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Re-Engineering A Ground Segment – Preparing Sentinel-3 for the Future

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Abstract

The European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) has been operating the Copernicus Sentinel-3 mission since early 2016. To prepare for the upcoming launches of Sentinel-3C and -3D and to address both software and hardware obsolescence, EUMETSAT initiated a comprehensive project named Sentinel-3 Re-Engineering in late 2018.

The Sentinel-3 Re-Engineering project marks a significant milestone as the first complete re-design of a Ground Segment, including sub-segment levels, within EUMETSAT. Leveraging both a deep integration with internal cross-mission shared services as well as porting all mission software to a virtualized computing infrastructure allowing to decouple upgrades from obsolescence removal of both hardware and software.

The initial EUMETSAT Sentinel-3 Ground Segment was a complex system, being built upon elements specified and procured by both ESA and EUMETSAT. To harmonise with EUMETSAT standards, solving obsolescence issues and other operational and maintenance reasons, EUMETSAT chose to redesign the Ground Segment using the Model-Based Systems Engineering (MBSE) approach at both ground and subsegment levels. All high-level documentation related to interfaces, data exchanges, architecture, requirements, and verification is now maintained and generated from two centralized tools, a MBSE tool and a requirements' management tool.

After nearly five years of re-design and extensive testing involving more than one hundred contributors at both supplier and EUMETSAT levels, the new system was declared operational in November 2023. The transition replaced the complete legacy Sentinel-3 Ground Segment in just two 30-minute sessions between satellite contacts, achieving zero downtime and no impact on users.

With greatly improved performance and reduced maintenance needs, the Sentinel-3 Re-Engineering serves as a role model for future and ongoing re-designs of other Ground Segments. This paper focuses on the general re-engineering efforts, the multi-mission approach, the lessons learned, and the benefits EUMETSAT has gained from this comprehensive undertaking.

Keywords: Copernicus, MBSE, Re-Engineering, Obsolescence Management

Acronyms/Abbreviations

CDR = Critical Design Review
CFI = Customer Furnished Item
C-MCS = Common MCS
COTS = Commercial Off-The-Shelf
CPOD = Copernicus Precise Orbit Determination
DEV = Development Environment
DOORS = Dynamic Object-Oriented Requirements System
DORIS = Détermination d'Orbite et Radio positionnement Intégré par Satellite
EA = Enterprise Architect
ECMWF = European Centre for Medium-Range Weather Forecasts
EEA = European Environment Agency
EPS = EUMETSAT Polar System
ESA = European Space Agency
ESOC = European Space Operations Centre
ESRIN = European Space Research Institute
EU = European Union
EUM, EUMETSAT = European Organisation for the Exploitation of Meteorological Satellites

FAR = Factory Acceptance Review
FDF = Flight Dynamics Facility
FOS = Flight Operations Segment
GMES = Global Monitoring for Environment and Security
GPS = Global Positioning System
GS = Ground Segment
HW = Hardware
IT = Information Technology
JRC = Joint Research Center
LEOP = Launch and Early Operations Phase
MBSE = Model-Based Systems Engineering
MCS = Mission Control System
Metop = Meteorological Operational Satellite
MIC = Muti Mission IT Computing
MME = Multi Mission Elements
MPF = Mission Planning Facility
MTG = Meteosat Third Generation
MTG-S = Meteosat Third Generation-Sounder
MWR = Microwave Radiometer
MICONYS = Mission Control Systems Infrastructure
NRT = Near Real-Time
NTC = Non Time-Critical
ODA = Online Data Access system
OLCI = Ocean and Land Colour Instrument
OPE = Operational Environment
ORR = Operational Readiness Review
OS = Operating System
PDGS = Payload Data Ground Segment
PDP = Payload Data Processing
PDR = Preliminary Design Review
POD = Precise Orbit Determination
Sentinel 5P = Sentinel 5 Precursor
S3GSRE = Sentinel-3 Re-engineering
SCOS2K = Satellite Control and Operation System 2000
STC = Short Time-Critical
SLSTR = Sea and Land Surface Temperature Instrument
SRAL = Synthetic Aperture Radar Altimeter
SRR = System Requirements Review
SW = Software
SSVT = Satellite System Validation Test
VAL = Validation Environment
VER = Verification Environment

1. Introduction

Copernicus, previously known as GMES (Global Monitoring for Environment and Security), is the Earth observation component of the European Union's Space programme, looking at our planet and its environment to benefit all European countries. It is implemented in partnership with the Member States, the *European Space Agency* (ESA), the *European Organization for the Exploitation of Meteorological Satellites* (EUMETSAT), the *European Centre for Medium-Range Weather Forecasts* (ECMWF), *EU Agencies and Mercator Océan*, the *European Environment Agency* (EEA), and the *Joint Research Center* (JRC) *[1]*. The Sentinel Spacecraft fleet is currently formed by different missions operated by ESA (Sentinels-1, 2 and 5P) and EUMETSAT (Sentinels-3 and Sentinel-6 as independent spacecraft and Sentinel-4 and Sentinel-5 as instruments carried aboard the Meteosat Third Generation-Sounder (MTG-S) and the Metop Second Generation satellites respectively).

