# Developing EGS-CC based applications; the EGOS-CC experience

**Workshop on Simulation and EGSE for Space Programmes (SESP)**
**26-28 March 2019**

**ESA-ESTEC, Noordwijk, The Netherlands**

**Anthony Walsh[1], Mauro Pecchioli[1], Klara Widegård[1], Catherine Lannes[1]**

*[1]European Space Agency, ESA/ESOC*
*Robert-Bosch-Str. 5, 64293 Darmstadt, Germany*
*Email: anthony.walsh@esa.int, mauro.pecchioli@esa.int, klara.widegards@esa.int, catherine.lannes@esa.int*

## INTRODUCTION

### Background

Many different systems are currently in use by European companies/agencies for monitoring and control of space systems. Different solutions are typically adopted to support the various mission phases, in particular for the Assembly Integration and Testing (AIT) and other pre-launch phases and post-launch mission operations. The lack of a common infrastructure leads to little synergy across missions and project phases.

Given the difficulties mentioned above, the ESA led European Ground System – Common Core initiative has been put in place (as described in [1]). The EGS-CC product provides the foundation to efficiently develop and deploy applications to monitor and control space systems. An appropriate functional scope and architectural layering has been devised in order to ensure all target applications and environments are adequately supported but without creating unnecessary complexity and dependencies. This makes the EGS-CC an ideal platform to develop common solutions targeting completely heterogeneous monitoring and control applications e.g. to support space segment or ground segment operations.

At ESOC a common infrastructure has since for many years been used as the basis for the development of mission control systems supporting spacecraft operations and for ground station network operations. The SCOS-2000 product forms the basis for the development of mission control systems supporting spacecraft operations. The STC2 is the product used for ground station network operations. However, the current generation of these products are expected to face significant obsolescence problems in the next decade, with the maintenance and evolution costs expected to become excessive with time. The EGS-CC therefore represents an opportunity to embark on the modernisation of the mission control and ground station network operations infrastructure and associated processes at ESOC. This is materialising at ESOC through the EGOS-CC initiative.

### EGOS-CC

The objective of the EGOS-CC initiative is the adoption at ESOC of the EGS-CC though the development of a new generation ground data systems infrastructure supporting all applications related to mission and network operations preparation and execution. This is necessary to tackle obsolescence of the current infrastructure and also re-think some of the current processes to pursue important strategic objectives, including;

- Leveraging on the EGS-CC as a European level initiative to minimise Cost of Ownership of the next generation M&C Ground Data Systems Infrastructure;

- Enabling long term reduction of development and maintenance costs of the ground data systems infrastructure and of the dedicated systems relying on it;
- Providing the users communities with an efficient environment to prepare and execute operations using modern technologies;
- Rationalizing the organization / architectures of the target systems to enable a clean split of responsibilities throughout the lifecycle;
- Promoting/enabling cross-fertilization of concepts / solutions with other European EGS-CC stakeholders;
- Promoting/enabling cross-fertilization of concepts / solutions between the Missions and Ground Station Network operations domains.

These are ambitious objectives and in the following sections we present the new EGOS-CC infrastructure currently under development at ESOC that aims the fulfil these ambitions.

## THE NEW EGOS-CC INFRASTRUCTURE AT ESOC

### High Level Decomposition

The adoption of the EGS-CC at ESOC leads to the production of a new EGOS-CC generation of infrastructure for monitoring and control systems. The following Figure 1 shows the high-level decomposition of the EGOS-CC infrastructure at ESOC.

