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Information Document

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

CGMS is informed of the status of the European Space Agency's **Earth Observation missions currently in-orbit**. Three of them – MSG, MTG and MetOp – are in co-operation with EUMETSAT, as are the future Aeolus-2 and EPS-Sterna programmes.

Meteosat Third Generation Imager 1 (MTG-I1) was launched successfully in December 2022, and this marked the advent of a new generation of meteorological satellites that will provide better monitoring and forecasting of severe weather events. Data from two instruments onboard MTG-I1 – the Flexible Combined Imager (FCI) and the Lightning Imager (LI) – were successfully combined for the first time in September 2023, highlighting their synergistic power potential impact.

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 series of satellites until Sentinel-6 Michael Freilich in November 2020. Others will follow in the coming years from the next generation of Sentinels and from the expansion missions. Sentinel operations continued nominally throughout 2023.

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 – SMOS, CryoSat-2 and Swarm – currently in orbit are 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. End-Of-Life Activities were conducted from 3 April to 5 July 2023, and Aeolus was successfully deorbited on 23 July 2023. Aeolus was the first satellite mission to successfully acquire wind profiles at a global scale and a follow-on Aeolus-2 mission is in the planning, in collaboration with EUMETSAT.

The Proba-V Cubesat Companion (PV-CC) was launched on 9 October 2023 as part of the Small Satellites Mission Service (SSMS) rideshare mission, on board Vega flight VV23. The PV-CC successfully concluded its LEOP activities less than 24 hours after launch and its commissioning activities began straight afterwards.

CGMS is further informed of the status of the European Space Agency's **Earth Observation future missions**. While ESA has a wealth of experience under its belt in observing Earth from space, the sector is changing rapidly – becoming increasingly competitive, but also offering new opportunities as concepts like New Space evolve and the digital revolution gathers pace. Through its Future Earth Observation programme (FutureEO), ESA is committed to remaining ahead of the game.

Progress in the preparation of the forthcoming Explorer missions – EarthCARE, Biomass, FLEX, FORUM and Harmony – is described in this report.

In November 2023 two candidates for the next and 11th Earth Explorer (EE11) research mission were selected to proceed to Phase A feasibility - CAIRT and WIVERN.

A call for ideas was issued for Earth Explorer 12 (EE12) proposals in February 2023, and 4 mission ideas were selected in March 2024 to proceed to Phase A assessment – CyroRad, ECO, Hyrdoterra+ and Keystone. Notably, each of the four EE12 recommended mission ideas were variants/improvements of previously submitted Earth Explorer proposals.

Activities related to Aeolus-2, Arctic Weather Satellite (AWS) in cooperation with EUMETSAT, TRUTHS, SCOUTs and ALTIUS are ongoing. Each of these missions are planned to contribute routine, operational monitoring data to improve our understanding of the Earth system and climate change.

Six Copernicus Expansion Missions – CHIME, CIMR, CO2M, CRISTAL, LSTM, and ROSE-L – are being studied to address EU policy and gaps in Copernicus user needs, and to expand the current capabilities of the Copernicus space component. The System Requirements Reviews for all 6 missions have been completed.

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 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. Specifically the CCI supports the study and monitoring of 23 essential climate variables (ECV) derived from satellite data, thereby helping to fulfil the objectives of the WMO Global Climate Observing System (GCOS).



Table of Contents

1. INTRODUCTION5

2. ESA COUNCIL MEETING AT MINISTERIAL LEVEL – 2025 (CM25)5

3. CURRENT ESA SATELLITE SYSTEMS6

4. STATUS OF CURRENT EARTH EXPLORER SATELLITES7

4.1. SMOS.....7

 4.1.1. Status of Spacecraft7

 4.1.2. Performance and results8

4.2. CryoSat-212

 4.2.1. Status of spacecraft and mission12

 4.2.2. Performance and results12

4.3. SWARM15

 4.3.1. Status of spacecraft15

 4.3.2. Performance and results16

4.4. Aeolus18

 4.4.1. Platform18

 4.4.2. Payload18

 4.4.3. Ground Segment.....19

5. STATUS OF CURRENT EARTH WATCH SATELLITES21

5.1. Proba-V and Proba-V CubeSat Companion21

 5.1.1. PV-CC Operations21

 5.1.2. Proba-V Operations22

 5.1.3. Data products and quality23

6. THE COPERNICUS SENTINEL PROGRAMME24

6.1. Sentinel-1A and 1B.....25

6.2. Sentinel-2A and 2B.....27

6.3. Sentinel-3A and 3B.....28

6.4. Sentinel-5P30

6.5. Sentinel-6 Michael Freilich (Jason-CS)31

7. FUTURE ESA SATELLITE SYSTEMS33

7.1. Future Earth Explorer and Earth Watch missions33

 7.1.1. EarthCARE : Earth Explorer 6th33

 7.1.2. Biomass: Earth Explorer 7th34

 7.1.3. FLEX: Earth Explorer 8th35



- [7.1.4. FORUM: Earth Explorer 9th 36](#)
- [7.1.5. HARMONY: Earth Explorer 10th 37](#)
- [7.1.6. Earth Explorer 11th 38](#)
- [7.1.7. Earth Explorer 12th 40](#)
- [7.1.8. NGGM Gravity Mission 42](#)
- [7.1.9. Aeolus-2 43](#)
- [7.1.10. Arctic Weather Satellite \(AWS\) 44](#)
- [7.1.11. TRUTHS 45](#)
- [7.1.12. ALTIUS 46](#)
- [7.2. Future Sentinel missions \(planned and potential\) 47](#)
 - [7.2.1. Sentinel-1 C and D 47](#)
 - [7.2.2. Sentinel-2 C and D 47](#)
 - [7.2.3. Sentinel-3 C and D 47](#)
 - [7.2.4. Sentinels-4/-5 47](#)
 - [7.2.5. Sentinel Next Generation 49](#)
- [7.3. Copernicus Expansion Missions 51](#)
 - [7.3.1. CHIME: Copernicus Hyperspectral Imaging Mission 51](#)
 - [7.3.2. CIMR: Copernicus Imaging Microwave Radiometer 51](#)
 - [7.3.3. CO2M: Copernicus Anthropogenic Carbon Dioxide Monitoring 52](#)
 - [7.3.4. CRISTAL: Copernicus Polar Ice and Snow Topography Altimeter 53](#)
 - [7.3.5. LSTM: Copernicus Land Surface Temperature Monitoring 53](#)
 - [7.3.6. ROSE-L: L-band Synthetic Aperture Radar 54](#)
- [7.4. ESA Climate Change Initiative \(CCI\) 55](#)
 - [7.4.1. Background 55](#)
 - [7.4.2. Current status 55](#)
 - [7.4.3. Scientific highlights 56](#)
 - [7.4.4. New Datasets 57](#)
 - [7.4.5. CEOS/CGMS Working Group on Climate \(WGClimate\) 57](#)

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 as of April 2024. 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 within this report.

Current in-flight missions include R&D satellites missions from the Earth Explorer series, small satellites of the Proba series, and Sentinel satellites. The Sentinels specifically respond to the needs of Copernicus, which is the Earth Observation component of the European Union's space programme. The status of these 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.

Important note: The status provided in this document reflects the situation as of April 2024. Dates for launches and all other activities in the future are indicative at the time of writing.

2. ESA COUNCIL MEETING AT MINISTERIAL LEVEL – 2025 (CM25)

ESA's Ministerial Councils bring together ESA's Member States and observers every three years to decide on new proposals and funding for ESA's next years of work. The last such an ESA Council meeting at Ministerial level was held in Paris from 22-23 November 2022.

The next ESA Council at Ministerial level will be held in 2025. Government ministers representing ESA's Member States, Associate States and Cooperating States will resolve together to strengthen Europe's space ambitions, ensuring a continuous concerted effort to serve European citizens.

3. CURRENT ESA SATELLITE SYSTEMS

Satellites	Equator Crossing Time /Altitude	Launch date	Access to data or products	Instruments	Status, Applications, and other information
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. (EOL 23/07/2024)
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
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		
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-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-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-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
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-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

4. 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 Aeolus (which was deorbited in July 2023) and GOCE (which was retired in 2013), have provided outstanding results of interest to the meteorological and climate research communities at large. The overall performance of the SMOS, CryoSat, and 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.

4.1. 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.

4.1.1. Status of Spacecraft

The platform is operated under CNES responsibility. Two Collision Avoidance Manoeuvres (CAM) had to be performed on the 29 December 2023 and on 3 January 2024, in both instances due to Chinese space debris. Two routine Orbit Correction Manoeuvres (OCM) were performed on 2 October and 26 November 2023.

During this period SMOS payload has been operated nominally except for some minor payload anomalies. In total, all the anomalies in this period caused 51 min and 3 sec of on-board data losses (0.04%) and 3 hours and 38 min of on-board degraded data (0.16%), from 1 October 2023 to 1 January 2024. This results in an overall mission performance of 99.79% during that period. The cumulative data, lost since 1 May 2010 amounts to 0.08% and the degraded data amounts to 0.49%, resulting in an overall mission performance of 99.43%.

The temperature of MIRAS segment A1 reached its first expected maximum, 30.16 degrees, at the start of the eclipse season on 11 November 2023. This value is well in line with the values seen in 2022 and inside its expected evolution.

4.1.2. Performance and results

Performance

Globally, 100% of the dumped passes have been acquired. The acquired data were successfully processed to 99.25% for all product Levels including near-real time (NRT) for the period between 15 September and 15 December 2023. Work is underway to recover the data. The timeline of 165 minutes for the NRT products was met in 98.1%.

A monthly report on SMOS data performances is available on:

<https://earth.esa.int/eogateway/instruments/miras>.

Data Access

SMOS data can now be accessed through the Copernicus Data Space where it is listed under complementary data <https://dataspace.copernicus.eu/complementary-data>.

Since the opening of the ESA SMOS dissemination data service in March 2016, approximately 45.5 million products have been downloaded by more than 4306 active accounts (cumulative number of accesses), with an average of 40 new users per month in the last year, for a total volume of about 2009TB up to 30 November 2023.

The reprocessing Metric Campaign L1 continued in this quarter adopting the last version of the L1OP v780. Preliminary results for the L1 metric dataset have been reported during the SMOS QWG (Quality Working Group) in November 2023. The Expert Support Laboratory has finalised the analysis of the retrieved soil moisture, L-VOD, and sea-ice thickness from the Principal Component Analysis (PCA) dataset. Results show improvements in L-VOD estimations and a slightly neutral impact for soil moisture and sea ice-thickness retrieval. The QWG agreed to include this algorithm evolution in the final reprocessing metrics. The analysis of the revised Gibbs-2 image reconstruction algorithm was also finalised and it will be included in the final reprocessing metrics. Results for Sun Glint correction at Level 1 and improved definition of radiometric resolution were presented with not optimal performances for sea surface salinity retrieval, therefore the QWG has agreed to further review the algorithms. SMOS-derived Sky map dataset generated during previous quarter has been further processed to obtain a complete L-band map of the sky. The new map still has calibration inconsistency with the reference ground-based sky map therefore further analysis will be done in Q1 2024 focussed on the calibration approach used to process data acquired in external pointing mode.

A reprocessing metric campaign will continue in Q1 2024 by assessing the ALL-LICEF mode and the RFI filtering algorithm at level 1. The results of the final metric exercise will be reviewed at the next

QWG in May 2024.

Radio Frequency Interference and Frequency Coordination

As of 30 November 2023, there were 437 RFI sources worldwide active, of which 40% are strong sources with brightness temperature (BT) between 1000 K and 5000 K, and 13% are very strong sources with brightness temperatures higher than 5000 K. The total number of RFI sources has decreased (-18) 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 Nigeria, Guyana, Mexico, Azerbaijan, Croatia, Sudan, and Brazil. Regular contacts have been made with the British and Canadian administration to update the status of interference in the country.

Unlike the rest of the world, the RFI situation in Eastern Europe remains challenging.

