

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

CGMS is informed of the status of the current European Space Agency Earth Observation missions. Two of them, MSG and MetOp are in co-operation with EUMETSAT. The Gravity field and steady-state Ocean Circulation Explorer, GOCE, the first Explorer satellite launched on 17 March 2009, ended its mission in November 2013. The SMOS satellite was launched on 2 November 2009. All reprocessed Level 1 and 2 data are available from the ESA Cal/Val portal since mid-March 2012. The CryoSat-2 satellite was launched on 8 April 2010. Release of systematic CryoSat products (Level 1b and 2) to scientific community is going on. The Proba-V small satellite was launched on 7 May 2013. Its coarse resolution imager continues the data acquisition of the Vegetation payload on-board SPOT-4 and 5. The Swarm satellites were launched on 22 November 2013. About 4,000 data user projects worldwide use data from the ESA EO missions and this number is increasing further. The total volume of ESA EO mission data downloaded exceeds 10 Petabytes per year, available to users free of charge.

CGMS is further informed of the status of the future European Space Agency Earth Observation missions. Two of them, MTG and Post EPS (now EPS SG) are in co-operation with EUMETSAT. The Living Planet Programme has three lines of implementation: Earth Explorer satellites, Earth Watch satellites plus services and applications demonstration. Progress in the preparation of the forthcoming Explorer missions ADM-Aeolus, EarthCARE, BIOMASS and FLEX is described.

Copernicus represents the major new initiative of European efforts in Earth Observation. The first Copernicus dedicated satellite (“Sentinel-1A”) was launched on 3 April 2014, followed by Sentinel-2A in June 2015, Sentinel-3A in February 2016, Sentinel-1B in April 2016 and Sentinel-2B in April 2017; other Sentinels will follow in 2017 onwards. Sentinel missions are developed in partnership with the European Union. 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.

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 Programme has continued to progress well. The existing project teams have made significant progress on algorithm development and on specifying a future operational system. The Programme achieved its Phase 1 objectives end-2013, continued in Phase 2 starting since early 2014 and represents a strong source of ECV data sets for the Copernicus Climate Change Services. ESA’s member states have extended the program to continue until 2024.

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1 INTRODUCTION

This paper provides information on the status of the current and future European Space Agency Earth Observation missions. ESA's Living Planet 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 with the European Organisation for the Exploitation of Meteorological Satellites (Eumetsat). These missions (MSG, MTG, MetOp and EPS-SG) are not dealt with in this report.

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

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

2 CURRENT ESA SATELLITE SYSTEMS

Satellites	Equator Crossing Time Altitude	Launch date	Access to data or products	Instruments	Status, applications and other information
PROBA-1	7:30 (D) 615 km	22/10/2001	Earthnet on line	CHRIS, SREM	The orbit is drifting from the original 10:30 desc. ECT.
SMOS (with CNES and CDTI)	06:00 (A) 755 km	2/11/2009	SMOS data centres	MIRAS (Microwave Imaging Radiometer using Aperture Synthesis), GPS, STA	L-band radiometer for salinity & soil moisture observation
PROBA-2	06:00 (A) 730 km	2/11/2009	Earthnet on line	SWAP, LYRA, TPMU, DSLP	2 nd 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
PROBA-V	10:30 (D) 820 km	5/07/2013	Earthnet on line	VEGETATION-P	2 nd flight unit of the PROBA programme. Main mission: vegetation monitoring
Swarm A & C (with CNES and CSA)	87.35° 460 km	22/11/2013	Earthnet on line	ACC, SM, EFI (SWARM), GPS (ESA), LRR (DLR), STR (SWARM), VFM	Earth magnetic field
Swarm B	87.75° 530 km	22/11/2013	Earthnet on line		
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	MSI (Multispectral imager)	Land and vegetation observation

			Ground Segment (PDGS). Real-time availability possible at appointed X-band stations.		
Sentinel-3A (with EC)	10:00 (D) 814.5 km	16/02/2016	Commissioning till about August 2016	DORIS, GPS, LRR, MWR, OLCI, SLSTR, SRAL	Primary mission: ocean observation. Secondary mission: atmosphere and land applications
Sentinel-1B (with EC)	06:00 (D) 693 km	25/04/2016	Commissioning	SAR-C	Radar imagery
Sentinel-2B (with EC)	10:30 (D) 786 km	06/03/2017	Data available from centres of the Payload Data Ground Segment (PDGS). Real-time availability possible at appointed X-band stations.	MSI (Multispectral imager)	Land and vegetation observation

3 STATUS OF CURRENT EARTH EXPLORER SATELLITES

Three ESA Earth Explorer missions are currently in operation, namely SMOS (launched in 2009), CryoSat-2 (launched in 2010) and Swarm (launched in 2013). All three missions, as well as GOCE, have provided outstanding results of interest to the meteorological and climate research communities at large.

