The CO3D mission, a worldwide one-meter accuracy Digital Surface Model

Laurent Lebègue, Fabrice Buffe, Olivier Melet, David Youssefi, Jean-Baptiste Henry

CNES, 18 avenue Edouard Belin, 31401 Toulouse, France – (laurent.lebegue@cnes.fr, fabrice.buffe@cnes.fr, olivier.melet@cnes.fr, david.youssefi@cnes.fr, jean-baptiste.henry@cnes.fr))

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Abstract

The objective of the CO3D (3D Optical Constellation) mission is the fully automated production of a worldwide accurate Digital Surface Model (DSM). This DSM is generated from stereoscopic acquisitions made by a new generation of high-resolution optical satellites, also called CO3D. The DSM's accuracy is one meter in relative altitude for moderate slopes and four meters in absolute altitude, with a grid spacing of one meter. Each of the constellation's four satellites provides images with a resolution of 0.50 m in the red, green, blue, and near-infrared bands. Satellite resources are shared between, on the one hand, CNES (National Centre for Space Studies), which serves French institutions (government, scientists involved in global Earth observation) and benefits from dedicated access and preferential pricing, and on the other hand, ADS (Airbus Defence and Space), customers interested in 2D and 3D products. This program is organized through a public-private partnership between these two entities. The constellation was launched on July 25, 2025. This article presents the mission's main challenges, the program's organization and timeline, as well as the system's implementation, including the space and ground segments and their key innovations. Finally, the initial results obtained during the commissioning phase are presented, highlighting the range of applications targeted by the mission.

1. Introduction

The objective of the CO3D (3D Optical Constellation) mission is the fully automated production of a precise global Digital Elevation Model (DEM). This DEM is generated from stereoscopic imagery acquired by a new generation of high-resolution optical satellites, also known as CO3D, which incorporates numerous innovations. The accuracy of the DSM is one meter in relative elevation for moderate slopes and four meters in absolute elevation, with a one-meter resolution. Each of the four satellites in the constellation provides images with a resolution of 0.50 m in the red, green, blue, and near-infrared bands. The constellation was launched on July 25, 2025. Calibration and data quality assessment are still ongoing and first data can be shown as in Figure 1.

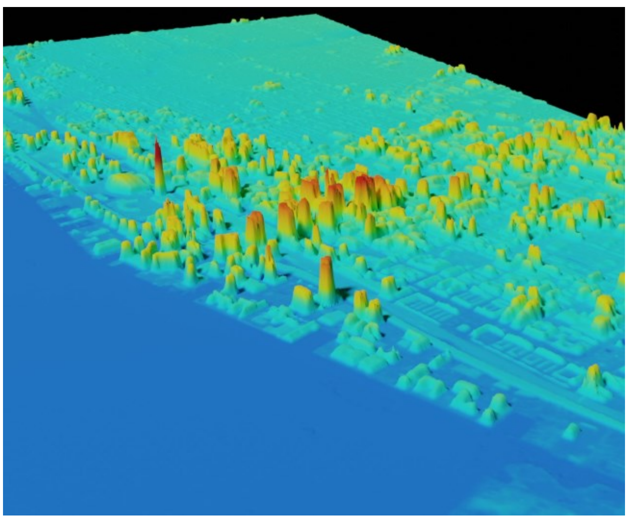

Figure 1: Perspective view of an extract of CO3D DSM of Toronto (Canada)

2. The applications

Digital surface models (DSMs) address a wide range of needs for both civilian and military users (dual mission), as illustrated in Figure 2.

Figure 2: CO3D mission applications examples

Civil applications include scientific research, civil safety, and land-use planning.

From a scientific perspective, CO3D’s coverage, revisit rate, and accuracy provide global-scale data, sparking growing interest in new areas of research. Thus, the CO3D project includes a scientific program supporting projects that plan to use CO3D products to address scientific questions covering multiple areas such as glaciology, hydrology, urban, costal, forestry, and many others.

