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In-Orbit Demonstration of the first hyperspectral imager for nanosatellites

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ABSTRACT

HyperScout-1 is the first smart hyperspectral imager for nanosatellites. It has been launched on the 2nd of February 2018 at 8:51 CET, from the Jiuquan Satellite Launch Center in China. The launch vehicle Long March 2D lifted off on schedule and the satellite was separated from the launch vehicle minutes later. Approximately after 6 hours the first contact was established.

HyperScout-1 is based on a long line of development led by cosine measurement systems. The project to develop, build and launch the first HyperScout-1 was funded by ESA, with support from the Dutch, Belgian and Norwegian national space organizations: Netherlands Space Office, BELSPO and Norsk Romsenter. cosine, as the prime contractor, enlisted the help of consortium partners S&T, TU Delft, VDL and VITO.

The aim of the demonstration mission is to assess the quality of the data that will be acquired and the consequent suitability for the intended applications. Furthermore, the basic functionalities of the instrument as well as the onboard processing in real time will be demonstrated. The demonstration is divided in three operational blocks, during which HyperScout® will be operated to acquire data from invariant sites for vicarious calibration, from application sites to qualify HyperScout® for all the applications it has been conceived for, and to perform software experiments to demonstrate the novel approach to overcome the bandwidth limitation on small platforms.

Keywords: hyperspectral, cubesats, innovative technologies

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1. INTRODUCTION

HyperScout-1 is a miniaturized hyperspectral imager based on a three mirror anastigmat telescope (TMA) and onboard processing units [1]. The extremely compact reflective telescope ensures high optical quality over the entire range of optical wavelengths. The operational onboard data handling system is designed for realtime data processing, enabling Level-2 generation onboard and therefore drastically reducing the amount of data to be downloaded and processed on ground [2]. This demonstration mission will benchmark the payload in flight performance and will demonstrate its functionalities.

The project was performed under ESA (European Space Agency) GSTP (General Support Technology Programme) contract, by a consortium lead by cosine measurement systems B.V. (NL), including VDL (NL), TUDelft (NL), VITO NV (BE) and S[&]T AS (NO).

2. HYPERSCOUT® OVERVIEW

The strength of HyperScout® lies in the compact design, low power consumption, low mass and on-board processing capabilities. HyperScout® is equipped with a 2D sensor and a spectral filtering element to separate the different wavelengths. The On-Board Data Handling system (OBDH) is able to process in real time the acquired L0 data performing geometric corrections and orthorectification allowing the L2 data processing algorithms to analyse the data for a variety of applications. The same data can be processed for all the different identified applications, for example for vegetation conditions and change detection. The objective is to enable the direct download of the processed geophysical data products with coordinate information and to enable early warning [2].
Although HyperScout® is conceived as a CubeSat payload, it can be installed on a large variety of platforms. HyperScout® occupies a volume of about 1.5 CubeSat units [U or dm3], has a mass of 1.3 kg and has a power consumption of 9 W (peak). Thanks to its small engineering budgets and its easily adaptable mechanical interfaces, it can be adapted for integration to any platform.
The telescope is an athermal system based on a monolithic structure. The FPA is based on CMOS sensor and a spectral filtering element used to separate the different wavelengths. The ICU is the S/C contact point for the HyperScout® allowing in-flight debugging of the BEE/OBDH subsystem. It is possible to completely power down each subsystem from the ICU.
The BEE is the electrical interface to the spacecraft and is latch-up protected. It distributes power, clocks, telemetry and commands between the units, controls the detector and serves as the data and control interface, providing clock timings, frame rate control, exposure and gain control. The OBDH then merges the data acquired with the platform ancillary information creating L0 data, which is then stored in the payload Mass Memory Unit (MMU).
The OBDH hardware serves multiple purposes, the most distinct being the platform for both the acquisition and the processing modes. During the acquisition mode, data will be transferred from the BEE into the memory of the OBDH, which is then written to the MMU via SATA. During processing mode (L0 to L2A-L2B), the data is retrieved from the MMU and processed in memory on the OBDH. Both the acquired L0 image data and processed data are stored on board the payload's MMUs. Two MMUs are operated in a hot and cold redundant configuration. The specification of the payload during its in orbit demonstration mission is reported in Table 1.