3.1 GOCE

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

3.1.1 Status of spacecraft

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

3.1.2 Performance and results

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

A method to remove a large part of the across-track gravity gradient disturbances found over the north magnetic pole region has been identified. This may lead to a re-processing of Level 1b and to improved Level 2 data products.

Internal ESA analysis of the GOCE gradiometer data processing has identified scope for improvement of the so-called yy-gradient (across the track) over regions where the accelerometer measurements were affected by large common-mode signals. Such disturbances in fact show up as quadratic acceleration terms. Newly discovered methods to improve the GOCE gravity gradient data will allow the development of a 6th set of GOCE-based gravity field models, with significant improvements over an already excellent product.

A study of the impact of the GOCE-based geoid on ocean modelling is about to enter into the user consultation phase, where gravity and oceanography specialists jointly assess the findings.

3.2 SMOS

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

3.2.1 Status of spacecraft

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

3.2.2 Performance and results

The data acquisition is split between the XBAS acquisition system at ESAC and Svalbard (operated by KSAT), due to the near-real time requirement for SMOS data. ESAC has successfully acquired 97.6% of the passes and Svalbard 100%. Globally, 99.5% of the passes have been acquired with both stations. Due to the 2.2-orbit overlap between ESAC and Svalbard acquisitions, there is no data gap due to acquisition failure, i.e. all data are ingested in the Data Processing Ground Segment (DPGS) at ESAC. The acquired data are successfully processed to more than 99% for all product levels including NRT. More than 95% of the NRT product is delivered in less than 165 minutes of the sensing time. For the whole reported period the data dissemination of the nominal data has continued from ESAC.

The ESA SMOS data portal <https://smos-diss.eo.esa.int> opened in March 2016, is providing a single entry point for all SMOS level 1 and level 2 data products (including NRT products), containing all operational and reprocessed data sets and auxiliary data. For Level 1 and Level 2 data products the web interface allows the selection by data type, acquisition date, and geographical area of interest. Level 2 data products are also available in NetCDF, in addition to the nominal Earth Explorer format. Since the opening of the service, more than 3.8 million products have been downloaded by 268 active accounts, with a total volume of 109 TB. The two SMOS data products available in NRT, the Level 1 brightness temperatures (NRT light data product) and Level 2 Soil Moisture based on a neural network approach, are also available from EUMETSAT's EUMETCast system and through the UK Met Office. Level 3/4 data products are available from the national data centres in France (CATDS www.catds.fr/Products/Available-products-from-CPDC) and Spain (BEC: <http://cp34-bec.cmima.csic.es/land-datasets>). SMOS users community confirmed the skill provided by the new SMOS-based wind speeds complementing existing measurements, in particular for higher wind speeds.

3.3 CryoSat-2

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

3.3.1 Status of spacecraft and mission

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

The new Star Tracker software loaded in autumn 2016 on all the units was closely monitored. Outstanding performance has been observed with a considerable increase in robustness against problems caused by the South Atlantic Anomaly (SAA) and in re-acquiring attitude when exiting from Sun or Moon blinding. Even when the Star Trackers are subject to extreme thermal conditions, the performance is comparable to those measured at beginning of life.

An on-board campaign, aiming at characterising the dependency of the SIRAL “CALIBRATION-1 Pulse Response” from the thermal environment, was performed in dawn/dusk orbit conditions. This activity completes the other campaign executed earlier in 2016 when measurements were acquired under different thermal conditions. Results will be made available first half 2017.

A total of 31.4 kg of fuel is still remaining on-board, allowing adequate orbit maintenance manoeuvres to keep the satellite within the required dead-band and to perform necessary Collisions Avoidance Manoeuvres.

3.3.2 Performance and results

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

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

The upgrade of the Payload Data System in Kiruna was completed. Despite the slight delay on schedule, there was no major impact on the acquisition, processing and dissemination of data. With this upgrade, the ground segment is fit to operate the mission in its new extended phase and able to accommodate new requirements issued by the scientific and operational community.

The end-to-end mission performance, namely the overall mission data return that takes into consideration the planned (0.08%) and the unplanned unavailability (0.50%) of the space and ground segments, was higher than 99%.

