CNES CO3D Image Ground Segment

Olivier Melet, Céline L'Helguen, Laure Pradines, David Youssefi, Valentine Bellet
Centre National d'Etudes Spatiales (CNES), 18 avenue E. Belin, Toulouse cedex 9, France – olivier.melet@cnes.fr

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Abstract

CO3D mission is a partnership between the French space agency (CNES) and Airbus Defense & Space, which aims at producing precise DSM (Digital Surface Model) data from optical stereo acquisitions by four satellites. The launch of the constellation was on July 25, 2025. A 6-months in-orbit commissioning period, including image quality calibration and validation activities, is being conducted. CNES is responsible for the performance of the CO3D system image products. To this end, it oversees the image performance and Digital Surface Model (DSM) activities and designs the operational computing software related to the image chain, which generates the 2D image products and 3D products. CNES thus develops the 2D and 3D image processing chain as well as the Image Calibration Center. This paper presents the composition of the L4 products (Surface Digital Model tiles), the algorithms, and the architecture of the image processing chain designed to meet production time and computational resource constraints. It also details the functionalities of the Image Calibration Center, its architecture, and the benefits gained from its deployment in the Cloud.

1. Introduction

CO3D mission is a partnership between the French space agency (CNES) and Airbus Defense & Space, which aims at producing precise DSM (Digital Surface Model) data from optical stereo acquisitions by four satellites, at a limited cost, in a constraint timing (Lebègue and al., 2025, Lebègue and al., 2026). Each of the four satellites of the constellation provides images at 0.50 m resolution in red, green, blue and NIR (Near-InfraRed) bands. The satellites resource is shared by, on one hand, the French institutions (defense, scientists concerned by global Earth monitoring) who have dedicated access and specific price conditions, and on the other hand commercial customers interested in 2D and 3D products.
The launch of the constellation was on July 25, 2025. A 6-months in-orbit commissioning period, including image quality calibration and validation (CAL/VAL) activities, is being conducted thanks to a dedicated Image Calibration Center (ICC).
A 18-month demonstration phase will start after this commissioning period. During this phase, a DSM (Digital Surface Model) over 90 % of France metropolitan territory (about 0.5 Mkm²) and 80 % of a large area (about 27 Mkm² covering north and central Africa, and Middle East) dedicated to French defense will be acquired, processed and assessed.
The aim of this paper is to describe the image ground segment designed for CO3D mission by CNES.

2. A ground segment designed for CO3D mission

The CO3D ground segment is composed of several centers work together to ensure the successful execution of missions (figure 1):
- The Command & Control Centre is responsible for managing satellite operations, including command execution, telemetry monitoring, and overall mission coordination.
- The Mission Control Centre (MCC) focuses on mission planning, scheduling, and execution. It oversees the day-to-day activities of the mission, including task prioritization, resource allocation, and ensuring that mission objectives are met.
- The Cloud Processing System (CPS), hosted in the cloud, is dedicated to processing and generating Digital Surface Models (DSMs), including both 2D and 3D products, using the CO3D image processing chain (CODIP). The cloud-based infrastructure provides scalable and flexible processing capabilities.
- The Image Calibration Centre (ICC), also cloud-based, ensures the accuracy and consistency of the imagery by calibrating sensors and the image processing chain. It applies radiometric and geometric corrections to maintain the highest standards of data quality.
Together, these centers form a cohesive system that supports the entire lifecycle of CO3D missions, from planning and execution to data processing and calibration.

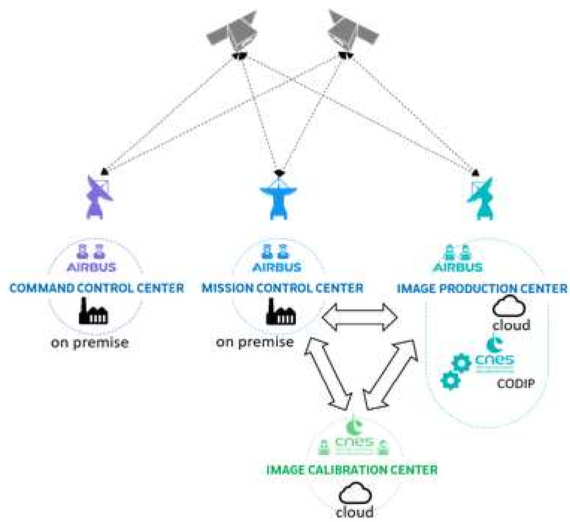


Figure 1. CO3D Ground segment Image.