With regard to the cryosphere, CO3D will complement the Pléiades Glacier Observatory (Berthier et al., 2024), by providing global glacier monitoring through up-to-date 3D observations and snow cover estimates. In hydrology, DSM are essential for numerical models and water storage assessments. Coastal sciences will benefit from intertidal mapping and erosion monitoring. Solid Earth studies will use 3D data to analyze landscape changes, earthquakes, and landslides. Biosphere research will assess above-ground biomass and forest structures. Innovations in synchronous stereo imaging also enable the creation of 3D models of clouds for atmospheric sciences or volcanic plumes for volcanologists. CO3D satellites also have acquisition capabilities that enable high-frequency time series (N-tuple or video mode), as described below. These capabilities will be tested to estimate surface water velocity in the context of river runoff, coastal current monitoring, and bathymetric measurement (Bergsma et al, 2026).

In terms of civil protection, DSM data are obviously essential for risk prevention—such as floods or landslides—but also for damage assessment and reconstruction following a natural disaster, through the application of change-detection techniques to 3D data. The CO3D constellation should be integrated into the “International Charter on Space and Major Disasters” by adding the third dimension.

Land-use planning will benefit from up-to-date maps and precise knowledge of the terrain, enabling the construction of roads and railways, as well as the monitoring of progress on major projects.

For military users, DSM are used for mission planning. They are essential for low-altitude drone flights, and derived versions for maximum altitude are generated for fighter jets. For ground vehicles, precise knowledge of the terrain is necessary to navigate off-road. In urban areas, artillery can perform line-of-sight calculations based on 3D modeling of obstacles.

The CNES S3D2 program is designed to encourage innovation from both the private sector and public research, covering a wide range of civil and dual-use applications. These projects leverage CO3D data to create value-added products and services built upon the source imagery and surface models. The potential of very high-resolution, up-to-date elevation data appears limitless, offering significant benefits for decision-makers and modern societies.

3. Program organization

3.1 A Public-Private Partnership

The program is based on a public-private partnership between CNES (the French space agency) and Airbus Defence and Space (ADS). ADS owns the entire system and is responsible for developing the space and ground segments, conducting in-orbit operations, and providing data to commercial users.

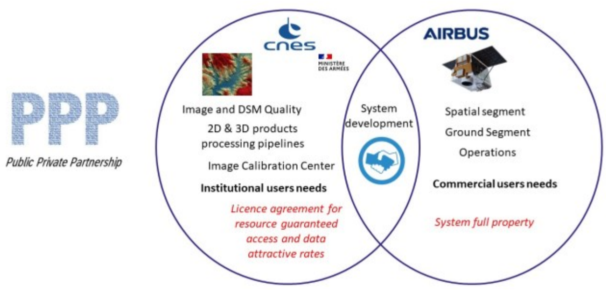

Figure 3: CO3D program organization

CNES is responsible for the quality of the images and digital surface models (DSMs), as well as for developing the processing chains for the 2D and 3D products integrated into the ground segment. It also develops and operates the Image Calibration Center (ICC), used during in-orbit testing (IOT) and the subsequent demonstration phase.The partnership also includes the co-development of the system. CNES, serving as the point of contact for its institutional partners (primarily French scientists), has signed a licensing agreement guaranteeing access to resources and preferential rates for data.

3.2 Program schedule

Following the launch of the constellation by a Vega-C rocket from the Guiana Space Centre in Kourou on July 25, 2025 (Figure 4), three major phases are planned: the IOT (In-Orbit Test) phase, the demonstration phase, and the commercial phase. CNES is involved in the first two.

Figure 4: CO3D constellation launched by a Vega-C rocket from Kourou (French Guiana).

The IOT phase is essential for configuring all system parameters before the start of routine operational phases. It primarily involves positioning the satellites in their nominal orbits, commissioning the platform’s equipment and instruments, and fine-tuning all parameters on board the satellites and in ground processing to achieve the best possible image quality (IQ). This phase lasts nine months.
The demonstration phase, which follows the IOT phase, will last 18 months. This phase is dedicated to evaluating the system’s performance over two areas: French territory and a 27-million-km² area of government interest for French defense (Figure 5), an example of which is shown in Figure 3. Global acquisitions will begin at the start of the phase, and mass production will commence six months after intensive qualification of the 3D products in partnership between CNES and IGN (National Geographic Institute), followed by the updating of the DSM processing algorithms

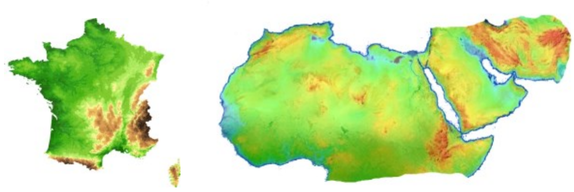

Figure 5: CO3D demonstration phase acquisitions areas, France territory and an example of governmental arc of interest.

