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Venμs Image Quality monitoring: a challenging multi-phased organization

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Venμs (Vegetation and Environment on a New μ-Satellite) is a joined ISRAELI – FRENCH micro-satellite, dedicated to a scientific and technological combined mission. Launched in 2017, August 2nd, the in orbit commissioning period has been a challenging multi-phased period from an image quality point of view. After a description of the whole Venμs system and mission, this paper details the different phases experienced during this in orbit test period, highlights the organization between CNES and IAI, and gives an overview of the different radiometric and geometric activities carried out to calibrate the onboard camera, and assess its in-orbit performances.

Nomenclature

AOC(S)	=	Attitude and Orbit Control (System)
ASD	=	Acquisition Set Definition
ATS	=	Antenna and Tracking Subsystem
CNES	=	Centre National d'Etudes Spatiales (French space agency)
DEM	=	Data Elevation Model
GAE	=	Ground Attitude Estimator
GCS	=	Ground Control Station
GEPO	=	Groups of Experts for Preparation of Operations
GIPP	=	Ground Image Processing Parameters
IAI	=	Israeli Aerospace Industry
IHET	=	Israeli Hall Effect Thruster
IMPS	=	Improved Multi Mission Satellite
IOT	=	In Orbit Test

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IQ = Image Quality
ISA = Israeli Space Agency
ISI = ImageSat International
JOPS = Joint OPerationS meeting
KRN = KiRuNa (station)
MBT = Israeli Aerospace Industries space division
NIR = Near Infra-Red
RAFAEL = Rafael advanced defense systems Ltd.
SAG = Structure d'Accueil Générique
SCC = Satellite Control center
SMIGS = Scientific Mission Image Ground Segment
TMC = Technological Mission Center
Venμs = Vegetation and Environment on a New Micro Satellite
VIP = Venμs Image Production
VIQ = Venμs Image Quality
VM = Venμs Mission
VRK = Venμs Receiving Kit
VRS = Venμs Receiving System
VSSC = Venμs SuperSpectral Camera

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I. Introduction

Venμs (Vegetation and Environment on a New μSatellite) is an Earth observation satellite jointly developed in cooperation between CNES (French space agency) and ISA (Israeli Space Agency). The program was developed by CNES, IAI (Israeli Aerospace Industry) and RAFAEL. Launched on August, 2017, 2nd , this satellite is dedicated to vegetation and land surface studies [1], with a unique combination of two main characteristics: the capability to acquire multi-spectral images at high spatial resolution, with constant scan angles over a significant amount of sites of interest all around the world, and with a high repetivity (2 day cycle). The scope of this paper is to accurately describe the in orbit test (IOT) phase (from launch till the beginning of a routine-like period) from the image quality standpoint. After a detailed presentation of the Venμs scientific and technological missions, and the breakdown of the image ground segment, the main phases driven during the 8 first months of Venμs will be detailed, in terms of activity, organization and planning. Eventually, this paper focuses on the lessons learnt from Venμs IOT.

II. Venμs Missions

In terms of operational concepts, two missions (each one driven by a specific payload) coexist on board, during the 4 years (nominal duration after the IOT) of the global mission.

A. Scientific mission: Earth observation

Venμs scientific mission [2] is dedicated to Earth observation. The onboard VSSC payload is a superspectral camera specified by CNES and manufactured by ELOP (subsidiary of Elbit systems, Israel).

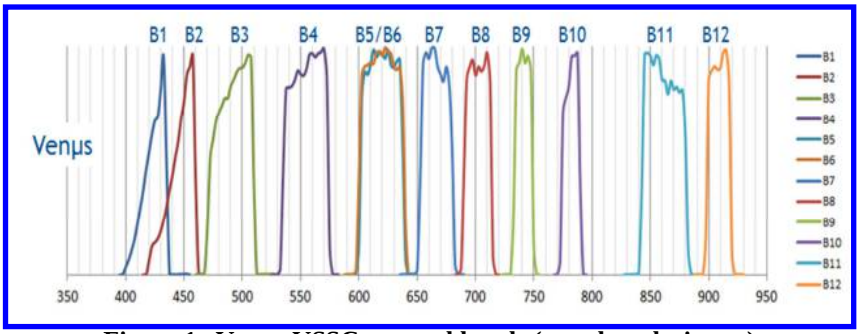

Figure 1: Venμs VSSC spectral bands (wavelengths in nm)

In terms of spectral resolution, this sensor is composed of 12 spectral bands (Fig.1) in visible and NIR spectrum (420 to 910nm), designed to study vegetation, atmospheric characterization and water color. Actually, 11 bands are featured, including the 620 nm band which is duplicated (B5 and B6).

Venμs combines high resolution and high revisit. It is important to emphasize that the Venμs orbit is ground phased with 2 days revisit time (the ground trace repeats every 2 days). Indeed, on a near polar sun-synchronous

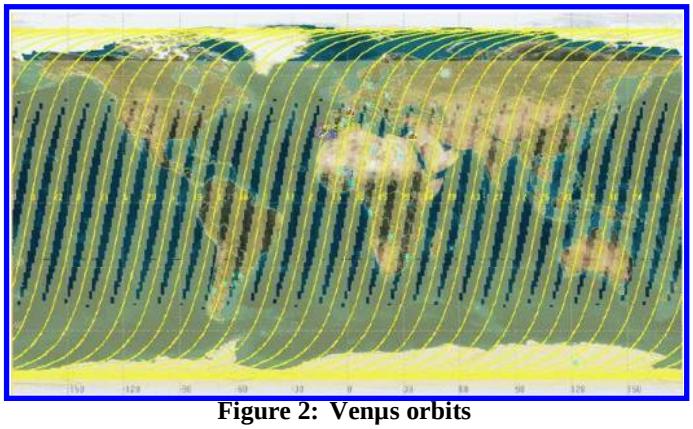

Figure 2: Venμs orbits

orbit (altitude 720km), images are acquired with a 2 day orbital cycle, at NADIR and out of NADIR (due to the satellite agility), and on ground resulting products are generated with resolution varying from 5.3m to 10m (depending on the level of processing). The number of revolutions per cycle (29), together with the limitation of the across track angle at 30° lead to a particularity of the mission: only a part of the globe is accessible to the camera (Fig.2).

The consequence of these particularities is that the mission is focused on a limited list of geographical sites (Fig.3), systematically scanned with constant viewing angles. This is a very important specificity of the project. Indeed, Venμs is dealing with a list of determined geographical sites (the list is named ASD in this article, Acquisition Set Definition). This list contains a set of calibration sites and scientific sites, in different proportions according to the project phase (test/calibration phase, routine phase). The way the sites are taken into account in image ground segment depends on the type of the site (calibration or scientific). The global list of the sites (and their purposes) has evolved for some reasons since the launch and has given birth to various ASDs programmed throughout the commissioning phase. At the beginning of IOT, these different ASDs have enabled the qualification of the camera. The ASD currently operational contains the sites of nominal scientific mission: around 150 elementary acquisitions (27km²), distributed over 110 geographical sites of interest (chosen after a scientific call for proposals). All these aspects (the evolution of the ASD, the different phases of the programming) are described more accurately later.