CNES is responsible for the performance of the CO3D system image products. To this end, it oversees the image performance and Digital Surface Model (DSM) activities and designs the operational computing software related to the image chain, which generates the 2D image products and 3D products. CNES thus develops the 2D and 3D image processing chain (CODIP) as well as the Image Calibration Center (ICC).
The design and development of these two ground segment components of CO3D (CODIP and ICC) have ensured the collective engineering necessary to maintain the consistency of

all algorithmic methods, calibration methods, and software components developed. This engineering effort has brought together all stakeholders mixing CNES and Airbus Defense & Space teams, including:
- Image Quality experts responsible for the algorithmic methods of calibration and image performance measurement,
- development teams responsible for designing and developing the software components to achieve mission performance,
- operations teams responsible for ensuring calibration operations and image performance measurement in support of the Image Quality experts,
- the project teams, including the mission performance manager.

ICC is developed and will be operated by CNES until the end of the demonstration phase. After this phase, Airbus Defense & Space will operate ICC for the commercial phase. In order to simplify the handover of the operation between the two companies, ICC is developed and deployed on the cloud. This design also allows adjusting the amount of calculation and storage resources according to the needs of the several phases (both in orbit commissioning and operation phases).
In order to achieve the production of about 27 Mkm2 DSM in 18 months, the processing chain CODIP developed by CNES have to process up to 26 000 Level 0 CO3D images a day, up to 2D (orthorectified and sensor images) and 3D (DSM) data. This large daily data volume is a major challenge for the CO3D mission that has been tackled by a new design of the processing chain based on big data paradigm and the use of the cloud for massive computation.
Furthermore, CNES will distribute the CO3D images and DSM products that will be available for French institutional partners, but also for a wider audience regarding DSMs with a resolution greater than 15m, which will be available as open data. These products will be distributed via the CNES Earth Observation data and services platform called GEODES (geodes-portal.cnes.fr). GEODES is an innovative Earth Observation (EO) catalogue that leverages open-source technologies in order to simplify access to geospatial data and offer advanced services to end-users. GEODES offers a wide range of open EO data and advanced products originating from CNES missions and from ESA'S collaborative ground segment initiative, as well as fully integrated processing chains providing on-demand products generation. As a free service dedicated to the global community, including researchers, developers, policymakers and enthusiasts alike, GEODES covers various non-EO-specific activities.

3. CODIP CO3D automatic image processing pipeline

A major challenge of the CO3D project is to reach, with CODIP automatic pipeline, a relative altimetric precision of 1m, which is a major improvement in altimetric accuracy while the absolute height errors of SRTM is between 5.6 m and 9.0 m (Rodríguez et al., 2006).

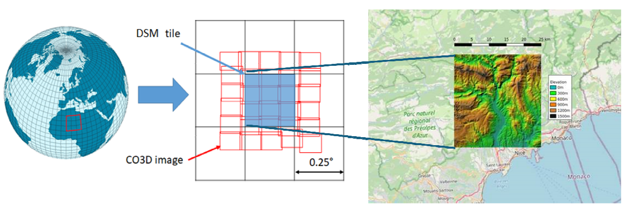


Figure 2. Definition of CO3D L4-tiles

To reach this objective, the world has been divided into L4 tiles (cf. Figure 2) of a quarter degree by a quarter degree. Each tile contains about 35 stereo pairs of CO3D L0 acquisitions and each L4 tile is processed independently in the operational pipeline. When processing a tile, CODIP implements different levels of parallelization. It begins by computing radiometric and absolute location corrections on each L0 products before mixing data from all the products over the considered tile for geometrical coherency. Then CODIP computes 3D altimetric values over the L4 tile. CODIP can also generate primary products L2A and orthorectified products L2C (cf. Figure 3).