Sentinel-3 is a multi-satellite and multi-instrument mission designed for a minimum of seven-years operational lifetime per satellite which supports ocean forecasting systems, as well as environmental and climate monitoring. The two current operational satellites, Sentinel-3A and -3B satellites were launched in 2016 and 2018 respectively, and are in a near polar, sun-synchronous orbit at an altitude of 814.5 kilometres *[3]* flying on the same orbital plane separated by 140 degrees. The launch of the next two satellites (Sentinel-3C and -3D) is planned for 2026 and 2028 respectively, which will guarantee the ongoing data continuity from the Sentinel-3 satellites well into the next decade and beyond.

The Sentinel-3 satellites carry four main instruments (see *Fig. 1*): The Ocean and Land Colour Instrument (OLCI), the Sea and Land Surface Temperature Instrument (SLSTR), the Synthetic Aperture Radar Altimeter (SRAL) and the Microwave Radiometer (MWR) whose data are used: to map ocean colour, vegetation cover, and land use; to track changes in sea ice, monitor ocean currents, and study climate change; to measure sea and lake surface height, significant wave height, ocean surface wind speed and sea ice height and thickness; and to measure atmospheric water vapour which is used to correct the data received by the SRAL instrument. This payload is complemented by a Precise Orbit Determination (POD) package, including a DORIS receiver, a GPS receiver, and a Laser Retro-Reflector system for orbit positioning.

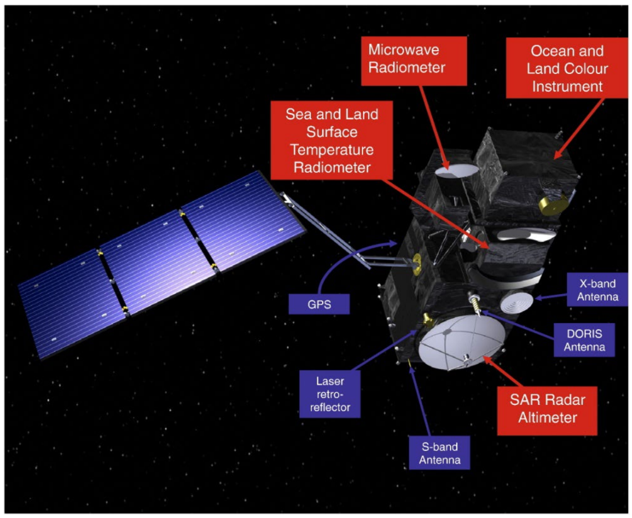

Fig. 1. Sentinel-3 Satellite and Payloads (Credits: ESA, *[2]*)

EUMETSAT operates the Sentinel-3 satellites, on behalf of the European Commission, in cooperation with ESA; with EUMETSAT responsible for Flight Operations during routine operations and also for processing and distribution of the marine data and near-real time atmospheric products, whilst ESA is responsible for Flight Operations during LEOP & Commissioning, some mission services (e.g. Copernicus Precise Orbit Determination, Ground Stations) and for the processing and dissemination of the land and non-time critical data products *[4]*. It is important to note that Sentinel-3 products are generated, as for most of Copernicus missions, at three levels of timeliness: Near Real-Time (NRT) delivered in less than 3 hours from data acquisition, Short Time-Critical (STC) delivered within 48 hours from data acquisition and Non Time-Critical (NTC) delivered within 1 month after data acquisition.

The initial Ground Segment (GS) used for Sentinel-3 operations was complex as it was jointly specified but was composed of elements developed by ESA (e.g. PDGS and MCS) and delivered to EUMETSAT as "Customer Furnished Items" (CFIs), in addition to elements fully specified and developed by EUMETSAT (e.g. MPF and FDF) although system integration was entirely performed at EUMETSAT. This initial Ground Segment was used for Sentinel-3A and -3B operations and later re-engineered due to the reasons which are described in the following sections.