Table 1: HyperScout®-1 specifications summary for the IOD mission

Parameter	Value
IOD Orbit	Sun Synchronous, 500 km altitude, LTDN 15:00 hrs
Field of view	23º (ACT) x 16º (ALT) - nominal FOV 31º (ACT)
Ground Sampling Distance	70 m @ 500 km
Swath IOD	200 x 150 km (ACT x ALT) @ 500 km
Spectral range	400 - 1000 nm
Spectral resolution	15 nm

Dynamic range	12 bit
SNR	50-100 @ 500 km
Mass	1.3 kg

2.1 HyperScout® acquisition strategy

The wavelength separation is performed in the along track direction, with a constant wavelength in the across track direction. The 2D sensor is used in pushbroom mode: the full hyperspectral datacube acquisition requires the acquisition of a series of subsequent frames, so that each region on ground is imaged in all wavelengths and can then be used to reconstruct the hyperspectral datacube. The acquisition sequence is depicted in Figure 1.

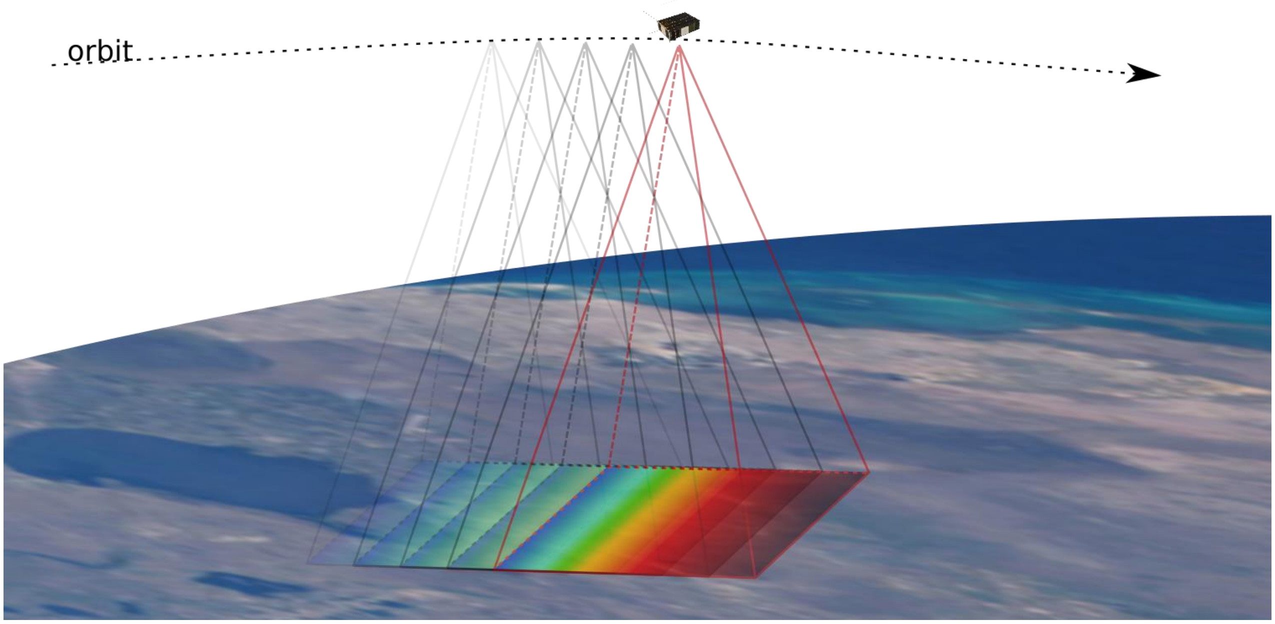

Figure 1: HyperScout® acquisition sequence

This system is extremely flexible and re-configurable in-orbit, resulting in a paradigm shift in the space asset use: different users may use the same sensor for different real time applications; the same nanosatellite can support precision farming in Northern America and flood monitoring in South-East Asia.

3. HYPERSCOUT: TIMELINE

The HyperScout development timeline is depicted in Figure 2.

