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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 exceeds 100 Terabytes 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 and BIOMASS 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 and recently, Sentinel-1B in April 2016; other Sentinels will follow in 2016 onwards. Sentinel missions are developed in partnership with the European Union. The Sentinel-4 and 5 instruments developed by ESA will fly respectively on MTG-S and Metop-SG.

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 thirteen 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 and continues in Phase 2 starting since early 2014.

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

1 INTRODUCTION

This paper provides information on the status of the current and future European Space Agency Earth Observation missions. ESA's 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 four Sentinel satellites. The status of future Earth Explorer and Earth Watch missions is presented, as well as the progress in the development of the ESA Climate Change Initiative (CCI).

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

2 CURRENT ESA SATELLITE SYSTEMS

Satellites	Equator Crossing Time Altitude	Launch date	Access to data or products	Instruments	Status, applications and other information
PROBA-1	7:30 (D) 615 km	22/10/2001	Earthnet on line	CHRIS, SREM	The orbit is drifting from the original 10:30 desc. ECT.
SMOS (with CNES and CDTI)	06:00 (A) 755 km	2/11/2009	SMOS data centres	MIRAS (Microwave Imaging Radiometer using Aperture Synthesis), GPS, STA	L-band radiometer for salinity & soil moisture observation
PROBA-2	06:00 (A) 730 km	2/11/2009	Earthnet on line	SWAP, LYRA, TPMU, DSLP	2nd flight unit of the PROBA programme. Main mission: space weather
CryoSat-2	717 km (92° incl.)	8/04/2010	Earthnet on line	SIRAL (SAR Interferometric Radar Altimeter), DORIS, LRR	Polar ice monitoring
PROBA-V	10:30 (D) 820 km	5/07/2013	Earthnet on line	VEGETATION-P	2nd flight unit of the PROBA programme. Main mission: vegetation monitoring
Swarm A & C (with CNES and CSA)	87.35° 460 km	22/11/2013	Earthnet on line	ACC, SM, EFI (SWARM), GPS (ESA), LRR (DLR), STR (SWARM), VFM	Earth magnetic field
Swarm B	87.75° 530 km	22/11/2013	Earthnet on line		
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 centers 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

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. The 5th generation GOCE gravity field solutions based on the so-called Time-wise (TIM) and Direct (DIR) methodologies, have been processed and verified by the GOCE High-level Processing Facility team, and made available to the public by ESA. This 5th generation solution spans the complete mission lifetime, including the low orbit data up to the re-entry of the satellite in November 2013. New global gravity gradient datasets based upon GOCE and GRACE at 225 and 255 km altitude derived from the full GOCE lifecycle have recently been made available to the research community, as an update of the earlier version based upon the nominal and lower orbit phase data respectively[1].
The gravity field data gap over the South Pole that still remained uncovered by GOCE has been measured in a highly successful airborne campaign in January 2016.

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.

[1] https://earth.esa.int/web/guest/missions/esa-operationaleo-missions/goce/geoexplore

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. The remaining amount of propellant is sufficient to maintain spacecraft operations for another 120 years! The performance of the instrument continues to be excellent, accounting for 98.25 % of availability for generating observation data.

After the successful SMOS Mission Extension Review, ESA's Member States and the French space agency CNES, which is responsible for operating the satellite platform, have decided to extend the SMOS mission into 2017. As a result of scientific recommendations provided as part of the SMOS extension review, major advances on the quality of salinity observations and related validation have been noticed.

3.2.2 Performance and results

The reprocessing for Level 2 soil moisture and sea surface salinity is completed; the data set has been released to the user community at the beginning of March 2016 through the new ESA's SMOS data portal.

The new soil moisture in NRT product is now distributed through the ESA's SMOS data portal since 17 March 2016 (https://smos-ds-02.eo.esa.int/oads/access/). Dissemination of the NRT product through EUMETCAST and GTS is planned for April 2016.

The special issue on SMOS in Remote Sensing of Environment "ESA's Soil Moisture and Ocean Salinity Mission after 6 years in orbit – Achievements and novel applications" was finalised for a release in spring 2016; accepted papers are available online.

Currently a total of 1,323 RFI sources have been detected worldwide, with 910 being switched off and 413 still operating (as of 29 February 2016). Preliminary results from the RFI tests over Japan indicate that the main contributors to the extended interference observed in Japan are malfunctioning TV-direct broadcast systems.

3.3 CryoSat-2

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

3.3.1 Status of spacecraft and mission

The overall performance of the CryoSat-2 mission's space and ground segments during the past year was nominal. The performance of the mission (i.e. 98.3%) remains well above the design specifications (i.e. 94.0%).