The data collection and production request service for institutional partners are being launched with this phase of mass production.

4. The system implementation

4.1 The spatial segment

The space segment consists of four satellites built by ADS, which “fly” in the same sun-synchronous orbital plane and operate in pairs to acquire two-satellite stereoscopic images. The two pairs are positioned opposite each other in orbit (180° offset) to optimize the revisit frequency of a given site. The orbital altitude is 502 km, and the average local time is 10:45 a.m. at the descending node, as shown in Figure 6.

Figure 6: CO3D constellation in-orbit configuration

Images are acquired using matrix sensors based on the “step-and-stare” principle. Each sensor has a footprint of approximately 7 km × 5 km, and the satellite's high agility allows it to cover an area of 4,000 km² in a single pass. One matrix acquires the red-green-blue spectral bands, while the other acquires the near-infrared band. A demonstration option has been added to a satellite to test an optical data download link at a considerable data rate of 10 Gbit/s (LASIN demonstration).

4.2 The ground segment

The approximately 6,000 TB of data required to cover all continental landmasses in less than four years will be generated using a dedicated architecture operating in a secure cloud. This architecture includes the CODIP pipeline (Melet et al, 2020), responsible for processing 2D and 3D products using the open-source CARS software (Youssefi et al, 2020), which is dedicated to generating digital surface models (DSMs). CODIP, including CARS, is developed by CNES (Melet et al, 2026) and provided to ADS for integration into its ground segment operated in Toulouse, which also houses the mission planning center and the satellite control center. The ICC is hosted at CNES and is operated by a joint CNES-ADS team responsible for image quality. Its facilities also operate within the secure cloud.

5. Innovations

The CO3D program offers many innovations in addition to its unique structure.

5.1 Synchronous stereoscopy

One interesting aspect concerns the orbital geometry of the satellite constellation, which offers new flexibility in acquisition configurations to improve MNS production. For example, stereoscopic images from two separate satellites enable synchronous acquisitions (Lebegue et al, 2024). Given that the two satellites in a pair are spaced 100 km apart and the orbital altitude is approximately 500 km, the B/H ratio for this configuration is 0.20. This ratio represents a good compromise for achieving good altimetric performance while limiting occlusions over rugged terrain. The design of CO3D took into account this ability to achieve synchronization of less than 10 ms for the same ground target. Thus, moving objects, generally at speeds below 100 km/h, appear in the same position on both images and can be reconstructed during 3D processing (Figure 7).

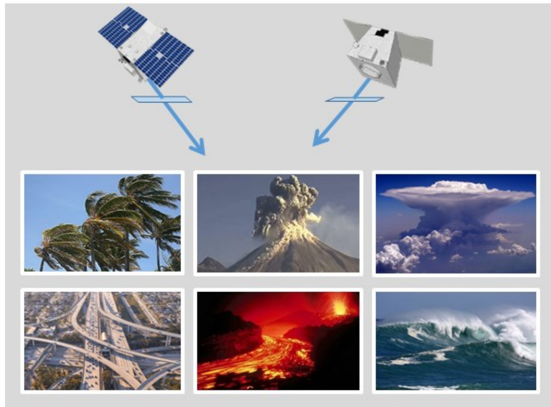

Figure 7: Synchronous stereo acquisitions benefits

Tests have been conducted on the initial data. The scientific value is particularly evident in the case of a volcanic plume during an eruption, which can be visualized in 3D from space when aircraft are prohibited from flying over the area. An example involving Mount Etna in Sicily is currently being studied at CNES.

For DSM generation, the approach appears promising for reconstructing high-traffic roads. An example of San Francisco is shown in Figure 8. The downtown area was captured using synchronous and asynchronous stereoscopic imagery during a single pass. In the classic asynchronous case, the road is rendered very poorly because vehicles moved between the two images; correlations fail to find matches or, when they do, generate incorrect elevations. In the synchronous case, vehicles are rendered accurately. Since the height of vehicles is generally less than 2 meters, the information remains masked by measurement noise associated with the road, and the result is cleaner in the DSM as shown in Figure 8.