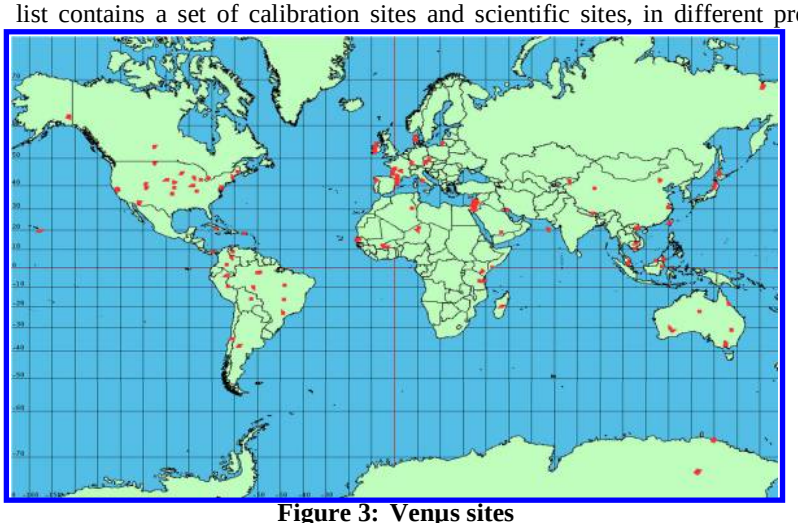

Figure 3: Venμs sites

The image products level considered in the ground segment are:

- Inventory and Level 0 products: raw products (over full data strip or extracted over a given site) and additional auxiliary data with no radiometric or geometric correction (5m resolution)
- Level 1A: internal CNES image segment format: product with radiometric equalization applied on Level 0
- Level 1: geolocated ortho-rectified products with top of atmosphere reflectance (5.3m resolution, multispectral registration, clouds identification)
- Level 2: ortho image with ground reflectance taking into account atmospheric correction (using only Venμs data) (10m resolution, improvement of cloud and shadow detection)
- Level 3: ortho image synthesis with ground reflectance, 10 day composite of level 2 products, leading to a cloud-free product (10m resolution)

B. Technological mission: electric propulsion

Based on an IHET (Israeli Hall Effect Thruster Fig.4) payload, the goals of the technological mission are to qualify in space this type of engine, and demonstrate the mission enhancement possibilities (orbit maintenance, orbit transfer, drag compensation).

This mission is managed almost entirely by IAI and RAFAEL, and has no link with image quality. This explains that this topic is hardly addressed in this paper. The only events that will be emphasized are some consequences

Figure 4: IHET instrument, HET-300 model (image credit: Rafael)

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experienced after IHET activation on Venμs orbit and, consequently, on images.

C. Missions schedule

In terms of schedule, three main phases can be emphasized in the 4 years mission life, after the IOT:

- First period of 2.5years (VM1 period): Scientific Observation mission and Technological IHET mission will be alternatively activated. The main mission will be the scientific one. During dedicated short periods, the IHET technological mission will be activated (2 or 4 days each month, named VM1aT period, and one month in each year, named VM1b period).
- Then, a 6 month period (VM2 period): thanks to IHET activation, orbit will decay during 6 months, enabling Venμs to reach a 410km orbit.
- Finally, a 1 year period (VM3 period): Venμs mission will ends by 1 year of technological mission IHET (to maintain the orbit and compensate drag), with image acquisition as secondary mission.

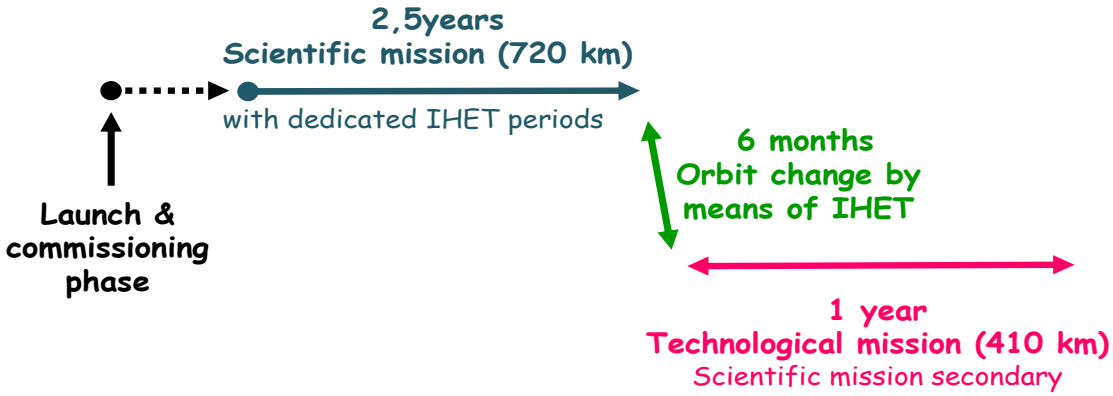

Figure 5: Venμs mission schedule

Figure5 illustrates this planning. The current article is focusing on the beginning of the satellite life and emphasizes the challenging schedule of this part, with a sequence of planned and unplanned activities.

D. Components of the Venμs system

The major components of the Venμs System are:
In space:

- The Venμs Satellite (Fig.6), injected into a low Earth polar sun synchronous orbit at the altitude of 720 kilometers. The Venμs Satellite is composed of:
  - The Venμs platform, based on the IAI IMPS (Improved Multi Mission Satellite) platform
  - The Venμs Super Spectral Camera (VSSC)
  - The Israeli Hall Effect Thrusters (IHET)

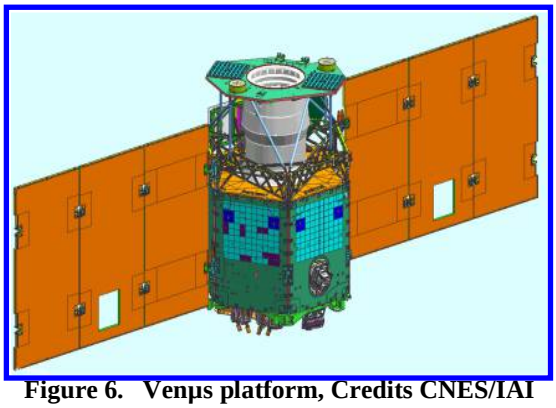

Figure 6. Venμs platform, Credits CNES/IAI

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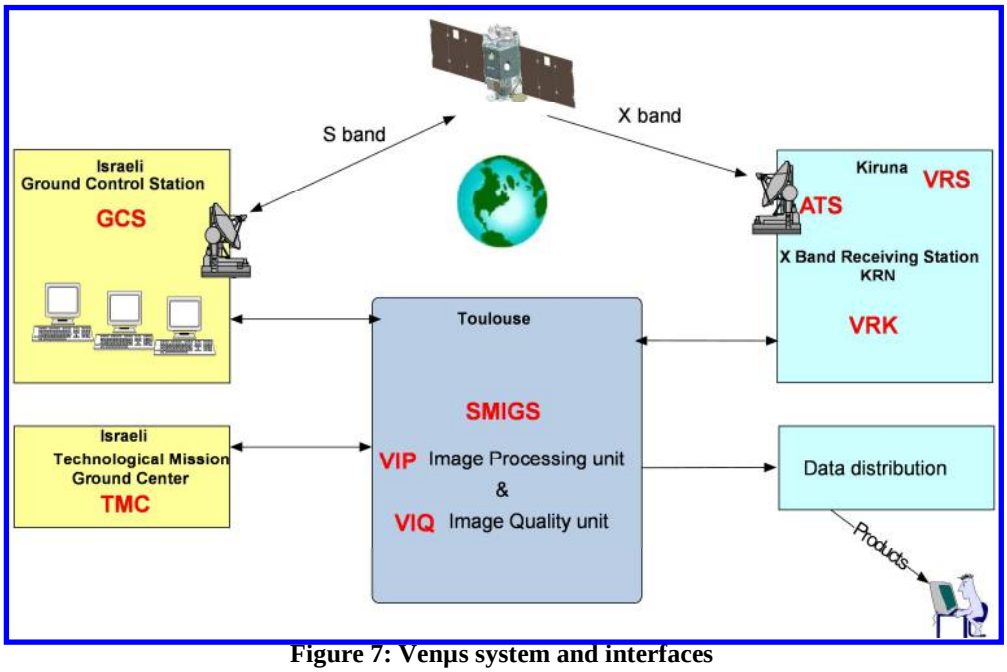

Figure 7: Venμs system and interfaces

On ground (Fig.7) :

- The Venμs Ground Segment (GCS) for Command and Control, at IAI/MBT premises close to Tel-Aviv, in Israel. It is in charge of operating, controlling and monitoring the satellite. It is composed of:
  - An S band earth terminal
  - A Tracking & Communication Center (TCC)
  - A Satellite Control Center (SCC)
- An X-Band Earth terminal (located in Kiruna) which receives image raw data and auxiliary data from the satellite. This station embeds in particular the so-named VRK, in charge of the interface between the SMIGS and the antenna system.
- The Venμs Scientific Mission Image Ground Segment (SMIGS), at CNES, in charge of programming the scientific acquisitions and processing the data from raw telemetry up to Level 3 image, archiving and dispatching the Venμs scientific and associated data to the end users. It is also in charge of image quality related activities.
- The Technological Mission Ground Center (TMC), located in Israel, which is in charge of planning the Technological Mission, analyzing and archiving the Venμs technological payload (IHET) data.
- The launch vehicle, in charge of injecting the Venμs satellite into its low Earth polar orbit, with specified orbital and attitude parameters accuracy.