SMAP-SMOS coordination to report together to those administrations affected by RFI, which was agreed in 2021, is working very well, contacting three National Administrations in this period. This cooperation is considered an important element to keep on getting better the RFI status all around the world.

SMOS Data Quality Evolution, Product Portfolio Evolution

The Expert Support Laboratory (ESL) team has worked following the Phase-2 workplan with a nominal progress. The Service Review #8 was passed successfully on 30 November 2023.

Level 1:

- The version of L1OP v780 is used for the generation of L1 metrics. A new L1OP version v781 correcting few Software Problem Report (SPR) and with minor evolutions is planned for Q1 2024. This version will be used as baseline for the 4th mission reprocessing.
- Analysis of telemetry dataset during the GPS anomaly has shown a corruption in the PVT which prevented the processing of the science dataset. A data patching strategy has been implemented with recomputed PVT from CNES.
- Optimal configuration for All-LICEF calibration mode and empirical correction to reduce “bowl-shape” bias has been selected for the metric computation. Consistency between antenna losses determination, looking to the cold sky and losses application when pointing nominally is still under investigation.
- Validation of prototype SMOS VTEC product has continued focussing on the Night Winter Anomaly (NWA) detection. The local time SMOS observing the region of interest is not optimal

therefore conclusion cannot be derived.

- Solar flux from SMOS dataset is operational generated by L1 ESL (latency one day) and used in the processing of the L2 sea surface salinity and sea surface winds to correct for Sun glint effect.
- A strong Solar Radio Burst (SRB) was detected by SMOS on 14 December 2023. ESL has analysed the event. The SRB was associated with a strong flare in X-ray peaking at 17:02 (UTC). The SRB had a strong circular polarization component which has impacted the GNSS signal over South America Area.

Level-2:

Soil Moisture (SM)

- The version v730 of the L2 soil moisture processor was delivered in June 2023. Acceptance and verification activities has been completed. The next version v740 delivery is planned by Q1 2024. This version will be used in the next 4th mission reprocessing. It includes improvements in auxiliary data for vegetation characterization by lidar dataset (GEDI, ICESat-2) and improvements in RFI screening by using available flags in the Level-1 product.
- ESL focused on analysing the L2 dataset derived from the L1 metrics campaign and reporting to QWG.
- Scientific activities have continued with slow progress:
 1. A specific test dataset for the parametrisation of the 2-Stream Radiative Transfer has been generated and is still under analysis. Results will be reported in a technical note in Q2 2024.
 2. For algorithm evolution, activities are on-going to retrieve ground permittivity, snow parameters and to screen out frozen soil.
 3. L-VOD dependency with temperature has been further analysed also considering frozen / unfrozen wood cells in the model.

Sea Surface Salinity (OS)

- Blind Test 2023 exercise (to compare the performance of the novel DnB algorithm with the nominal one) is now ready for execution, but still on-hold, waiting for the consolidation of L2OS v730 DnB chain. The validation protocol overhaul has been performed. A dedicated script to merge the blind test outcomes for easier inspection is on hold.
- The L2OS v730 processor will focus on the DnB temporal correction and the nominal algorithm latitudinal/seasonal correction. Its implementation is finalised. Related documentation has been prepared/reviewed and the related FAT was held in September 2023. Additional verification resulted in geophysical discrepancies with the breadboard, which was assessed and sorted out.

A novel 3-yr dataset to compile again two critical LUTs is now being processed at the NoR facilities. It will be the software version to be used in the “Blind Test” exercise and a batch processing to be undertaken in AdwisEO facilities is ready to be launched.

- A reshuffling of the activities to meet time constraints has been discussed at the PM#52 in October 2023. During QWG-37, it was agreed that a novel L2OS v735 version will be implemented in parallel, with a major focus on the ice-sea contamination correction proposed by ODL. This would enable the generation of a novel dataset with remarkable improvements in view of the next mission extension preparation. Processor delivery is estimated for March 2024.

Sea ice thickness

- The ESL has continued to work on the validation of a Level 3 sea ice thickness product for the Antarctic region. The product, considered experimental, has been delivered to users in November 2023: <https://earth.esa.int/eogateway/news/experimental-version-of-smos-antarctic-sea-ice-thickness-product-is-now-available>. The validation paper is under review.
- ESL has updated the Level 4 SMOS/Cryosat sea ice thickness product to v206. The new product has been disseminated to users since November 2023. The full archive has been reprocessed: <https://earth.esa.int/eogateway/news/new-version-v206-of-the-smos-cryosat-level-4-sea-ice-thickness-product-is-now-available>.

Wind

- Algorithm improvements have been validated. The operational processing chain at FMI has been implemented and the full mission archive has been reprocessed. Since the beginning of November 2023, the new product v300 has been disseminated to users: <https://earth.esa.int/eogateway/news/14-years-of-reprocessed-smos-freeze-thaw-soil-status-products-are-now-available>. A minor update to version v301 was implemented in December 2023 to cope with an interface change in the L3 input product from CATDS.
- A further processor upgrade is envisaged by exploration of the usage of the multi angle measurements during phase-2 of the ESL contract.

Soil Freeze/Thaw

- Algorithm improvements have been validated. The operational processing chain at FMI has been implemented and the full mission archive has been reprocessed. Since the beginning of November 2023, the new product v300 has been disseminated to users: <https://earth.esa.int/eogateway/news/14-years-of-reprocessed-smos-freeze-thaw-soil-status-products-are-now-available>. A minor update to version v301 was implemented in December 2023 to cope with an interface change in the L3 input product from CATDS.
- A further processor upgrade is envisaged by exploration of the usage of the multi angle

measurements during phase-2 of the ESL contract.

4.2. 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.

4.2.1. Status of spacecraft and mission

Overall, the space segment performed nominally with no major issues. The payload units MMFU, SIRAL and DORIS were fully nominal.

For the payload, the reconfiguration of the RCS from the leaking A branch to the B one was performed successfully on 21 November 2023. Preliminary assessment of the RCS-B and propellant consumption indicate no leakage and performance like those of the RCS-A side prior to the anomaly. However, during a slew test, a significantly higher use of the roll control thrusters and higher roll errors than using the RCS-A were observed. Also, during nominal fine pointing mode, a higher actuation of the roll control thrusters was observed. This behaviour is under investigation and could be due to a slight mis-pointing of the yaw control thrusters which introduce a parasitic roll.

Six Orbit Control Manoeuvres (OCM) were executed during the reporting period to keep the satellite within the required ground track dead-band. The current high rate of manoeuvres is the result of the increased drag due to expansion of the atmosphere density approaching the peak of the 11-year solar cycle. At the time of the last minimum, 2018 to 2020, the annual average was 6 manoeuvres.

4.2.2. Performance and results

Performance

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

Continuous efforts are underway to improve the stability, functionality, and business continuity of the Payload Data Ground Segment (PDGS). These efforts are focused on ensuring robust support for mission operations in the foreseeable future. A critical aspect of this initiative is the implementation of a new system architecture for data dissemination, designed to align with the ESA Earth Observation Programme (EOP) Security Framework requirements, with a targeted deployment in the first quarter of 2024. Concurrently, there is an ongoing process to assess and integrate additional new security requirements. This also includes evaluating mitigation actions to address the obsolescence of legacy

systems, ensuring long term service continuity. In view of the planned dismissal of the ESRIN private cloud infrastructure, a new pilot project has started to migrate the miniPDS to the esa-cloud infrastructure. The SIRAL instrument was programmed according to the current CryoSat Geographical Mode Mask 5.0.

During the reporting period, the end-to-end mission performance, namely the overall mission data return that considers the planned (0.48%) and unplanned unavailability (0.01%) of the space and ground segments, was 99.50%. Since the start of the mission, the overall availability of the science data has been 98.69%, well above the design performance of 94.00%. The system availability, which considers only failures, is 99.17%.

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

Availability of the NRT and NOP operational products were in line with the expected performance.

Data Access

Over the reporting period, an aggregate grand total of more than 97 TB of products were downloaded from the Science Server (<https://earth.esa.int/eogateway/missions/cryosat/data>).

Data Quality and Evolution

During the reporting period, no major issues were found, confirming the excellent status of the instrument. The overall quality of the CryoSat product portfolio was very good. The daily quality and operational control of the ice and ocean CryoSat products were carried out by IDEAS+ (UK). Detailed quality control of the L2 ice products was carried out by Mullard Space Science Laboratory (MSSL, UK). The National Oceanography Centre (NOC, UK) produced validation reports specific to L2 CryoSat Ocean Products (COP), including reprocessed datasets.

The Technical University of Delft (TUD, NL) carried out complementary quality control and long-term science validations of the L2 CryoSat Ocean products (COP) and CryoSat orbit solutions. A paper investigating temporal gravity field modelling for precision orbit determination of CryoSat-2 was published *Advances in Space Research* by Schrama, *et al.* A second paper on the performance and validation of CryoSat ocean data was published by Naeije, *et al.* in the *Remote Sensing* journal.

Long-term monitoring of the instrument performance is constantly carried out by ARESYS (IT) and periodically reported. During the last quarter, no major issues were found except for a slight decrease

in the phase difference (in absolute value), observed between March and June 2023, which seems to have stabilised in the recent period. No root cause was found.

IsardSAT (ES) and Technical University of Crete (TUC, Gr) continued to perform independent quality control of the SIRAL radar parameters throughout the processing of the transponder data over Svalbard, Crete and Gavdos, including the comparison of sea level at tide gauges in Crete and Gavdos.

Product portfolio evolution

CRYO-TEMPO EOLIS (<http://www.cryotempo-eolis.org>)

During the reporting period, the team continued working on the development of the algorithm to produce a new gapless product over the two ice sheets from the combination of CryoSat-2 Swath and POCA data generated by Cryo-TEMPO Land Ice. In addition, gridded products have been prepared for release in 2024 over new glacier regions, including Arctic Canada, Russian Arctic, Southern Andes, Alaska, Greenland periphery glaciers, Antarctic and Subantarctic Islands and the expansion to all of Svalbard and Iceland. An analysis on the algorithm for new products over Antarctic ice shelves has started.

CRYO-TEMPO

During the current reporting period, activities continued across all Thematic Areas; Land Ice, Winter and Summer Sea Ice, Polar Ocean, Coastal Ocean, and Inland Water, with a focus upon the final validation of the Phase 2.2 algorithms and preparation for their transfer to operation. Assessments of the Phase 2.2 products across all themes, by both the science teams and the Thematic User Group, were presented and discussed at the third User Consultation Meeting, which took place in ESRIN in November 2023. Analysis based upon Cryo-TEMPO data was published in a high-impact paper in Nature Communications by Wallis *et al.* and presented at the ESA-EC Earth System Science Initiative.

Ocean Level-1 and Level-2 Baseline D

Following recommendations from the CryoSatQWG#9 meeting hosted by the University of Porto on 26-28 September 2023, work is ongoing to fix remaining anomalies. Transfer to operation is planned for Q2 2024.

Ice Level-1 and Level-2 Baseline F

Anomalies to be fixed and evolutions to be implemented in the next Ice Baseline F was frozen in January 2024 and active development started right after. Transfer to operation is planned for Q3 2025.

4.3. 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.

4.3.1. Status of spacecraft

Overall, the three-spacecraft performed nominally during the reporting period.

The high trend of collision warnings increased in the current quarter, with eleven escalated events and two CAMs executed, including one with a return manoeuvre. In total, during 2023, 32 high risk events were escalated and required effort to be analysed in detail; in some cases a CAM to be prepared and in 7 cases to be executed. In comparison, in 2022 the escalated events were 28 and CAMs executed 6. The most relevant cases in the quarter are reported hereafter.

Following a close approach warning between Swarm-C and Cosmos-1455 (1983-037A), with a collision probability of $2.89E-4$ and a time of close approach 17 November 2023 18:44:19 UTC, a collision avoidance manoeuvre was successfully executed on 17 November 2023 to raise the orbit of the satellite and reduce the collision risk. A return manoeuvre was also executed to keep the along-track separation of the lower pair in the routine deadband (4-10 seconds).