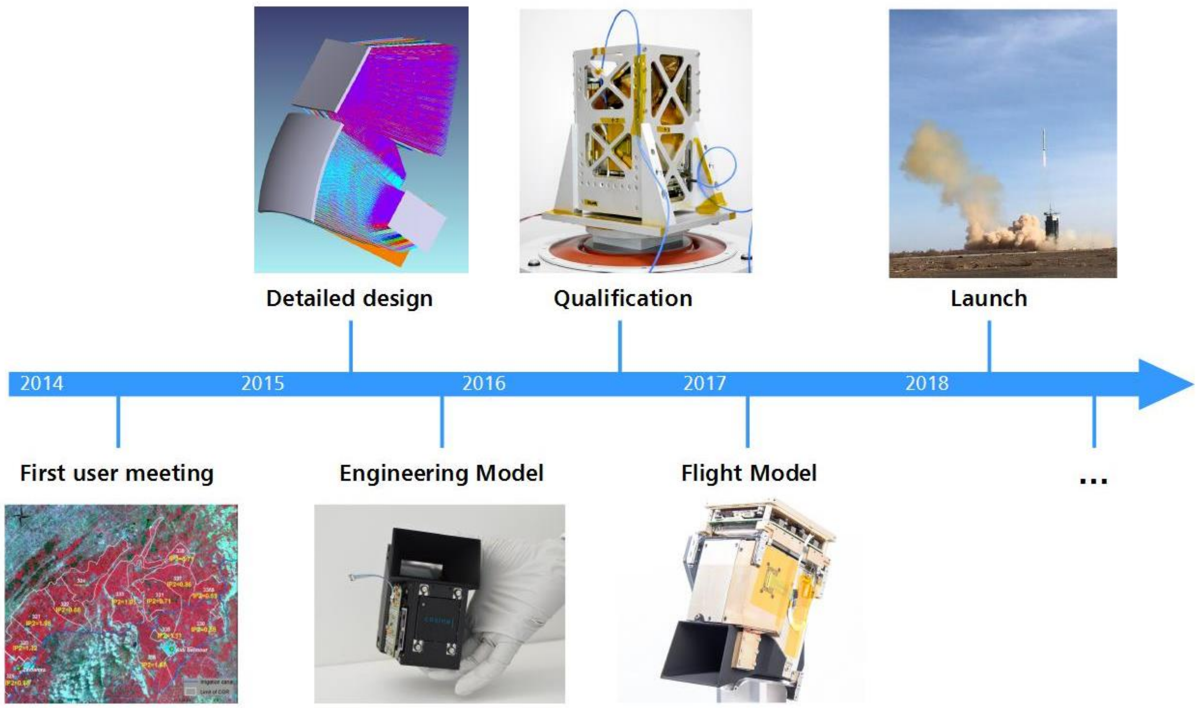

Figure 2: HyperScout timeline

3.1 The first user meeting

The first user meeting took place in May 2014. The outcome of the user meeting has been a list of down-selected applications and requirements to be used as drivers for the instrument development, all targeted for real time processing onboard. The HyperScout® selected applications exhibit a worldwide relevance and some of the applications rely on spectral indices as proxy, as are described in the following paragraphs.

3.1.1 Monitoring of vegetation conditions (drought)

Unlike other forms of severe weather or natural disasters, droughts often develop slowly and their effects vary from region to region. Hence the early detection plays an important role in the mitigation process. The Normalized Difference Vegetation Index (NDVI) provides generic information related to the presence and concentration of chlorophyll in plant leaves. The vegetation index has been considered by numerous scientists as one of the important parameters for the mapping of agricultural fields, estimating weather impacts, calculating biomass, crop yield, drought conditions and determining the vigor of the vegetation.

3.1.2 Crop water requirements

The crop water requirement (CWR) is defined as the amount of water needed by the various crops to balance the water loss through evapotranspiration, necessary for an optimal plant growth. NDVI is a reliable indicator of crop phenology and as such of leaf display. The latter leads to a correlation with maximum plant transpiration under optimal water supply. Estimation of crop water requirements (CWR) is based on the correlation between the NDVI and the crop coefficient (Kc). HyperScout® can generate Kc values which can are then used to calculate CWR for any determined area of interest.

3.1.3 Fire hazard

Observations of spectral reflectance are widely used as an indicator of foliage (fuel) conditions and can be used as a forest fire hazard indicator. HyperScout® can acquire and process data over large forest areas which would be otherwise difficult to monitor with traditional methods. For this application the issue of early warnings is essential and is enabled by the real time processing and the short data timeliness.