As this article is mainly concentrated on image quality and related activities, it addresses almost exclusively the activities and exchanges within the SMIGS (described precisely below) and between VRK, SMIGS and GCS (Fig. 7) (in a more minor way with TMC).

Another component deserves to be highlighted (even if internal in SMIGS architecture): the HUB. This component is an FTP exchange server in CNES premises, used by TMC, GCS, VIP, VIQ and VRK to communicate and exchange data.

III. Scientific Mission Image Ground Segment

A. Image Ground Segment features

The main features of the Scientific Mission Image Ground Segment (SMIGS & X-Band station) are

- to inventory the raw image telemetry received from the Venμs satellite through X-Band station

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- to generate products on the acquired sites, with the following frequency specificities based on the type of the site:
    - Calibration sites: for these sites, the products are generated by the VIP "on demand" initiated by VIQ. Level 0 (L0), Level 1A (L1A) or Level 1 (L1) products are thus produced and provided to VIQ for expertise
    - Scientific sites: for these sites, there is an automatic production of the Level 1 (L1) products. (ortho-rectified - top of atmosphere multispectral images) and of the "value-added" products (L2 - top of canopy - and L3 - temporal syntheses -) dedicated to the international scientific community
- to guarantee an optimal image quality level of the final products, compliant with the scientists requirements

For this last point, in the specific frame of the Venµs mission, the multi-temporal and multi-spectral registration performances are fundamental criteria to be respected for the scientists. To reach these performances, the reference data is a key-notion in the image ground segment. Indeed, within the SMIGS, for each geographical site, a pool of reference data (reference image, reference DEM for Level 1 and Level 2 products) is needed, for which the consistency with regular acquisitions is monitored during the whole mission life. This aspect is introduced more precisely in the image quality loop further described in this paper.

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B. Image Ground Segment Breakdown

The Venµs Image Ground Segment consists of the following set of main functional units (Fig.7):

- Located in Kiruna (Sweden)
    - The Venµs Receiving Station unit (VRS) which realizes all real time operations for tracking, receiving and ingesting the Venµs satellite image telemetry. The VRS is composed of 2 main systems: the Antenna and Tracking **S**ubsystem (ATS) which is under the responsibility of Swedish Space Corporation (SSC) and the "Venµs Receiving Kit (VRK)" subsystem, which is under the responsibility of CNES. This latter is performing a baseband function (to demodulate the IF coming from the antenna, and to modulate a test signal), an ingestion function (recording data on a numerical support) and a monitoring and control function (handling pass plans, recording demodulation and ingestion parameters, sending commands to equipment and pass follow-up)
- Located in CNES premises in Toulouse (France)
    - The Venµs Image Production unit (VIP), part of SMIGS, which performs pre-processing, inventory, Level 1 to Level 3 products generation (with light quality control), data archiving and cataloguing, and generates programming and downlink requests to the Israeli control ground segment,
    - The Venµs Image Quality unit (VIQ), part of SMIGS, which monitors accurately the imaging system performances, generates calibration and reference data by processing of image quality products and monitoring data, and generates the Ground Image Processing Parameters (GIPP) used by the VIP.

C. Image Ground Segment Main Activities

From the SMIGS (image ground segment) point of view, some communication loops are critical. They are introduced in this section.

1. Programming loop

The goal of this loop is to select and program the acquisitions for each cycle (Fig. 8). It mainly deals with interfaces and exchanges between VRK, SMIGS/VIP and GCS.

Two main steps are identified in this loop:

- the definition of the set of acquisitions (step A), where SMIGS and GCS agree on the feasibility of a set of acquisitions
- and the eventual operational programing (step B), where VRK,SMIGS and GCS interface to plan and download the data relative to the acquisitions.

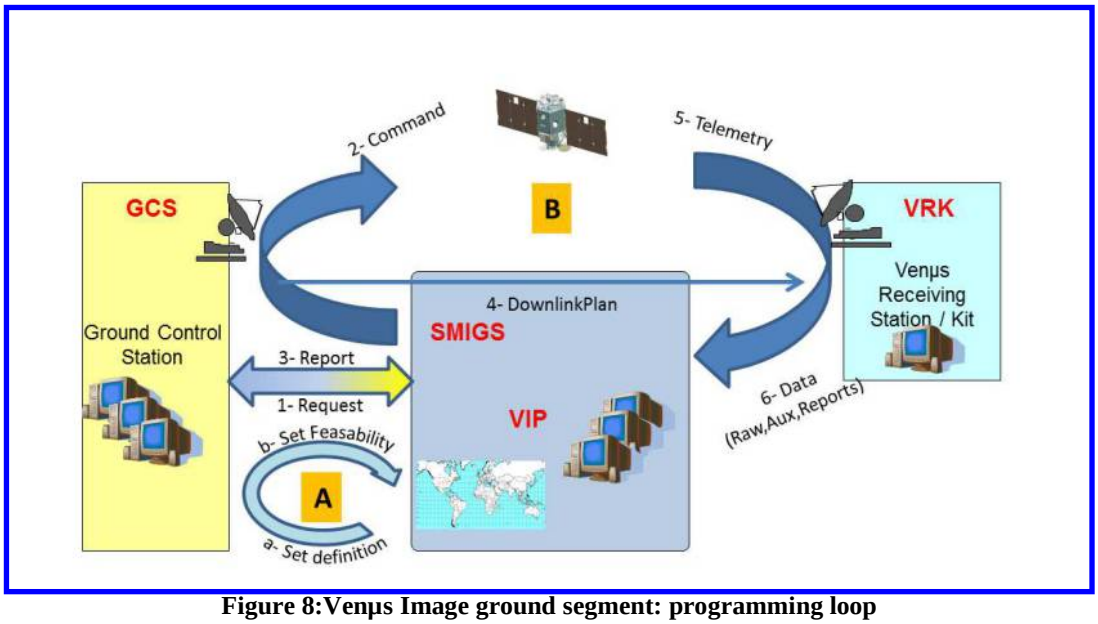

Figure 8:Venµs Image ground segment: programming loop

These two different set of operations are detailed below.