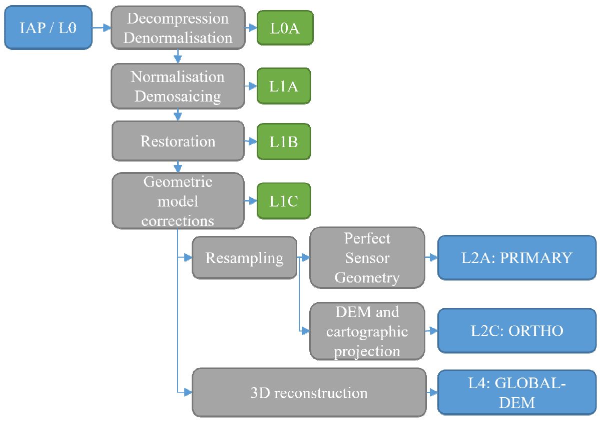


Figure 3. CO3D product levels

CODIP integrates high level algorithms to improve the radiometric and geometric quality of raw CO3D products to get automatically he best 3D performance accuracy (cf. Figure 4).

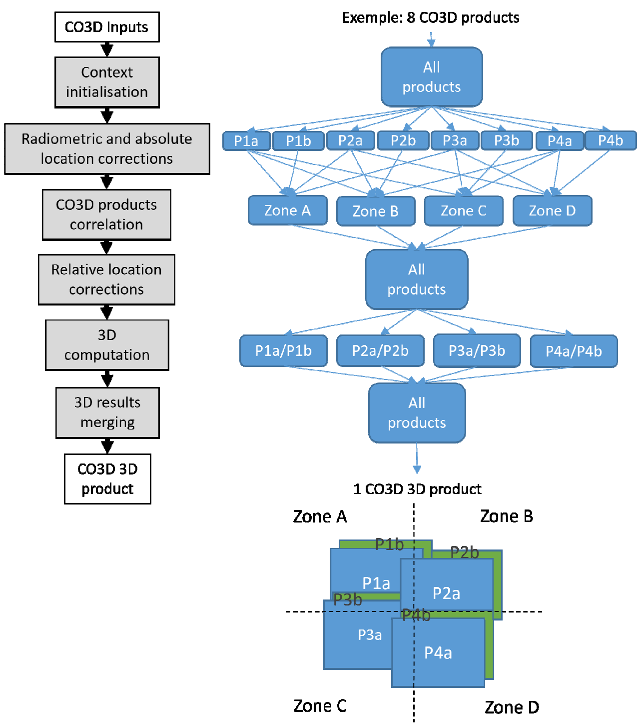
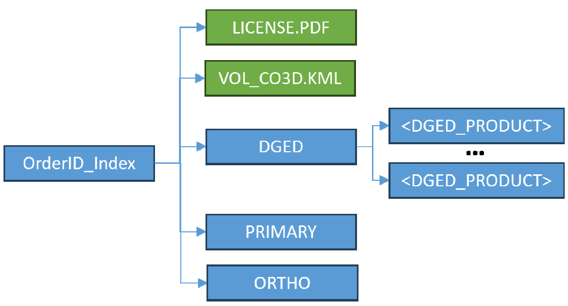
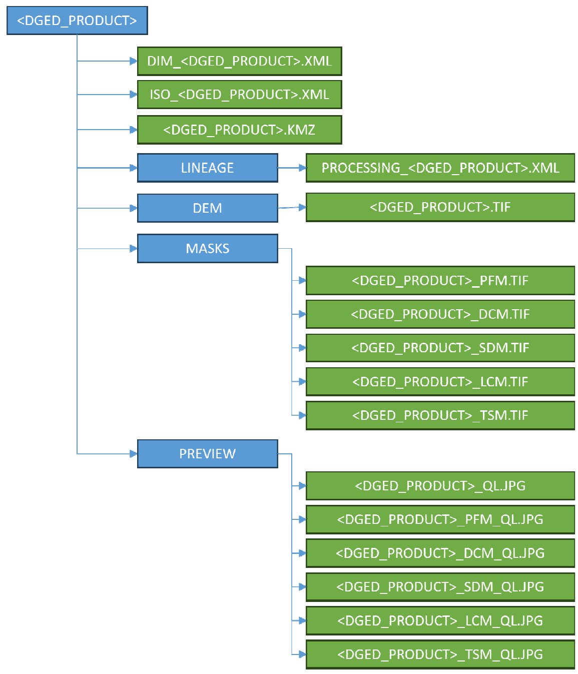