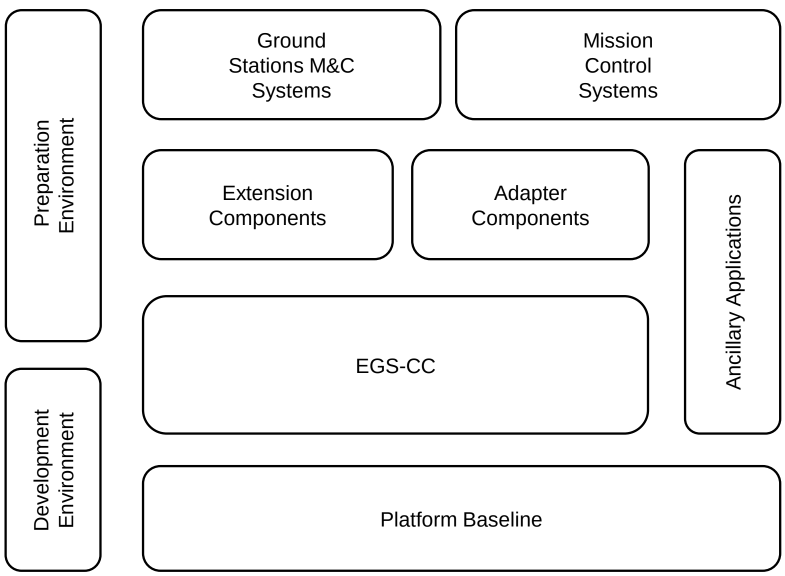


**Figure 1. High-level Decomposition of the EGOS-CC Infrastructure**

The elements shown in the Figure 1 are described below;

- The Development Environment is based on the adoption of the EGS-CC Software Development Environment (SDE) and includes all tools supporting the development, integration and validation of EGS-CC components as well as EGS-CC based applications;
- The Preparation Environment provides the user communities of EGS-CC based applications with the ability to define and manage configuration, tailoring and deployment data (e.g. the definition of the monitoring and control model, TM/TC packets, automation procedures, user defined displays) which customise an EGS-CC based application for a

given controlled system and associated operations. The Tailoring Environment at ESOC will be based on the OPEN framework [3] which is currently supporting the common functions and services (e.g. import/compare/merge, consistency check, versions and baselines management, products generation and export) and a library of editors which are specific of a given data type (e.g. procedures, displays, M&C elements);

- The Platform Baseline consists of the operating system and the complete stack of third party products which constitute the run-time environment of the EGS-CC. The platform baseline at ESOC is based on SLES12;
- The EGS-CC provides the main functions of space system M&C applications and will constitute the core of the new generation infrastructure in this domain at ESOC. It is an objective to enable the adoption of the EGS-CC without modifications in order to minimise the efforts involved in integrating new EGS-CC releases into EGOS-CC;
- Extension Components complement the functional scope of the EGS-CC itself with additional features required by ESOC for mission operations of ground station operations;
- Adapter Components provide the necessary bridging between the EGS-CC supported interfaces and other ground systems contributing to the overall ground segment and with which information is exchanged, including the Mission Planning System, the Flight Dynamics System and other external ancillary applications;
- External Ancillary Applications play a complementary role to EGS-CC based applications and are largely based on legacy implementations.

The top layer of Figure 1 shows the two main application domains which will be developed on the top of the EGOS-CC infrastructure at ESOC. The main design drivers and challenges are characterised by:

The **Mission Control Systems** constitute the basis for mission operators to interact with the elements of the space segment while in flight. The main design drivers for this category of M&C systems are:

- Support of many dozens of users in parallel, in particular during critical mission phases such as the LEOP;
- Support of ‘off-line operations’, whereby the real-time interactions with the flying spacecraft may either be restricted to very short intervals (e.g. for LEO missions) or be affected by extremely long propagation delays (e.g. for deep space missions);
- Handling of real-time as well as deferred data to reconstruct the state of the controlled system. This poses severe requirements in terms of complexity and performance of the monitoring data processing;
- Ability to provide the operators with a comfortable and reliable environment supporting the execution and end-to-end verification of complex operations;
- Ability to automate the execution of routine operations which typically involve a large variety of systems, belonging to both the ground and the space segment;
- Management and ability to access/disseminate the full set of operational data accumulated during an entire mission.

The **Ground Station M&C System** provides local and remote network operators with the ability to configure and monitor the ground station equipment in order to e.g. support visibility passes for a given spacecraft. The key aspects of these systems are:

- Fully automated operations planning, scheduling and execution cycles. This includes among others the ability to react to unexpected conditions/events and selectively re-plan the operations for a given ground station or for a given spacecraft;
- Ability to share common definitions (tailoring data) across equivalent units deployed within the same or different ground stations. This is necessary to minimise the efforts involved in the definition, validation and maintenance of e.g. M&C model, procedures, displays for a significant number of similar equipment;
- Support of local (within the ground station site) as well as remote (from the control centre) M&C operations. The local operator may need access to the full monitoring and control capabilities e.g. to intervene in case of problems and/or validation activities. The network operator is responsible for the execution of routine operations and needs to be provided with an overview of the state and operations execution status for all ground stations. One specific design challenge is due to the very limited bandwidth to accommodate the delivery of the necessary M&C data.