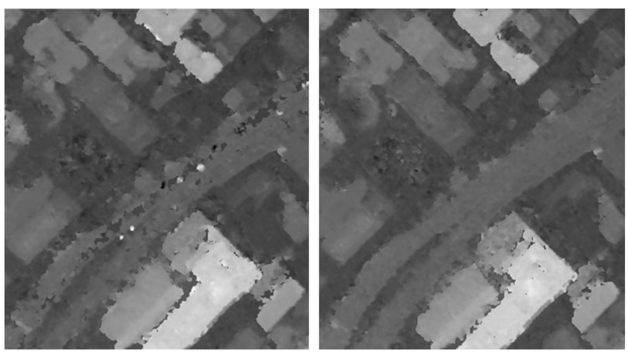

Figure 8: DSM rendering over roads with heavy traffic thanks to synchronicity (left: asynchronous, right: synchronous)

Global acquisitions are performed automatically using B/H ratios derived from a world map, with values that depend on the local slope. For gentle slopes, the B/H ratio is 0.30, and for steep slopes, it is 0.20 to minimize occlusions.

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There is also a quad-stereo acquisition mode that allows for at least two stereoscopic pairs with a B/H ratio of 0.20 and roll angles of opposite signs. The distribution of azimuthal viewing angles further reduces occlusions, which is particularly useful in urban environments for visualizing streets between buildings. Since the B/H ratio corresponds to the synchronous case, the rendering of city streets will be even better.

5.2 Native high colour resolution

The CO3D instrument, which relies on matrix sensors equipped with specialized spectral filters, produces high-resolution native color images, unlike satellite families that combine (using a "pan-sharpening" algorithm) a high-resolution panchromatic band with color band whose resolution is four times lower. This results in better color rendering, particularly for objects with fairly fine details, as shown in Figure 9.

Figure 9: Example of color rendering over Glénan achipelago (France) – © CNES-Airbus

Similarly, NIR images have a native resolution of 50 cm, which is significantly better than that of most civilian observation satellites. This capability is expected to benefit many vegetation-related applications and improve the accuracy of measurable textures. Figure 10 presents a comparison between RGB and NIR images to illustrate the advantages of NIR in vegetation detection and the resulting accuracy.

Figure 10: Example of 50 cm resolution RGB and NIR images over Vietnam – © CNES-Airbus

In the context of the CO3D mission, the NIR is primarily useful for detecting water and vegetation masks. The high resolution of the textures makes it easier to distinguish between high and low vegetation.

5.3 Images in low signal conditions

Unlike the "pushbroom" acquisition mode used by most high-resolution observation satellites, CO3D's so-called "step & stare" acquisition mode allows the image to be frozen during acquisition while stabilizing the pointing on the target. This stabilization makes it possible to use significantly longer exposure times without introducing blur into the images. Combined with the low-noise performance of the new generation of sensors, the images obtained under difficult lighting conditions are of a quality unmatched by previous generations, and it is even possible to capture very impressive nighttime images in the visible spectral bands. In the example shown in Figure 11, one can see the streetlight network, all the artificial lighting associated with the buildings, and even vehicles at well-lit intersections.

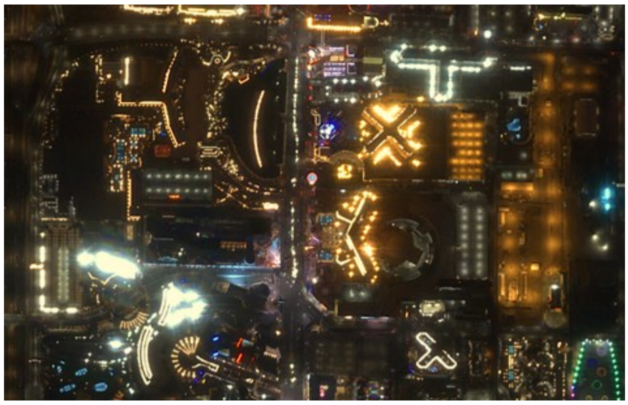

Figure 11: Example of nighttime acquisition over Las Vegas (USA)

To optimize image quality, particularly the radiometric signal-to-noise ratio, the integration time is automatically adjusted based on the sun's elevation angle. This enables data collection at high latitudes as winter approaches, thereby increasing the capacity for large-scale data collection.

5.4 Video from space

The range of sensors used in the instrument enables video recording. The ICC is capable of generating such products for demonstration purposes. This could prove useful for detecting activity at various sites or for the scientific analysis of the Earth's dynamic behavior. CNES has conducted internal tests to observe the deformation of volcanic plumes and wave movements near coral reefs, with the aim of feeding data into bathymetric reconstruction models.