3.3.2 Performance and results

Activities related to the development of Baseline C of ocean products are continuing. This new version is expected to be released into operations by beginning of 2017. It will incorporate the NETCDF data format and be compliant with existing missions (i.e. Sentinel-3) and with those under development (e.g. Sentinel-6).

The start of the development of Baseline D ice products have been postponed to 2016 Q2. The scope of this new baseline is to include recommendations from the next user workshop (i.e. May 2016) and correct software issues that have been identified meanwhile. 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 aiming at increasing the uptake of the CryoSat products by the user community in the next decade.

The Antarctica field work of PolarGAP 2015/16 campaign, which took place from December 2015 through January 2016, was successful considering the extreme and challenging Antarctic environment. The collected dataset are currently being processed; preliminary results show that the dataset is very good. The first progress meeting will occur in May 2016. This campaign had both CryoSat and GOCE components in joint collaboration with the US National Science Foundation (NSF).

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.

A recent article published in the Journal of Geophysical Research (http://bit.ly/25GsCju) by a JPL team lead by Ron Kwok, examined four years (2011–2014) of sea surface heights (SSH) data from CryoSat over the ice-covered Arctic and Southern Oceans. Results showed that variability in the retrieved SSHs is between 2 and 3 cm (standard deviation) in the Arctic and is slightly higher (3 cm) in the summer and the Southern Ocean. Intraseasonal variability of CryoSat dynamic ocean topography in the ice-covered Arctic is nearly twice as high as that of the Southern Ocean.

The 4th CryoSat International User Workshop is planned to be held as part of the next ESA Living Planet Symposium (9-13 May 2016). This workshop is intended to provide a scientific forum to present and discuss all topics related to the exploitation of the CryoSat mission and to identify novel scientific and operational challenges.

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

The three Swarm satellites were successfully launched on 22 November 2013 into their circular polar target orbit at 490 Km altitude. Two satellites are now flying at an altitude of about 460 km and an inclination of 87.35°. They orbit almost side by side, about 150 km apart as they pass over the equator. The third satellite is flying in a higher orbit of 530 km and at a different inclination of 87.75°, slightly closer to the pole. All platforms and instruments are fully functional apart from the Absolute Scalar Magnetometer (ASM) on Swarm-C, after the loss of the two on-board instruments.

3.4.2 Performance and results

The main technical and scientific issues are related to the absolute scalar magnetometer situation (loss of both nominal and redundant unit on Charlie satellite), the limited availability of high-quality accelerometer data, the search for optimised operational 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.

The "Swarm4Anom – Investigation of the linkage between ionospheric plasma night-time density enhancements and magnetic field variability" study looks at upper atmosphere dynamics as a result of interaction of the solar wind with the Earth magnetic field. The focus is on the Weddell Sea anomaly and the mid-latitude night-time summer anomaly. This topic is also relevant to space weather science and applications.

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.

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

The Proba-V mission has been running nominally since it was declared operational. All the key parameters on-board have been well within their design margins. No platform and payload degradations have been detected. The Vegetation Instrument acquisition and calibration requests have been performed nominally.

4.1.2 Performance and results

ESA announced in December 2015 that accessing Proba-V data is easier than ever (and always free):

- All level 1C (NRT), all 1Km products (NRT), and all 333 m and 100 m products (older than 1 month) can be downloaded immediately after registration to the Proba-V portal[2].
- All 333 m and 100 m in Near Real Time are also offered to ESA PIs by ESA (free of charge) Access is granted after ESA project proposal acceptance (proposal submission).

[2] http://www.vito-eodata.be/PDF/portal/Application.html

The Proba-V Symposium was held successfully in Ghent 26-28 January 2016, with around 150 participants, as well as very good feedback from the user community on the mission performance and products quality

As of 15 March 2016 a total of 750 users with 94 different nationalities representing 586 different companies or universities had registered for Proba-V data access.

Further information about Proba-V products can be found in Earth Online portal[3].