The variety of EGS-CC based systems which will be needed and supported shows the versatility and wide applicability of the EGS-CC design but also provides an evidence of the complexity of the process to adopt them to produce the new generation of M&C systems at ESOC, considering in particular the level of reliability, performance and maturity required for operational applications interacting with complex and costly space systems. The products which comprise the EGOS-CC infrastructure are described in the following sections.

**EGOS-CC Products**

The main EGOS-CC Products and their constituent elements are shown in Figure 2 below.

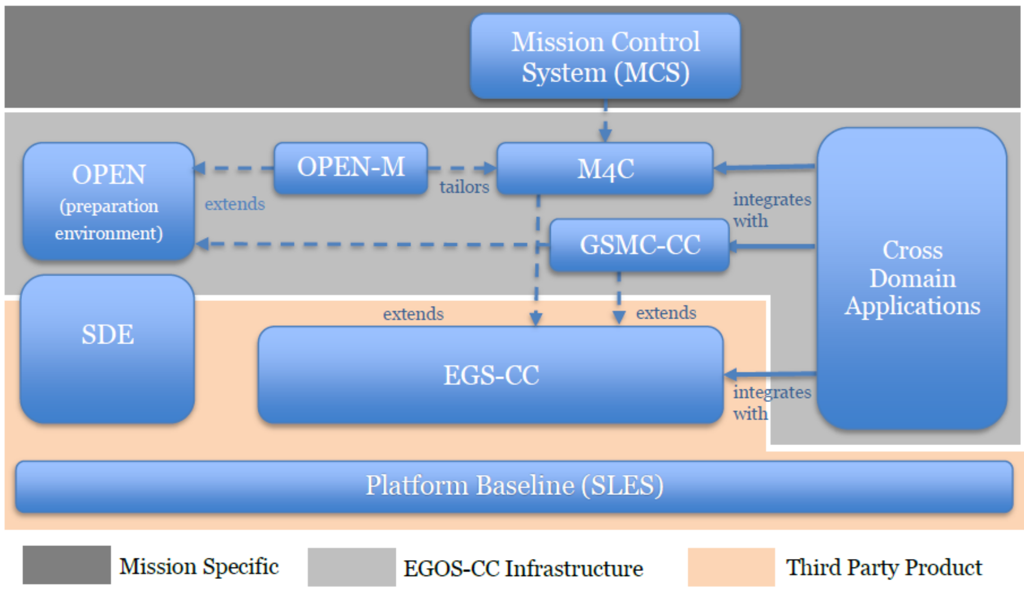


**Figure 2. The main EGOS-CC Products**

The Mission Control Core based on Common Core (M4C) and Ground Station Monitoring and Control System based on Common Core (GSMC-CC) are the EGOS-CC infrastructure domain products which are the evolution of the current generation of Mission Operations and Ground Station Monitoring Control products. The functional scope of M4C and GSMC-CC are very similar to the SCOS-2000 and STC2, respectively. The majority of the functionality is provided by EGS-CC, but when required functionality is outside of the scope of EGS-CC, it is provided by M4C and GSMC-CC extensions and adapters. This approach reduces the EGOS-CC infrastructure which needs to be developed and maintained by ESOC where EGS-CC is considered as a third party product which is developed and maintained at European level by all EGS-CC stake-holders. The M4C can be extended for a specific Mission Control System (MCS) to implement mission specific functions. The GSMC-CC is not mission specific due to ground stations being shared resources used across multiple mission.

There are a number of EGOS cross domain applications which are outside the functional scope of EGS-CC but which are supported by the current generation of EGOS infrastructure. These include functions such as data distribution or long term data archiving. Existing cross domain applications (CDAs) are being adapted so that they integrate with M4C and GSMC-CC as well as the current S2K and GSMC software infrastructure. The CDAs are data system applications (primarily legacy systems) which are not specific to a given user community or domain and run outside of the EGS-CC run-time environment (i.e. are not extensions of EGS-CC). Traditionally the CDAs have been deployed as dedicated mission applications which are managed by the individual mission teams. A separate initiative is currently on-going at ESOC to provide cross domain applications as Multi-Mission Services where the functionality offered by the application is provided as a service which is managed centrally and offered to multiple mission's/target applications.