6. Image Quality and DSM qualification activities

6.1 Image Quality commissioning

Many innovative methods have been implemented as part of IQ activities, as the imaging techniques themselves are cutting-edge and the performance required are extremely high in order to achieve the accuracy needed for the DSM. These activities are described in (Buffe et al, 2026).

These can be broadly divided into three categories: radiometry, resolution, and geometry.

Radiometry primarily involves absolute radiometric calibration—which converts digital counts into physical quantities such as radiance or reflectance, correcting response differences between pixels in matrix sensors, evaluating signal-to-noise ratios (Lucas et al, 2026), and adjusting onboard compression parameters.

Resolution concerns the adjustment of the instrument's focus (Figure 12), the estimation of MTF (modulation transfer function) and WFE (wavefront error) levels characterizing all optical aberrations, as well as all image restoration parameters, including deconvolution and denoising steps (Figure 13).

Figure 12: Two different focus state before calibration.

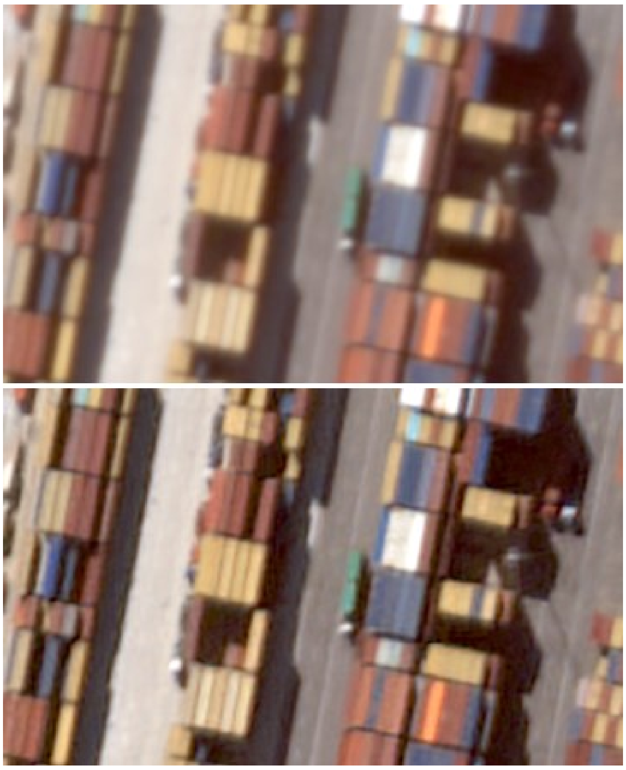

Figure 13: Extract of CO3D image before and after restoration process.

Geometric performance is the key factor in producing high-quality DSM. This encompasses activities related to precise positioning, knowledge of pixel line-of-sight (LOS) within the focal plane (Laurent et al, 2026), correction of potential residual microvibrations, and, more generally, the adjustment of all parameters of the geometric models used as input data for bundle-adjustment and DSM production processes. For example, the specified accuracy for the LOS is 0.1 pixels, which is three times more accurate than the conventional performance of optical observation satellites.

6.2 3D products qualification

6.2.1 CO3D 3D products

Two levels of 3D products are available to end users (L3 and L4). Level L3 is reserved for specific productions limited to regional areas, generally covering less than 2,500 km². Level L4 provides global coverage of DSM (example given Figure 14), distributed across a regular grid of 0.25° x 0.25° surface tiles.
These two levels provide geometrically consistent multi-resolution DSM. The available resolutions are 1 m, 4 m, 12 m, 15 m, and 30 m. The DSM complies with the DGED format to meet government requirements and ensure compatibility with most high-resolution 3D application interfaces.