- Definition of the whole set of acquisitions (Fig.8-loop A):
  - Usually, the acquisition sets are predefined in an off-line loop. The VIP submits (Fig.8-point a) AcquisitionSetDefinition (ASD) to the GCS in order to check its feasibility. This ASD contains calibration and scientific acquisitions. It has to be emphasized that some acquisitions are not needed at each cycle (some special calibration programing are done once a month for example, and not every 2 days).
  - The GCS checks the feasibility of the set in its planning tool on a nominal, pre-defined Venµs orbit, and acknowledges to this request through an AcquisitionSetFeasibilityReport (Fig.8- point b). In case of failure, the VIP should correct the Acquisition Set according to the feasibility report and reiterate the request until the acquisition set is feasible.
- Programming of the acquisition set (Fig.8- loop B) :
  - A pre-approved acquisition set (a cycle of acquisitions and download directives) is activated by SMIGS as needed through a so-named AcquisitionSetRequest, sent to GCS by SMIGS (Fig.8-point1). On CNES side, an AcquisitionSetRequest is a "long-term" requirement. Using the 2-day revisit advantage of the locked-orbit, it is not necessary to send an AcquisitionSetRequet every 48 hours. Indeed, the rule is that an AcquisitionSetRequest is valid till a new AcquisitionSetRequest is sent (at an extreme point, the nominal AcquisitionSetRequest can last 2.5 years!).
  - On GCS side, on the opposite, 3 times a week, GCS generates a new satellite command file, based on current predicted orbital data (Fig.8-point2), and uploads it to the satellite through the S-Band communication link.
  - Afterthat, GCS sends to the VIP the corresponding AcquisitionSetReport (Fig.8-point3) and DownlinkPlan (Fig.8-point4), which are forwarded by the SMIGS to the VRS.
  - The satellite carries out image acquisitions and downlinks according to the telecommand file uploaded. During each downlink, the VRS receives the corresponding PayloadTelemetry (Fig.8-point5) through the X-Band communication link. It then ingests the PayloadTelemetry in order to collect the ImageSourceRawData and the AuxiliarySourceRawData, which are transmitted to the VIP (Fig.8- point6). The AuxiliarySourceRawData is provided by network and is made accessible to the VIP, the TMC and the GCS (Fig.7 and Fig.8).

Concerning the data transfer, ImageSourceRawData are transmitted to the VIP by postmail and network at the beginning of the in orbit test period. After a few months, all the ImageSourceRawData have been transferred by network, thanks to the establishment of a dedicated link.

A peculiar point must be highlighted due to the characteristics of the nominal working periods on CNES and IAI side. As shown in Fig.9, Friday and Saturday are off on Israeli side, and Saturday and Sunday are off on French side. The consequence is that there are 4 days per week left in joint working. Moreover, for satellite operations, on the 3

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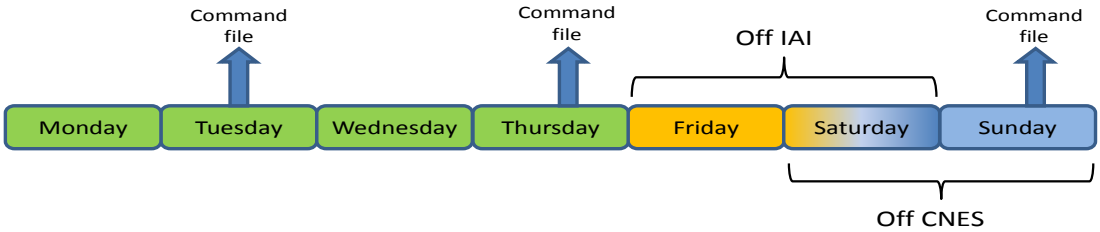

Figure 9: typical weekly planning of programming loops

telecommand sessions planned every week, one takes place Sunday. This means that, on CNES side, every special need related to the scientific mission should be handled on Monday (for Tuesday programming) or Wednesday (for Thursday and Sunday programming).

2. Technological loop

This loop (Fig.10) involves the TMC (Technological Mission ground Center), the VIP and the VRS/VRK.
A first coordination (Fig.10-point1) is established between TMC and VIP on the periods when IHET is activated. Once planned, technological request (Fig.10-point2) is sent to SCC, The corresponding DownlinkPlan (Fig.10-point3) is provided through the HUB to SMIGS, to be forwarded to the VRS/VRK. Once the command file (Fig.10-point4) is uploaded and the IHET activated, the telemetry (Fig.10-point5) is downloaded and AuxiliarySourceRawData (Fig.10-point6) is provided to TMC through the HUB. In such a loop, the role of SMIGS is mainly devoted to data transfer.

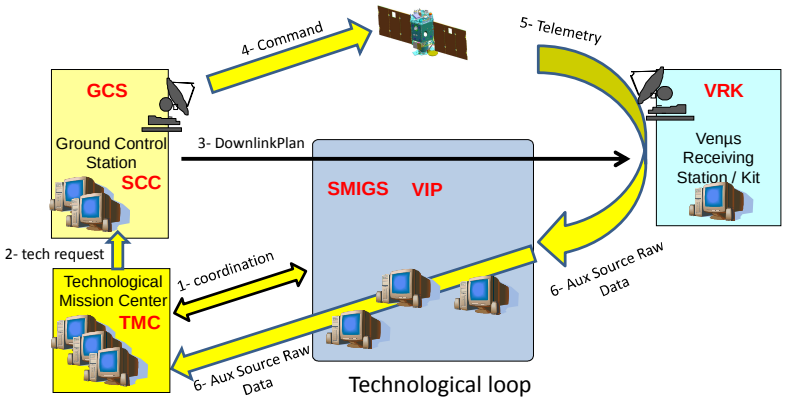

Figure 10: Venμs technological loop

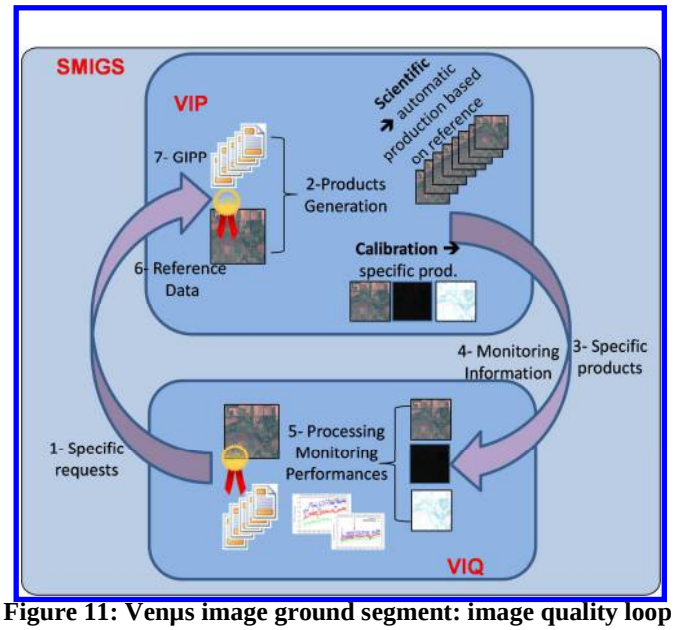

Figure 11: Venμs image ground segment: image quality loop

3. Image Quality loop

This internal SMIGS communication loop (Fig.11), between VIQ and VIP, is used to monitor and maintain Venμs image quality (performances assessment, elaboration of reference and calibration data…). It is the result of a continuous improvement of image quality, but can also be activated every time performances need to be checked.

- Usually, the VIQ operating team asks for specific requests to the VIP (Fig.11-point1). These commands concern calibration sites (to assess radiometric or geometric performances) or scientific sites (to check multi-temporal and multi-spectral registration performances).
- Afterthat, the VIP generates (Fig.11-point2) the corresponding products and sends them to the VIQ (Fig.11-point3). In parallel, the VIP processes automatically the nominal data flow of scientific sites, up to Level 1.

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This activity generates automatic monitoring information (cloud coverage evaluation, correlation results between reference image and acquisition…), also provided to VIQ (Fig.11-point4).

- All these different sources and types of information are processed within the VIQ (Fig.11-point5) in order to maintain an optimal image quality for the delivered products. For this purpose, the VIQ checks and monitors radiometric and geometric performances (on demand or at a frequency decided by experts).
- Typical examples of these performances are the multi-temporal and multi-spectral registration of Venμs products. For these crucial performances, the Reference data is a key notion to guarantee a consistency with specifications. Every geographical site has its own pool of reference data (composed of a reference image, and reference DEM for Level 1 and Level 2 products). In some cases, inconsistencies are expected between these reference data and current acquisitions (due to seasonal landscape evolution or human activities). This phenomenon can trigger drifts in performances, which must be corrected. As a consequence, in these specific cases, the VIQ should generate new Reference data, and provides them to VIP (Fig.11-point6).
- For other types of image quality performances (radiometric noise related to equalization, localization performances…), some anomalies can be detected through VIQ monitoring activities. Thanks to the calibration data processing, the Ground Image Processing Parameters (so called GIPP) are updated and provided to VIP (Fig.11-point7), in order to maintain optimal image quality.