2. The Initial Sentinel-3 Ground Segment

Sentinel-3 was the first Copernicus mission operated by EUMETSAT and the Ground Segment was jointly designed by ESA and EUMETSAT, where possible reusing elements used by both ESA and EUMETSAT for other missions. The Ground Segment was composed of two main functional blocks (see *Fig. 2*):

- The Flight Operations Segment (FOS) responsible for the monitoring and control of the spacecraft including the following functions:
  - Mission Control System (MCS) developed by ESA based on SCOS2K and delivered as a CFI to EUMETSAT.
  - Flight Dynamics Facility (FDF) developed by EUMETSAT and based on the FDF used in the EPS mission.
  - Satellite Simulator developed by ESA delivered as a CFI to EUMETSAT.

- The Payload Data Ground Segment (PDGS) mainly responsible for the generation and dissemination of L0, L1 and L2 products (in NRT, STC and NTC):
  - The PDGS was specified by a joint ESRIN/EUMETSAT team, with two instances: one running at EUMETSAT for processing marine and NRT atmospheric products and a second one running at several ESA's contractors' premises for land and NTC atmospheric processing. This was developed under an ESA contract and delivered as a CFI to EUMETSAT and was complemented by.
  - The Mission Planning Facility (MPF) which was developed by EUMETSAT based on the EPS MPF.
  - EUMETSAT Multi Mission Elements (MME): Including amongst others: system/facility monitoring functions, long term archiving functions, dissemination functions (e.g. EUMETCast), and supporting FOS and PDGS main functions.

The development of the first version of the Sentinel-3 Ground Segment was a big challenge considering varying organisational constraints, expertise, and philosophies at each agency.

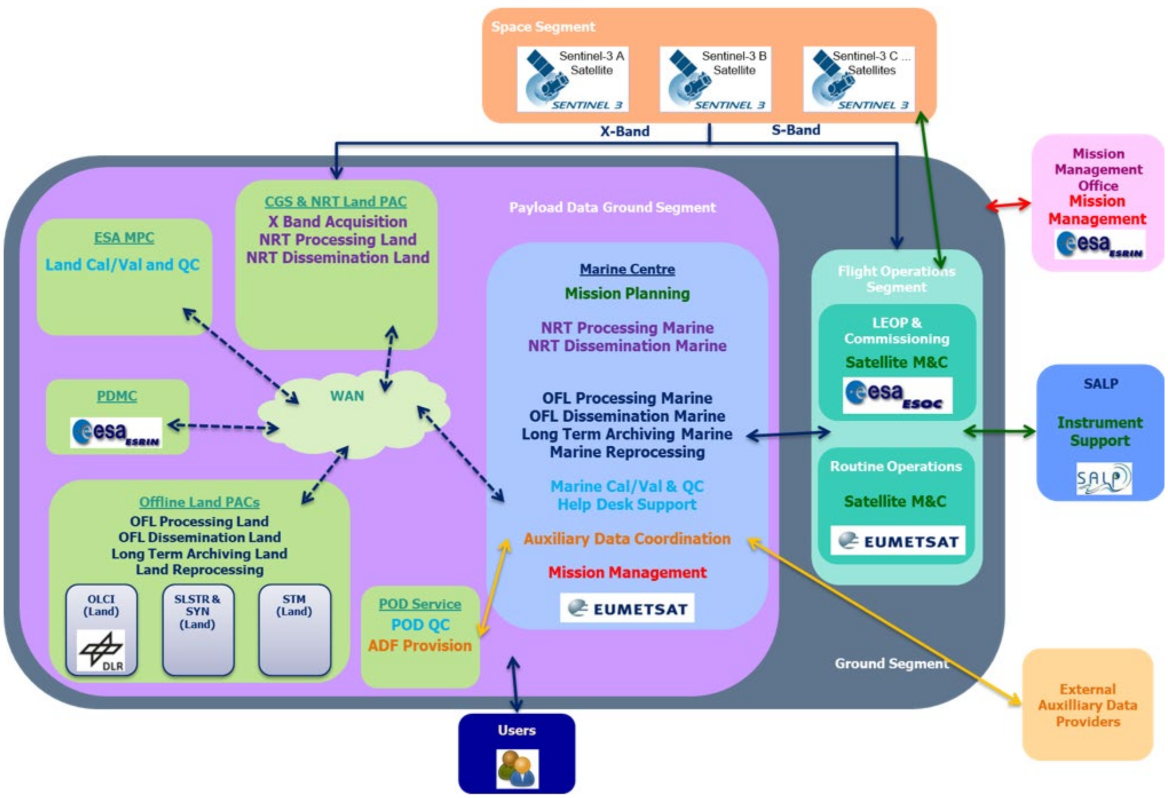

Fig. 2. Sentinel-3 Initial Ground Segment

During the initial few years operating the Sentine-3 Ground Segment several significant changes were made to address urgent issues, however, several issues were identified/became apparent:

- The Sentinel-3 Ground Segment architecture was not in line with the current EUMETSAT Ground Segment standard architecture for several reasons:
  - In the past, at the time of the old Sentinel-3 Ground Segment design and development, Ground Segments at EUMETSAT were developed focusing on the specific needs of the individual missions with dedicated personnel for operations & maintenance. Sometimes facilities for new missions were based on heritage from previous ones for certain functions, e.g. flight dynamics, long term archiving, as these are typically similar from mission to mission. This approach allowed/allows synergies to be exploited to improve efficiency and the cost-effectiveness of the maintenance and operations of these facilities. EUMETSAT has continued to build on this concept and is progressively moving to a different model, restricting bespoke, mission specific, elements and moving to a more "plug & play" approach for common functions. EUMETSAT has thus developed multi-mission infrastructure, facilities and tools which can be used to perform tasks or support

activities which are common to missions operated by EUMETSAT, e.g. data dissemination, archiving, networks. Current EUMETSAT Ground Segments are making extensive use of the multi-mission concept to reduce costs and improving systems maintainability and operability (as described in *Marston, 2016) [5]*).
  - For meteorological missions (e.g. EPS, MSG), the Mission Planning Facility (MPF) is usually part of the Mission Monitoring and Control system and not part of the Data processing. This is in line with the standards (ECSS-E-ST-70C, *[6]*) and with best engineering practices (*Sellmaier et al. 2022 [7]* and *Nejad 2022 [8]*). By relocating the MPF as part of the FOS the complexity of the interfaces is simplified, and the architecture is fully compatible with the rest of the EUMETSAT Ground Segment architectures.
  - Sentinel-3 Ground Segment was not following a consistent environment approach (operational/validation/verification) across Ground Segment building blocks. This heterogeneity of the environments did not facilitate the system maintenance and evolution activities.
- During operations and maintenance activities, the different teams involved were identifying not only improvements on efficiency and performance, but also potential simplification of operations and maintenance which required changes in the Ground Segment architecture.
- In EUMETSAT, the Hardware (HW) obsolescence cycles take approximately, as minimum, five years. This limit was almost reached after Sentinel-3B commissioning activities; thus, it was required to plan the resolution of the HW obsolescence. In addition, several software elements reached end of life and end of warranty and needed to be upgraded to the current versions (e.g. the operating systems for MCS).
- The Sentinel-3 Ground Segment was initially dimensioned to support Sentinel-3A and -3B operations but not the upcoming Sentinel-3C and -3D satellites, so the extension of the Ground Segment was required.

3. The Sentinel-3 Ground Segment Re-Engineering Project

3.1. Project Objectives:

With the goal to mitigate all the issues identified in previous section, at the end of 2018, EUMETSAT Management authorised the setup of a dedicated project named as Sentinel-3 Re-engineering project (S3GSRE project) with an estimated duration of around four years, for addressing the following aspects:

- Re-engineering of the Sentinel-3 Ground Segment without impacting operations performance and external users.
- Re-engineering and evolving the PDGS parts to a new Payload Data Processing (PDP) improving its maintenance and operations.
- Re-engineering the FOS for implementing version updates (e.g MICONYS V7) and re-locating the mission planning function to the FOS improving its maintenance and operations.
- Re-engineering activities for fully integrating the PDP and FOS with the EUMETSAT MMEs and with shared computing infrastructures in the new Ground Segment architecture.
- Implementation of EUMETSAT standards regarding business continuity, security, and architecture (split environments concept, list of standard COTS, platforms, etc.).
- Resolution of HW and SW obsolescence.
- Implementing simplified operations and maintenance concepts.
- Extension of Ground Segment capabilities to Sentinel-3C (implemented) and -3D (growth capability), for three or four satellites scenarios.
- Ground segment validated End-to-End and to support Sentinel-3A and -3B satellite operations and verified to support Sentinel-3C operations being ready to support operations preparation activities for Sentinel-3C.

The operations and maintenance simplifications with other needs derived from the extension to Sentinel-3C/D and additional requirements coming from operations lessons learned were included in Ground Segment Delta Operations Concept which was used as an input for the Ground Segment requirements.

3.2. Project Constraints:

The project was initiated with several important constraints:

- The development of the new Ground Segment should be done in parallel to the Sentinel-3A and 3B routine operations; then, the evolutions and corrective maintenance activities must be implemented in parallel in the system under development and in the one to be replaced and this could impact project scope, schedule and costs, and cause requirements creep and increased risks. This issue is especially relevant for the operational validation phase, where human and non-human resources are shared with the Sentinel-3 Ground Segment operations teams.