The EGS-CC only provides very limited support for the preparation of operational tailoring and configuration data. EGOS-CC therefore provides a comprehensive framework for a preparation environment called the Operations Preparation Environment for EGS-CC based systems (OPEN) [3]. OPEN does not provide all functionality required for mission operations and ground stations and therefore specific extensions are necessary to complete the preparation environment required in each of these domains. In the case of mission operations, this is provided as a standalone product called OPEN-M. In the case of ground stations, this is provided by an application called OPEN-S which represents the off-line tailoring application of the GSMC-CC product. The OPEN, OPEN-M and OPEN-S products are currently under development and will be available to the EGS-CC community under the ESA Software Community License.

**EGOS-CC Extensions and Adaptors**

As discussed previously, the EGOS-CC extension components complement the functional scope of the EGS-CC itself with additional features required by ESOC for mission operations of ground station operations and EGOS-CC adapter components provide the bridging between the EGS-CC supported interfaces and other ground systems contributing to the overall ground segment. The following tables present the EGOS-CC components that are being or will be developed for either the mission operations and ground station operations domains, or for both (i.e. cross-domain components).

Table 1 Cross Domain Extension / Adapter Components

| Extension / Adapter Components | Descriptions |
|---|---|
| EGOS Remote Alert System Adapter | Adapts to the EGOS Remote Alert System (REALS) application by providing an adapter capable of generating REALS alert files based on EGS-CC monitored M&C events and operational system messages. |
| CSTS MD Provider and Adapter | Provider side implementation and consumer side adapter of the CCSD Cross Support Transfer Services Monitoring Data service. |
| Ground Schedule Increment Loader | Loads a Ground Schedule Increment from file into the EGS-CC run-time. EGS-CC only provides an API for loading Ground Schedule Increments and loading from file is not supported. |

Table 2 Ground Station Operations Doman Extension / Adapter Components

| Extension / Adapter Components | Descriptions |
|---|---|
| Ground Station M&C Interface | Interface component between the ground station equipment and the EGS-CC. Is used for equipment supporting the ESA Ground Station M&C ICD. |
| ESTRACK Ground Station Schedule Interface | This component is responsible for the reception of ESTRACK ground station schedule files from ESTRACK Management System. The files are validated and converted into EGS-CC Ground Schedule Increment files which are loaded into the EGS-CC. |
| STDM Interface | EGOS-CC component for receiving the orbit prediction information (STDM files) created by the Flight Dynamics System (FDS) and control its distribution to ground station equipment. |

Table 3 Mission Operations Doman Extension / Adapter Components

| Extension / Adapter Components | Descriptions |
|---|---|
| File Based Operations | Provides a set of functions which are assembled to fulfil ESOC's operations requirements of a mission supporting the exchange of files between the ground and the space segment. |
| OBSW Management | Covers the management of patch and dump images of the on-board software, including generation of the telecommands to upload a patch and the processing of telemetry data to verify the proper upload. |
| TM Files Ingestion \ | This EGOS-CC subsystem, provides support for the reception and processing of TM files containing either TM frames or TM packet recorded at the Ground Station or received as TM files using the services of File Based Operations. |
| Command Request Management | Receives and processes Command Request Files (CRF) from mission planning, flight dynamics and external users and converting them into either EGS-CC stack or ground schedule increment files which can be loaded into the EGS-CC run-time. |
| Tm Packet Interface Adapter | EGOS-CC component which acts as a server to retrieve requested TM packets from the EGS-CC and provides them via a simple sockets interface to the Tm Packet Interface Library (TPL) used within the Flight Dynamics software.. |

| Extension / Adapter Components | Descriptions |
|---|---|
| Mission Propagation Delay | Extends the EGS-CC time correlation component and is used to compute the One Way Light Time (OWLT) propagation delay based on OWLT file provide by Flight Dynamics and which can be loaded on request by the operator when new OWLT files are generated. |
| PUS-C Service 11 | Implements the PUS-C service 11 and replaces the PUS-A service 11 service reference implementation for those missions which implement the PUS-C scheduling service. |