This major image quality loop is completed by some minor internal test loops, specifically devoted to elementary tests. One typical example concerns the iterative tests of GIPP validation. Indeed, GIPP can be tested through single tests (without being operationally used in nominal data flow production by VIP). For this purpose, the VIQ can ask the VIP to generate a product, using as parameters both the operational GIPP identified in its database and some specific GIPP chosen by the VIQ. The resulting image products are then analyzed by the VIQ to tune the parameters in the GIPP.

D. Image activities: human organization

1. Human resources

In terms of human organization, the following teams are involved in image quality activities during IOT.

- Head of project position, both on CNES and IAI side, in charge of global coordination of activities, human resources involvement and purchases/expenses
- System engineer position, both on CNES and IAI side, in charge of the system design and of the accurate coordination of activities
- SMIGS exploitation teams : responsible for the image production operations on VIP side and for image quality monitoring operations on VIQ side (specific commands, routine image quality activities, support to experts)
- Image quality expertise teams : in charge of the accurate analysis of radiometric and geometric performances and for the elaboration of monitoring procedures to be executed in routine

There is a close communication between exploitation and expertise team . Based on procedures built by experts, VIP and VIQ operators generate products and many intermediate data. A first level of analysis is elaborated on VIQ side and information is regularly provided to the experts. Therefore, these latter can easily decide if the global image quality level is acceptable, or if new parameters should be delivered to on ground systems.

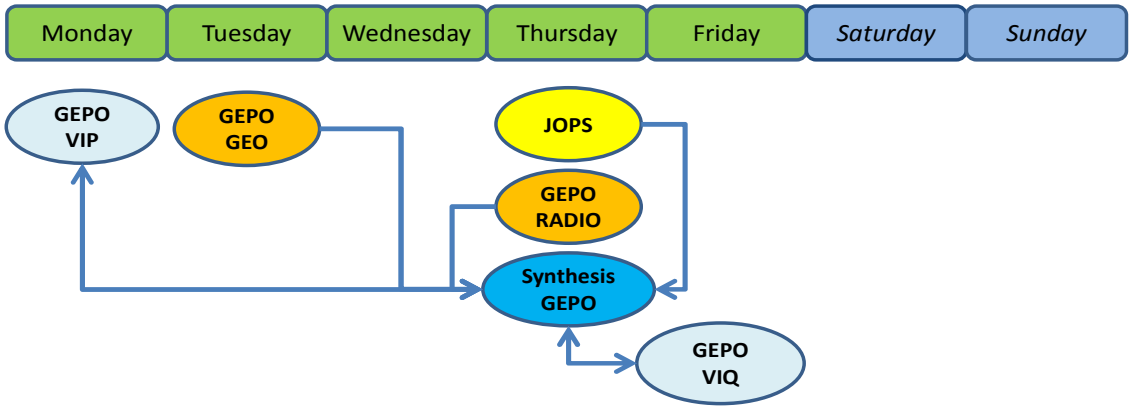

Figure 12: Venμs meetings organization

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This coordination was possible thanks to a strict CNES internal meetings organization illustrated with Fig.12 and introduced hereafter. During Venµs IOT, the following meetings were driven each week to coordinate internal activities, with a potential feedback to IAI.

2. Coordination meetings: Joint OPerationS meeting (JOPS)

During this meeting, the people in charge of each activity (radiometry, geometry, head of project, system engineering, VIP and VIQ) exchange with IAI (GCS essentially), during teleconferences, in order to review the past and upcoming operations in relation with onboard modifications or GCS/CNES coordination. The conclusions and rising points are given to the whole Venµs team during the synthesis meeting.

3. Image quality Expertise meetings: Groups of Experts for Preparation of Operations (GEPO)

These internal CNES meetings, are specifically dedicated to geometric and radiometric topics. Experts deals accurately with the calibration of image quality parameters, assessed performances, their consistency with specifications, and try to find solutions if anomalies are identified. They exchange on special needs and rise the main points during the synthesis meeting.

4. SMIGS Operations meetings: GEPO for VIQ and VIP

During these internal CNES meetings, the VIP and VIQ operation teams review the activities around image operations. The main topics addressed during these meetings are the status of programming and reception of images (completeness, quality, Kiruna passes, …), the generation of the different levels of products, the needs of hardware or software updates, the schedules of possible reprocessing, and study the experts specific demands raised during synthesis meetings. The global status of SMIGS (operation activities, software and hardware issues and status) is given to the whole Venµs team during the synthesis meeting. All the topics addressed during these meetings are articulated around image quality monitoring.

5. Synthesis meeting:

The teams involved in image quality in orbit test period gather in these internal CNES meetings to sum up the situation, and to point out the main topics and issues.

IV. Venµs IOT period: phases and schedule

After having introduced the global context of Venµs from an image quality point of view (mission, image ground segment, interfaces, main activities and communication loops, specificity of the 2-day cycle organization), this section deals with how these activities have been carried out during the first 8 months of Venµs mission life. As it will be developed in this part of this article, a challenging multi-phased organization has been built to achieve this complex period. After an introduction of the different phases of this period, the main events and issues handled are described.

A. A multi-phased project

During the Venµs commissioning phase, various periods can be distinguished. Fig.13 illustrates these different phases. As shown in this figure, this global 8-month period could be split in various phases:

- the classical BOL (Beginning Of Life) period,
- a long period alternating scientific and technological mission (in various durations), associated with AOCS on board analysis (linked to an issue in AOCS accuracy, detailed further in this paper). This period can be divided in 4 phases (depending on the inclusion of IHET periods or not)
- a pseudo-routine phase (VM1) which closes the period considered in this paper. This last phase could not be completely named “routine” since it was still associated with the same AOCS accuracy issue (this time considered in a ground workaround frame).

All these phases, including the periods with no image programming, are explained in this section. The main image quality events occurred during these phases are, for their part, detailed in dedicated paragraphs further in this paper.