Following a close approach warning between Swarm-B and Cosmos-1703 (1985-108A), with a collision probability of $1.2E-4$ and a TCA 9 December 2023 21:25:00 UTC, a collision avoidance manoeuvre was successfully executed on 9 December 2023 to raise the orbit of the satellite and reduce the collision risk.

In the last quarter, several close approach warnings were escalated but did not require a CAM due to the favourable evolution of chaser and/or target orbit, amongst these:

- Swarm-A with INS-2TD (2022-013C) cubesat, Cosmos-1515 (1983-122A), Unknown catalogued object (2023-081G), Yinhe 2-04 (2022-023D), Unknown catalogued object Unknown (2023-081AB) and LINCS 1 (2021-059Z).
- Swarm-B with Jilin-1 Gaofen 3D-53 (2022-155D) cubesat and Wenchang 1-02 (2022-019E);
- Swarm-C with ADLER-2 (2023-054K) cubesat.

As mentioned before, in some cases, the preparations went up to the preparation of the CAM, the generation of the commands and the booking of extra passes to uplink, but they were stopped in time before the uplink of the commands to the on-board timeline.

To increase the altitude separation between Swarm-B and the Swarm lower pair, decreased to 13km

after the last Alpha and Charlie orbit raise campaign, it was decided to increase Swarm-B's orbit by ~18-19km. The altitude raise was a trade-off between the altitude evolution in the next years and the altitude of big constellations a few kilometres above the new Swarm-B mean orbit. The operation took benefit on the long-duration manoeuvres approach carried out in 2022 and 2023 for the lower pair and consisted in 4 double-revolution firing manoeuvres, one per week for a total of 4 weeks. The manoeuvres were performed on 28 September, and 5, 12 and 19 October 2023. The different altitude decay of Swarm-B versus Swarm-A/C, and possible orbit raises, will mean an accumulation of a more substantial vertical separation over the next months and years.

4.3.2. Performance and results

Performance

On 28 September 2022, the new Level-1 v3.24p4 and Level-2 Cat-2 v1.20 processing baseline was put into operation, simultaneously with the release of the 2nd full mission reprocessed products, providing fully consistent datasets from the beginning of the Mission to the present. Since then, the nominal processing chain has been fully operational. The patch for the Level-1 operational processor (v03.24p5), fixing some minor issues with MOD data, was transferred to operations on 27 June 2023, but was rolled back to the previous version on 28 August 2023 due to some regression problems found.

All ingestion, Level 1 and Level 2 processing, archiving, and dissemination functions are running nominally. During the period from mid-September to mid-December 2023, 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 also 100%. Daily EEF production is received regularly from the University of Colorado since mid-March 2020. The actual data availability, taking also into account spacecraft tests, instrument problems, failures in previous processing steps, and missing auxiliary files, was 100% for both Level 1 and Level 2 products.

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

Data Access

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 reporting period, more than 11.1 TB of Swarm data products - corresponding to almost 1.47 million files - have been distributed to Cal/Val and general users. The ESA Swarm dissemination server also hosts under the Multimission folder CryoSat-2, CASSIOPE/e-POP, CHAMP, GRACE, and GRACE-FO data coming from several Swarm related projects.

Data Quality Evolution

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 Swarm Level 1B v03.24p4 and Level2-Cat2 v01.20 Operational Processors have been working nominally in the reporting period. A new patch for the L1B Operational Processor (v03.24p6) has been delivered and validated in November 2023. This patch includes fixes of the two issues related to MOD data that was already included in v03.24p5, together with the fix spotted after the TTO of the previous patch relevant to the computation of quaternion for the transformation between the Spacecraft and NEC (North-East-Centre) reference frames.

The reprocessing with v03.24p6 of ORBATT and MAGNET data between October 2018 and August 2023 has started in December 2023 and will be completed in the next reporting period.

After that, the L1BOP v03.24p6 will be transferred into operations.

The Data Quality Team continues working to implement further evolutions to be included in the upcoming L1BOP v03.25 release. The key improvements will be:

- New particle counter product based on Star Tracker data.
- Improved dB_Sun model that considers the degree of Earth's eclipse of the spacecraft and the direction towards the Sun in the Magnet processing chain.
- New parameters related to ion density measures in Plasma products and error computation improvements.
- Flagging improvements on Plasma products.

4.4. Aeolus

Aeolus was launched on 22 August 2018 and was deorbited on 23 July 2023. Aeolus was the first satellite mission to acquire profiles of Earth's wind on a global scale. The primary objective of the Aeolus mission was to demonstrate the Doppler Wind Lidar technique to measure wind profiles from space. The mission set 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 was assimilated into NWP models, to improve the analyses and forecasting of the 3-D vector wind field. A secondary mission objective was to provide datasets suitable for the evaluation of climate models.

4.4.1. Platform

In 2023, activities were focused on the completion of the transition to the non-operational Phase F1 which mainly consisted in the post-re-entry processing of in-flight data for platform behaviour analysis, collection of lessons learnt and the completion of decommissioning activities of ground systems used for the space segment operations, including the Flight Control Team, IT systems and infrastructures.

It is worth mentioning that, at the dedicated re-entry lessons learnt workshop held in November 2023, industry presented a convincing hypothesis for the in-flight behaviour of the platform during the final phase of the re-entry. According to this assessment, a thruster plume impingement, causing an inward deflection would be a potential explanation for the excessive platform thrusting (hence fuel consumption) observed during the final phases of the re-entry operations. This forced the Flight Control Team to use the equilibrium attitude, which ultimately allowed to complete the re-entry successfully.

Following the re-entry of the satellite, the Aeolus ITU radio frequency assignment was cancelled. All Phase E2 related activities on the platform side are now considered completed. Phase F1 platform post-mission analysis and in-flight data transfer to data retention platforms will continue. The Aeolus in-flight platform data and operational experience will be made available for future missions and operations projects.

4.4.2. Payload

A series of End-of-Life Activities (EOLA) were conducted from 3 April to 5 July 2023 with two main objectives: 1) to investigate issues during in-orbit operations, and 2) to transfer technology and knowledge to future missions. In total, there are 22 tests. Several of them, especially those to be performed in nadir pointing, were executed in April 2023 during the nominal mission with the nominal laser (FM-A) in operations. All activities went as planned until 3 May 2023 when the ALADIN instrument was switched to Standby due to an issue in preparing the EOLA#03 test (ACCD Temperature – Hot

Pixel). FM-A recovery attempts were not successful, and it was then decided to switch on the redundant laser (FM-B) and continue the test with this laser. On 18 May 2023, FM-B was brought to an optimum configuration which allowed the EOLA to be back in full swing.

The knowledge gained will be fundamental to improve the data processing and calibrations of Aeolus, Aeolus-2 and EarthCARE, and will be important for the development of future Doppler Wind Laser instruments. The main preliminary highlights from EOLA are:

- The root cause of the frequency stability issues was found and solved.
- Dark current signals (i.e. hot-pixel types) were characterised. An ideal ACCD operational temperature for Aeolus-2 (hot-pixel mitigation) was identified.
- Potential additional secondary products of Aeolus-2 were identified.
- The equilibrium attitude, used during the re-entry campaign (60% less fuel consumption due to significantly reduced drag-torque), was validated.
- At the end of ALADIN operation, we achieved a record-breaking UV energy of 182mJ.

Extensive analyses carried out by ESA, DISC and Industry are still ongoing and will be documented in a final Report to be released in Q2 2024. The Report will also include a collection of Lessons Learnt and Recommendations for future missions.

The Aeolus EOLA phase has demonstrated the usefulness of turning a small period of mission timeline into laboratory activities in space which benefits future missions as well as to address issues raised during the nominal operations. A final recommendation will be issued to include a Phase E3 - dedicated to end-of-life activities - in the baseline life-cycle framework of any future mission.

4.4.3. Ground Segment

During the reporting period, the Aeolus Ground Segment focused on coordinating and executing preparatory activities for the upcoming Phase F1. These activities include:

- Coordination of Phase Out of services: focusing on specific activities, notably COSA and DAMI.
- Review and Update of Communication Channels: a comprehensive review of the operational communication channels, involving key stakeholders such as EOHelp, TellUS, and HCINSS, is taking place.
- Infrastructure Optimization and dismissal: a detailed review of the Aeolus infrastructure was conducted to identify and dismiss obsolete systems no longer required for Phase F1. It focused also on collecting all the facilities configurations, planning coordinating and preparing the final mission reports and statistics.

Data Access

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

- Aeolus Online Dissemination http Service: <http://aeolus-ds.eo.esa.int/oads/access/>
- ESA Aeolus Online Dissemination ftp Service: <https://aeolus-ds.eo.esa.int>
- WMO in BUFR format: <https://acquisition.ecmwf.int/index.html>
- VirES: <https://aeolus.services> & <https://earth.esa.int/eogateway/missions/aeolus>

Data Quality Evolution

Nominal data production ended in April 2023, while ALADIN continued to operate until the 5 July 2023 to support the end-of-life tests. Monthly data quality reports for the publicly available L2B wind products remain available via the Earth Online Aeolus site: <https://bit.ly/3ESsnIK>.

During the reporting period, activities were dedicated to check the data quality of the reprocessed data (B16 FM-B). The reprocessing campaign is already showing an improved quality compared to previous reprocessed and near-real time NRT products. Also, it is the first time that valid L2A Feature Mask and EarthCARE-like retrieval products (AEL-PRO) are available.

The experience gained during the nominal Aeolus mission and EOLA will also have a significant effect on the improvements of future Aeolus products and update algorithms for the planned reprocessing campaigns.

5. 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.

5.1. Proba-V and Proba-V CubeSat Companion

The operations of the Vegetation instrument on-Board Proba-V ended as planned in October 2021, while the Proba-V secondary instruments (e.g., EPT instrument) are operated regularly. The Proba-V programme element remained into a period of minimal activities until the launch of the Proba-V CubeSat Companion (PV-CC), which took place successfully on 9 October 2023.

At time of writing, PV-CC is in the commissioning phase. Issues on the attitude control systems are delaying the nominal plan and Aerospacelab is dealing with them together with the component manufacturers. Some images have been acquired in the first part of the commissioning.

5.1.1. PV-CC Operations

The Proba-V CubeSat Companion (PV-CC) was launched successfully on 9 October 2023 at 1:36 UTC with the Vega flight VV23. The goal of PV-CC is to evaluate whether it is possible to mount the same sensor of Proba-V (a spare camera has been used) on a much smaller satellite and still have the same data quality. The initial plan was to make a direct comparison with Proba-V with simultaneous acquisitions, but due to the delays of the project and the launch, this comparison will be done vs Proba-V archived data and with Sentinel-3 and Sentinel-2 data.

The development of PV-CC was supported by ESA's General Support Technology Programme, based on the initiative of BELSPO and Belgium's VITO research institute. It has been built by Belgian prime contractor Aerospacelab, who also performs initial operations. Mission telecommanding and data reception services are provided by the Swedish Space Corporation (SSC – Kiruna and Inuvik ground stations) and ESA ESEC (Redu), while acquisition planning and data processing are done by VITO in Belgium. The PV-CC LEOP campaign has made use of the 3 stations (Redu, Kiruna, Inuvik) to get frequent contact with the satellite.

The PV-CC successfully concluded its LEOP activities less than 24 hours after launch and its

commissioning activities began straight afterwards. The PV-CC commissioning phase, initially planned as 3 months, will last longer due to additional time needed for the platform commissioning, followed by 2 months for the payload. The PV-CC operations during the commissioning is performed from Aerospacelab premises in a first phase, then from ESA-ESEC in Redu by Aerospacelab people with ESEC witness. After IOCR the PV-CC operations will gradually be transferred to ESEC personnel.

