the recently released IPCC AR6 working group 2 report on the climate impacts, adaptation and vulnerability.

• **Permafrost**: A ground temperature map from CCI for the northern hemisphere features in a paper (Miner et al., Nat Rev Earth Environ., 2022) on advances in tracking permafrost carbon dynamics, one of a special collection of papers on permafrost thaw and its impacts. The permafrost CCI project is promoting the definition of standard guidelines for the inclusion of kinematic information for inventories of rock glaciers, which are highly sensitive to climate change. A paper in review tests the feasibility of the common rules across 11 regions for 3,600 rock glaciers – the first internationally coordinated effort for rock glaciers.

• **Aerosol**: Popp, T.; Mittaz, J. Systematic Propagation of AVHRR AOD Uncertainties—A Case Study to Demonstrate the FIDUCEO Approach. Remote Sens. 2022, 14, 875. https://doi.org/10.3390/rs14040875

• **Ozone**: Coldewey-Egbers, M., et al.: Global, regional and seasonal analysis of total ozone trends derived from the 1995–2020 GTO-ECV climate data record, Atmos. Chem. Phys. Discuss. [preprint], https://doi.org/10.5194/acp-2021-1047 , in review, 2022.

• **GHG**: Copernicus Climate Change Service released a press release ("Globally, the seven hottest years on record were the last seven; carbon dioxide and methane

concentrations continue to rise") which uses the C3S/CCI CO2 product the C3S/CCI CH4 product.

• **Sea Ice:** introduces a set of 7 sea ice variables for the GCOS update: Lavergne, T et al, A new structure for the sea ice essential climate variables of the Global Climate Observing System, Bulletin of the American Meteorological Society pp. 1-41. ISSN 0003-0007 (2022) doi:10.1175/BAMS-D-21-0227.1

• **Sea Level:** New monthly sea level anomalies and associated trends at specific coastal sites located in almost all the world coastal ocean covering 2022-2020 has been distributed for users (https://doi.org/10.17882/74354). The description of the dataset has been accepted for publication: Cazenave et al., New network of virtual altimetry stations for measuring sea level along the world coastlines, Nature Communications Earth and Environment.

• **Ocean Colour**: Afonso Ferreira, Joaquim Dias, Vanda Brotas, Ana C. Brito. A perfect storm: An anomalous offshore phytoplankton bloom event in the NE Atlantic (March 2009), Science of The Total Environment. Volume 806, Part 3, 2022, https://doi.org/10.1016/j.scitotenv.2021.151253

• **Glaciers:** Tielidze, L. G. et al: Strong acceleration of glacier area loss in the Greater Caucasus between 2000 and 2020, The Cryosphere, 16, 489–504, https://doi.org/10.5194/tc-16-489-2022 , 2022. The study mapped glacier glacier changes in the Caucasus using Landsat TM and ETM+ and Sentinel-2 and SPOTS 6/7 images. The glacier area decreased by 23.2% or -1.16% a-1. Compared to earlier inventories this is more than a doubling of the area loss rate, with rates of loss highest towards smaller glaciers.

• **Greenland Ice Sheet:** Horwath, M., et al .: Global sea-level budget and ocean-mass budget, with a focus on advanced data products and uncertainty characterisation, Earth Syst. Sci. Data, 14, 411–447, https://doi.org/10.5194/essd-14-411-2022 , 2022

• **CMUG:** all newly developed CMUG diagnostics for the CCIs sea surface salinity, land surface temperature, ocean colour, water vapour and greenhouse gases (xch4) are included in the next official ESMValTool release (v2.5).

6.3.6 New Datasets

The following new datasets are available on the CCI Open data portal (http://climate.esa.int/data):
• **Water Vapour Total Column Water Vapour over land** (CDR1), v3.2 dataset collection
• **Land Surface Temperature:** Multisensor Infra-Red (IR) Low Earth Orbit (LEO) land surface temperature (LST) time series level 3 super collated (L3S) global product(1995-2020), version 2.00
• **Lake products**, Version 2.0
• **Snow:** Daily global Snow Cover Fraction - snow on ground (SCFG) from AVHRR(1982 - 2018), version 2.0

• **MODIS Fire_cci Burned Area Grid product**, version 5.1
• **Sea Level Budget Closure Climate Change Initiative** (SLBC_cci): Time series of global mean sea level budget and ocean mass budget elements (1993-2016, at monthly resolution), version 2.2.