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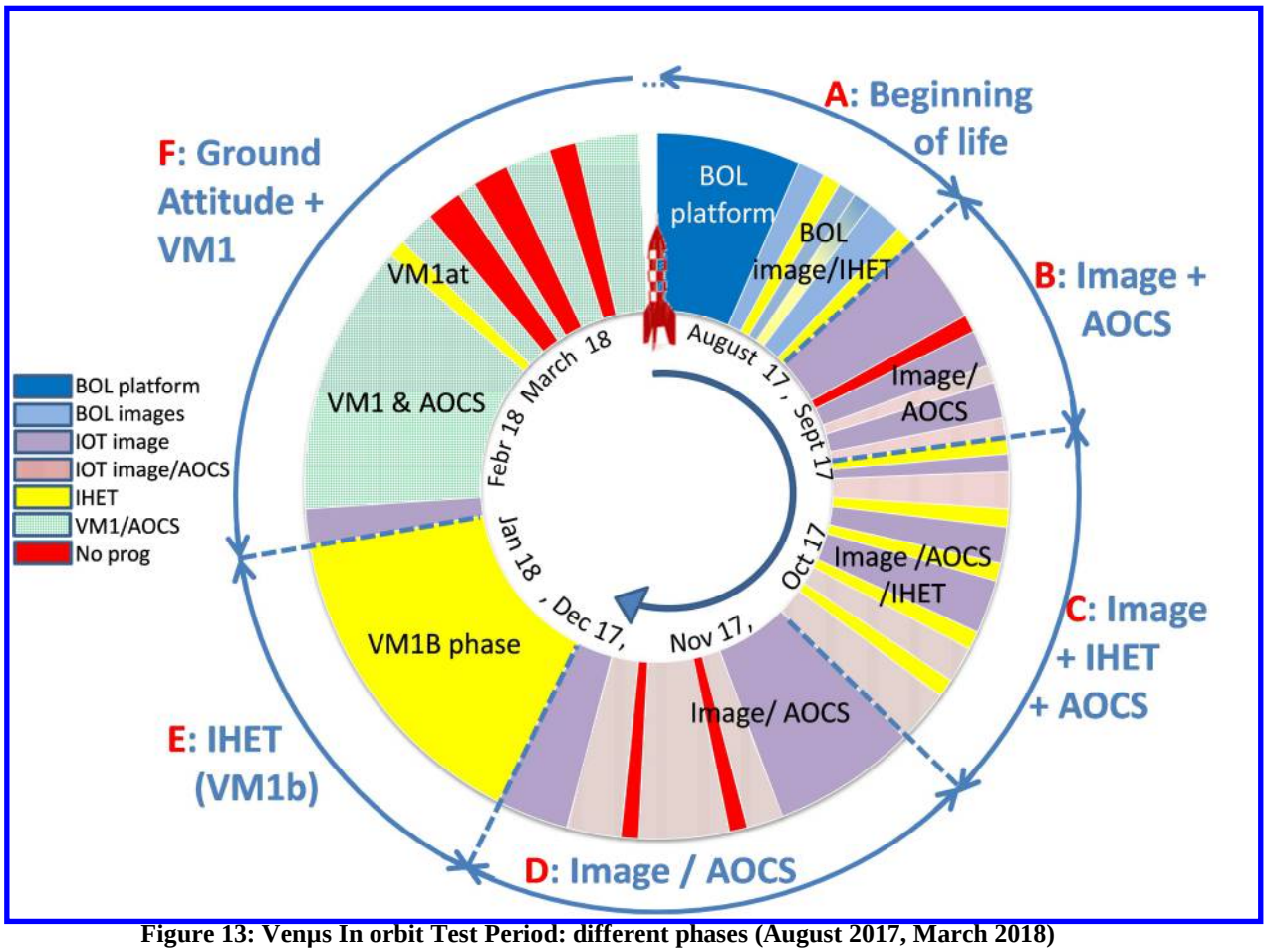

Figure 13: Venμs In orbit Test Period: different phases (August 2017, March 2018)

1. *Phase A: Beginning of life (BOL)*

In august 2017, just after the launch, the satellite was not phased and many activities were carried out manually. A dedicated paragraph details this BOL month, combining imaging and IHET.

2. *Phase B: Phased images and AOCS campaigns: the first IQ results*

Once the satellite phased, the nominal cycles started (September, 1st corresponds to the beginning of cycle1) during September and the first phased images were processed in SMIGS system. During this one-month phase, radiometric and geometric performances were assessed, involving the image quality loop between VIQ and VIP. Numerous specific calibration sites (precious since different from the calibration sites acquired in routine) were acquired in this beginning of IOT, in order to quickly accumulate image quality measurements. The first image quality results showed then unexpected issues in geometric performances (multi-spectral and multi-temporal registration performances). The analysis rapidly led to the identification of the cause: the knowledge of the attitude was not accurate enough to meet the image requirements. The consequence was the setting-up of various AOCS campaigns on board which began during this September month. This topic (which covers all the IOT), is accurately detailed in a specific paragraph, later in this paper.

3. *Phase C: Cohabitation of IHET cycles, imaging cycles and AOCS campaigns*

After discovering this AOCS issue, a new phase began in October, mixing various activities. During this period, which duration was close to 1 month, some tricky organization was experienced to be able to carry out IHET cycles, imaging cycles, and also, in parallel, on board modifications to handle the AOCS issue. In such situations, GCS, TMC, VRK and SMIGS communicated to handle all the data loops detailed previously in this article. Various data exchange loops were carried out to execute both technological and scientific missions: technological loops for IHET, programming loops to get the appropriate acquisitions, and image quality loops to process and analyze them.

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During this complex phase, mixing IHET cycles, imaging cycles and also AOCS parametrizations, the firsts active tests of IHET were carried on, which triggered some side effects on scientific mission. Indeed, at the end of some cycles, when the scientific mission was starting again, some images were lost because the downloading commands were based on orbital data that did not take into the account the IHET firing. At the end of cycle 27, another consequence was experienced. Indeed, at this time, the orbit after the IHET cycle was some 400 meters higher than the nominal one, and the satellite sub-track left its maintenance window (which is defined as a 25 kms wide corridor centered on a nominal subtrack). This global configuration, for which the orbit was not anymore considered as "ground locked", triggered a failure in moon acquisitions (because of sun telescope mission rules violation), an additional orbit correction, and almost all the acquisitions of cycle28 useless because of datation inconsistencies. All these different events were studied and taken into account by GCS for the following technological mission activations.

4. Phase D: Imaging cycles and AOCS campaigns

After the previous complex phase, a new period without IHET activity took place in Venμs IOT, between November up to mid-December. This phase was the occasion to focus both on image quality monitoring and AOCS campaigns. IAI and CNES teams decided to test the whole system behavior and robustness (batteries charges and discharges, camera, Kiruna downloads, image ground segment loops of production and analysis…) with a routine-like ASD (which should be experienced during 2.5 years). In parallel of this programming, AOCS campaigns were carried on since the last assessments of geometric performances were still not compliant with mission requirements.

5. Phase E: VM1b mission: IHET cycles only

During VM1b period, the Venμs mission was entirely technological and dedicated to IHET tests.

No acquisition was programmed by SMIGS, which role was to monitor the Kiruna downloads and provide data to TMC. From an image quality point of view, considering the geometric performances, the conclusion of the AOCS campaigns carried out was that the AOCS issue couldn't be corrected only by on board modifications. As a consequence, a two day meeting was held between IAI/MBT and CNES, in order to review entirely this topic, and to discuss upon on-ground workarounds. Indeed, the various onboard tuning of AOCS parameters showed their limits. Global image quality performances have certainly been improved but still were not compliant with scientific requirements. An on ground solution had to be developed.

6. Phase F: Imaging cycles and on board / on ground AOCS tuning, VM1 beginning

This last phase (we only consider the 8 months following Venμs launch) was devoted to the on ground attitude workaround, which also involved on board modifications. Indeed, a new packet of on board attitude data has been defined by CNES and IAI, and rapidly updated on board. Additionally, a lot of work was done to conceive how these new attitude data should be processed on ground to improve the image quality performances.

After the new attitude data first downloading (2018, January, 25th), geometric performances were still not compliant with requirements. Nevertheless, taking into account that these data could be stored and process by SMIGS after the attitude workaround operational, CNES and IAI considered that this step marked the beginning of the routine phase named VM1. Of course, this assumption was based on the hypothesis that future geometric performances would be consistent with the requirements

Actually, this phase was not a routine at all… At the end of this period, many disturbances have been experienced both on the platform and on the ground system. A first collision avoidance manoeuver was carried out, which triggered a maintenance mode (meaning that scientific mission stopped). This was followed by a "single event upset" on the mass memory which made the mission to stop again (new maintenance mode period). After that, on SMIGS side, the HUB experienced an interruption for some days, with again a loss of data (since all the downlink commands were transmitted through the HUB). All these events explained the lack of acquisitions during this phase.

It has to be noticed that, during this period, the first "VM1at" activation occurred (short IHET activation once a month).

B. Beginning of Life (BOL)

During the first month of Venμs mission, in August 2017, the satellite was not phased on a 2 day cycle, as it was not on its final orbit. Two main periods were experienced, described below.

1. IOT platform

During the 15 first days after launch, all the activities were in priority focused on the platform validation. This IOT platform was fully under Israel responsibility (IAI platform). Information was thus communicated to CNES (global schedule, main results) in order to prepare the following period, dealing with image and IHET.

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Nevertheless, the first image was acquired during this period of platform tests, after all the necessary camera verifications were completed. As a consequence, this period ended successfully, with a first image giving the indication of a global correct location.