- In a matrix organisation like in EUMETSAT, the expert support in projects is guaranteed. This is a clear benefit, but this has some drawbacks because this requires a complex coordination with other on-going activities. To have the right teams at the right moment requires a precise scheduling and continuous monitoring to ensure project activities do not interfere with other organisational activities and vice versa. In this case, some of the key members of the S3GSRE project team were also responsible for maintaining the operational Ground Segment. That introduced an additional constraint: in case of operational issues, the operations continuity takes precedence to any other activity and then project schedule is impacted.
- Sentinel-3C launch date, at the time of project setup, was estimated to be around 2023 with the Sentinel-3C FAR planned in 2021 and SSVTs planned for the second quarter of 2020.
- Schedule constraints due to the regular refresh/retendering of the maintenance contracts for FOS and PDGS.
- As mentioned before, the (HW) obsolescence cycle was almost reached for the complete system; however, in the case of FOS it was considered that its resolution should be made the priority before the rest of the Ground Segment elements.

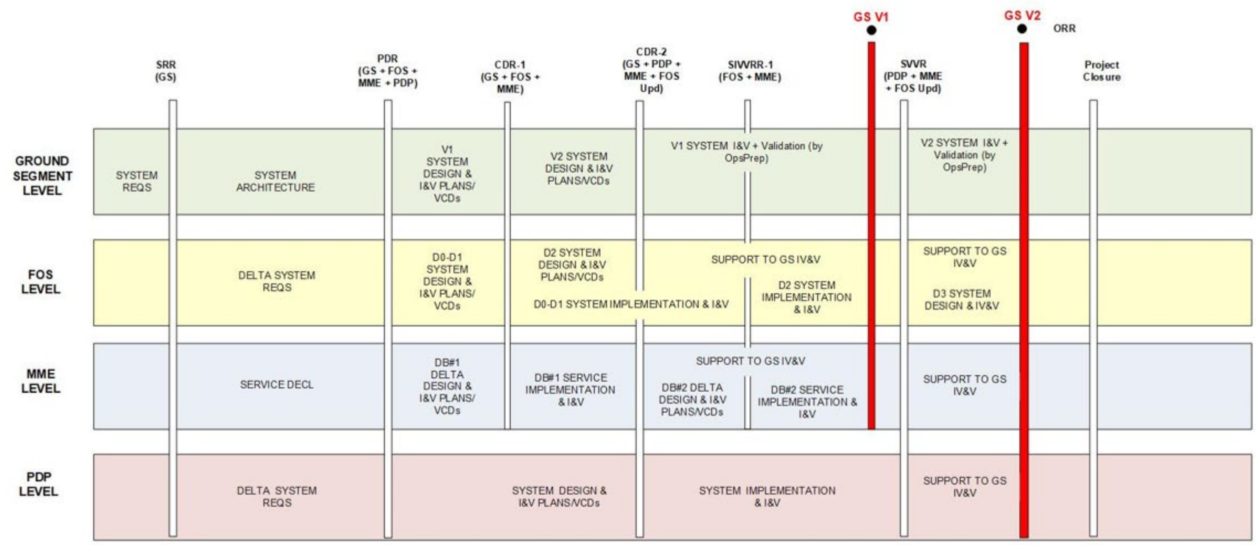

Fig. 3. Sentinel-3 Ground Segment Re-Engineering Project Lifecycle

3.3. Project Lifecycle:

The project lifecycle was based on a classical "V-model" (*Forsberg et al., 1991 [9]*), with some adaptations applied (see *Fig. 3*) to be able to timely fulfil the objectives and to cope with the constraints described before. The most notable adaptations were:

- Splitting of the production phase (implementation, integration, verification, and validation) in two steps to cope with the different time constraints applicable to the FOS and PDP subsegments.
    - GS Version 1: Integration, verification, and validation of the new FOS with the relevant MMEs and with the operational PDGS.
    - GS Version 2: Full integration, verification and validation of the new FOS, new PDP and all MMEs.
- Combining as much as possible, system, and sub-segment reviews for the design phase. That means the V-model was not strictly followed for System Requirements Review (SRR), Preliminary Design Review (PDR) and Critical Design Review (CDR) because of stringent schedule constraints but also taking into consideration the limited changes to be applied to the existing Sentinel-3 Ground Segment and the fact that the changes were very well bounded and controlled. To cover the resolution of the FOS obsolescence in advance, the CDR was split in two parts: a first CDR (CDR-1) with scope limited to FOS and relevant MME elements, which allowed the anticipation of FOS procurements, and a subsequent CDR (CDR-2) involving all Ground Segment elements i.e. including also the PDP and all the MMEs.

- Combining at maximum extent integration, verification, and validation activities to reduce the duration and the control milestones needed, but keeping an ordered and controlled sequence of test campaigns and limiting the extra resource effort.