Figure 4. CODIP parallelisation levels

So CODIP applies decompression over image raw data, it corrects saturated and defective pixels, it converts the decompressed data into Red, Blue, Green and Near InfraRed (NIR) images, it applies a denoising step (Masse et al., 2018), and deconvoluates the data. Once images radiometry has been improved, CODIP corrects the absolute location of each CO3D product relatively to the AIRBUS Space Reference Points (SRP) database of ground control points (Chandelier et al., 2020). The relative location between CO3D products is then corrected thanks to correlation and spatio-triangulation algorithm (Buffe et al., 2024). CODIP also eliminates vibrations by taking advantage of CO3D instruments design and correlation of the RGB and NIR focal planes. Afterwards, CARS (Michel et al., 2020) is the CNES software component used to compute DSM by triangulation in epipolar geometry. Finally, CODIP generated L4-tiles in standard DGED format (cf. Figure 5) to facilitate the use of CO3D L4 products by final users.
The operational processing chain is deployed on the remote OVH SecNum Cloud infrastructure. CODIP offers a micro-service architecture to easily increase the number of processes executed in parallel. A CODIP production order takes as inputs all the L0 CO3D products over the L4-tile (with margins) to be generated by the production. Then CODIP will chain all its microservices thanks to the orchestrator Zeebe and the use of chart helm to define dependencies between microservices. A microservice is defined by a level of granularity (either one product, two products, all the products over a zone on ground or all the products of the production) and a functionality (initialization, radiometric and geometric location, correlation, global spatio-triangulation, 3D computation, 3D merging, report). The aim is to reduce the Input/Output flux during the processing pipeline and to offer a high level a parallelization. As several L4 productions will be run in parallel, the use of computing resources should be optimized thanks to this architecture; all the instances of microservices shall process data most of the time.





	Definition
DCM	Digital Color Model
LCM	Land Cover Mask
PFM	PerFormance Mask
QL	QuickLook
SDM	Source Data Mask
TSM	Time Stamp Mask

Figure 5. CO3D DGED content in L4 products

CO3D mission shall keep a constrained schedule for DSM availability. So the operational AIRBUS CPS facilities, which integrate CODIP, need to highly scale up the computing resources, during a limited period of a few months to compute L4 tiles before the end of the demonstration phase because of two reasons. The first one is that CO3D satellite mission will take a little over a year to get a full stereo cover of all the Regions of Interest. The second one is that stereo acquisitions at level L0 should be available over the full L4 tile to be produced by CODIP; once all necessary CO3D products have been acquired over a specific L4 tile, CODIP can process this L4 tile. As the number of L4 tiles completely covered by stereo L0 acquisitions will grow up to more than 35 000 L4 tiles to be generated by the end of the demonstration, the number of required computing servers will also be increased.

CODIP shall compute L4-tiles by respecting a dedicated budget. To achieve this challenge, CODIP uses standard computing resources and optimizes the usage of CPU. CODIP paradigm is not to optimize the production time for one single L4 tile but to master the production budget on the OVH SecNum Cloud platform by optimizing production pace and rate.

CODIP shall also offer log data for operational monitoring to easily and efficiently identify the cause of the production rate drops to limit the operational impact and cost. The strong partnership between CNES CODIP team and CO3D AIRBUS CPS team, responsible for CODIP exploitation and operation for L4-tiles generation, enables to simplify the integration of CODIP in the operational CPS pipeline.

Finally, CODIP requires parameters, which need to be calibrated for each satellite (Lebègue and al., 2024). CODIP is also deployed in the CO3D ICC to enable CNES and AIRBUS image experts to calibrate and validate CODIP algorithms during the In-Orbit Test phase and to follow the CO3D product quality during the mission lifetime.

4. Image Calibration Center

4.1 What is the ICC, and what is it used for?

In a space program, the instrument needs to be calibrated. This is done first on the ground before launch, then at the beginning of its operational life during the in-flight acceptance phase, and throughout its life through calibration campaigns.
The Image Quality experts, until the end of the in-flight acceptance phase, and then the Image Quality operators, aim to measure instrumental performances and propose corrections onboard or on the ground for instrumental effects. They therefore need a dedicated IT environment (other than the operational production center) to launch calibration and performance measurement processes and generate ground and onboard parameters that will be integrated into their respective chains. This center is called the ICC CO3D, Image Calibration Center, which generates the ground parameters of the CODIP image production chain of CO3D.