Since the start of the mission, the overall availability of the science data has been 98.37%, well above the design performance of 94%.

Activities related to the development of Baseline C of *ocean products* in NETCDF are progressing according to schedule with a minor delay expected in the final stage. It is recalled that this version will include the SAMOSA re-tracker for ocean areas covered by SAR and SARIN.

The development of Baseline D *ice products* is also progressing according to schedule. The scope of the activities of this baseline was frozen in a meeting with industry in July. Similarly to the ocean products, the new Baseline D *ice products* will be released in NETCDF format. This new approach is considered as a fundamental evolution; its aim is to increase the uptake of the CryoSat products by the user community in the next decade.

Preliminary results on calibration campaigns were presented during the 13th *CryoSat Calibration Meeting* which took place in November 2016 but were not conclusive. Final ones including recommendations were presented at the following meeting in May 2017.

In October, a short validation autumn campaign, in collaboration with UK, took place in the Arctic, over land (i.e. EGIG line) and sea-ice regions. The campaign was the first one to employ airborne Ka and Ku capabilities and collect co-located airborne altimetric data in support of the evolution of this mission concept. It is experimental but will provide

fundamental inputs for the larger campaign planned for spring 2017. Preliminary results will be presented on 11 January 2017 in ESTEC.

The spring 2017 (March/April) campaign has begun. The campaign focuses on major sources of uncertainty in the products including snow loading on sea ice and temporal changes in land ice radar signatures (e.g. due to melt events and changing climate). This larger campaign has both ground and airborne teams. There are plans to collaborate once again with the NASA IceBridge team in the form of simultaneous flights underlying CryoSat and Sentinel-3.

The primary web interface for users uses the CryoSat Mission pages within Earth Online <http://earth.esa.int/cryosat>. Its main purpose is to provide a one-stop shop for all matters regarding the CryoSat mission including data access.

Using data dating back to 1992 from the ERS- mission, together with information from ERS-2, ENVISAT, CryoSat and NASA's IceSat, scientists from the UK's Centre for Polar Observation and Modelling reconstructed surface heights along a series of glacial flow lines to see how thinning at the grounding lines had been passed further inland. In 1992, all three were already experiencing height loss at or near the grounding line, with Pine Island Glacier losing height by around 1 m every year – although the interior surface was stable. Thinning then spread steadily, first up the glacier's main trunk, and then further inland. While the pace at which it spread across the surface varied, rates of thinning reached up to 13 km/year. The study was published in Geophysical Research Letters and presented at the American Geophysical Union's Fall Meeting which was held in San Francisco (USA) in December.

CryoSat revealed lake outbursts beneath Antarctic ice using a novel processing technique. An Antarctic digital elevation model using 250 million CryoSat points is now available to the scientific community.

3.4 SWARM

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

3.4.1 Status of spacecrafts

All satellite platforms are performing very well, essentially free of any anomalies, and the space segment constellation geometry evolves in line with expectation. The fifth biannual In-Orbit Performance Review held in November has again confirmed the excellent health of the space segment, including its perspectives for long-term operations far beyond the nominal lifetime.

3.4.2 Performance and results

The main technical and scientific challenges remain the limited availability of high-quality accelerometer data from Alpha and Bravo, the search for optimised (near-continuous) operations scenarios for the Thermal Ion Imagers and the search for the optimal understanding of the optical bench performance for magnetometry and attitude observations. The Swarm constellation and its operations are otherwise in perfect shape.

Three discoveries from the Swarm mission have been recently published: (i) an unprecedented quality and spatial resolution model of the crustal magnetic field, (ii) an asymmetry in ionospheric currents amounting to several hundred thousand amperes between

the northern and southern winters, and (iii) supersonic plasma jets around the boundaries of field-aligned current regions.

Using Swarm data researchers have discovered a powerful, up to 45 km/year, jet stream in the outer core below Siberia, Canada and Alaska. This accelerating core flow is so strong that it is even bound to constrain the rotational state of the inner core, and signifies a new way to probe the deep Earth. The discovery was also the most-read article in Nature Geoscience in the month of December 2016.