Since the initialisation of the platform commissioning and the first light on 12 October 2023, the team has uncovered issues in the form of unexpected behaviour of some units in the attitude control subsystem. Initially, those issues were intermittent and allowed to acquire few images allowing for initialising radiometric calibrations, as the geometric would require the final performances of the attitude control subsystem. However, at the end of November 2023, as the issues persisted and propagated to a second unit, the satellite was put in safe mode until a resolution can be identified. It is to be noted that this part of the attitude control subsystem (reaction wheels) is virtually identical to the equipment and configuration flying on Aerospacelab ARTHUR-1 satellite (known as Risk Reduction Flight).

Aerospacelab is in contact with the reaction wheel supplier to characterise the behaviour of the unit. There are multiple options that can be evaluated, tested, and implemented before resuming imaging for the PV-CC mission. Additional nominal acquisitions were performed in the first days of the commissioning and processed by VITO, showing overall good radiometric performances of the payload camera.

5.1.2. Proba-V Operations

The Proba-V satellite remains healthy. 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. The use of the Vegetation instrument is limited to carrying out lunar calibration observation campaigns during the full moon periods plus a few acquisitions on a single test side for calibration purposes. Instrument data, including Vegetation calibration acquisitions, were downloaded using S-Band passes at Redu (more than 3 per day) with additionally one download per month in X-Band.

The ESA Space Debris Office regularly informs the Proba-V Mission Control Centre at Redu about any potential collision risks with space debris (Proba-V does not feature the capability to perform debris avoidance orbit manoeuvres).

5.1.3. Data products and quality

The activities preparing the Fundamental Data Record for VGT (FDR4VGT) are progressing nominally, aiming to have a consistent 20+ years data archive from VGT instruments (SPOT-VGT and Proba-V). The Phase 1 is jointly funded by the Earthwatch Proba-V element and by the ESA Basic Activities Heritage element. In the 1st year of the Phase 1, the focus is on radiometric and geometric harmonisation of the full Level 1 archive. An update of the cloud mask and atmospheric correction algorithms for ensuring consistent Level 2 and Level 3 archive were done in Q1 2024.

The SPAR@MEP project was successfully completed in December 2022 demonstrating the potential of the PROBA-V and SPOT-VGT data series for the generation of a long-term 20+ years record of surface and aerosol products. The outcomes of the project were recently summarised in a journal paper, which was published in MDPI Remote Sensing: <https://doi.org/10.3390/rs15215109>.

The project for Land Cover at 100m aims to generate cropland, irrigated cropland, and oil palm plantation annual global maps at 100m resolution. In Q1 2024, efforts were focused on developing an advanced algorithm for oil palm plantation mapping and change detection. The algorithm baseline and validation results are really promising, showing very good overall accuracy in the classification of different oil palm plantation stages.

6. THE COPERNICUS SENTINEL PROGRAMME

Copernicus provides access on a full, free, and open basis to its Sentinel data and the Copernicus services information products. In addition to data provided by the Sentinel satellites, the missions contributing to Copernicus – the Copernicus Contributing Missions – play a crucial role, delivering complementary data to ensure that a whole range of observational requirements is satisfied.

This activity is operated by ESA as entrusted entity on behalf of the European Commission (COM). The primary users of the Contributing Missions activity are the six Copernicus services, mainly the Land, Emergency, Security and Marine services, while other users, such as EU Public Authorities, are secondary users (currently over 3000 registered users). The existing or planned Contributing Missions include commercial missions from EU Member States or Copernicus Participating States, commercial Very High Resolution (VHR) optical and radar mission operators, and other emerging European mission operators that make some of their data available for Copernicus.

Following the agreement reached between the Commission and UK on 7 September 2023, the Council of the EU gave its green light on 15 November 2023 on the UK's participation in the Copernicus programme (and Horizon Europe). On 4 December 2023, the EU-UK Specialised Committee on Participation in Union programmes signed the protocol finalising the UK's association to Copernicus as of 1 January 2024.

The VEGA-C's return to flight is planned during Q4 2024. The decision to launch Sentinel-1C on the return to flight, or on an alternative launcher, will be taken by the Commission in early 2024.

The progressive degradation of the Sentinel-1B thruster performance will prevent it from reaching the disposal orbit objectives within this year. The disposal activities might then be performed concurrently to other critical activities like Sentinel-2C and Sentinel-1C In-Orbit Commissioning (IOC) preparation and execution.

The Sentinel-2 reprocessing campaign, to generate the Sentinel-2 Collection-1, was completed during the reporting period and the distribution of the reprocessed data is being performed through the Copernicus Data Space Ecosystem and the DIAS.

The Copernicus Data Hub service was decommissioned on 2 November 2023 with the Copernicus Data Space Ecosystem service taking completely over the data access operations.

6.1. 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 that provides all-weather day-and-night images for GMES user services. The SAR operates in two main modes: Interferometric Wide Swath and Wave. The first has a swath width of 250km and a ground resolution of 5x20m.

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 operations continued nominally and the overall performance was steady during the last quarter. The occurrence of satellite anomalies and mission unavailability periods remained very limited.

Sentinel-1B satellite unavailability started on 23 December 2021. The satellite remains under control, and regular orbit control manoeuvres are routinely performed. On 3 August 2022, the end of exploitation was announced by ESA and COM with news released on the ESA Corporate and Sentinel Online portals and in parallel on the EU Copernicus portal.

The Sentinel-1B re-orbiting strategy (or more exactly the strategy for the re-orbiting to the disposal orbit) has been fully defined and agreed. It is based on an uncontrolled re-entry within 25 years. A disposal plan was defined in 2023, with a full re-entry in the atmosphere estimated to be within 12 years, well within the 25 years re-entry requirement. The targeted disposal orbit is a circular orbit below 530km with a passivation initially thought to happen in November/December 2024. However, following the SAFE Mode event (25 July 2023), the disposal activities continued at slower pace than originally planned. Since then, a progressive degradation of the thruster performance has been seen, impeding the team to deploy the activities in a routine manner. Several special operations, resulting from the numerous ARB, have been performed (new FDIR, change of propulsion branch, removal of the thruster off-modulation, etc.) allowing the non-cooperative satellite to continue lowering its orbit. Consequently, the disposal objectives won't be reached in 2024 and might be performed concurrently to other critical activities like S-2C and S-1C IOC preparation and execution. Despite the adverse circumstances, progress has been achieved as the 25-year lifetime orbit is now within reach. However, the complete fuel depletion (~88kg remaining) with a fast-degrading propulsion system is a major challenge. Disposal is anticipated to take considerably longer than initially projected, prompting the implementation of several strategies to address this issue.

The Sentinel-1 constellation observation scenario is available for consultation online and is described in version 3.1 of the Sentinel HLOP. Detailed Sentinel-1A acquisition plans are regularly published on Sentinel Online. Two worldwide maps of the Sentinel-1A high level observation plan have been released on Sentinel Online under “Observation scenario”. In May 2023, Sentinel-1A entered in eclipse leading to a reduction of the sensing capacity from 30 to 25 min (within rolling window of 100 minute). The satellite is used at full capacity.

During the reporting period Sentinel-1 contributed again to several emergency events (floods mainly), particularly in response to activations from the Copernicus Emergency Management Service and from the International Charter Space and Major Disasters. On several occasions, Sentinel-1A also contributed to the imaging of Tropical Cyclones.

The Flight Operations Segment (FOS), ensuring the monitoring, control, and commanding of the satellites, operated nominally. During the reporting period one CAM was executed successfully on Sentinel-1A (1 November 2023). Several other events of close approach were monitored but did not lead to a CAM.

The Copernicus Ground Segment operations continued nominally for Sentinel-1 during the quarter, ensuring regular planning of the Sentinel-1 observations as well as data acquisition on ground via X-Band and EDRS, systematic processing of acquired data into User Level Data and long term archival of essential mission data.

The products quality has continued to be ensured by the Mission Performance Cluster (MPC) service provider.

Sentinel-1 X-band pass-through acquisitions are regularly performed in support of the European Maritime Safety Agency (EMSA) CleanSeaNet service, as well as national activities. X-band pass-through acquisitions are being performed by several Collaborative local passive ground stations in overlap with the core ground stations (CGS). The following Collaborative Ground Stations are currently included in the regular Sentinel-1 operations plans: Tromsø and Svalbard (Norway), Matera (Italy), Brest and Toulouse (France), Santa Maria (Portugal), Sodankyla (Finland), Neustrelitz (Germany), Puertollano (Spain, operated by KSAT Norway), Athens (Nemea, Greece, operated by KSAT Norway) and Skarfia (Greece, operated by CLS).

Regular Sentinel-1 mission status reports are released weekly on Sentinel Online (available at <https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-1/mission-status>), with emphasis on the response to emergency situations, provision of mission unavailability information, and user / product statistics.

6.2. 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.

During the quarter, the Sentinel-2 operations proceeded nominally, with a good overall performance for all mission/system operational domains. Both satellites demonstrated good health, with no major anomalies detected or significant degradations observed.

An observation scenario, according to the latest HLOP (Sentinel High Level Operations Plan) version 3.1, is being operated for Sentinel-2A since 6 June 2022 and for Sentinel-2B since 11 June. This observation scenario includes all land surfaces within reach including the acquisition of all small islands and atolls worldwide.

The feasibility of an extended coverage of Philippine Sea is being performed aiming at a potential operational deployment during the following reporting period. Additionally, to be noted that the feasibility of the *ad hoc* campaign providing an extended coverage over Antarctica for all regions within reach of Sentinel-2 sensor is still on-going, and therefore not yet confirmed for this coming Austral winter.

The Sentinel-2 archive reprocessing was completed during the reporting period. The distribution of the reprocessed data is being performed through the Copernicus Data Space Ecosystem and the DIAS (Data and Information Access Systems) CREODIAS, MUNDI and ONDA. Distribution is planned to be completed by Q2 2024. The overall status of Sentinel-2A satellite functional health is good, with few anomalies and little, if any, evidence of long-term significant degradation. Optical Communication Payload (OCP) units continue to suffer periodic outages due to radiation sensitivity, but mitigation measures are in place minimising unavailability periods.

The Flight Operations Segment (FOS), ensuring the monitoring, control, and commanding of the satellites, operated nominally. A routine decontamination activity of the Sentinel-2A MSI took place over a continuous period of 24-hours between 6 November 2023 08:30 UTC and 7 November 2023

08:30 UTC, and for Sentinel-2B between 4 December 2023 at 09:00 UTC and 5 December 2023 at 09:00 UTC.

The Copernicus Ground Segment operations continued nominally for Sentinel-2 during Q1 2024, ensuring regular planning of the Sentinel-2 observations as well as data acquisition on ground via X-Band and EDRS, systematic processing of acquired data into User Level Data and long term archival of essential mission data.

Since 13 December 2023, The Level-1 and Level-2 processing chains make use of the Copernicus Digital Elevation Model (DEM) at 30m spatial resolution. This replaces the previously used instance of the Copernicus DEM at 90m spatial resolution and aligns the processing chains with the same DEM used for Collection-1.

Product quality is routinely ensured by the Optical Mission Performance Cluster (MPC) service provider, that supports both Sentinel-2 and Sentinel-3.

The Sentinel-2 GRI (Global Reference Image) was made available to all users as a free and open product. Beyond being used by the Sentinel-2 mission for the geometric refinement of the images, it is also being used operationally by third-party missions benefiting from the reference geometry from Sentinel-2. To be highlighted is the usage of the Sentinel-2 GRI by the Landsat mission in order to improve the geometric accuracy of their images as well as the co-registration with Sentinel-2, for the benefit of the large user communities of these two missions.

The 6th S2VT (Sentinel-2 Validation Team) meeting took place at ESA/ESRIN on 12-14 September 2023. The aim of the S2VT meetings is to collect independent data quality feedback and validation results obtained by international experts and users. All presentations from this meeting are now available at: <https://nikal.eventsair.com/6s2vtm/>.

Regular Sentinel-2 mission status reports are released weekly on Sentinel Online (available at <https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-2/mission-status>).

6.3. 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.