With respect to the development logic, the one adopted for each component was an incremental approach (*C. Larman, Basili, 2003, [10]*) which combined with an incremental integration strategy was considered good enough to facilitate a) the schedule constraints (particularly tight on new FOS part), b) the phasing with the development and maintenance contracts, and c) the parallel evolution of the operational Ground Segment.

3.4. Project Execution:

The actual schedule of the project, as envisaged, was affected by known constraints, some managed as risks, which in some cases materialised. In addition to those, there were other unexpected external worldwide contingencies which affected the normal evolution of the project: One was the coronavirus pandemic which restricted some activities in 2020 and 2021 (COVID-2019), and the other one was related to the chip shortage between 2020 and 2023 which caused HW delivery delays. In addition, there were changes made by ESA to their Sentinel-3 Ground Segment which required equivalent adaptations to be made in EUMETSAT to the operational ground segment to accommodate them. This included an extension to the project to develop a cut-down remote instantiation of the FOS to support business continuity operations. All of these, together with: the increasing number of anomalies in the old Ground Segment; the ending of existing maintenance contracts and the inherent complexity of the project, consumed the project schedule margins and forced the team to make optimisations in the schedule to ensure it was finished in time to fulfil the external hard deadlines (e.g. the need to start the operations preparation activities for Sentinel-3C). One example of the urgency to deliver the new Ground Segment, was the catastrophic HW failure due to obsolescence in the PDGS happened in Q2 2023 which caused significant operational impact in product generation and confirm the urgent need to include changes in the project schedule.

The main changes included were the following:

- To skip the operational activation of the GS version 1 and therefore not performing the integration with the old PDGS. This integration activity was identified as complex and risky. GS version 1 thus became an intermediate and incomplete version; it was not released for operations.
- To overlap the verification and validation activities, when possible, maximising the use of the validation (VAL) environment.
- To descope some initially planned activities, identified as non-essential (e.g. implementation of processing managers improvements, calibration & validation SW improvements, some updates in the backup control center). These were included in the Sentinel-3 Ground Segment backlog activities and some of them, were later implemented after Ground Segment operational activation.
- To not interfere with Ground Segment operational activities and to facilitate the transition to operations, staging environments for FOS and PDP in the operational (OPE), validation (VAL), verification (VER) and development (DEV) were created (note that for MMEs these environments were already available). The objective of these staging environments was to replace directly the new OPE and VAL environments with the ones used in operations at the time of the Ground Segment operation activation. This saved time during the integration of PDP, FOS and, when no risk identified, MMEs and was possible because the reengineered Ground Segment System was developed in new environments and therefore the integration could start with the operational environment followed by the validation and verification environments, whereas for operational Ground Segments the order is the opposite, from DEV to OPE.

However, all these schedule optimisation measures were not free of risk of impact on operations, or on external or internal users. To mitigate that risk, the following decisions were made:

- To consider the S3GSRE Operations Migration Plan a key document subject to detailed and dedicated, successive reviews by development, operations, and maintenance teams.
- To split the Operational Readiness Review (ORR), whose objective was to assess the maturity of the S3GSRE system for operational use and give the authorisation to replace the operational Sentinel-3 Ground Segment, in two parts separated by an operations rehearsal phase of two weeks in parallel to routine operations performed with the old Ground Segment. The first part of the ORR was more focused on assessing the operations suitability of general functionalities, FOS and MMEs while the second one was focused on final product validation activities and end-to-end performance measured during rehearsal phase and its comparison with that of the operational

system. This split offered the possibility to gain margin for the implementation of fixes or workarounds for anomalies and to discard regressions and de-risk the operational activation.

4. Sentinel-3 Ground Segment Changes and Improvements

The new Sentinel-3 Ground Segment System includes significant improvements with respect to the first operational Ground Segment System. This section summarises those improvements.

4.1. Changes at System Level:

- A Model Based Systems Engineering (MBSE) approach has been adopted (*Weber et al. 2025*, *[11]*) both at Ground Segment and at sub-segment levels (see *Fig. 4*), to support the requirements specification, design, implementation, verification, and validation activities. The system has been modelled using SysML *[12]* by means of Enterprise Architect (EA) *[13]*. The requirements have been specified and verified (*Wodnicka et al. 2025*, *[15]*) using DOORS *[14]*, and they are traced to the model, easing future simplifications during Ground Segment maintenance and evolutions. Adopted techniques have been reused for modelling other Systems and Ground Segments at EUMETSAT.
- As mentioned before, one of the objectives of the new Ground Segment was to implement the EUMETSAT standards regarding to the environment concept. The old Ground Segment did not follow a consistent environment differentiation approach across the different elements; this issue caused frequent problems during operational validation activities (e.g. PDGS Operational and Reference environments). This was corrected in the new Ground Segment by imposing a consistent environment segregation approach by using DEV, VER, VAL and OPE environments in all Ground Segment elements.