3.1.4 Delineation of flooded areas

The Normalized Difference Water Index (NDWI) provides information directly related to the presence of water within a heterogeneous scene including vegetation, soil and built-up areas. Specifically, the water land boundary line over land can be clearly delineated. Open water areas are identified and subtracted, highlighting the flooded areas. This application can be used to define the floodplain hydraulic model of a particular region of interest, providing a great insight into the response and the behaviour of the region under analysis.

3.1.5 Land cover and land use – change detection

Land cover and land use - change detection algorithms have been implemented for onboard processing. HyperScout® will create an on-board database of the regions of interest (ROIs) divided in classifiers in which each specific spectral signature feature is recorded. In order to do so, the ROIs need to be observed at all wavelengths (400-1000 nm). Onboard processing aims at detecting spectral changes in the various segments. When this occurs, data is downlinked indicating the detected spectral features change and location. This data product satisfies a number of applications and it can be applied to multiple scenarios, as for example:

- Identification of illegal waste dumping sites and assessment the degree of environmental contamination;
- Monitoring of water quality, identifying algae concentration and suspended contaminants. A major global ecological problem is the increasing eutrophication and pollution of coastal and inland water bodies caused by fluvially transported substances such as phosphate and nitrogen compounds, which derive from intensified agricultural and industrial activities;
- Monitoring of oceanic phytoplankton is also of high interest since it is responsible for about 50% of the global oxygen production;
- Identify and track oil spills both on marine and land areas. Hyperspectral data can also be used to determine the oil type and thickness;

- Monitoring of urban areas development;
- Monitoring of coastal and port areas;
- Monitoring of ice, snow-covered areas and sea ice.

3.2 The HyperScout® Engineering Model

The HyperScout® Engineering Model (EM) was built in 2015. It was used for a number of verifications spanning from functional, performance to environmental.

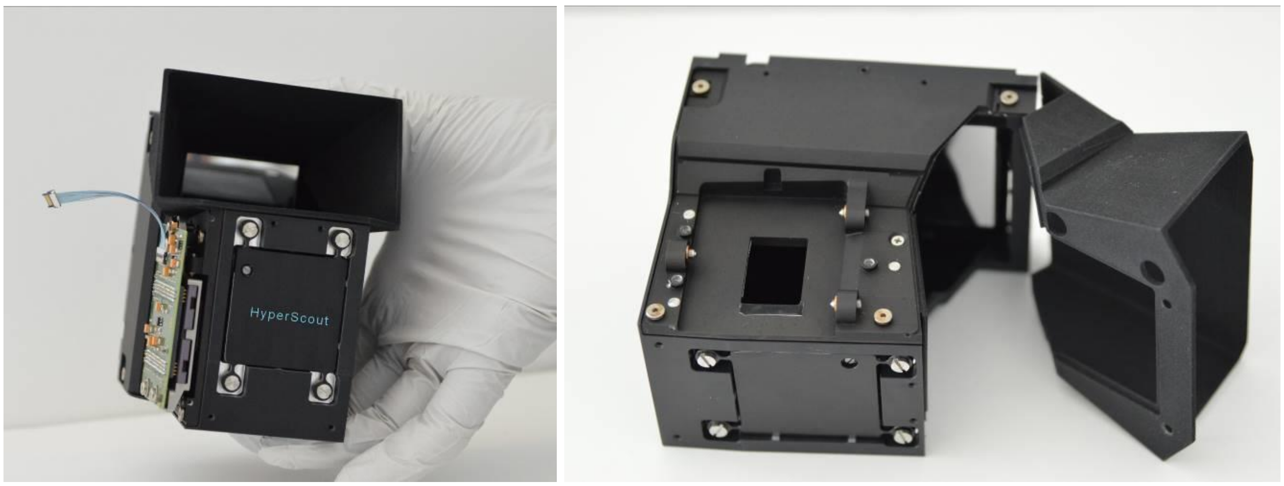

Figure 3: The HyperScout EM

The main achievements during the verifications of the EM are related to the telescope production and alignment strategy as well as the software implementation on the flight computer able to process data from level 0 to level 2B i.e. geophysical variables. The processing modules and their relations are represented in Figure 4.