4 STATUS OF CURRENT EARTH WATCH SATELLITES

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

4.1 Proba-V

Launched on 7 May 2013, Proba-V is tasked with a full-scale mission: to map land cover and vegetation growth across the entire planet every two days. Proba-V is flying a lighter but fully functional redesign of the 'Vegetation' imaging instruments previously flown aboard France's full-sized Spot-4 and Spot-5 satellites, which have been observing Earth since 1998. The Spot Vegetation dataset had close to 10,000 registered users around the globe and has contributed to hundreds of scientific papers over 15 years. But with further Spot satellites lacking the capacity to carry Vegetation instruments, Proba-V has been designed to meet the future needs of this group. Proba-V's Vegetation instrument boasts improved spatial resolution from its Spot predecessors: 350 m resolution compared to 1 km for Spot Vegetation, with 100 m resolution available within its central field of view. The Proba-V mission is operating in its extended mission lifetime since November 2015 for another 2.5 years lifetime. Based on the excellent mission results, the user community need, and the technical and programmatic feasibility, the ESA Program Board on Earth Observation (PB-EO) has approved a further extension of 1.5 year until autumn 2019.

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

4.1.1 Status of spacecraft

Proba-V spacecraft has been operated nominally and is very stable with no safe mode occurrence.

However, the flight system has experienced an event which caused the complete emptying of the Mass Memory Module (MMM). On one occurrence at the end of a satellite X-band pass, the on board scheduled command which stops the MMM Vegetation data downlink was not properly executed resulting in the emptying of the MMM. Analysis is ongoing to determine the possible cause of this event.

The main point of discussion was the extension of the Proba-V mission beyond its current end of life (March 2018). The need of extending the mission is justified by the fact of ensuring a smooth running of the Service based primarily on ProbaV data until the Sentinel-3 constellation (A+B satellites) will have achieved its full operational capacity. Taking into

account the Sentinel-3B current launch date (Q4 2017) and the related commissioning and ramp-up phases, this translates in the necessity to ensure that Proba-V will continue its operations until at least mid 2019. Following these considerations, the programme extension until autumn 2019 has been approved by the ESA member states.

4.1.2 Performance and results

The reprocessing of the full Proba-V mission data (acquired since Oct 2013) started in August 2016 with the latest processor version. The new dataset, called “Collection 1”, includes several improvements; in particular, an enhanced cloud screening algorithm and the usage of a refined set of radiometric calibration coefficients. Furthermore, the Plate-Carrée projected Top-of-Atmosphere (TOA) segments (Level 2A products) will be distributed to the users for the first time, in response to a specific request from the CGLS. The reprocessing of the full mission has been completed in January-February 2017. As of 15 March 2017, a total of 1,073 users with 105 different nationalities representing 818 different companies/universities (status) are registered for Proba-V data access.

Further information about Proba-V products can be found in Earth Online portal¹.

4.2 The Copernicus Sentinel programme

4.2.1 Sentinel-1A and 1B

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

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

The Sentinel-1A and Sentinel-1B routine operations are on-going and the overall operations mission performance has been nominal. The Sentinel-1 observation scenario supports the systematic coverage of Copernicus Services areas of interest, of European land and coastal waters, of global tectonic/volcanic areas, as well as of other specific areas worldwide for various applications. The observation plan also includes a regular mapping of all land areas worldwide, with a frequency largely increased with Sentinel-1B in operations. Starting on 26 September 2016, the Sentinel-1 observation plan is implemented with the combined use of Sentinel-1A and Sentinel-1B.

Sentinel-1 data can be accessed from <https://sentinels.copernicus.eu>.

World maps providing a high level description of the overall Sentinel-1 constellation observation scenario, in terms of SAR modes, polarisation, observation geometry, revisit and coverage frequency are available at:

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

By 6 April 2017, a total of 77,128 users have self-registered on the Sentinels Scientific Data Hub; 7,6 million Sentinel-1 product download have been made by users, corresponding to

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

about 9.1 PB of data. 1.2 million Sentinel-1 products are available on-line for download, representing 1.6 PB of data. Statistics of last 24 hours are available in real time at the Data Hub home page: <https://scihub.copernicus.eu>

4.2.2 Sentinel-2A and 2B

A pair of Sentinel-2 satellites will routinely deliver high-resolution optical images globally, 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 06 March 2017. The In-Orbit Commissioning Review (IOCR) should be terminated by the end of June 2017.

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

More information can be found at: <https://sentinel.esa.int/web/sentinel/sentinel-data-access>

4.2.3 Sentinel-3A

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-3B is scheduled to be launched end 2017 (see below §5.2.1).

The overall status of the spacecraft is nominal, with all subsystem performing nominally and all instruments, including OLCI, SRAL, SLSTR and MWR, are switched on and performing as expected.