## ENGINEERING APPROACH

This adoption of EGS-CC has considerable impact on the EGOS infrastructure and in order to minimise the changes, the following engineering principles are being applied to the engineering approach:

- Minimise the impact on existing implementations of systems complementing the EGS-CC functionality, ideally using the system “as is”;
- Adopt a black-box approach to the use of the EGS-CC product, such that no modifications of source code are required for both Kernel and Reference Implementation components;
- Adoption of the EGS-CC technology baseline on the top of the ESOC SLES baseline;
- Adoption of the Software Development Environment (SDE) tools as used for the EGS-CC phase C/D development (e.g. UML modelling tool, Version Control System, etc);
- Adoption of the EGS-CC product requirements (e.g. modelling, rules, conventions, testing) for all EGS-CC extensions (i.e. components running within the EGS-CC environment).

A fundamental prerequisite is that the new products will be they are at-least equivalent to the current generation in all relevant aspects. The current infrastructure generation provides a solid reference to determine the functional scope as well as the external interfaces to be supported. This is however very wide and a ‘flat specification’ of the full infrastructure would be of prohibitive complexity (e.g. the current specification contains thousands of user and software requirements). For this reason, a top-down engineering approach was adopted. The full scope of the ground data systems monitoring and control infrastructure has been captured in a formal specification defining the functions and interfaces by means of a hierarchical model. Each layer of the model provides a functional view which is appropriate for a given purpose e.g. to provide an overview of the new generation infrastructure as exposed to external systems, to identify the macro products to be developed, to assess the overlap of existing implementations with the EGS-CC, to identify the internal interfaces which will have to be supported in order to ensure backwards compatibility with legacy implementations, and so on.

The hierarchical functional model has been used to perform a ‘functional gap analysis’ of the EGS-CC: which of the required functions will be natively supported by the EGS-CC itself? Which of the required functions will have to be implemented as EGS-CC extensions? Which of the functions currently supported can be dropped as conflicting with the principles and concepts of the EGS-CC based applications? Following a traditional engineering process, all these questions would be answered by producing a full and detailed specification of the future generation infrastructure, from which a ‘delta specification’ focusing on the EGS-CC extensions would be derived. The approach which has been adopted also aims at producing the ‘delta specification’ but this is being done using a top-down approach which progressively goes to the level of detail which is most appropriate for the various engineering processes.

For each functional gap the key driving requirements and the most appropriate development approach have been identified. The key requirements have been specified starting from the end user perspective, focusing on the exact operations that this functional extension is expected to support (e.g. upload file from ground to on-board file-store). Design trade-offs have been performed to assess in particular whether the missing functions should be newly implemented as EGS-CC extensions or rather by re-using the relevant existing application. This latter option has only been selected in all those cases where there was a clear evidence that it would minimise the total costs to operational deployment but without jeopardizing the long term maintainability and the modernity of the future infrastructure. The list of EGOS-CC extension and adapter components is provided in the tables 1-3 of the previous section.

It is equally important to emphasize that the EGS-CC extensions are being be developed following the same engineering processes, architectural concepts and quality requirements of the EGS-CC components proper. This ensures implementation uniformity of all components running natively in the EGS-CC run-time environment, independently on their source, whether belonging to the EGS-CC as developed as an ESA specific extension. This however brings challenges for the development teams at ESOC which must learn the EGS-CC engineering approach which is very different to those applied to ESOC's current infrastructure products, such as SCOS-2000.

## PROGRAMMATICS

The design and development of the EGS-CC based M&C infrastructure at ESA is being executed under the so called "EGOS-CC Project" using an incremental approach, including:

- System engineering
- Progressive development, integration and validation of EGS-CC based products
- Progressive deployment and infusion in a real mission environment.

The high-level design and specification of the EGOS-CC Products, the required EGS-CC extensions and the preparation environment OPEN for the EGS-CC based applications has been completed. The development of OPEN and EGS-CC extensions (i.e. EGOS-CC extension and adapter components) was started in 2017 and is currently on-going. Progressive deliveries of OPEN are made monthly for evaluation by end users. The delivery of the first EGOS-CC components is planned in quarter 2 of this year to support the progressive integration and validation of a pilot mission control system.