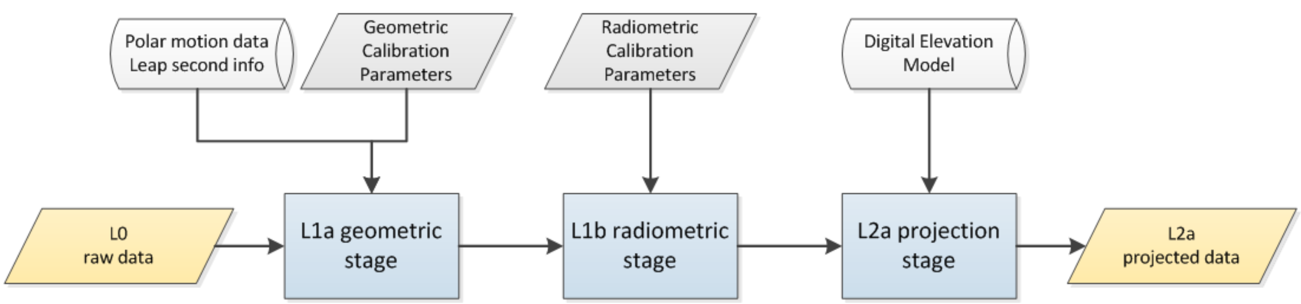

Figure 4: HyperScout software modules and their dependencies

3.3 The HyperScout-1 Flight Model

The HyperScout-1 is the Flight Model (FM) built and delivered for integration into the platform in March 2017 and it has been launched as part of the GOMX-4B mission [3] on the 2nd of February 2018. HyperScout-1 is depicted in Figure 5 also configured for vibration testing along the Y-axis.

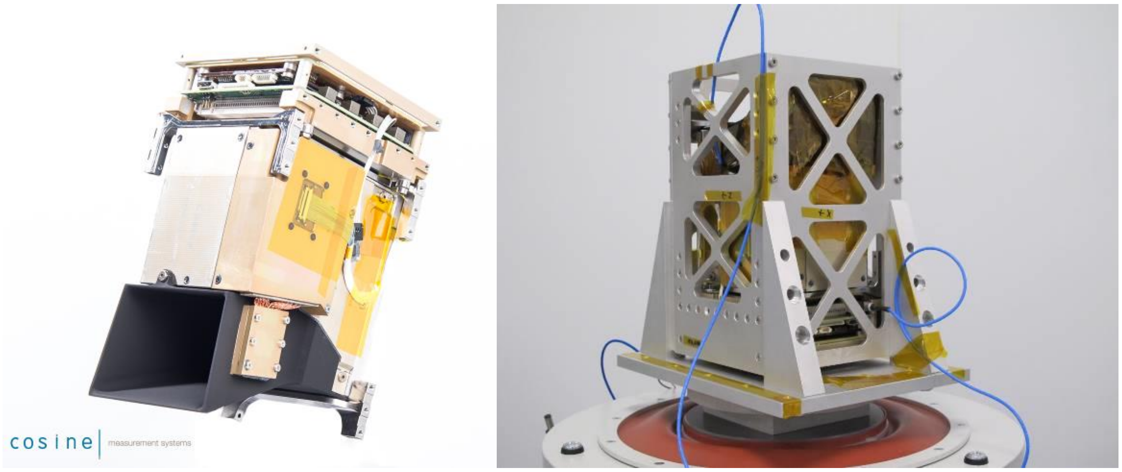

Figure 5: The HyperScout-1 FM (left). The HyperScout-1 configured for vibration testing (right)

3.4 HyperScout-1 launch and commissioning

HyperScout-1 was launched on the 2nd February 2018 as part of the GomSpace GOMX-4B on a Long March 2D launch vehicle from JSLC (Jiuquan Satellite Launch Center), China. Besides HyperScout-1, the CubeSat carries onboard a number of experimental payloads. During the Launch and Early Operations Phase (LEOP) HyperScout® performed its first functional tests including the acquisition of the first 2 images. The HyperScout-1 commissioning was performed following the GOMX-4B satellite main subsystems commissioning. The HyperScout-1 commissioning phase aimed at validating the payload functionality chain, from acquisition to compression and downlink to the ground, and assesses the status after launch and after the first weeks of space environment exposure. The payload is therefore powered ON, communication established with the S/C subsystems and a single frame is acquired. Being a single image, each horizontal line shows the scene at a different spectral band.