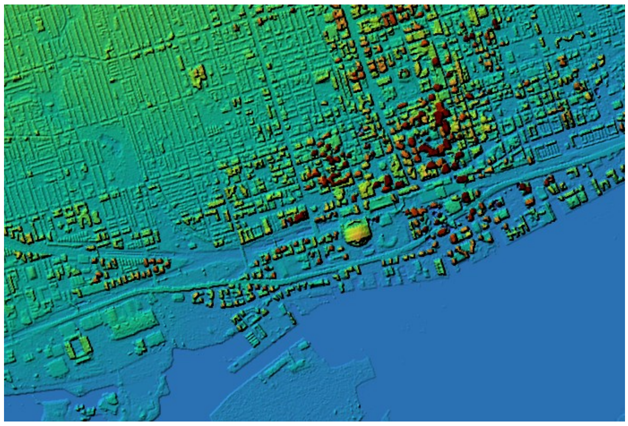

Figure 14: Extract of CO3D DSM of Toronto (Canada)

The fully automated process involves filling in gaps that may result from obscured areas (such as clouds, buildings, or very rugged terrain) or poor correlations (untextured landscapes, large waterways, or highly noisy radiometry). The method used to fill in gaps depends on their origin and size. This involves either simple contour interpolation or replacement with a low-resolution digital elevation model (DEM). This DEM can be the automatically calculated endogenous Digital Terrain Model (DTM) or the 30-meter Copernicus DSM.
This process also involves the flattening of water bodies such as seas and lakes.
Numerous raster layers (masks), which align perfectly with each DSM, are provided with the products to facilitate the interpretation of 3D data. These masks include the Digital Color Mask (DCM) containing radiometry, the Source Data Mask (SDM) indicating the processing history of the pixels, the Performance Mask (PFM) indicating relative elevation accuracy, the Timestamp Mask (TSM) indicating the data date, and the Land Cover Mask (LCM) indicating land cover for several classes.
At the request of users, the 3D product also includes the series of high-resolution images (50 cm GSD) that are geometrically consistent and were used to generate the 3D data. The level of these 2D products may correspond to sensor geometry images (level L2A) and/or orthoimages (level L2C). In the latter case, orthorectification is performed using the 3D product's in-situ DSM (at 12 m GSD, to be confirmed) to ensure the best possible geometric and temporal consistency between the 2D and 3D data.

For Level L3, the key feature of this product is the dating of the 3D data, as the stereoscopic acquisition period is one of the key requirements from users. In addition, to assist users in their 3D change detection applications, they will be able to order L3 series corresponding to different dates, all processed through the same pipeline to ensure the best possible geometric consistency through bundle-adjustment. It is also possible to order the 3D point cloud calculated prior to DSM rasterization.

For Level 4, the main challenge in processing tiles is ensuring good geometric consistency along their edges, which requires optimal planimetric alignment and minimizing elevation discrepancies. The overall production strategy aims to achieve this goal while providing accurate absolute elevation data for large-scale 3D models.

6.2.2 Qualification methods

CO3D's methods for qualifying 3D products fall into three main categories:

- Comparison with reference DSMs at different scales, using the XDEM software. This tool aligns the two DSMs being compared using the method of Nuth and Kääb and provides a wide range of standard metrics, which can be sorted by slope or land cover type.

- Comparison with vector data, such as stereoscopic reconstruction datasets or automatically extracted terrain features (ridges, valleys), analyzed using tools developed by IGN.

- Take into account feedback from users working in various fields. Prototypes currently under development are provided to a panel of future users at relevant sites. These users conduct an initial assessment of the suitability of the formats and the representativeness of the data in relation to their needs, with the aim of improving the content of the products before the operational launch of mass production.

The purpose of these qualifications (Youssefi et al, 2026) is to verify compliance with specifications, regardless of configuration: B/H, stereo, or quad-stereo, landscape type, etc. Absolute performance is assessed by comparison with reference DSM, as well as with lower-resolution DSM such as TREX, or 3D point databases such as ICESat-2. Rendering performance on specific objects is also studied, particularly using stereoscopic renderings based on image pairs.
Finally, performance stability is verified by generating the same benchmark site on multiple dates.

The type of reference datasets is selected based on three scenarios, corresponding to different qualification objectives:

- Validation is performed at reference sites located in mainland France: in this case, we have access to national databases recognized for their quality, such as the IGN's LiDAR-HD database (Figure 15). Stereoscopic reconstructions are also carried out. These sites enable us to accurately assess the absolute planimetric and altimetric performance of the CO3D 3D products.
- The qualification process is conducted at reference sites located within the area of government interest: no DSM of sufficient quality is available to serve as a reference. For these sites, nine images from the Pleiades-Neo satellites are acquired and processed to create a reference DSM. Stereoscopic reconstructions are also produced.

- On-the-fly calibration at various sites where no qualified DSM is available: the reference DSM is calculated using an improved CO3D (n-tuple) acquisition configuration to combine several images.