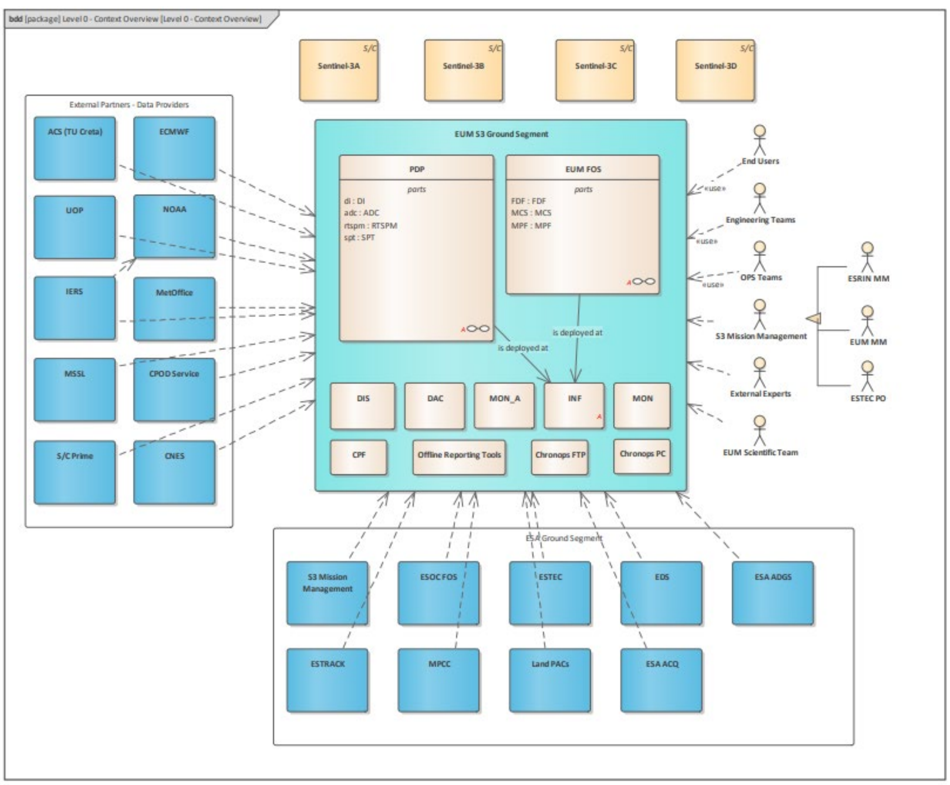

Fig. 4. Sentinel-3 New Ground Segment main blocks.

4.2. Changes in Infrastructure:

- The new Ground Segment and all the sub-elements (i.e. FOS and PDP) use shared computing and virtualised infrastructures able to support Sentinel 3 operations for three satellites and to be easily expanded to support up to four satellites.

- The new infrastructure implements EUMETSAT standards regarding business continuity, security, and architecture (split environments concept, list of standard COTS, platforms, virtualisation). The infrastructure as well as the redundancy concept (not covered in this paper) have now been reused in other EUMETSAT Ground Segments. The Muti Mission IT Computing (MIC) infrastructure developed in parallel to Sentinel-3 Ground Segment incorporates some of these concepts and now is considered the baseline IT for all EUMETSAT Ground Segments.
- The virtualised platforms reduce significantly the EUMETSAT technical infrastructure building resources allocated to Sentinel-3 decreasing the power consumption and freeing space for other missions/programmes.
- The flexibility of the virtual infrastructure of the new Sentinel-3 Ground Segment allows the adaptation of the resources, extending or reducing them based on the real need and simplifying the impact of the regular future obsolescence removal activities.
- The new infrastructure reduces the future costs of HW and OS license maintenance.
- The new Ground Segment uses the latest development and services provided by EUMETSAT Infrastructure.

4.3. Changes in Multi Mission Elements:

- PDP and FOS are now fully integrated with the relevant MMEs and benefiting from the latest developments in the MME area.
- The dissemination systems used in Sentinel-3 are now fully in line with EUMETSAT standards (e. g. Data Store, EUMETSAT Data Lake) maintaining and, in some cases, exceeding the original timeliness and performance requirements achievement. The Sentinel-3 Ground Segment is fully integrated with all “Big Data Services” provided by EUMETSAT.

4.4. Changes in the new FOS:

- The FOS has been re-engineered for full integration with the relevant EUMETSAT multi-mission elements and with shared computing and virtualised infrastructures.
- The FOS has been re-engineered to implement new major version updates for its components (e.g. C-MCS - latest EUMETSAT Common Mission Control System).
- The Mission planning function has been relocated from the PDGS to the FOS and is now consistent with EUMETSAT standards.
- The FOS has been extended to be able to support Sentinel-3C operations.