2. Image and IHET first non-phased cycles: ramp-up phase

The second main period of Venμs mission was articulated around the image and IHET pseudo-cycles (non-phased cycles during BOL).

From an image point of view, this period was been instructive despite its complexity.

Indeed, on one hand, this short period needed a lot of manual workarounds to be able to ingest, in the global Venμs system, the appropriate data to be able to program acquisitions. On the other hand, it was also a great opportunity to test the manual tools elaborated before launch, and to program promotion acquisitions (on dedicated places excluded from the nominal routine set of acquisitions).

Considering IHET pseudo-cycles, after coordination between CNES, RAFAEL and GCS, some IHET cycles were carried out. The data downloaded at Kiruna was nominally transmitted as expected to TMC.

Some figures can be enhanced for this period:

- 5 image cycles were carried out, 2 IHET cycle, and a cycle mixing both missions.
- every two days, a set of acquisitions (ASD) was manually built, based on the current orbit information provided by GCS. Once these ASD elaborated (containing between 30 and 55 acquisitions during this ramp-up phase), they were ingested in the SMIGS and the regular programming loop was activated.
- At the end, 266 acquisitions were planned on VIP side. The resulting raw data received at VIP were processed by operation team, and around 350 products (all levels considered) were checked on VIQ side to have a first idea of the radiometric and geometric performances. In these circumstances, a light image quality loop was tested, to check that interfaces between VIP and VIQ are correct and compliant with specifications.

C. Programming loop and IHET cohabitation

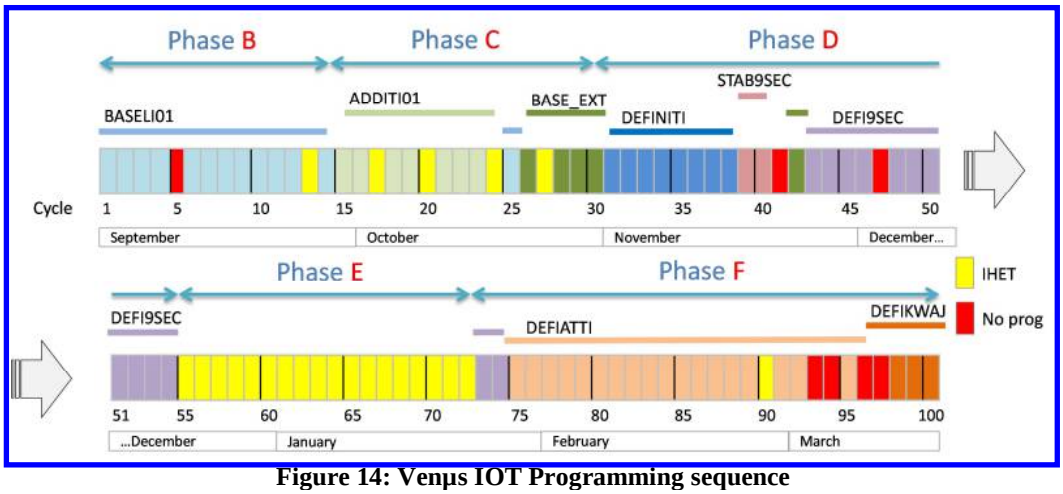

Figure 14: Venμs IOT Programming sequence

Venμs acquisitions are obviously the basis of image quality activities. That's why the programming loop was one of the key activities during the commissioning phase. Fig.14 gives an overview of the different ASDs which have been planned during the first hundred cycles.

Since 2017, September, 1st, Venμs satellite has reached its final 2-day cycle phased orbit. Starting from this first cycle, various full ASDs (containing almost the maximum number of acquisitions allowed) were programmed by the VIP in regular programming loops. After the main project phases detailed before, the programming phases are discussed hereafter. It has to be noticed that the programming phases were nested within the project phases described below, but did not strictly match them. Clearly, the fact that project phases and programming period were closely interlocked added complexity in the global project frame.

1. BASELI01: first phased imaging

At the beginning, the mission was only scientific (no IHET), and the first phased acquisitions were planned over 80 sites contained in the first phased ASD named BASELI01. This ASD was mainly dedicated to the assessment of the first radiometric and geometric performances of the Venμs products. To this purpose, this ASD was composed

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of a quite important part of calibration sites (66 sites), in comparison with the scientific ones (14 sites). Nominal exchanges between VRK, VIP and GCS led to 12 acquisitions cycles with this ASD. At the end, only one cycle was not programmed: cycle 6 (between 2017, September 11th and 13th), as black out period was decided by GCS (maintenance mode) due to solar activity. As there was a risk of coronal mass ejection and potential impacts on electric devices onboard, the VSSC camera was switched off during this cycle. The last cycles of this ASD were dedicated to the first AOCS campaigns (aiming at analyzing AOCS data).

2. ADDITI and BASE_EXT: AOCS campaigns began

Once the AOCS issue was observed, confirmed (both on CNES and IAI side), a new phase of the IOT began. During this phase, 2 new ASDs (a "calibration-based" named ADDITI01 and a "scientific-based" named BASE_EXT) were generated, in order to characterize accurately the AOCS topic. These sets of acquisitions had various goals: to focus on the AOCS telemetry (by acquiring some long strips of data), to have complementary acquisitions for multi temporal and spectral registration performances assessments and to check the satellite (and ground system) behavior with a number of acquisitions close to the routine one (more or less 150 acquisitions every 2 days).

3. DEFINITI: the routine acquisitions tests

Following the activities carried out with previous ASDs, focused on AOCS topic, the decision was made to test the system with and ASD strictly corresponding to the routine acquisitions. This ASD, named DEFINITI, was thus activated during 8 cycles: the whole system ran nominally and numerous products were acquired to improve the image quality performances calculations and to test all the image quality monitoring activities foreseen in routine.

4. STAB9SEC, DEFI9SEC: AOCS campaigns still ongoing

After running the system with a routine-like ASD (DEFINITI), the image quality performances were still not compliant with requirements due to the AOCS issue. A new approach was decided (detailed in the specific paragraph dedicated to the AOCS issue): to increase up to 9 seconds the on board stabilization time (before imaging). Various new ASD based on this principle (explaining the suffix 9SEC in their denomination) was thus generated. The first one, named STAB9SEC, was aimed at acquiring few long acquisitions to have a first idea of the on board modification impacts on geometric performances. The second one, DEFI9SEC, was mainly adapted from DEFINITI. It was dedicated to accumulate image acquisitions in order to make radiometric and geometric performances more reliable.

5. VM1b: imaging pause

Between cycle 55 and 73, as foreseen in Venμs mission life, the scientific mission stopped to leave the floor to the technological mission. During this part, where no acquisition is planned, all the IHET telemetry was transmitted to TMC.

CNES and IAI took advantage of this technological period to meet in order to sum up the situation on AOCS issue (still existing), and decided to implement a ground workaround. The goal was to process, on ground, new on board AOCS data in order to reach a sufficient accuracy in attitude knowledge, which should lead to geometric performances consistent with mission requirements.

6. *DEFIATTI: Ground Attitude Estimator tests*

In order to test this attitude ground processing (named GAE : Ground Attitude Estimator), a new ASD was then generated : DEFIATTI (almost identical to DEFINITI with the addition of only 1 site). The scheduling of this ASD corresponds to the first acquisitions with new on board AOCS data, meaning also the beginning of official VM1 mission.

7. DEFIKWAJ: when Venμs can help a future mission

The very last ASD of this period was generated completely outside the AOCS issue and the image quality concerns. Indeed, Venμs scientific mission, combining a high revisit frequency and agility, gave a chance to acquire specific images for a future mission, aimed at monitoring the evolution of the top layer of clouds. By acquiring the same site, with 3 different viewing angles, it should be possible to modelize the cloud evolution and to estimate updraft velocities. For this purpose, a new site was added to DEFIATTI to make DEFIKWAJ ASD. This site was chosen carefully, in some equatorial area (often cloudy), without any impact on the other regular sites.