Between 6 to 8 sites are planed both in mainland France and the Arc of Interest.

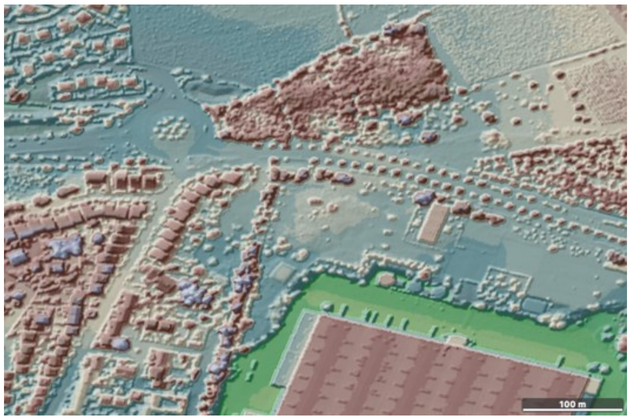

Figure 15: Example of LiDAR-HD derived DSM over Montpellier (France).

7. First results

As of the time of this writing, activities related to image quality IOT are underway and nearing completion, prior to the start of the demonstration phase and the qualification of 3D products.
Nevertheless, the first DSM results have been obtained, and it is now possible to provide preliminary estimates of altimetric performance. Tests were conducted on areas covered by a matrix sensor footprint and on larger surfaces, including that of an L4 tile (Figure 16), in order to begin adjusting the bundle-adjustment parameters.

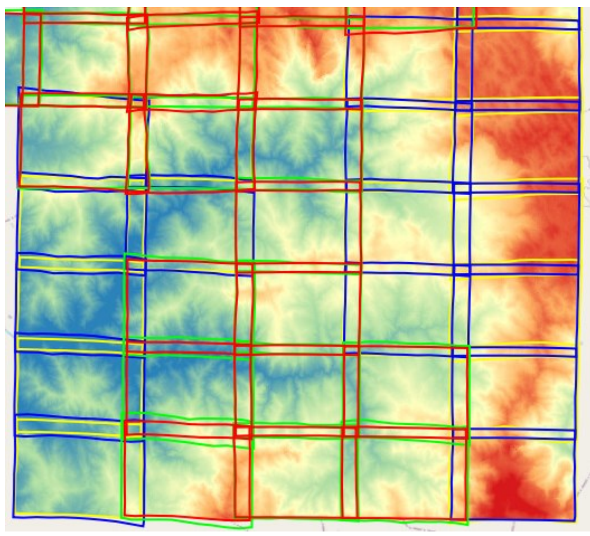

Figure 16: L4 tile over Topia (Mexico). About 30 elementary stereo pairs are needed to cover one 30x30 km² surface tile.

The main steps in the geometric processing of a set of images to obtain high-quality DSM are attitude refinement for each image individually and a global high-precision global bundle-adjustment (Erblang et al, 2026).
The individual attitude refinement process involves re-aligning biases against reference data and correcting for any drift and residual microvibration. The reference data used to correct biases are, first and foremost, Sentinel-2 images (with an accuracy of approximately 10 meters) and, secondarily, the

ADS/IGN SRP database (with an accuracy of approximately 3 meters).

To address drifts, a dedicated imaging system is integrated into the CO3D instrument to measure and correct them. As for high-frequency microvibrations, the CO3D satellites were designed to limit their amplitude, since this is a well-known phenomenon in most observation systems that causes altimetric waves in the DSM (Berthier, 2024). If any low-frequency vibrations were to occur, the CODIP chain measures and corrects them so that they do not affect either the images or the DSM.
Bundle-adjustment allows for the refinement of certain parameters in the geometric models of the images, such as orientations and the overall scale factor, in order to reduce low-frequency geometric distortions and elevation shifts at the junctions of the individual scenes.

The 3D product qualification phase is intended to allow for the tuning of all parameters in order to obtain reliable results across different terrain types. Currently, block adjustment processing still reveals some elevation gradients and slight misalignments between scenes, but apart from these low-frequency effects, the relative elevation performance appears to meet the specifications for low to moderate slopes, namely 1 m LE90 (slope < 5%) and 1.5 m LE90 (slope < 20%).