Currently all instruments, including OLCI, SRAL, SLSTR and MWR, on both satellites, are switched on and performing well except a Sentinel-3A OLCI instrument anomaly occurring on 21 and 22 November 2023 (now back to nominal).

The joint ESA-EUMETSAT mission management is on-going, following the provisions in the Joint Operations Management Plan (JOMP) actions agreed at the 2nd Sentinel-3 Steering Group on 27 March 2019. An updated version of the JOMP document is currently under preparation and should be consolidated in Q1 2024.

Discussion between ESA and EUMETSAT S3 teams are continuing regarding a potential tandem phase and in-orbit stand-by scenarios after the launch of Sentinel-3C. Different options are identified and analysed in terms of technical feasibility and cost impacts.

The Flight Operations Segment (FOS) for Routine Operations is operating according to plan, providing the required service to the EUMETSAT FOS, namely the S-Band TT&C ground station network.

The Copernicus Ground Segment operations continued nominally for Sentinel-3 during Q1 2024, ensuring data acquisition on ground via X-Band, systematic processing of acquired data into Sentinel-3 User Level Data and long term archival of essential mission data.

Efforts are continuing to further improve the quality of Sentinel-3A/-3B Level 1 and Level 2 core land altimetry ("Hydro-Cryo"), optical and NTC atmospheric data products, based on the results of the validation activities performed by the Optical & Altimetry Mission Performance Cluster's (MPC), and the feedback from the respective Quality Working Groups (QWG) and Sentinel-3 Validation Team (S3VT) meetings. The quality of the Sentinel-3 products is operationally monitored at the Optical & Altimetry MPC's, and the cyclic reports are nominally published on the ESA Sentinel on-line web site. The overall performance of the Sentinel-3 core products during the reporting period is nominal.

The 8th S3VT Meeting jointly organized with EUMETSAT, was held 5-7 December 2023 in Darmstadt, Germany. This was a successful event with more than 160 participants, 145 oral presentations and 10 posters. The meeting was particularly fruitful in compiling new recommendations guiding the roadmap definition for future evolutions of the Sentinel-3 altimetry and optical data products.

Concerning the optical payload, the S3VT community is very satisfied with the quality of related products. The daytime accuracy of Land Surface Temperature (LST) products has however drifted to be greater than the mission requirement of 1K, driven by larger biases for some biomes. This is due to

errors in the cloud masking and the higher global temperatures observed in 2023 which require to adapt processing algorithms for the retrieval coefficients. This update is a high priority activity for the beginning of 2024.

Concerning the OLCI L2 products, validation activities showed good results, but additional efforts are required for extending the validation to more sites. Finally, for the SYN-VGT product, the community strongly recommends performing a full mission re-processing to establish a continuous and consistent time series over +25 years. The reprocessing should be triggered after two major product evolutions which are already planned (the inclusion of a cloud shadow flag and the improvement to the AOD retrieval).

Level 2 Thematic Land (aka “Hydro-Cryo”) Altimetry products generated with improved and tailored processing algorithms are now operationally released to the end-users for the sea ice, the land-ice, and the inland water domains. An associated Full Mission Reprocessing (FRM) campaign back to the beginning of the S-3A and S-3B missions has been completed in September 2023. The reprocessed data have been fully validated and released to the Copernicus Services and the user community. The Validation Report for the FMR is under final review and will be available online by the end of the year. The validation results for the Level-2 Hydro-Cryo dataset have been presented and discussed extensively at the 8th S3VT Meeting and in difference international conferences such as the OSTST, Hydrospace and AGU.

6.4. Sentinel-5P

The Sentinel-5P mission status is reported at:

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

The Sentinel-5 Precursor mission is 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.

Since April 2018, Sentinel-5P has been in routine operations, having reached full operational capacity in early March 2019.

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

No major satellite anomalies occurred during the reporting period. The Flight Operations Segment (FOS) is operating according to plan.

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.

Level 1B Radiance/Irradiance, Level 2 Methane, Tropospheric Ozone (Offline), Carbon Monoxide, Formaldehyde, Nitrogen Dioxide, Sulphur Dioxide, Total Ozone, Ozone Profile, 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.

A new prototype algorithm for Methane retrieval has been implemented into the PDGS to be used as a fallback solution in case SUOMI-NPP VIIRS data are missing. The quality of the Cloud and Aerosol Layer Height products has also been improved.

Six Sentinel-5P pre-operational products (Aerosol Optical Thickness, Bromine Monoxide, Glyoxal, Sun-Induced Fluorescence, Water Vapour, and a Sulphur Dioxide product using the new Covariance-Based Retrieval Algorithm (COBRA)) are being provided to the public via: <https://data-portal.s5p-pal.com>.

6.5. 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 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) was 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 Sentinel-6 MF satellite was handed over to Mission Operations (Phase E2) after its successful In-Orbit Commissioning Review on 16 November 2021. EUMETSAT is responsible for the mission's operations. The mission's operational performance fully meets or exceeds expectations.

7. FUTURE ESA SATELLITE SYSTEMS

7.1. 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.

7.1.1. EarthCARE : Earth Explorer 6th

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.

In the last reporting period, the launch vehicle adapter fit check and separation/shock test was successfully performed with only very low shock levels observed inside the satellite. All functional and instrument performance tests after the satellite shock test were successfully completed confirming good health of the satellite. The satellite was disconnected from its test setup and was prepared for transport to the launch site.

Detailed investigations of new ATLID related issues were performed and concluded "use as is" considering the very low probability of occurrence of the issues for ATLID compared to the risks to the instruments when attempting replacements. Manufacturing, testing and qualification test campaign of the N-HVGM was successfully completed by Leonardo. Preparations for launch campaign, LEOP and commissioning are ongoing.

The Launch service contract with SpaceX was successfully kicked-off and is ongoing. All pending compatibility issues (e.g. qualification for random vibration) have been analysed and closed except for

the agreement on a sine vibration notch for which analysis are still ongoing. The launch site survey was held at Vandenberg with industry, JAXA and SpaceX and iterations of formal ICD is ongoing.

Ground Segment Overall Validation (GSOV) was successfully completed with a successful run of processing run#3. The Ground Segment Acceptance Review was completed in January 2024.

A very successful pre-launch EarthCARE Science and Cal/Val workshop was held at ESRIN, as well as regular coordination meetings with the JAXA ground segment team and with ECMWF.

The EarthCARE launch slot is formally agreed for May 2024. The satellite arrived at Vandenberg Space Force base on 10 March 2024 and plans are for launch on a Falcon 9 Block 5 launcher, with all parties targeting the end of May as the launch date.

7.1.2. Biomass: Earth Explorer 7th

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.

Substantial progress has been made towards the completion and delivery of the Power Amplifier Subsystem. Four out of six Solid State Power Amplifiers (SSPAs) have passed acceptance testing. A partial PAS with four SSPAs was delivered in February 2024, and the remaining two became available in March 2024. The AIT work in the EVT, Toulouse, have resumed after a break due to the non-availability of the PAS. Progress on the completion of the control electronics of the ground calibration transponder is still not made at the expected pace. The activities are now scheduled to complete in

summer 2024. Ground Segment activities are progressing in line with the kick off of the GS Acceptance Review in March 2024.

A schedule consolidation has been performed with the aim to reach launch readiness in mid-December 2024.

7.1.3. FLEX: Earth Explorer 8th

On 19 November 2015, ESA's Member States selected FLEX as the 8th Earth Explorer mission 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 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 mid-December 2025.

Since the last reporting period, the FLORIS instrument PFM AIT progressed with a perfectly aligned HR focal plane. This completes the integration of the LR and HR optical chains. Next units to be integrated are the Calibration Unit and the Polarisation Scrambler. The Polarisation Scrambler PFM has been delivered to LDO and a successful incoming inspection held. The Calibration Unit PFM vibration test has failed – the root cause has been understood and a new test load profile adapted accordingly. Testing will resume in early 2024.

A conflict with MetOP 3MI using the same TV chamber at CSL (BE) during Q3/Q4 2024 was identified. Mitigations to perform straylight characterisation in a different chamber or at a different facility are being investigated.

Video Acquisition Units (VAUs; CRISA) are progressing. Radiated EMC tests after unit refurbishments were successful.

Instrument Control Unit (ICU) development is slow and causing overall delays. The Flight Printed Circuit Boards (PCB) manufacturing is further delaying the ICU PFM delivery to after summer 2024. The ICU EM test campaign had to be interrupted for several reasons and refurbishments, also accumulating ~2 months of delay.

The Payload Data Handling Unit flight FPGAs have been coded with the wrong version; however, a software workaround has been found and implemented. A slight DRB delay of 2 weeks can be accommodated in the platform AIT schedule.

The Platform (PF) Integration Readiness Review (IRR-1) has been held and the PF mechanical integration is progressing well at TAS-UK facilities in Belfast. The Functional Chain Verifications (TAS, FR) for the full FLEX functional perimeter is now completed. Remaining activities are related to ICU SW regression testing in Q1 2024. Following a FLEX Fluorescence Workshop in September 2023, a first meeting with ISRO has taken place.

The driver for the launch date remains the availability of a Vega-C launcher. Currently the Vega-C manifest foresees a launch slot in July 2026.

7.1.4. FORUM: Earth Explorer 9th

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 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.

The Interferometer Mechanical Assembly (IMA) has been submitted to vibration and shock tests for the second time and, despite the higher clamping torque on the Beam Spitters (BSs), the optical performances were degraded. After 2 months of investigation of a tiger team, the problem has been

isolated in the micro-slippage of one BS while the second BS has been stable.

OHB has considered that the accuracy of the manufacturing is too tight to ensure a repeatable clamping on the BSs on all models and that the mechanical design of the IMA needs to be upgraded with local modifications. The tiger team has concurred that the upgrade does not modify the alignment concept and performances achieved by the IMA. The IMA EM will be re-aligned and refurbished with the Laser Unit (LAU) COTS and Receiver Unit (REU) EM, and then to start Instrument Development Model (IDEM) testing. The upgrade of the IMA will be implemented directly on the EQM and PFM models.

Equipment Qualification Status Review for almost all platform units have been held successfully. Organisation of the development of the FORUM End to End simulator (FEES). The L1 Processor, involving Airbus UK, OHB D, MICOS CH and HULD(FIN) has been consolidated.

A 2nd Earth Explorer 9 FORUM workshop took place in the Leicester Space Park, UK.

The FORUM Launch date is planned in Q3 2027

7.1.5. HARMONY: Earth Explorer 10th

Harmony was selected on 22-23 September 2022 as Earth Explorer 10. Harmony will, in turn, also help address societal issues such as those laid out in the World Climate Research Programme's Grand Challenges and several of the UN's Sustainable Development Goals. Harmony will provide a wealth of new information about our oceans, ice, earthquakes, and volcanoes.

The mission will comprise two identical satellites orbiting Earth in convoy with a Copernicus Sentinel-1 satellite. Each Harmony satellite will carry a receive-only synthetic aperture radar and a multiview thermal-infrared instrument.

Together with observations from Sentinel-1, Harmony will deliver a wide range of unique high-resolution observations of motion occurring at or near Earth's surface.

The four remaining Phase B1 studies have been closed. The TIR SRR was closed in November 2023. The System and Satellite Intermediate SRR was closed in December 2023 according to schedule.

The 5 pre-developments for the SAR instrument started during 2023 are progressing.

To secure the schedule of the TIR instrument, two pre-developments on the Front-End Electronics were initiated with Surrey Satellite Technology Limited (UK) and ABB Inc. (CA). The contract was started with ABB and is under agreement with SSTL.

A Mission Advisory Group (MAG) recommendation endorsed the baseline solution for data volume

elements (mass memory and Ka-band data downlink strategy) and for the TIR performance achievements. This will translate in a revision of the SRD to set achievable requirements in preparation to the satellite/system B2/C/D/E1 ITT.

The launch of HARMONY is planned for 2029.