4.2 The Copernicus Sentinel programme

4.2.1 Sentinel-1A

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 Sentinel-1A operational qualification phase is proceeding according to plan. The end of this phase is planned for May 2015. The overall operations mission performance has been nominal during the reporting period. The opening of the Sentinel-1 product dissemination to all users took place on 3 October 2014. Sentinel-1A data can be accessed from https://senti nels.copernicus.eu

The observation scenario supports the systematic coverage of a first set of Copernicus Services areas of interest, of European land and coastal waters, of global tectonic/volcanic areas, as well as of other specific targets worldwide for various applications. The observation plan also includes regular mapping of all land areas worldwide. An overview of the observation scenario is available at:
https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-1/observation- scenario

As of 28 April 2016, a total of 31,841 users had self-registered on the Sentinels Scientific Data Hub; 4,192,382 product download have been made by users, corresponding to 4.84 PB of data. At the time of publishing this report, 509,000 Sentinel-1A products are available on-line for download, representing 647 TB of data.

4.2.2 Sentinel-1B

Sentinel-1B was successfully launched from Kourou on 25 April 2016. It is now in the commissioning phase. The In-orbit Commissioning Review is planned on 14 September 2016.

4.2.3 Sentinel-2A

A pair of Sentinel-2 satellites will routinely deliver high-resolution optical images globally, providing enhanced continuity of SPOT- and Landsat-type data. Sentinel-2A 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.

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

The Sentinel-2A launch was successfully launched by VEGA (VV05) on 22 June 2015.

In accordance with the Copernicus data policy, Sentinel-2A 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-acces

4.2.4 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. Its innovative instrument package includes:

- A Sea and Land Surface Temperature Radiometer (SLSTR), based on Envisat's Advanced Along Track Scanning Radiometer (AATSR), to determine global sea-surface temperatures to an accuracy of better than 0.3 K.
- An Ocean and Land Colour Instrument (OLCI) based on heritage from Envisat's Medium Resolution Imaging Spectrometer (MERIS). With 21 bands, compared to 15 on MERIS, a design optimised to minimise sun-glint and a resolution of 300 m over all surfaces, OLCI marks a new generation of measurements over the ocean and land. The swath of OCLI and nadir SLSTR fully overlap.
- A dual-frequency (Ku and C band) advanced Synthetic Aperture Radar Altimeter (SRAL) based on CryoSat heritage and providing measurements at a resolution of ~300 m in SAR mode along track. SRAL is supported by a microwave radiometer for atmospheric correction and a DORIS receiver for orbit positioning.

The Sentinel-3 mission will be jointly operated by ESA and Eumetsat to deliver operational ocean and land observation services.

Sentinel-3A was successfully launched on 16 February 2016. Sentinel-3A Satellite in orbit verification took place smoothly in the three weeks following the launch. The satellite is still in its commissioning phase until August 2016.

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.

The overall critical path remains driven by the development of the ATLID and its two laser transmitters. The planned delivery dates of the two pressurized laser heads have remained quite stable during the reporting period (respectively July 2016 and October 2016). These dates lead to an instrument delivery to the prime contractor in October 2017 and an Acceptance Review in October 2018.

Current plans call for an EarthCARE Flight Acceptance Review in late 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 Aladin instrument is undergoing final functional and performance test at Airbus Defence and Space-France. The third laser transmitter is undergoing life test and has so far executed more than 300Mshots out of 780 Mshots intended. All relevant performance parameters are adequate and stable.

Aladin delivery to Airbus Defence and Space -UK is further delayed due to the cleanliness precautions and detector electronics anomalies; best estimate is now June 2016 enabling a best case launch readiness in July 2017.

5.1.3 BIOMASS

The Biomass mission has been 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 that are 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 our understanding of 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 were conducted in the recent period, and 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.

5.1.4 FLEX

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 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.

The planned launch date for the FLEX mission is in 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.

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 aimed at continuing high-precision altimetry observations of the ocean beyond the current Jason-1, -2 and 3 series.

5.2.1 Sentinel-2B

The Sentinel-2B satellite is being developed for a launch with Rockot in early 2017.

5.2.2 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 has been 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° to 140° 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 is therefore sought from CMEMS (and other Copernicus Services) that the topography sampling strategy defined by a 140° 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. This clarification could then form the basis to trigger a change request from the EC to ESA to take further action.

5.2.3 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.

5.2.3.1 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.

5.2.3.2 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.

5.2.3.3 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 in October 2016.

5.2.4 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. A The Copernicus Procurement Board accepted the Sentinel-6/Jason-CS contract proposal for the combined procurement of the recurrent B model.

On 24 June 2015, the EUMETSAT Council achieved progress in the approval process for the optional Jason-CS Programme with 77.83% of the financial envelope of the programme covered by Participating States. The optional Jason-CS programme entered into force on 9 September. On December 3, the Council welcomed Norway as the 13th Participating State, which increased the coverage of the financial envelope of the programme to 93.07%. In addition, the Council approved the cooperation arrangement to be signed with ESA for the

implementation of the programme. This secured the EUMETSAT funding share 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 in preparation (approval expected in mid-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. Working groups are under discussion to foster interactions and jointly address those mission performance aspects, with possibly a Mission Performance Working Group (MPWG) and a System Engineering Working Group (SEWG).