As part of the CO3D project, the following requirements have been formulated for the development of the ICC. The ICC must be developed in 2 years, transferred to Airbus 18 months after the end of the in-flight acceptance phase, and Airbus must be able to sell it for export. The program must be Low Cost. The solution must be scalable, as it has been demonstrated that this environment requires many resources during the in-flight acceptance phase, so it must be possible to easily increase resources during this phase and then decrease them. The solution must also be as automated as possible, with more than 400 products requested per day and per satellite.

These requirements have led to various opportunities. The ICC is hosted in a French Cloud (OVH) to avoid dependencies with the CNES’s Information System during the transfer of the ICC to Airbus and to improve the scalability’s management thanks to the ease of procuring hardware. The design of the ICC promotes the use of Open Source tools to avoid license costs, facilitate the transfer of licenses during the transfer of ownership, and avoid dependencies with the CNES tools. The use of cloud-compatible tools (Kubernets/S3 storage) is essential to be compatible with cloud offerings. The Devops/Agile methods implemented allow development to meet just the needs, by priority for agility, and automatic deployment of the platform for Devops. Finally, the implementation of automation solutions and collaborative tools allows users to gain efficiency.

The main user needs are presented in the figure 6 below :

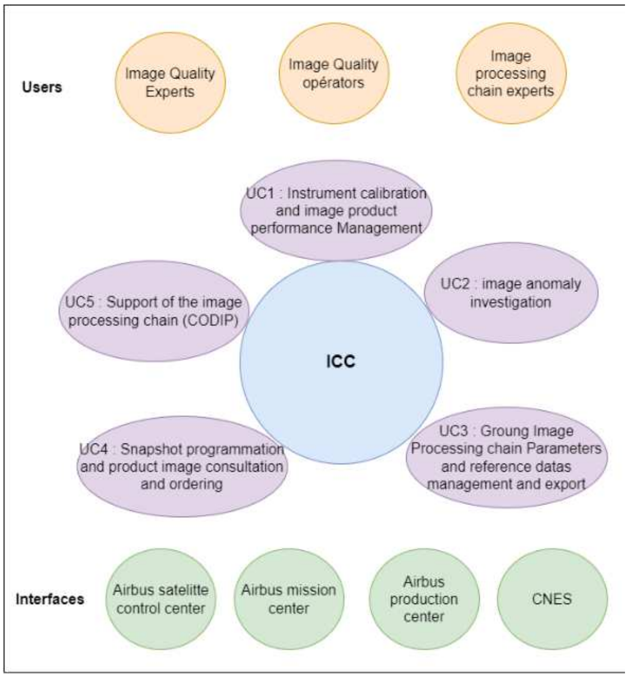


Figure 6. ICC use cases.

The needs are focused around five use cases. The first is the management of instrument calibration and product performance, which allows users to develop, integrate, and automate the launch of processes. The second is the management of image anomalies, which involves receiving and processing image anomaly contexts detected by customers once the CO3D products are commercialized. The third is the management and export of the ground parameters of the CODIP image chain and the reference data also used by the chain. The fourth is the programming of specific image captures dedicated to calibration (Moon, Burst..) and the ordering of image products from Airbus' CPS production center. Indeed, this use case allows users to order and receive specific products that enable the calibration of the instrument and its reaction to the requested optimizations. The fifth and final use case is the maintenance of the CODIP image chain to test a new version of the chain in a representative environment and validate the ground parameters to be input.

4.2 Functional architecture

To cover these use cases, solutions were implemented to meet the need for an ICC in the cloud and therefore Open Source solutions, with a Helm chart and compatible with Kubernetes and S3 storage. We therefore started with functionally unitary software bricks.

The implemented functional architecture is as follows in the figure 7 :