The first light image has been software binned 2x2 and compressed in order to fit within the 1.5 MB allowed data volume requirement dictated by the satellite resources available during the commissioning phase. The image is rendered with false colours based on raw data, therefore the expected effects due to the spectral filtering, the presence of the atmosphere and the solar spectrum are visible as variation of the response along track. This effects will be later calibrated as part of the processing chain. The imaged region is selected randomly based on weather conditions. The first light of the HyperScout® was taken over Scotland and is presented in Figure 6. During the first commissioning image acquisition a race condition in setting the region of interest on the sensor prevented acquiring a full frame. This resulted in cropping the image on the sensor covering only the 400-600 nm spectral bands. This issue was swiftly identified and fixed in order to acquire a second commissioning image, which resulted the full frame image over Cuba, shown in Figure 7.

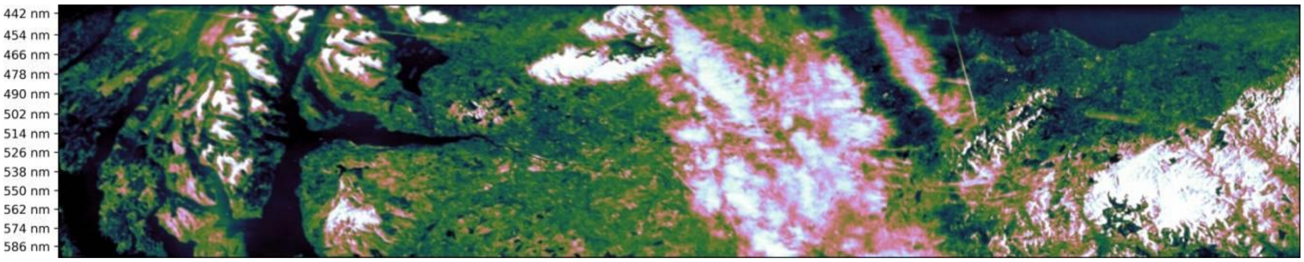

Figure 6: First light of HyperScout. False colour single image of the Scottish landscape between Glasgow and Edinburgh. Image acquired on the 20th of March 2018