An anomaly is re-occurring from time to time on SLSTR, causing the instrument temperature to rise from the expected 77K. In the subsequent days the instrument is cooled down again and is set at nominal temperatures for both VIS and IR channels. The respective outages and information about degraded data are communicated to users through the ESA and EUMETSAT webpages and User Notification Services. The root cause of this anomaly is known and a faster recovery procedure is under development and testing to allow a shorter mission data outage should the anomaly re-occur.

The Flight Operations Segment (FOS) for Routine Operations is operating nominally. The Payload Data Ground Segment (PDGS) for Land and Marine are operating broadly as expected in the mission ramp-up phase, gradually moving towards full operational capacity. Some outages and data delays may continue to occur due to upgrading/maintenance of the PDGS systems and the on-going core data release.

5 FUTURE ESA SATELLITE SYSTEMS

5.1 Future Earth Explorer 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.

5.1.1 EarthCARE

EarthCARE – the largest and most complex Earth Explorer mission to date – is being developed as a joint venture between ESA and the Japan Aerospace Exploration Agency, JAXA. 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 main EarthCARE risk was associated with the development of the ATLID and its challenging transmitter, due to the technologies involved and the complexity of this instrument.

Current plans call for an EarthCARE System Qualification Review in October 2018 and a Flight Acceptance Review in May 2019, after agreement with JAXA on planned CPR refurbishment and delivery in redundant configuration in May 2018. The mission has a design lifetime of three years, including a six-months commissioning phase.

5.1.2 ADM-AEOLUS

The ADM (Atmospheric Dynamics Mission)-Aeolus satellite will carry a single, but complex, instrument that will probe the atmosphere to profile the world's winds. Reliable and timely wind profiles are urgently needed by meteorologists to improve weather forecasts. In the long term, they will also contribute to climate research. Aeolus will carry a pioneering instrument called ALADIN that uses laser light scattering and the Doppler Effect to gather data on wind.

Developing the laser transmitter has been a very long and difficult undertaking – forging new technologies in many areas such as optics, opto-electronics, precision mechanics and thermo-mechanical design.

The satellite initial functional testing, including the Aladin instrument commanding and data reception has been completed successfully, as well as the system validation test with the Flight Operations Segment. The life test of representative samples of all optical elements of the Aladin transmit optics is successfully completed at representative fluence after more than 1.3 Gshots, equal to ten months of continuous operation. The overall reduction in transmission is estimated to be 8%, which is in line with the test predictions. Detailed inspections of the optics after these tests are being performed.

With the successful completion of all initial functional tests of the satellite, the consolidated planning leads to a Qualification and Acceptance Review completion in October 2017, commensurate with a launch period opening on 1 November 2017. A launch period of

November 2017 to January 2018 has been agreed with Arianespace. Discussions are on-going with Arianespace to identify the one month launch slot.

5.1.3 BIOMASS

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

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

Negotiations with industry concluded with the signature of a contract with the Airbus Defence and Space (ADS) covering the phases B2/C/D/E1. The launch of the mission is foreseen for Q2 2021. All Core Team contracts between the prime contractor ADS-UK and its major industrial partners have been signed. The System Requirements Review has been formally closed in January 2017. The build-up of the industrial team will have progressed such that Phase C/D will start in Q4/2017. The current planning calls for a launch in July 2021.

A call for a special issue in the IEEE JSTARS journal on “Forest Structure Estimation in Remote Sensing” has been initiated to collect and promote recent results from Biomass campaigns and scientific activities. A joint science workshop with the Biomass, GEDI (NASA), NISAR (NASA) and Tandem-L (DLR) science teams on “Measuring Forest Structure Parameters using Space-Based Observing Systems” is organised at ISSI in Bern on 6-10 November 2017. The meeting will include a CEOS LPV meeting for biomass.

5.1.4 FLEX

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

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

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

As of April 2017, the FLEX Instrument (FLORIS) pre-development activities are progressing well. The Instrument Requirements Review is running with the Board meeting in early May 2017. The technical ITT documentation for the space segment procurement is under completion. The instrument PDR is now planned for completion in April 2018 and a kick-off of the FLEX space segment contractor shortly thereafter. To achieve the latter, the release of the FLEX Prime ITT is planned for April 2017.

The planned launch date for the FLEX mission is Q4 of 2022.

5.1.5 9th Earth Explorer mission

On 23 November 2015, ESA announced an opportunity for scientists involved in Earth observation to submit proposals for the next potential Earth Explorer satellite mission.