With their heritage in space altimetry, the CNES support will be essential to the mission success and agreements are in preparation to define the activities.

Following a meeting of the Partners at the end of 2015 in Washington, ESA was tasked to propose the terms of reference and governance principles of the Mission Advisory Group agreed by the Partners. The two documents are under review at EUMETSAT and will be issued shortly to the US Partners for further discussions. 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 October 2015 in Reston, VA, USA. A dedicated Sentinel-6 session was convened at the 2016 Living Planet Symposium, 9-13 May 2016, held in Prague, Czech Republic.

Activities are ramping up in both Europe and the US, with a Flight Acceptance Review in April 2020 for Sentinel-6A.

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. The ECV_cci teams are consortia of between six and 15 European partner institutions, including academia, government agencies and system engineering companies.

In addition to the ten ECV_cci teams, a CCI Climate Modelling User Group (CMUG) consisting of major European climate modelling centres has been set up. At all stages of the program, its task is 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. The existence of CMUG emphasizes the important role of climate modelling as a primary user of CCI output. 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.

The ECV products for nearly all the projects are freely and openly available, via the project websites, accessible from the main CCI website: http://www.esa-cci.org.

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, so that all currently active projects now have started Phase 2, but the Fire_cci project, for which a RFQ is soon to be released.

A number of programme-wide activities are planned for Phase 2, one of which – the CCI Visualisation Tool – has already begun. The CCI is producing a Visualisation Tool as a communication aid, to showcase the ECV data products from the programme. Animations have been put together for the key variable from each project where data is currently available. These help demonstrate to both a scientific and lay audience the global nature of the products, the temporal coverage achieved and can highlight climate phenomena or events in the data, such as El Niño years.

As the ECV products mature, the focus of project teams has 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.

For example, a new cross-cutting activity has emerged from a CCI meeting held at the International Space Science Institute from 2-5 February 2015. Representatives from seven of the CCI projects came to a meeting organised by Sea Level science leader, Dr Anny Cazenave, on ‘An Integrative Study of the Sea Level Budget’. A proposal has been put forward to ESA for a new project on the ‘CCI Global Water Cycle’. This would use CCI products to give a systematic assessment of global water cycle sources and sinks and produce the first synoptic assessment and first systematic closure of the global sea level budget. This information will also improve understanding of the drivers of sea level rise.

The CCI project teams continue to make scientific publications in high impact scientific journals. These report progress on the retrieval algorithms resulting from the round robin exercise, as well as new results related to climate process and trends, based on analysis of the ECV data sets being generated in CCI. A special issue on the round robin processes performed by the CCI teams during Phase 1 was accepted in the journal *Remote Sensing of Environment*. A special issue of *Remote Sensing of Environment* that focuses on the use of CCI data is being organised by the projects. The call for abstracts was issued in February, and

if deemed suitable for the special issue, the papers will be submitted between June and October 2016.

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.

The 6th CMUG integration meeting took place from 14-16 March, attended by all of the projects, as well as the ESA Climate Office. This helped to consolidate many of the projects' plans to submit their datasets to the recent call for Observations for Climate Model Intercomparisons (Obs4MIPS) in support of CMIP-6 (Coupled Model Intercomparison Project), which forms a large part of the IPCC's Working Group I. The Data Portal team have also been assisting the projects prepare their data for submission to Obs4MIPS. Nine CCI projects have submitted datasets to the WCRP Data Advisory Council's (WDAC's) calls for observations for Obs4MIPS.

The CCI programme is making good progress with its current objectives, as well as the preparations for CCI+. The Executive has issued a call within the CCI programme and has had an excellent response from the projects. More proposals have been received than can be implemented in the current geo-return situation so the selection process has been started to refine the most feasible and promising options. The call remains open for the time being.

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), oil Moisture, Glaciers and Ice Caps, and, Albedo, Fapar and LAI.

ESA took over the chairmanship of the Joint CEOS/CGMS Working Group on Climate (WGClimate) in November 2015 for a period of two years. The Vice Chair is from EUMETSAT and will take over the chairmanship at the end of that period for another two years. A 4-year work plan has been prepared and endorsed by the Working Group during its last meeting which was hosted by CNES in Paris on 7-9 March, 2016.