7.1.6. Earth Explorer 11th

The previous Call for Mission Ideas for a large 11th Earth Explorer (EE11) research mission had taken place in May 2020 resulting in the selection of four EE11 candidate missions to enter Phase 0 studies, namely: CAIRT, Nitrosat, Seastar and WIVERN. In November 2023, CAIRT and WIVERN were selected to proceed to Phase A feasibility study.

CAIRT

CAIRT (Changing-Atmosphere Infrared Tomography) would provide the measurements needed to make a necessary step change in understanding the links between climate change, atmospheric chemistry and dynamics in the altitude range of about 5 to 115 km. CAIRT would be the first limb-sounder with imaging Fourier-transform infrared technology in space.

Two parallel systems studies were kicked-off in April and May 2022 for Consortium A and B respectively. Consortium A is led by ADS (FR) with ADS (DE), ABB (CA) and GMV (PL) as subcontractors. Consortium B is led by TAS (FR) with OHB (DE), Micos Engineering (CH) and TAS (UK) as sub-contractors.

The Report for Assessment (RfA) and the technical presentation for the User Consultation meeting were prepared by the ESA CAIRT team and are now available for consultation on the EE-11 Phase 0 UCM website.

Following the recommendation of ACEO for CAIRT to continue in Phase A, a number of preparation meetings were held with industry in October 2023 in order to tailor the scope of work of Phase A to the specific needs of the CAIRT mission. In parallel, progress was made on preparing the CCNs for the critical CAIRT technology pre-developments on detectors and Integrated Detector and Cooler Assembly (IDCA) with the suppliers selected by each consortium following the outcome of the Phase 0 Risk Retirement Activities where all three potential suppliers were consulted. Moreover, a final Risk Retirement Activity was placed on ROIC performances measurements, and its final review took place on 12 December 2023.

Following the down-selection of the CAIRT mission by PB-EO on 21 November 2023, the Close-Out Meeting of Phase 0 and the Technical Kick-Off of Phase A system studies took place on 6 December

2023 with each industrial consortium. The contractual kick-off of the Phase A system studies for both consortia was held in January 2024.

WIVERN

WIVERN (Wind Velocity Radar Nephoscope) would provide the first measurements of wind within clouds and precipitation. There is a notable gap in global observations of wind in cloudy regions. The mission would also deliver profiles of rain, snow, and ice water. Carrying a dual polarisation, conically scanning, 94 GHz Doppler radar with an 800 km swath, the mission would improve forecasts of hazardous weather and provide new insights into severe storms. It would also contribute to the climate record of cloud and precipitation profiling.

Two parallel studies were kicked-off in May 2022 with the following consortia: Consortium A is led by ADS (ES) with ADS (FR), ADS (UK), ADS (DE), GMV (ES) and Aresys (IT) as sub-contractors. Consortium B is led by OHB (DE) with TAS (FR), ASP (DE), Honeywell (UK), Radiometer Physics (DE), Thomas Keating (UK) and DEIMOS (ES) as sub-contractors. The Report for Assessment (RfA) and the technical presentation for the User Consultation Meeting (UCM) were prepared by the ESA WIVERN team and are now available for consultation on the EE-11 Phase 0 UCM website.

Following the recommendation of ACEO for WIVERN to continue in Phase A, several preparation meetings were held with industry in October 2023 to tailor the scope of work of Phase A to the specific needs of the WIVERN mission. In parallel, progress was made on preparing the major CCNs for the critical WIVERN pre-developments on High Power Amplifier Power Supply (HPA EPC) and Ferrite Switches with the suppliers selected by each consortia following the outcome of the Phase 0 Risk Retirement Activities where all potential suppliers were consulted. A proposal for the HPA EPC from ASP (DE) has been received by industry to bring ASP technology to TRL 4 and avoid a European single source supplier. This pre-development will be shared by both industry primes to optimise cost efficiency and will be based on an ESA generated common specification.

Following the down-selection of the WIVERN mission by PB-EO on 21 November 2023, the Close-Out Meeting milestone of Phase 0 and the Technical Kick-Off of Phase A system studies both took place in December 2023 for ADS and in January 2024 for OHB.

The Phase A contractual kick-off meeting with OHB consortium was held in January 2024 and for ADS consortium in February 2024.

7.1.7. Earth Explorer 12th

The call for ideas for the next Earth Explorer 12 (EE12) research mission opened in 2023. The motivation behind this Call of Mission Ideas was ESA's wish to engage the scientific community as far as possible in determining and advancing the research mission activities within FutureEO-1 Segment 2. Through the Call the Agency gathered the science community's views on which mission ideas could maximise scientific impact and innovation whilst responding to scientific and societal challenges, within the guidelines and constraints established within the Call. Considering the experience from previous calls, and in line with the spirit of the FutureEO programme, the call solicited innovative and scientifically excellent ideas to be implemented as ESA-led Earth Explorer research missions.

The deadline for submissions was 29 September 2023. A scientific peer review process was then carried out with the support of 3 independent, double-blind reviews of each idea. In parallel to the scientific review, two optical and radio frequency technical panels (including six specific technical expert groups) evaluated the technical and programmatic elements of each of the mission ideas. In addition, a cost assumptions coordination group was set up to compile the basis used for the independent cost estimations for each mission idea. Finally, a harmonisation and programmatic panel was set up to harmonise the Scientific, Technical and Programmatic content across each of the mission ideas and to establish final programmatic statements in the Evaluation Reports. The panels set up by the Executive involved more than 60 technical experts from the Directorate of Earth Observation Programmes and the Directorate of Technology, Engineering and Quality.

In March 2024, the Advisory Committee for Earth Observation (ACEO) recommended the following four Mission Ideas to be selected for Phase 0 assessment studies:

CryoRad - A Low frequency wideband radiometer for the study of the cryosphere

ECO - The Earth Climate Observatory

Hydroterra+ - A mission to observe rapid processes of the water cycle

Keystone - Unlocking the Upper Atmosphere.

Notably, each of the four recommended mission ideas were variants/improvements of previously submitted Earth Explorer proposals.

CryoRad

The novel broad-band radiometer measurements of the proposed CryoRad mission would fill an important gap in satellite observation capabilities of the cryosphere, through the direct measurement of temperatures deep inside large icesheets, and improved accuracy and ability for measuring other key

cryosphere and ocean parameters, such as improved measurements of sea ice thickness, supplementing the Copernicus CRISTAL mission over thin sea ice in the 0.5 - 1 m thickness range. The proposed mission would also enhance mapping of sea surface salinities in cold waters, contributing to enhanced detection of meltwater from the melting glaciers and icesheets, and understanding ocean salinity exchange processes, complementing the Copernicus CIMR mission, with a higher spatial resolution and enhanced sensitivity. The mission would also enhance understanding and monitoring of permafrost active layer changes, and water content over soils and vegetation.

ECO

ECO aims at measuring the difference between the solar radiation entering the Earth and the radiation outgoing from the Earth in global annual mean with unprecedented accuracy and stability. Earth Energy Imbalance (EEI) is the most fundamental climate variable as it reveals the trajectory of the future climate warming decades earlier in time than the global temperature monitoring because the global temperature rise is a time delayed response of the accumulation of past EEI. The EEI has been increasing rapidly in recent decades, nearly doubling, and the underlying reasons for this surge remain incompletely understood. Therefore, accurate and stable monitoring of EEI is essential 1) for societies to anticipate and adapt to global warming, 2) to monitor the effects of the decreasing emissions of greenhouse gases due to the Paris agreement on the global warming, 3) to progress on our current scientific understanding of how the overall Earth climate system works.

Hydroterra+

The mission proposal Hydroterra+ places a C-band Synthetic Aperture Radar (SAR) in a quasi-geostationary (GEO) orbit to observe rapid processes tied to the water cycle and to tectonic events in Europe, the Mediterranean basin and northern Africa. The GEO orbit leads to a revolutionary temporal resolution, with twice daily observation on a basic acquisition scheme for nine focus areas of 210 000 km² each, and spatial resolution of 60x60 m². The steering capabilities of the beam would allow reaching 1-hour temporal resolution of focus areas requested upon demand, affected by inundation, landslides, earthquake or volcanic unrest. Ionospheric effects shall be compensated by split band observation. Science objectives address the monitoring of intense storms, the diurnal land surface water budget, the cryosphere water budget, and ground changes due to earthquakes and volcanism. The C-band radar enables continuous monitoring of integrated water vapor, soil moisture, snow water equivalent and ground deformation.

Keystone

The mesosphere-lower-thermosphere (MLT) region at altitudes from 70-120 km is an intriguing part of the Earth's atmosphere due to several reasons: it is a unique altitude range that is strongly influenced

by energy input both from above (by energetic particle precipitation) and below (by upward propagating waves like thermal tides and gravity waves) with leading order effects on composition, thermal structure and dynamics. It is the region where meteoroids (and space debris) ablate, where atmospheric composition transitions from a well-mixed state (due to turbulence) to a state governed by molecular diffusion, and where significant concentrations of charged constituents start to occur (i.e., the lowermost layers of the ionosphere, the D- and E- region). Thus, electrodynamic effects become more and more important as altitude increases and contribute to Space Weather effects. Hence, this altitude range has long been a focus region of study. Nevertheless, many fundamental properties remain unknown or poorly constrained due to the difficult accessibility of that altitude range. The Keystone mission would provide the measurements necessary to finally quantify these fundamental properties.

7.1.8. NGGM Gravity Mission

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. 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.

In the frame of Missions of Opportunity made possible by international cooperation, ESA and NASA have coordinated studies of optimal gravity monitoring constellations formed by two or more pairs of satellites to observe mass changes in the Earth system. In 2016, the ESA-NASA Science Working Group issued the document “Towards a sustained observing system for mass transport to understand global change and to benefit society”.

Programmatic discussions were also held in March 2020 between ESA and NASA, based on a series of meetings and teleconferences held 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.

The global science and user requirements were consolidated in a uniform traceable manner together with NASA. These requirements and a corresponding traceability matrix have been used to establish the mission requirements. The first issue of the Mission Requirements Document (Next Generation Gravity Mission as a Mass-change And Geosciences International Constellation (MAGIC) - A joint

ESA/NASA double-pair mission based on NASA's MCDO and ESA's NGGM studies) - was released on 18 December 2020, following signatures of ESA and NASA. The MRD was distributed to Delegations in early 2021. In close coordination with NASA the Joint Mass Change Mission Expert Group (JMCMEG), consisting of 9 European members and 9 US members, was established to support the Phase A.

An ESA/NASA Joint Engineering Team (JET) has been set up with the goal to support and coordinate the technical interaction between ESA and NASA to enable the implementation of an affordable, technically feasible and scientifically valuable observing architecture for MAGIC. The JET was kicked-off on 20 May 2021 and the JET subsequently agreed. The JET scope is to technically assess the conditions of delivery to ESA of the potential NASA contribution items (i.e., the cavity, Scale Factor Unit and the LRP with no adaptations from GRACE-C) on the P2 Laser Tracking Instrument (LTI). JET is also working on the evaluation of the environmental requirements applicable to US units and the discrepancies with the ESA requirements, and the high level interfaces between the ESA and NASA science data systems for the exchange of P1 and P2 Level-0 and Level-1 products.

7.1.9. Aeolus-2

Aeolus-2 is a Doppler Wind Lidar designed to measure atmospheric winds through measurement of doppler shifts in the backscatter of emitted laser light from molecules, water droplets and aerosols in the atmosphere. The measurement principle has been successfully demonstrated on the first Aeolus mission and the Aeolus Doppler Wind Lidar instrument has been ranked by ECMWF as having the second highest impact on the accuracy of Numerical Weather Prediction of any single Satellite instrument.

The Aeolus-2 development will be based on an evolution of the Aeolus heritage, taking into account the lessons learned from the Aeolus development and in-orbit performances / operations, as well as from other similar spaceborne laser projects. The objective of the Aeolus-2 mission is to provide Europe and, by extension, the international community, with the unique capability to measure atmospheric winds for the support of Numerical Weather Prediction and to improve the understanding of atmospheric dynamics and associated processes.