Traditionally, Earth Explorers use new measurement techniques to explore and understand different aspects of the Earth system. Reflecting the new Earth Observation Science Strategy for ESA, proposals for the ninth Explorer should not only demonstrate scientific excellence and innovative technology, but also address important scientific questions that have a direct bearing on societal issues humankind will face in the coming decades. This includes, for example, the availability of food, water, energy and resources, health, risk of disaster and climate change.

A revised Call for EE-9 'Fast-Track' Mission Proposals was released on 13 December 2016 (http://explorercall.esa.int/images/callee9documents/Revised_EE-9_Call_Text.pdf). The Agency is soliciting proposals for mission concepts fitting in a Vega-C dual-launch configuration that will not exceed a 260 M€ budget to ESA for implementation as EE-9. The Call notes that the EE-9 mission concept does not necessarily have to be a single satellite but could be composed of a constellation of (smaller) satellites, if they allow addressing the outlined science challenges. Deadline for the receipt of full Proposals is 15 June 2017. Announcement of results of evaluation of Proposals is in end November 2017.

It is foreseen that the 9th Explorer will be launched no later than 2024.

5.2 Future Earth Watch missions

In addition to meteorological satellites, the GMES (Global Monitoring for Environment and Security) Sentinel missions, which form part of the GMES Space Component, will collect robust, long-term climate-relevant datasets. Also ESA has initiated studies on a Jason-CS mission (now known as Sentinel-6) aimed at continuing high-precision altimetry observations of the ocean beyond the current Jason-1, -2 and 3 series.

5.2.1 Sentinel-3B

Sentinel-3B is being developed for a launch in 2017.

At the request of the EC a study has been conducted to consider alternative phasing of the Sentinel-3B unit. The EC request was: *“Given that the Sentinel-3 series of satellites is principally aimed at supporting the Oceanography community, and in particular given that the altimetry observation capacity is of key importance for CMEMS, we would like to examine*

the technical and financial feasibility of the optimisation suggested by Mercator Océan [phasing between the Sentinel-3 series of satellites], leading to the best possible trade-off between the optical and topography missions.”

A technical note was then prepared and sent to the EC for their consideration. From the preliminary analysis, a candidate orbit phasing for the Sentinel-3A and Sentinel-3B satellites has been found that addresses the concerns of the CMEMS Service. The solution is to change the phasing of Sentinel-3A and Sentinel-3B from 180 degree to 140 degree phase separation to improve the topography mission sampling over a time window of 4 days. However, the ocean colour mission global coverage revisit is reduced from 2 days to 3 days over sun-glint free areas and there is a small impact on the SLSTR mission. Confirmation was therefore sought from CMEMS (and other Copernicus Services) that the topography sampling strategy defined by a 140 degree phase separation for the Sentinel-3 mission is acceptable, and that the consequent reduced ocean colour (and to a lesser extent SLSTR) coverage from 2 to 3-days is also acceptable to their primary users.

The orbit phasing between Sentinel-3A and 3B has been confirmed to shift from 180 to 140 degree, as agreed for implementation by the EC in December 2016. ESA and EUMETSAT have jointly finalised the assessment and reached a technical agreement for the implementation of a Tandem phase, i.e. flying Sentinel-3B around 30 seconds apart from Sentinel-3A during the Sentinel-3B commissioning phase. The Tandem phase is planned to last 4-5 months with two drift phases of up to 6 weeks, one before and one after the tandem period. After a first iteration with the Commission on this topic in January 2017, which was received positively, the final assessment was communicated to the Commission in March 2017. The implementation will start in Q2 2017 following their go ahead.

5.2.2 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.

The next meeting of the Sentinel-4/5 Mission Advisory Group (MAG) is planned to take place on 23-24 May 2017.

5.2.2.1 Sentinel-4

Sentinel-4 is dedicated to air quality monitoring. To be carried on the geostationary Meteosat Third Generation satellites, the Sentinel-4 mission aims to provide continuous monitoring of the composition of the Earth's atmosphere at high temporal and spatial resolution and the data will be used to support monitoring and forecasting over Europe. It comprises an Ultraviolet Visible Near-infrared (UVN) spectrometer and data from Eumetsat's thermal InfraRed Sounder (IRS), both embarked on the MTG-Sounder (MTG-S) satellite. After the MTG-S satellite is in orbit, the Sentinel-4 mission also includes data from Eumetsat's Flexible Combined Imager (FCI) embarked on the MTG-Imager (MTG-I) satellite. The Flight Readiness Review of the first MTG-S1 satellite is expected to take place in Q1 2021. The recurrent Flight Model 2 will be embarked on board the second MTG-S satellite (MTG-S2) whose Flight Acceptance Review is presently planned in Q1 2029.