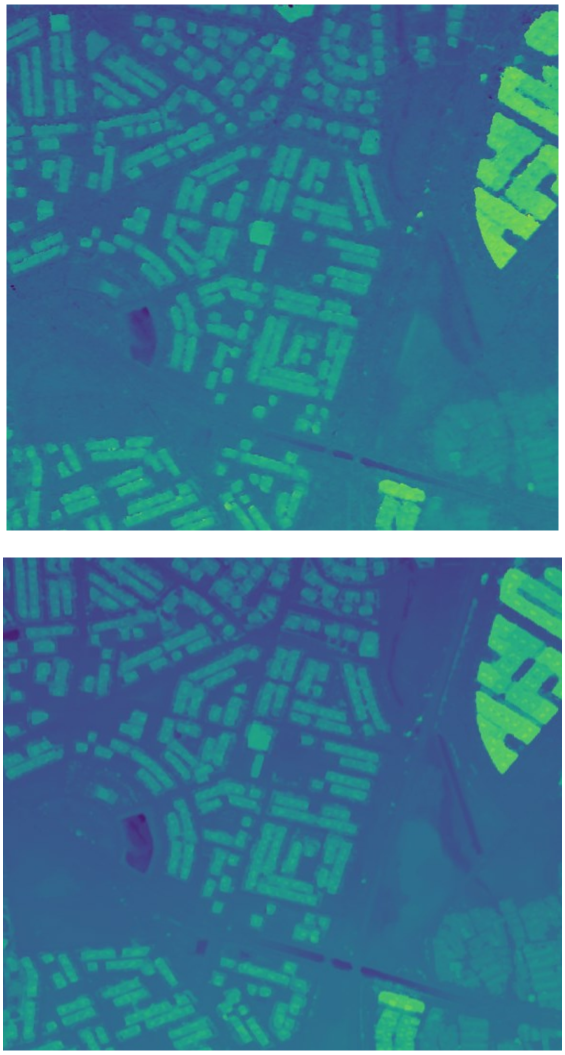

Figure 17: Comparison of 2 extracts of DSM of Marrakech. Top: CO3D, Bottom: Pleiades-Neo reference.

Figure 17 compares a DSM extract obtained with a single CO3D stereoscopic pair of images of Marrakech (Morocco) and the same extract from the Pleiades-Neo reference DSM, built from nine 30 cm resolution images. Naturally, the reference DSM shows slightly more details on the buildings and the edges are generally sharper, but the result obtained with CO3D appears to be of quite good quality for a fully automated process using only two images.

To measure the quality of the DSM's rendering in urban areas, we began by comparing altimetric profiles measured on the reference DSM derived from Pleiades-Neo, on a DSM measured from Pleiades-HR images, and on our CO3D DSM (Figure 18). We can see that the Pleiades-Neo reference is slightly better, but again, the CO3D DSM provides acceptable results, even though it was obtained with only two images. The comparison will be made with a DSM obtained by quad-stereo to see the contribution of this acquisition method.

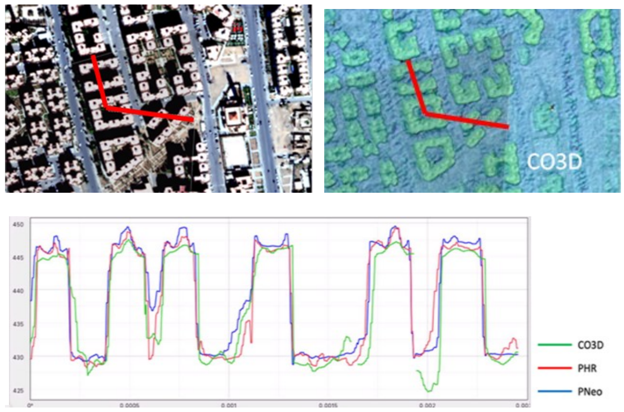

Figure 18: Comparison of elevation profile on Marrakech between several DSM

8. Conclusions

The CO3D constellation was successfully launched in July 2025. Image Quality's commissioning activities are nearing completion, and the qualification of 3D products can now begin in parallel with the massive data collection. Initial data demonstrates the potential offered by innovations in the system and its components, such as synchronous stereoscopy, night vision, high native color resolution including near-infrared, and video recording. The expected altimetric performance of the DSMs seems achievable given the quality of the image calibrations. Initial examples demonstrate this, but significant work remains to be done in qualifying and adjusting the processing chains to achieve the robustness required for automated global coverage across different landscape types.

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