Launch of the first Aeolus-2 Satellite is foreseen in 2030, with a series of two Satellites providing over ten years of operations. The Aeolus-2 Space Segment consists of a series of two Satellites. The primary Payload is a Doppler Wind Lidar instrument operating in the ultra-violet spectrum (355 nm). In addition, provided the accommodation is confirmed to be feasible, a Radio Occultation sounder (to provide high vertical resolution, all-weather atmospheric sounding by tracking Galileo, GPS and Beidou

satellites) will also be embarked. The Aeolus-2 Satellites will fly in a “dawn-dusk”, sun-synchronous orbit, with the Satellite orbiting above the day-night terminator and the Doppler Wind Lidar instrument pointing 35° off-nadir, perpendicular to the ground track, to the night side of the Earth.

The Programme will be implemented in co-operation with EUMETSAT. The ESA Aeolus-2 Programme will fund the development (Phase B2/C/D/E1), including the Proto-Flight Model Satellite. EUMETSAT will provide a fixed financial contribution to the ESA Aeolus-2 Programme for Phase C/D/E1, and will fully fund the recurrent Satellite. In addition, EUMETSAT will develop the Ground Segment, procure the Launch Services and perform the operations. The roles and responsibilities of ESA and EUMETSAT regarding cooperation on the development of Aeolus-2 will be based on the successful cooperation model previously used for the Meteosat Third Generation and MetOp Second Generation Programmes.

A set of critical technology pre-development activities and an instrument consolidation study have been initiated, considering the feedback from the development, operations and data exploitation of Aeolus, namely:

- Pre-development of an Engineering Model of a wind lidar detector, with Teledyne-e2v (UK).
- Two parallel pre-developments of an Engineering Model of an improved Transmitter Laser Assembly, with Leonardo (IT) and Fraunhofer ILT (DE).
- Instrument Consolidation Study with ADS (FR).

To encourage competition at system prime level, an open ITT for a System Accommodation Study was issued and two parallel contracts kicked-off to ensure a level playing field between LSIs. To this end, the Instrument Consolidation Study has provided at Final Review in October 2023 inputs (instrument design description, instrument DDV plan, instrument interfaces to the platform, instrument operations concept) for the System Accommodation Studies ISRR. Furthermore, additional technology pre-developments have been initiated for critical elements of the instruments.

7.1.10. 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.

Since the last reporting period, the Payload and Platform were integrated. The Satellite environmental test campaign has started and the satellite TVAC tests have been completed. System Validation Test 2.1 was completed. The Ground Segment Verification & Validation was completed.

AWS has a nominal launch date of 1 June 2024.

7.1.11. 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 technology pre-developments initiated in Phase B1 Bridging are continuing. The Cryogenic Solar Absolute Radiometer (CSAR) cavities and baffles manufactured at PMOD (CH) have been manufactured with different substrate materials and shapes, then coated and finally tested against mechanical loads. An assessment of the coating stability versus the trade-off of the best cavity design is to be addressed based on the results of these tests and will be proposed for the implementation in Phase B2.

The three Ground Segment consolidation studies initiated within Phase A/B1 budget to facilitate the formation of consortia, in view of TRUTHS Ground Segment Phase B2/C/D/E1 ITT, are close to completion. After successful Mid-term reviews held in early October 2023, the Teams prepared for the Final Review in January 2024.

The Mission Advisory Group met in October 2023 and provided additional inputs about the detailing of mission products, giving advice about the selection of the orbit parameters to optimize the climate and cross-calibration objectives and the implementation of the climate modelling activities.

The TMAC (TRUTHS Mission Accompanying Consolidation) Bridging phase kicked-off in October 2023 and a 1st Progress meeting was held in December 2023. New simulated TRUTHS hyperspectral scenes have been generated and initial evaluation of the impact of TRUTHS measurements on long-term climatological series performed and presented at the progress meeting. The 1st Progress Meeting of the Space Segment was held 24-25 January 2024.

A very successful TRUTHS event was organised by UKSA at the COP-28 conference on 3 December 2023, including presentations of the TRUTHS mission and the formal signature of the Phase B2 contract

between ESA and Airbus Defence and Space Ltd and Teleyne-E2V. The event was also attended by NASA officials and climate scientists.

TRUTHS has a target launch date of 2030.

7.1.12. 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.

The System CDR was kicked-off in November 2023. RIDs were all released on time for deadline.

A second STM campaign was completed successfully. The Front-End optics (FEO) QM (after shock failure) was tested (vibration, shock and TVAC) – settlements and rotations identified mainly after vibration and TVAC requiring minor design adjustment. Acoustic-Optical Tunable Filter QM tested in vibration and TVAC successfully. Coating qualification: band pass filter coating successfully passed the qualification. Focal Plane STM failed shock test (glue broke) and the root cause has been identified. The instrument EM three channels testing is complete.

The three units from Syrlinks (X-Band, S-Band and GNSS) EMs and FMs are under assembly and testing at board level. The propulsion PFM assembly has successfully passed the acceptance vibration test. The Star Tracker FM resumed acceptance testing.

For the Ground Segment, a System Performance Simulator (SPS) version 2.0 was delivered and the ITU filing has been submitted to ITU.

The instrument schedule is under pressure with a delivery now planned for December 2025. The platform schedule is now secured with the propulsion system ready for delivery and the Syrlinks units under final assembly. Flight Platform acceptance is scheduled for October 2024. The launch readiness is delayed to May 2026 with no margin to the latest VEGAC launch manifest.

7.2. 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.

7.2.1. Sentinel-1 C and D

The VEGA-C's return to flight is planned during Q4 2024. The decision to launch Sentinel-1C on the return to flight, or on an alternative launcher, will be taken by the Commission during early 2024.

7.2.2. Sentinel-2 C and D

Sentinel-2C is expected to be launched on the last VEGA launcher during the period August-September 2024. Both Satellites (Sentinels-2 C and D) are in storage and the yearly health check is completed for Sentinel-2C and in progress for Sentinel-2D.

7.2.3. Sentinel-3 C and D

The current hypothesis for the launch of Sentinel-3C is Q2 2026. However, Sentinel-3C is a potential candidate for the VEGA-C return to flight scheduled in Q4 2024, should the Commission decide to launch Sentinel-1C on an alternative launcher. The Sentinel-3C satellite readiness for launch would be compatible with this period.

Discussion between ESA and EUMETSAT S3 teams are continuing regarding a potential tandem phase and in-orbit stand-by scenarios after the launch of Sentinel-3C. Different options are identified and analysed in terms of technical feasibility and cost impacts.

7.2.4. 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.

Sentinel-4

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.

Two Sentinel-4 instruments, procured within the Copernicus Space Component (CSC) Programme, will be delivered to the Meteosat Third Generation (MTG) programme to be embarked on the two sounder satellites (MTG-S1 and MTG-S2), as Customer Furnished Items, fully verified, qualified, and calibrated together with the necessary ground support equipment, test models and system deliverable inputs.

The main elements of the Sentinel-4 system are:

- The Proto-Flight Model (PFM) and the Flight Model (FM2) instruments, consisting of three main components: the Optical Instrument Module (OIM), the Instrument Control Unit (ICU) and the Scan Drive Electronic (SDE) unit.
- The Level 0 to Level 1b processor (L1OP) and the Level 1b to Level 2 Processor (L2OP), both hosted by the MTG Ground Segment. They include the interfaces to the users, the mission performance functions and the performance analyses, related, for example, to the instrument monitoring and trending together with the algorithms' maintenance and validation.

During this reporting period the Project focused on support to the MTG-S1 S/C level AIT activities and preparation for the final PFM instrument Qualification & Acceptance Review (QAR):

- MTG-S1 S/C level AIT: preparatory activities related to the microvibration test, the TV/TB test and the light-tightness test, were completed during this reporting period. Since then, the microvibration test and the TV/TB test were executed and completed on time on 3 December 2023: the Sentinel-4 instrument performed nominally during the TV/TB test campaign. The TV/TB chamber door opening occurred. During the TV/TB test the Sentinel-4 short performance test was also executed: post-test data processing is currently on going and is planned to be completed in early 2024. The Light Tightness test is planned to be completed in December 2023 prior to the start of the MTG-S1 mechanical test campaign expected to be run in Q1 2024.
- QAR preparation: the preparatory activities for the final PFM QAR have steadily progressed during this reporting period.
- Instrument Flight Model (FM2): the integration activities are currently on hold due to a non-compliance affecting the Front-End Support Electronic (FSE) unit identified during a routine electrical functional test prior to its integration onto the Optical Instrument Module. Failure investigation has been completed and root cause has been identified. Repair activities are ongoing at the subcontractor premises. Shipment back of the repaired unit to the Prime

premises is expected in early Q1 2024. Completion of the FM2 integration now expected by late Q1 - early Q2 2024.

- Ground Support Equipment / Facilities: RAL STC-2 TV chamber - the formal ESA certification has been successfully accomplished in November 2023.

S4 / MTG Interface meetings: the S4–MTG interfaces are in a very satisfactory status with no critical aspect identified.

Sentinel-5

The Sentinel-5 mission, jointly with data from other future meteorological missions, will cover the need for continuous global monitoring of atmospheric composition and air quality. The main data products will be O₃ (Ozone), NO₂ (Nitrogen dioxide), SO₂ (Sulphur dioxide), HCHO (Formaldehyde), CHOCHO (Glyoxal), aerosol optical depth and layer height, CH₄ (Methane), CO (Carbon monoxide), UV index and vegetation fluorescence (through the NIR channel extension).

The Sentinel-5 project comprises the development and production of three instruments to be embarked on subsequent MetOp-SG satellites (type A):

- The Sentinel-5A Proto-Flight Model (PFM) unit development, including the Level-1b and Level-2 ground processor prototypes, covered by the GMES Space Component Programme; and
- The Sentinel-5B and -5C units development up to the Pre-storage Review covered by the Copernicus programme, and including the long term storage of both instruments subject to approval by COM.

In the last reporting period, system level activities were focused on the start and execution of the PFM instrument calibration. This required the resolution and follow-up of the various technical issues, regarding the Mechanical Ground Support Equipment and the vacuum chamber optical windows of the RAL facility.

The Intermediate Integration Model (IIM), currently still integrated on the MetOp-SG PFM satellite, successfully passed vibration, thermal vacuum (TVAC) and EMC tests at spacecraft level. The Satellite System Validation Test (SSVT2a), including the Sentinel-5 IIM, also took place in November. The IIM will now be dismantled from the spacecraft.

7.2.5. Sentinel Next Generation

Sentinel-1 NG

Following the completion of the Phase A/B1 with TAS-I and ADS GmbH in February 2023 and April 2023, respectively, their predevelopment activities are running beyond the ISRRs with an expected

completion in mid 2024. These predevelopments are focused on SAR technological innovations. Additional analyses with both consortia were completed to define potential First Generation "Legacy Mode" that would allow demonstration of full continuity of the Next Generation with the First Generation and, in time, be a compatible mode with a potential mission extension of Harmony beyond Sentinel-1C and D. These analyses were based on using the respective proposed designs resources (i.e. no hardware modifications) to define a S1CD-like SAR Mode. The results were very satisfactory for both designs.

Sentinel-2 NG

The final meeting of the Phase 0 science support study took place on 23 October 2023. The deliverables are under review and will be finalised after acceptance from ESA technical officer. The second meeting of the MAG took place on 24-25 October 2023, with further iteration on the draft MRD based on the results of the science support study and the first feedback from industry. After the release of the Phase A/B1 ITT in May 2023, and subsequent evaluation of the proposals, activities were kicked-off at the end of September 2023 with two parallel contracts with consortia led by ADS and OHB. In addition, the ITT for the SWIR detector pre-development to support both Phase A/B1 contracts was issued early November, for an expected start of activities in March 2024.