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

The first Sentinel-4 instrument deliverable model to MTG, was shipped on 4 April 2017 to the MTG Prime Contractor (OHB-Bremen) for further mechanical integration and verification onto the MTG-S platform.

The following two papers will be presented at the September 2017 EUMETSAT Meteorological Satellites Conference in Rome: “*The Sentinel-4 and Sentinel-5 Missions and their Atmospheric Composition Products*” and “*Knowing what we breathe: Sentinel-4 a geostationary imaging UVN spectrometer for air quality monitoring*”.

5.2.2.2 Sentinel-5

To be carried on the polar-orbiting MetOp Second Generation satellite, the Sentinel-5 mission comprises an Ultraviolet Visible Near-infrared Shortwave (UVNS) spectrometer and data from Eumetsat's IRS, the Visible Infrared Imager (VII) and the Multi-viewing Multi-channel Multi-polarization Imager (3MI). The first MetOp Second Generation satellite is expected to be launched in 2020.

With the close out of the System PDR in December 2015, the Sentinel-5 project initiated the start of Phase C. The full development programme of the Proto-Flight Model (PFM), together with the manufacturing and qualification of the recurrent models, Flight Modules FM2 and FM3, are committed. The Sentinel-5 Acceptance Review is planned for June 2019.

5.2.2.3 Sentinel-5P

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

The Sentinel-5P satellite is now slated for launch by Rockot on 16 August 2017.

In the coming period, contacts will continue between the Sentinel-5P Project at ESA and NASA/NOAA on finalising a strategy for a loose in-orbit formation between Sentinel-5P and the Suomi-NPP spacecraft. Furthermore, the launch of the S-NPP follow-on mission JPSS-1 is scheduled for September 2017 so that a coordination of planned orbit manoeuvres, before reaching the final target orbits, will be required between the Sentinel-5P FOS and the S-NPP operations centre at NOAA. The draft technical agreement with NOAA will be submitted to review by the Commission, in accordance with the standard process, before being formalised.

5.2.3 Sentinel-6 (Jason-CS)

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

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

The industrial contract for the procurement of the Sentinel-6/Jason-CS A satellite has been signed by ESA and Airbus DS. The Copernicus Procurement Board accepted the Sentinel-6/Jason-CS contract proposal for the combined procurement of the recurrent B model. Within EUMETSAT, the optional Jason-CS programme entered into force on 9 September 2015. The EUMETSAT funding share is secured for both the A and B Sentinel-6/Jason-CS satellites procurement, as required to proceed with phase C1.

NASA and NOAA jointly acting as the US party will provide the launch services for both Sentinel-6 A and B satellite, US payload instruments and ground segment support, and will contribute to the operations. Through the MOU approved in 2016, the three Parties (NASA and NOAA, ESA and EUMETSAT) have agreed to manage jointly the mission performances; each partner taking ownership of the mission results. With their heritage in space altimetry, the CNES support will be essential to the mission success. The ESA/CNES collaboration scheme agreed for Sentinel-6 is now implemented and effective.

A total of 43 applicants registered at the European call for participation for the Sentinel-6/Jason-CS Mission Advisory Group, which was issued on line on 16 December 2016 and closed on 21 January 2017. Three EUMETSAT, three ESA and two CNES members were selected by consensus to cover the necessary core competencies. U.S. MAG members were nominated directly (2 by NASA and 2 by NOAA) making a total of 12 MAG members. The first MAG meeting will be convened at ESTEC in summer 2017.

A dedicated Sentinel-6 session was convened at the 2016 Living Planet Symposium, 9-13 May 2016, held in Prague, Czech Republic. An essential link to the Ocean Surface Topography Science Team (OSTST) is maintained through the yearly reporting by the MAG to the OSTST about the Sentinel-6/Jason-CS status. The last OSTST meeting was held in November 2016 in La Rochelle, France.

Activities are ramping up in both Europe and the US, with a Flight Acceptance Review in April 2020 for Sentinel-6A. The mission PDR took place at EUMETSAT with the participation of all the partners and CNES. The satellite CDR is taking place in May 2017. The Poseidon-4 altimeter delivery is planned for November 2018, and the AMR-C instrument delivery is planned for March 2019. The Sentinel-6 satellite Final Acceptance Review is planned for April 2020. NASA will initiate their competitive procurement for the launch service for Sentinel-6A in April 2017. This LSTO will result in the selection of the launch service provider by September 2017. Considering Sentinel-6B will be launched in 2025, NASA did not include that service in their procurement. It is not given that the same launcher will be used again.