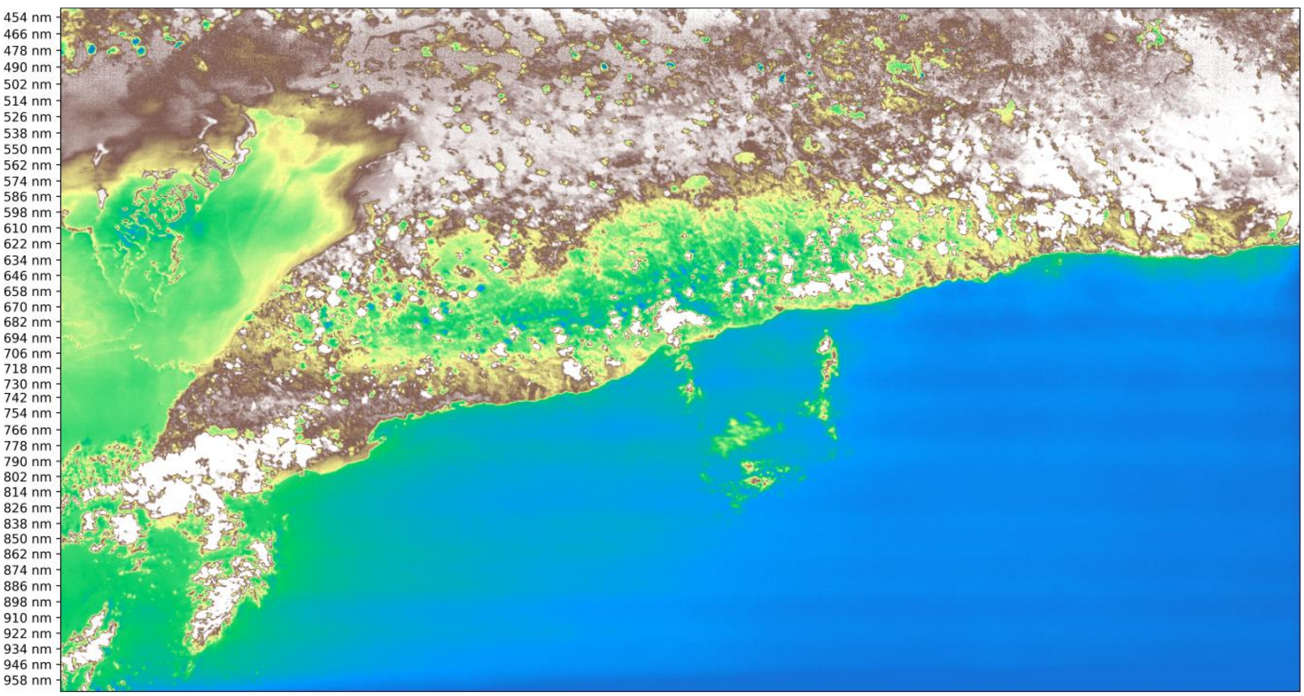

Figure 7: Commissioning image of HyperScout®. False colour single image of the southern Cuban coastline. Image acquired on the 26th of March 2018

3.5 HyperScout-1 first calibration and acquisition activities

The HyperScout-1 In-Orbit Demonstration is currently ongoing. The sites depicted in Figure 9 have been acquired until August 2018.

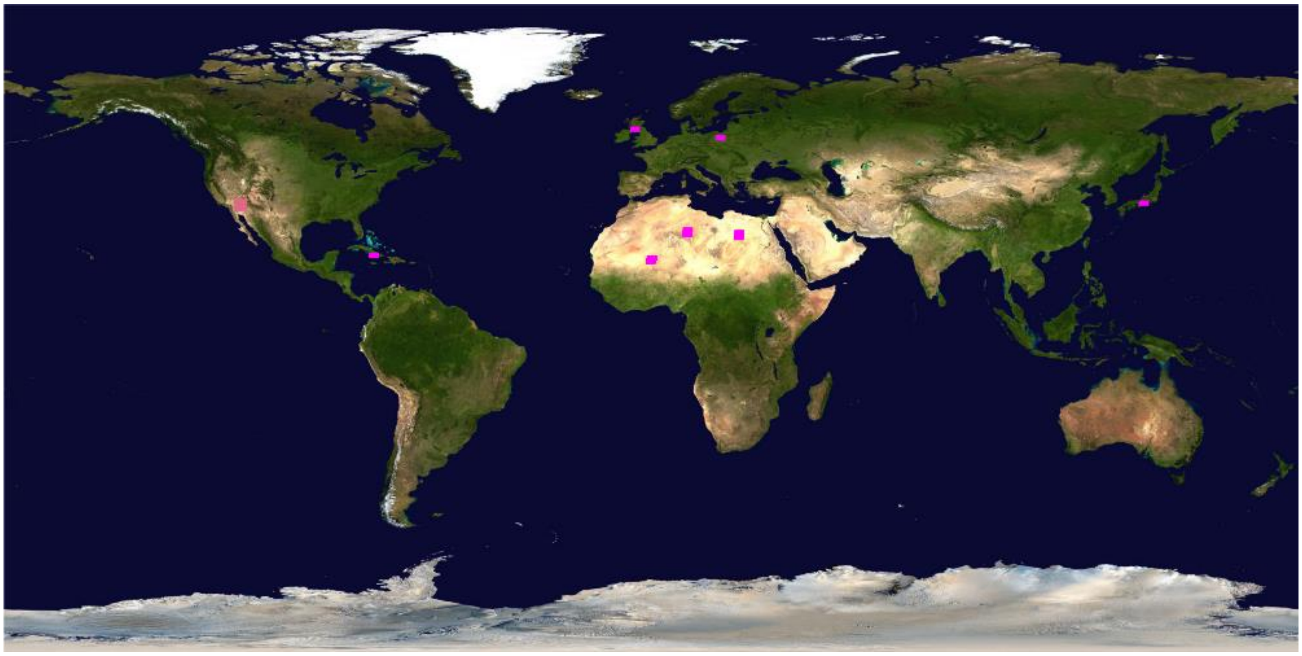

Figure 8: acquisition sites performed until August 2018

Most of the acquisitions have been performed over invariant sites for spectral, radiometric and spectral calibration purposes. One of the acquisitions over the Algeria-3 [4] is reported in Figure 9. The calibration analysis is currently ongoing, and the acquisitions for the validation of the applications are expected in September and October 2018.