Sentinel-3 Optical NG

The MAG had its third meeting on 30 November - 1 December 2023. Two science support studies (NGS-AOLCI and NGS-ASLSTR) have started and are providing input for the consolidation of the mission requirements. The Phase A/B1 Procurement proposal was presented at the IPC meeting on 26 June 2023 and the ITT was published on 5 October 2023. The KO meetings of two parallel study contracts are planned for Q1 2024.

Sentinel-3 Topo NG

The Phase A/B1 activities are proceeding to plan, building on the outcome of the PRR, in preparation of the ISRRs for both OHB and ADS. The Mission Gate Review is planned for March 2024 (TBC) to assess the results of the on-going Phase A/B1 study and confirm the adequacy of the swath altimetry measurement system.

Sentinel-6 NG

The Assessment SEa Level rise Stability Uncertainty (ASELSU) study aimed at developing a detailed uncertainty budget in support of this mission development has concluded. A CCN is currently in preparation to extend the work for 2 more years.

7.3. 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, six Copernicus Expansion missions 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.

7.3.1. 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.

Both Phase A/B1 contracts are closed. During this reporting period, the CHIME team concentrated on the Phase B2/C/D/E1 Contract progress.

7.3.2. 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.

During this reporting period, the CIMR team concentrated on the following main tasks:

- Progress on flow-down of the Contract Rider to lower levels.
- Progress on technologies maturation and equipment development.
- Progress on the Antenna and LDRS PDRs.
- Consolidation of Spacecraft mechanical and AOCS design.
- Execution of a number of reviews (EQSR, PDR, ...) at lower levels.
- Progress on GSE procurement through the Best Practices process.
- 12th round of Progress Meetings with Industrial Consortium.

7.3.3. 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.

During this reporting period, the CO2M team concentrated on the following main tasks:

- Launcher PMAR with exchange of mechanical, thermal models and EMC environment to assure compatibility between launcher provider and Industry to get the overall boundaries frozen to run Spacecraft analysis.
- Implementation of the workplan and follow up of analysis test activities necessary to reach Payload CDR and Space Segment CDRs objectives completion.

- Run of the PL CDR part 1 to authorise the start of the CO2I PFM AIT (starting with the spectrometer alignment).

Phase A/B1: Activities from the Phase A/B1 contract are completed (contract to be formally closed).

7.3.4. 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.

During this reporting period, the CRISTAL team concentrated on the following main tasks:

- Further Preparations of System CDR and instrument CDR, consolidating planning and data pack.
- Most of the PFM platform flight hardware is now under manufacturing and first flight hardware already under acceptance testing.
- Good progress on IRIS instrument lower level CDR's, with Antenna CDR and PSUCDR Calibration Coupler CDR completed; CEU and SSPA CDR started.

7.3.5. 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.

During this reporting period, the LSTM team concentrated on the following main tasks:

- Agreement on all details of the design verification approach as input for the Instrument CDR.
- ICU PDR successful.

- Successful Ambient Optical Bench (AOB) detailed design review.
- Delivery of all Engineering Models and GSE models required to initiate the satellite Electrical Functional Model.
- Agreement on the Instrument Key Interface Data necessary to guarantee the preparation of the satellite CDR.
- LSTM/TRISHNA/SBG Land Surface Temperature Workshop held in November 2023.

7.3.6. ROSE-L: L-band Synthetic Aperture Radar

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 European Ground Motion service (EGMS).

Its target applications are the measurement of surface deformation of vegetated and faster moving 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. Applications will be further enhanced through the combined use of ROSE-L and Sentinel-1. The ROSE-L mission will provide repeat-pass SAR interferometry (InSAR).

During this reporting period, the ROSE-L team concentrated on the following main tasks:

- Completion of Prime Progress Meeting #15 (November 2023).
- Schedule review meeting with System and Instrument Prime's (November 2023).
- Completion of Instrument Progress Meeting #15 (November 2023).
- Mission Advisory Group Meeting #14 (December 2023).
- Further iteration of TED analysis of the SAR antenna and elaboration of mitigation measures.
- Progress towards completion of TRL6 related achievements (TRM).
- Progress of SAR instrument EQM programme.
- Progress in the analysis of on-ground RFI issues.
- Monitoring of unit level progress and reviews.

7.4. ESA Climate Change Initiative (CCI)

7.4.1. 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 was 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, with a focus on datasets characterising meteorological aspects of the climate system.

7.4.2. Current status

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

- ESA successfully contributed to COP28 with a dedicated pavilion in the blue zone, presentations at the Earth Information Day and the Space Leader Summit and various side events.
- At COP28, discussions with the chair of IPCC, Prof Jim Skea, took place focussing on the preparation of the assessment report #7. A scoping meeting is foreseen by IPCC for early 2024, with the approval of a special report on Cities being planned.
- The implementation of CCI phase 2 is on-going, with most extensions to existing ECV projects, and the associated funding, being placed.
- The new climate initiative, CLIMATE-SPACE, was presented and over-subscribed to at the Ministerial Council 2022 (CM22). The first three procurement activities, focussing on GHG Emissions, Cross-ECVs and the Global Land Carbon Budget and Attribution to Regional Drivers have been released.
- WCRP’s Coupled Model Intercomparison Project International Project Office (CMIP-IPO) continues to establish its activities in preparation for CMIP-7. The CMIP-IPO and the ESA Climate Office contributed to the WCRP Open Science Conference in 2023.
- The next Climate Science Advisory Board (CSAB) planne for Q1 2024 will review progress in the programme implementation and discuss the impact of strategic developments such as the outcome of the Space Summit, S4GF and agreements with UNEP and DG-CLIMA.
- The 13th CCI and Climate Modelling User Group (CMUG) colocation meeting took place 7-10

November 2023 at ECSAT. The summary is available at:

https://climate.esa.int/media/documents/Summary_of_CCI_colocation_and_CMUG_integration_meeting_2023.pdf

- Collaboration with operational climate services and with the international climate network are on-going. Discussions are planned with the Copernicus services and DG-CLIMA.
- The CEOS/CGMS Working Group on Climate (WGClimate) took place 16-17 October 2023 in ESRIN with a special focus on the space agencies' response to the updated GCOS implementation plan.

7.4.3. Scientific highlights

Snow: New paper: *Assessment of Arctic seasonal snow cover rates of change. The Cryosphere* by Derksen, & Mudryk (2023) <https://doi.org/10.5194/tc-17-1431-2023>.

Permafrost: New review paper: *Permafrost Monitoring from Space – a review: Understanding the implications of thawing permafrost is expected to advance with enhanced data availability and products*, April 19, 2023 <https://climate.esa.int/en/news-events/permafrost-monitoring-from-space-a-review>.

Lakes: The Lake Water level product features in a recent study published by Science (Yao *et al*, (2023)). The study evaluated the total storage change of ~2000 lakes and reservoirs over the period 1992-2020 <https://doi.org/10.1126/science.abo2812>

Biomass: Version 4 of the CCI Biomass dataset was officially released at the GFOI Plenary in Rome. Version 4 consists of above-ground biomass (AGB) maps at 100 m resolution for 2010, 2017, 2018, 2019 and 2020, as well as decadal AGB change from 2010-2020 and annual AGB change for the period 2017-2020.

Cloud: A 1-year demonstrator datasets for SEVIRI and SLSTR providing cloud properties as well as the radiative flux properties at top and bottom of atmosphere was completed. A new study: *Validation of the Cloud_CCI cloud products in the Arctic* (Vinjamuri *et al* (2023)) <https://doi.org/10.5194/amt-16-2903-2023>.

GHG: Several data sets have been used for the recent CAMS greenhouse gas reanalysis (Agustí-Panareda *et al.*, 2023). Data products initially developed in GHG-CCI and now operationally generated in C3S have been used for the Copernicus ESOTC 2022 assessment (see <https://climate.copernicus.eu/esotc/2022> and <https://climate.copernicus.eu/climate-indicators/greenhouse-gas-concentrations>).

Glaciers: A review paper by Berthier *et al.* (2023) *Measuring glacier mass changes from space* (doi.org/10.1088/13616633/acaf8e). The study gives an overview on the available sensors and stresses the importance of accurate glacier outlines to correctly calculate glacier volume changes. The different methods are intercompared for two test regions (Iceland, Himalaya) to highlight the strength and weaknesses of each method.

Ice Sheets: The latest Mass balance of the Greenland and Antarctic ice sheets from 1992 to 2020 has been published (Otosaka *et al.*, 2023) [doi:10.5194/essd-2022-261](https://doi.org/10.5194/essd-2022-261). The project also contributed to a major paper: *Heat stored in the Earth system 1960–2020: where does the energy go?* (von Schuckmann *et al.*, 2023) in Earth System Science Data, <https://doi.org/10.5194/essd-15-1675-2023>.

7.4.4. New Datasets

The following new datasets are available on the CCI Open Data Portal (climate.esa.int/data):

- **Biomass:** Global datasets of forest above-ground biomass for the years 2010, 2017, 2018, 2019 and 2020, v4 <https://dx.doi.org/10.5285/af60720c1e404a9e9d2c145d2b2ead4e>.
- **LST:** Extensions to existing datasets: SLSTR v4.aa, MODIS v4.aa, GOES v3.00. New datasets for Himawari-8 v1.00, Metop-A AVHRR v1.00, NOAA 15-19 AVHRR v1.00.
- **Sea ice:** The High(er) Resolution SIC CDR (1991-2020) <https://catalogue.ceda.ac.uk/uuid/eade27004395466aaa006135e1b2ad1a>.
- **Sea level:** Coastal sea level dataset of monthly sea level trends at virtual stations (v2.2, <https://doi.org/10.17882/74354>) <https://catalogue.ceda.ac.uk/uuid/90049a6555d1480bb5ce9637051dede8>.
- **Soil Moisture:** v08.1 version (including ACTIVE, PASSIVE and COMBINED) has been produced.

7.4.5. CEOS/CGMS Working Group on Climate (WGClimate)

The 19th CEOS/CGMS WGClimate meeting took place on 16-17 October 2023 at ESRIN in Frascati, Italy. The agenda covered the ECV inventory status and gap analysis report version 4, discussing its capacity to address GCOS updated implementation needs, the evolution of the WMO use cases and their uptake, the CDR definition and the Space agencies' response to GCOS' updated implementation plan. The next meeting is planned for spring 2024, in Boulder, Colorado, USA. Regarding the GCOS updated implementation needs, an action is ongoing to address the space agency relevant contributions to the identified actions. ESA has submitted its input to the actions being prioritised for 2024.



In the Greenhouse Gas (GHG) Task Team is led by ESA and sits under the CEOS WGClimate. ESA is also co-lead of the CEOS Atmospheric Composition Virtual Constellation AC-VC. Jointly with ESA's Climate Office and input from ESRIN, ESA has provided feedback on the GHG Roadmap implementation actions. The GHG Task Team has completed the *Roadmap for Implementation of a Constellation Architecture for Monitoring Carbon Dioxide and Methane from Space* in cooperation with CGMS and GSICS. As a further important contribution that ESA have been heavily involved in, was the *CEOS Agriculture, Forestry and Other Land Use (AFOLU) Roadmap*. This was presented to the CEOS SIT Technical Workshop and later endorsed at the CEOS Plenary in November 2023 in Thailand.

ESA, as the 2022-2023 CEOS Strategic Implementation Team (SIT) chair, coordinated the publication of a *CEOS Strategy to Support the Global Stocktake of the UNFCCC Paris Agreement* paper, authored by the CEOS Global Stocktake (GST) team. The GST team combined more than ten CEOS groups involved in the preparations of the CEOS' contribution to the 2023 GST. This paper sets out a way forward by which CEOS Agencies can coordinate their efforts to support the first and subsequent GSTs of the 2015 Paris Agreement among Parties to the United Nations Framework Convention on Climate Change (UNFCCC). The paper covers the specific modalities of the GST and proposes where and how Agencies can support its implementation. Support may be either to the overall assessment of collective progress through the GST, or to individual parties in their transparent reporting as required by the Paris Agreement. The paper includes a series of recommendations with corresponding future actions, building on the significant efforts to date.