4.5. Changes in the new PDP:

- The PDP has been re-engineered and fully integrated with the relevant EUMETSAT multi-mission elements and with shared computing and virtualised infrastructures.
- The PDP architecture has been revised and will simplify the incorporation of future processor improvements and is prepared and sized to support Sentinel-3C operations.
- The PDP performance has been significantly improved being almost twice faster than the legacy PDGS. PDP interfaces are now much simpler.
- The Operational configuration has been updated to improve PDP operability and maintenance increasing the cost effectiveness.

5. Sentinel-3 Ground Segment Changes Handover to Operations

The Ground Segment Operational Readiness Review was successfully finalised on November 10th, 2023. After that, the operations teams started the migration to the new Sentinel-3 Ground Segment. The activation was split in two sessions, following the detailed instructions included in the S3GSRE Operations Migration Plan:

- Following the activation sequence, Sentinel-3A/3B spacecraft operations were transferred to the new FOS on November 14th, 2023. The new system was instantly put to work and demonstrated a good performance by executing first a planned spacecraft manoeuvre, followed by an unplanned Sentinel-3B collision avoidance manoeuvre and a Sentinel-3A instrument recovery, all within the same week.
- The operational activation of the Payload Data Processing system was performed successfully on November 20th, 2023. The seamless activation took only 40 minutes and there were no gaps, data losses or impact to the end users

during the transition. During December, the new system was under observation and no operational anomalies were observed. The migration of the ESA acquisition data circulators to the new PDP was successfully carried out by November 28th, 2023.

- During 2024, the new Ground Segment has been used in routine operations without major anomalies (a reduction of approximately 60% of anomalies has been observed being related mainly to external factors, e.g. network issues, etc.) and it is used also for Sentinel-3C operations preparation activities; this has clearly demonstrated its robustness and reliability. The improvements applied to enhance the maintenance and to simplify evolutions have also been proved to be highly effective. During 2024, the system has been updated several times to accommodate a large number of new functionalities requested by EUMETSAT partners with no major complications.

6. Conclusions

After nearly five years of project development with several internal and external constraints and more than 2100 requirements (at Ground Segment and subsegment level) verified and validated after more than forty testing campaigns; the project is considered very successful and provides demonstrated excellent results. Some key considerations:

- The main objective of the S3GSRE project was to replace an operational Ground Segment which was already producing good performance but needed to be replaced because of obsolescence, maintenance, and expandability reasons. The requirement to deliver equivalent or superior performance without disrupting operations or end-users' expectations was the most critical factor, making the task even more challenging. For that reason, for operational systems' re-engineering or obsolescence removal projects, it is necessary to be very careful and adapt and optimise the lifecycle profile and the effort increasing the validation activities and optimising the verification activities to take into account operational usage of the system, thus optimising the usage of resources available for verification.
- It was important, from the very beginning, to have the full involvement of all resources and knowledge within the organisation ensuring that the development, maintenance, and operations teams were working as an integrated team. This required an intense coordination activity across multiple teams, across multiple Ground Segment development and operational activities and with other projects and activities in the organisation.
- The objectives of this project combined activities to resolve the obsolescence of HW and SW and the re-engineering of the main components of the Ground Segment and this caused the emergence of different kind of issues. Although the experience was finally successful, in the future it is recommended to break down any evolutions into smaller building blocks, then resolving the obsolescence issues into different steps. This approach does not only reduce the risk of failure but also avoid long duration of projects allowing the organisation to not block resources for other organisational activities. This approach has been taken in other EUMETSAT new projects.
- The intensive level of testing performed at verification and validation stages and at subsystem and system level, combined with a very detailed operations transition plan, an effective rehearsal phase and a conscious analysis of system and subsystem anomalies, have allowed to the transition to operations to be performed in a very smooth way, without any operational impact to the end users.
- The definition of clearly segregated environments ("model philosophy") for different purposes (development, verification, validation, operations, etc.), while essential, requires also a trade-off analysis that takes into account the cost of the representativeness of each environment to the level of representativeness required for that environment. This analysis was demonstrated to be useful and was properly done in this project reaching an optimal cost/benefit balance.
- The virtualisation technology applied in the S3GSRE project together with the use of the EUMETSAT multi-mission elements and multi-mission services' approach have allowed significant improvements in the Sentinel-3 Ground Segment, in terms of operational performance and dependability. The continuous advance of the EUMETSAT multi mission approach (at all service levels: software, platform and infrastructure) will allow even a higher degree of flexibility in the design of the systems and on the allocation of resources; and will maximise the flexibility and dependability of future Ground Segment Systems while reducing their total development, operations and maintenance costs.

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