The Juice MCS (J-MCS) is the first target mission control system to be developed based on EGOS-CC. As EGS-CC and EGOS-CC are still under development, a pilot J-MCS is being developed to demonstrate the stability, reliability, maturity and functional scope of EGOS-CC before a commitment is made in September of this year to proceed with the J-MCS development based on EGOS-CC. A similar approach is being taken for ground station operations, where a pilot GSMC-CC is being developed with a final decision to proceed with a full development at the end of 2019.

It is clear that delays or problems on the EGS-CC side impact on EGOS-CC. While it is not possible to fully mitigate risks, some measures are being taken. ESOC is actively participating as an EGS-CC integrator and we are involved in the validation of EGS-CC itself. The EGOS-CC team members also participates in various EGS-CC boards such as the EGS-CC Engineering Team, EGS-CC Integrators' Team and not the least the EGS-CC Steering Board. In this manner we can actively influence decisions taken and prioritisations made in the EGS-CC project.

As discussed previously, the approach is taken where EGS-CC is treated as a third party product. However, considering the schedule, in case of show-stopping issues, the EGOS-CC integration team investigates problems also on the EGS-CC software and issues patches and workarounds which are reused internally. As part of this process, it is absolutely mandatory to raise the associated SPRs on EGS-CC providing the related fixes. An open dialogue with the EGS-CC development consortium provides feedback and ascertain that changes from which other stakeholders might benefit are fed back to EGS-CC for inclusion in future releases. The integration, verification, validation and deployment activities are progressively implemented using an incremental approach similar to the one adopted for the EGS-CC product itself.

Numerous mock-up reviews, demonstrations and test sessions have been held with the future users with the aim that users will be less alienated by the new approach. The capability of EGS-CC to run parallel sessions makes it possible to simultaneously connect to the EGS-CC delivered RTF Simulator and the mission simulator, currently Bepi Colombo simulator. This approach not only facilitates familiarisation and comparisons and but also helps in finding problems which otherwise might have remained unnoticed until much later in the project. It is our intention to keep this set-up, not the least in order to be able to run regression tests based on the reference simulator in parallel to the operational validation whenever there are new deliveries released and integrated.

## SUMMARY

This paper has introduced the main technical and programmatic aspects of the EGOS-CC project, which is aiming at the development of a future generation EGS-CC based monitoring and control infrastructure at ESOC. It has described the objectives but also the challenges that this activity is facing and the principles which are being adopted in order to mitigate the associated risks.

The high-level specification for the main EGOS-CC products has been completed. A comprehensive functional model of the complete system identifies the necessary EGOS-CC extensions and adaptations of the EGS-CC implementation, the definition of the target applications, including the preparation environment OPEN, and their external interfaces. The trade-off between possible design and implementation approaches has been performed, leading to a concrete definition of the necessary EGS-CC extensions and adapters as well as of the evolution path for the ancillary applications which complement its functional role.

An incremental approach for the development phase has been defined which is based on the progressive implementation, integration and validation of the extensions on the top of the EGS-CC integration releases. This is taking place in parallel with the final phases of the EGS-CC development project, following the spirit of component and interface based design and aiming at an 'off-the-shelf' adoption of the EGS-CC deliverables. This approach is being applied to the development of an EGS-CC based pilot MCS for the Juice mission and a pilot for Ground Station monitoring and control. The results of these prototypes will be a major input in the decision to proceed with the full development of the operational systems,

Both the EGS-CC and the EGOS-CC projects are still on-going and it might be too early to talk about conclusions or lessons learned. However, while there are major challenges both technically and programmatically, good progress is being towards the adoption of EGS-CC in the renewal of ESOC's monitoring and control infrastructure.

## REFERENCES


[1] M. Pecchioli, J. M. Carranza, A. Walsh, "The Highlights of the European Ground Systems - Common Core Initiative," SpaceOps 2014, Pasadena

[2] M. Pecchioli, J. M. Carranza, A. Walsh, "The Operational Adoption of the EGS-CC at ESA", AIAA Paper 2016-2304, June 2016

[3] F. Trifin, A. Walsh "OPEN: A community based preparation environment for EGS-CC based systems", SESP 2019, March 2019

[4] K. Widegård, M. Pecchioli, "Harmonisation of products for ground segment operations at ESA" SpaceOps 2018, May 2019