5.3 The ESA Climate Change Initiative (CCI)

5.3.1 Background

Combined satellite and *in situ* data archives can be used to produce data products for climate monitoring, modelling and prediction. To this end, the ESA Climate Change Initiative (CCI) was launched in 2009. The CCI has been created to address the GCOS Essential Climate Variable (ECV) requirements for satellite datasets and derived products. Its principal objective is “*to realize the full potential of the long-term global Earth Observation archives that ESA together with its Member states have established over the last thirty years, as a significant and timely contribution to the ECV databases required by the UNFCCC*”. The CCI focuses on the exploitation of data records primarily, but not exclusively, from past ESA satellite missions, for the benefit of climate monitoring and climate research. It complements existing efforts in Europe (e.g. led by EUMETSAT through the CM SAF) and internationally which focus on datasets characterizing meteorological aspects of the climate system.

5.3.2 CCI Phase 1

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

5.3.3 CCI Phase 2

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

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

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

5.3.4 Current status

The CCI programme is making good progress with its current objectives, as well as the preparations for CCI+. A call within the CCI programme had an excellent response from the

projects. More proposals were received than could be implemented in the current geo-return situation.

The CCI programme is well established and successfully delivering on its original objectives. The focus for the current programme is on promoting and exploiting the use of the ECV datasets, both to the core audience of climate modellers, as well as to other climate and environmental change researchers. CCI data is available a number of different ways through the Open Data Portal ([http](http://www.esa.int/ESASDP/CCI), [ESGF](http://www.esa.int/ESASDP/CCI), [OpenDap](http://www.esa.int/ESASDP/CCI), [ftp](http://www.esa.int/ESASDP/CCI), [WMS](http://www.esa.int/ESASDP/CCI)), as well as through the project websites and is now also available through the GEOSS portal.

The Copernicus Climate Change Service (C3S) issued a number of tenders on Observation Gridded Products in February 2016. These will be used to establish a service delivering a series of gridded long-term Climate Data Records (CDRs) of Essential Climate Variables (ECVs), along with the associated input data and user support functions. The first tender is for the following ECVs: Sea Ice, Sea Level, Sea-Surface Temperature, Ozone, Aerosol Properties, Greenhouse Gases (carbon dioxide and methane), Soil Moisture, Glaciers and Ice Caps, and, Albedo, Fapar and LAI.

Eight of the CCI project consortia successfully bid to provide the ECV data sets for the Copernicus Climate Change Service (C3S). It is to be noted that an additional ECV (Albedo, LAI, FAPAR), not part of the CCI programme, was selected by C3S in this first lot.

Following the ESA Ministerial in December 2016 during which the ESA member states decided to renew the CCI funding for a new period of 8 years, the Climate Science Advisory Body (CSAB) meeting was held on 17 January in ECSAT. A CCI info day will be organised at ESRIN on 6 July 2017 to provide potential bidders and stakeholders with information on future procurements under the CCI programme elements over a first period 2017-2020. According to the Implementation Plan, the first Calls for tender should be released beginning of September for a new set of 9 ECVs (Water Vapour, Ocean Surface Salinity, Sea State, Snow, Permafrost, HR Land Cover, Lakes, Above Ground Biomass and Land Surface Temperature) and the CMUG.

The Climate Modelling User Group (CMUG) meeting took place from 13-14 February 2017 in Paris, bringing together members from all projects and from ESA to discuss feedback from the CMUG team on their use of the ECV datasets. Highlights included the improvement of results from the assimilation of Ocean Colour products into a shelf seas model; better agreement of an atmospheric chemistry-climate model with observations than in most of the CMIP5 models; and substantial improvements of sea ice reanalysis at regional levels when using CCI sea ice data.

The focus for many of the projects has been on finalising updates to their ECV datasets before the end of their current contracts, and for some, before uptake by the Copernicus services. For the most part this is a one-year addition of data, performed annually; however some projects have larger updates in the pipeline. `Land_Cover_cci` will shortly release an annual land cover dataset, spanning 24 years, while `SST_cci` will expand their 20-year dataset to 35 years.

The Open Data Portal continues to add CCI data sets to the archive; newly available data are: Cloud, Sea Ice Concentration, Sea Level and Antarctic Ice Sheets.

An electronic Book has been developed to describe the CCI activities. This App called Climate from Space can be accessed on iTunes for iOS and on ... for Android platforms.