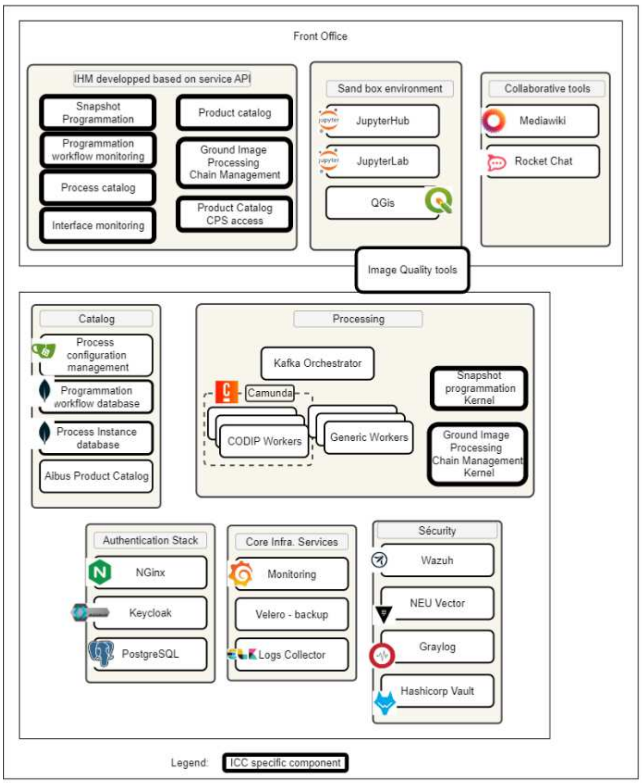


Figure 7. ICC Functional architecture.

The solution is based on a front-office IHM calling the APIs of the back-office tools (catalogs, databases..). These APIs are also documented and directly callable by the users's processes.
The solution contains a development environment, sandbox type (Virtual Research Environment) based on JupyterHub and JupyterNotebook (Brunet et al., 2021) with the same libraries as the processing environment via an NFS share containing the Image Quality tools (Image Quality expert's library).
A programming software is also instantiated, allowing to plan and export image snapshot requests while knowing in advance the constraints of Airbus' programming center (Weather, maintenance slots or operational slots). This tool is a CNES development.
To manage the interfaces with Airbus System, a gateway has been developed. This gateway is configured to transfer data, index data in the ICC catalog and/or execute processes or the image chain depending on the interfaces. This gateway is a set of microservices that work together to achieve these goals.
An Airbus-provided product catalog has also been deployed. This catalog allows geolocating an image product, viewing its properties, and accessing the link to its storage in Orange's public S3 for downloading. This tool is based on Arlas and Elastic Search.
Additionally, a treatment catalog combining a treatment configuration management tool and a database for tracking treatment instances has been made available. This catalog integrates the reference image chain.
To simplify the integration of processes developed in the sandbox by the image quality experts, the interfaces/communications between the sand box and the process launch production environment have been developed (cf. figure 8).

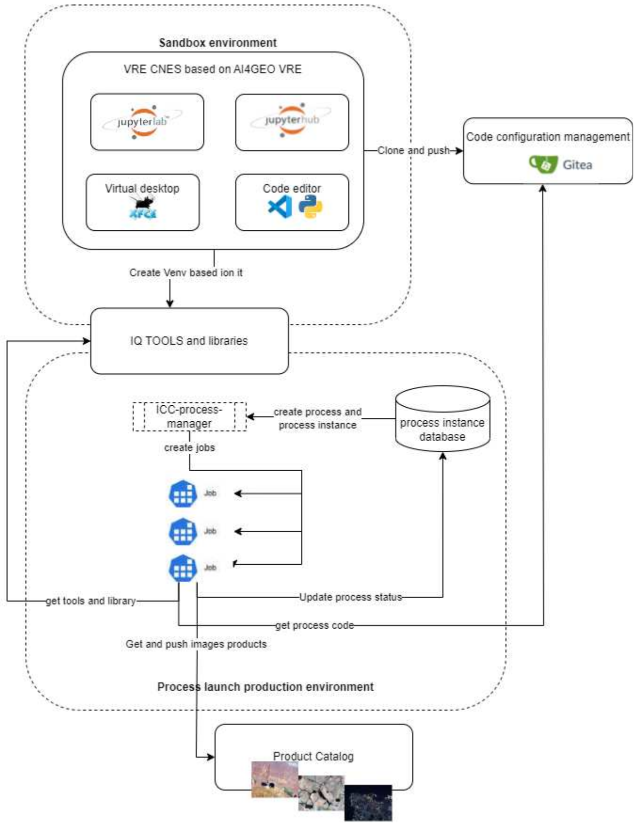


Figure 8. Process integration and launch communication.

Collaborative solutions have also been integrated. A wiki centralizes user procedures, and an instant messaging system (Mediawiki) greatly facilitates communication between Airbus and CNES personnel.