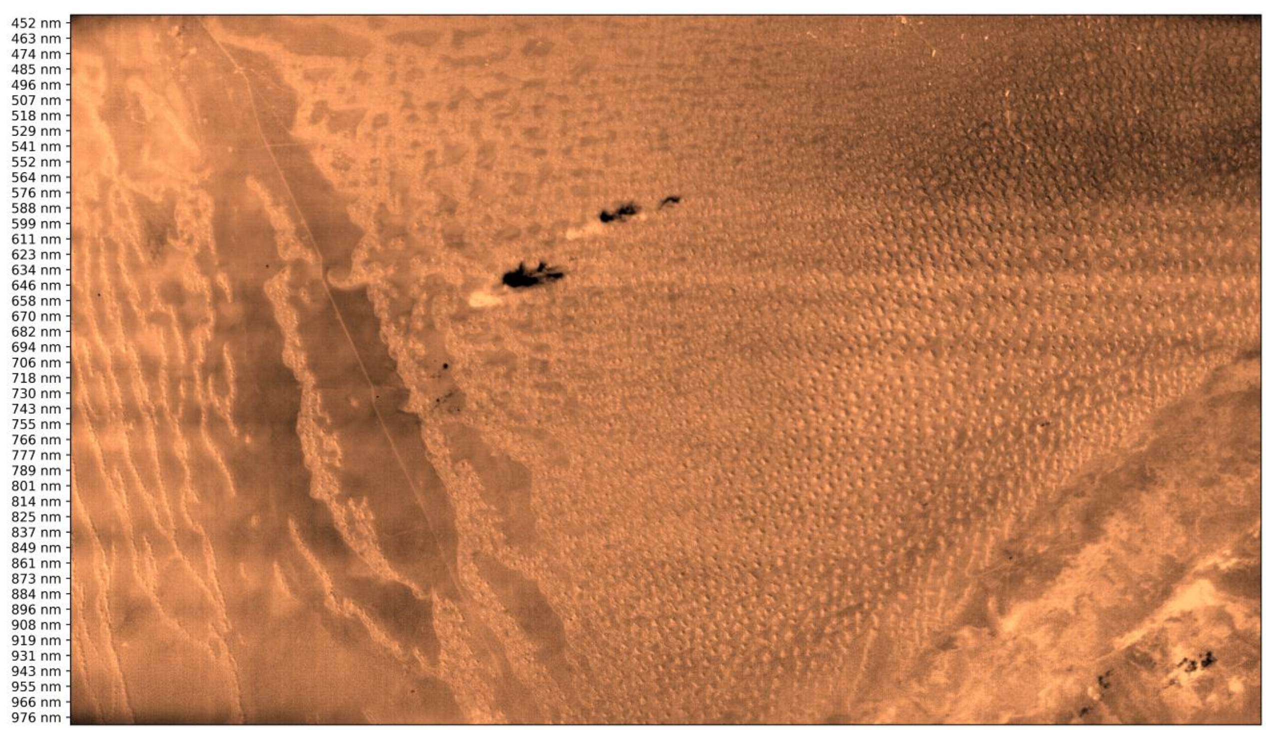

Figure 9: Hyperspectral frame image acquired by HyperScout-1 over the invariant site Algeria-3

Preliminary comparison with spectra produced by other satellites over same and/or similar sites have been performed. In particular, the HyperScout-1 spectral response across the invariant site has been qualitatively compared with spectra produced by Hyperion, the imaging spectrometer for the NASA EO-1 [5], mission currently dismissed. Even though the spectra have been produced at different times, and HyperScout data have not been corrected for the atmospheric presence, the spectra show spectral features with similar bandwidth, mostly located at the same wavelength positions. Intensity is not yet assessed as the calibration activities are yet to be completed.

4. ACKNOWLEDGEMENTS

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5. REFERENCES

[1] Esposito M. et al, "Initial operations and first light from a miniaturized and intelligent hyperspectral imager for nanosatellites" Proc. 4S Symposium 2018, Sorrento (Italy).
[2] M. Soukup et al, HyperScout: Onboard Processing of Hyperspectral Imaging Data on a Nanosatellite. Proc. 4S symposium 2016, Malta.
[3] http://www.esa.int/Our_Activities/Space_Engineering_Technology/The_size_of_a_cereal_box_ESA_s_first_satellite_of_2018
[4] https://calval.cr.usgs.gov/rst-resources/sites_catalog/ceos-reference-sites/
[5] https://earthobservatory.nasa.gov/Features/EO1/eo1_2.php