The platform obviously has all the elements necessary for its operational and security maintenance with an authentication stack, backup, supervision, and application's log management solutions, and a security stack.

4.3 Cloud and resources

The ICC is deployed in a secure OVH Cloud (SecNumCloud) shared with Airbus's production center. The data is on Orange's public cloud. OVH is responsible for managing the infrastructure up to the Vcenter. CNES is responsible for deploying the Kubernetes solution and all the applications but also the network configurations.

The sizing of the infrastructure has also required a strict partitioning of resources between automatic processes, user sandboxes, and the various instances of the image chain.

In terms of resources, since the ICC is scalable, here in the figure 9 is the evolution of the main resources since its commissioning:

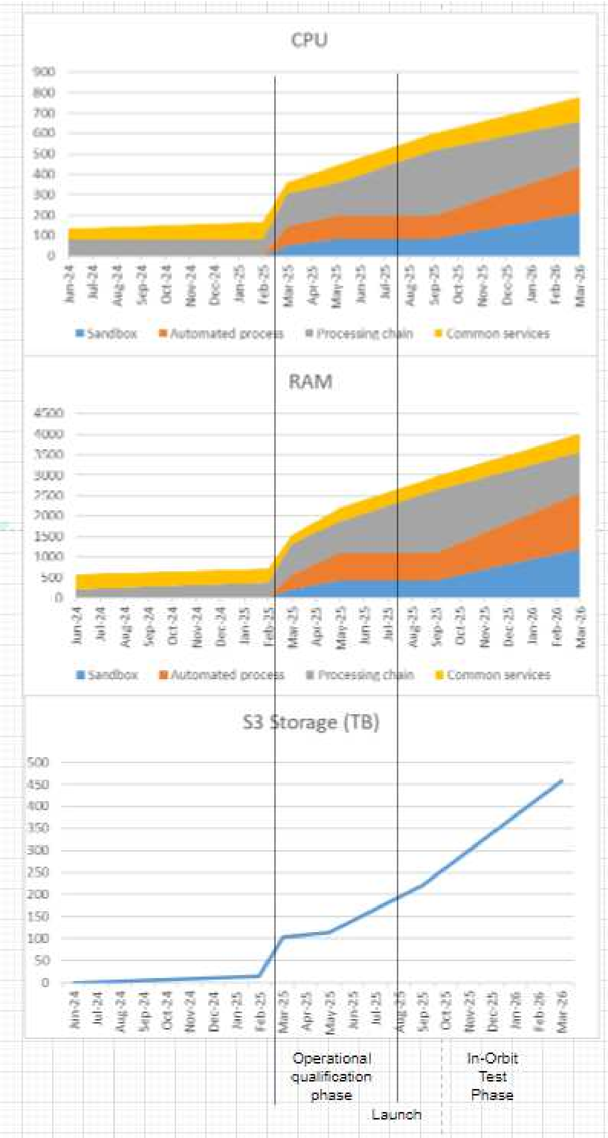


Figure 9. Cloud consummation.

The end of the in-flight acceptance phase is scheduled for late April 2026, followed by a 3D acceptance phase until mid-2026 to calibrate the produced DSM. The reduction in resource needs is estimated at the end of these phases.

5. Conclusion

The in-orbit commissioning period is currently underway, with the Cloud-deployed Image Calibration Center and the image processing chain being used operationally and intensively.

Since CO3D launch, CODIP has been used during the in-orbit commissioning phase to help Image Quality experts to parameterize operational image processing algorithm. This phase has enabled the validation of the architecture of this image processing pipeline on the different platforms where it is deployed. It has also demonstrated its ability to scale up, which enables the production ramp-up phase to begin shortly.

The ICC CO3D has met expectations thanks to efficiency and collaboration-oriented development and also an automated and sized center for multi-satellite calibration. This solution has indeed been reused as part of the Smart Image Quality Office of the DominoX project (Novak et al., 2022).

The demonstration phase is scheduled to begin in May 2026, aiming to produce the first 27 million square kilometers of Surface Digital Models within 18 months before transitioning to the operational phase. CNES will distribute, via the GEODES platform (geodes-portal.cnes.fr) the CO3D images and DSM products that will be available for French institutional partners, but also for a wider audience regarding DSMs with a resolution greater than 15m, which will be available as open data.

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