D. Image Quality activities and AOCS topic

1. Radiometric Image quality

In terms of image quality, thanks to the specific productions over calibration sites (radiometric and geometric), the image quality monitoring loop between VIQ and VIP was successfully carried out since Phase B (Fig.13).

The results concerning this topic are accurately detailed in Ref. [3,4], and are briefly discussed hereafter.

The main radiometric results which could be raised were :

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- The straylight concern was confirmed, and the first calculation of ground image processing parameters devoted to its correction gave optimistic results.
- The radiometric equalization was more difficult than expected, due to the discovery of spikes in the detectors responses. Nevertheless, on this point also, the spikes seemed to be constant in time, and thus this issue could be handled thanks to a precise characterization of this phenomenon.
- The calibration activities (based on various methods) were nominally handled, and regularly updated during the IOT thanks to refining of the electronic spikes observed (position, dependence with radiance…), and improvements in characterization and correction of straylight. The moon acquisitions and a huge accumulation of desert acquisitions have allowed tuning the various spectral bands calibration parameters. At the end of Phase D, VIQ tools (which were activated by experts before) were well enough tuned to be delegated to the operation team, through a precise procedure.

2. Geometric Image quality: the AOCS issue

All the details of the geometric part of the commissioning phase are largely discussed in Ref. [5]. This paper focuses on some aspects of this topic, emphasizing the influence of AOCS data accuracy on specific geometric performances (which must be monitored accurately in routine).

In this frame, the main point was that the first performances assessments at the beginning of Phase B were worrying. Indeed, the multi-spectral and multi-temporal registration performances were not compliant with scientific requirements. As previously mentioned, this was caused by the attitude accuracy error knowledge that did not meet the image processing requirements (which was found only during IOT). Indeed, the satellite on-board software estimates the attitude by combining reaction wheels and star trackers. This on-board attitude estimation is reflected in the telemetry, and is unfortunately not accurate enough for Venμs image requirements. In this frame, the platform should have also gyroscopic actuators.

As a consequence, this led to some complementary analysis and tuning on board, identified as "AOCS-tuning" campaigns, dedicated to solve the attitude estimation issue. During more than 3 months, from mid-september to mid-december, many on board configurations were tested to get the most accurate AOCS estimations:

- the weight of star tracker measurements in the global AOCS on board estimation was lowered during a campaign, and increased in the following campaign.
- modifications on covariance matrix and attitude quaternions have been tested
- different star tracker integration times and time stabilizations (between the moment camera was switched on and the effective beginning of the acquisition) have been updated on board

In each case, the image quality loop was executed to check the effects of the operation (whether the results on the multi-spectral registration have been improved or not). Such analysis needed some cloudless acquisitions to be downloaded (providing from various ASD such as DEFINITI, STAB9SEC, DEFI9SEC), processed up to level 1A and analyzed accurately to judge the efficiency of the on board modification. This explains that a few days were needed between two consecutive on board tunings.

Unfortunately, the results were quite disappointing after these on board tunings. Even if an optimized combination of on board parameters (star-tracker integration time, stabilization time, weights in AOCS estimators…) was decided by CNES and IAI, the geometric specification on multi-spectral registration was still not met, which, at this point, forbid any scientific use of the Level2 products at 10m.

Nevertheless, during Phase D, a first attempt of ground processing was implemented. Indeed, one of the attitude specificities that prevented from using them correctly was their noise. For that purpose, a modification was implemented in the Level 1 production chain to smooth the AOCS data associated to raw telemetry. This allowed some improvement in the performances. Without being reliable for every acquisition, for some L1 products image (with no clouds and few water areas) performances were consistent with requirements.

However, the next step, developed in the scientific phase (Phase F, post-VM1b), was then to study a robust ground workaround to post-process the attitude data.

3. AOCS ground workaround: the GAE implementation

Phase F was dedicated to the GAE conception: from the on board collection of new auxiliary data packet to its processing through on ground system.

Figure15 illustrates this significant evolution of the global system. The top schema presents the initial architecture of the ground segment without accurate ground attitude estimation. The bottom schema shows the new architecture, including in red the evolutions which had to be implemented operationally in coordination with GCS.

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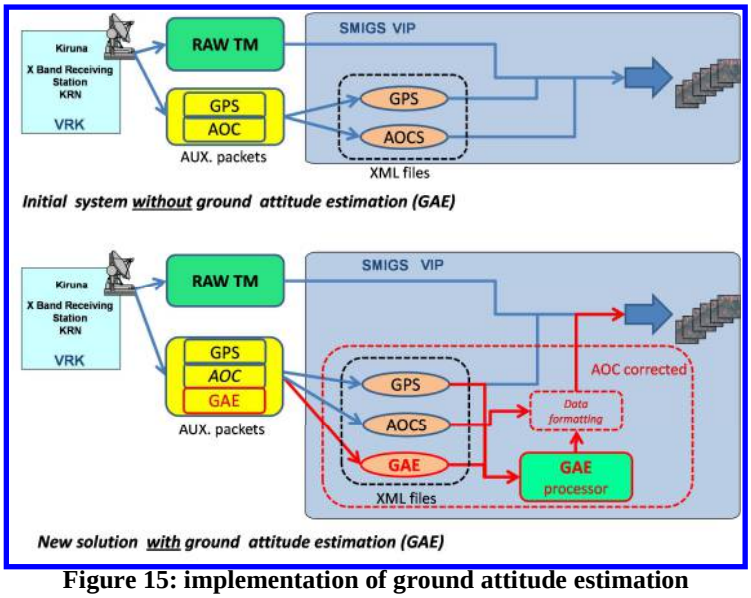

Figure 15: implementation of ground attitude estimation

First of all, the efforts focused on the onboard collection of a new information packet (named GAE auxiliary packets). Indeed, this step had to be done urgently because the downloading date of the first GAE packets determined the virtual beginning of VM1 official scientific mission. Actually, VM1 mission, which nominal duration is 2.5 years, should have started when radiometric and geometric performances of Venμs image products were met. Being optimistic with the efficiency of the on ground attitude computations, the sooner new auxiliary data packets were downloaded, the sooner multi-temporal series of correctly registered Venμs products could be generated. This hypothesis assumed that the completeness of data series would be obtained through reprocessing, starting back to the first collection of GAE packets. After discussions between IAI/MBT end CNES, the global format of these new data packet have been decided and their downloading started at cycle 74 (January, 25th). Many options have been considered to build the new GAE packet. Eventually, it was decided that a completely new GAE packet of attitude parameters would be collected.

Secondly, the processing of this new packet had to be developed and implemented. As illustrated in Fig.15, numerous changes had to be analyzed between GCS and CNES. Several iterations led to some compromises, on IAI and CNES side, in order to minimize the impacts in global SMIGS architecture. In this context, interfaces had to be studied carefully. The first needed inputs were, obviously, the new GAE auxiliary packet, processed to generate a GAE XML file. Also essential for the attitude data correction, the GPS auxiliary packet was read to produce a GPS XML file (also used internally in SMIGS to produce inventory and upper level image products). Finally, the previous AOC packet was kept in the whole design and similarly processed to an XML file. All these data (GPS, AOC and GAE XML files) were provided to the GAE processor to elaborate an accurate attitude XML file. These accurate attitude data, combined with GPS and RAW data (like in the first initial architecture) were then nominally used in SMIGS system to generate inventory and upper-level products.

Concerning the practical implementation of this algorithm, the global processing would be done, at the end, internally in SMIGS. Nevertheless, the ground attitude estimation was on IAI responsibility. In such a context, a validation test campaign was established between IAI and CNES:

- on IAI side : the GAE processing (from auxiliary data packets decoding to AOC corrected data generation) was implemented in a software, first functionally validated in GCS premises. Some corrected attitude data (XML files, output of the global GAE processor) have been provided to CNES
- on CNES side : these XML data were injected in SMIGS system (with GPS data and the raw telemetry associated) to produce inventory and level0/level1 products. The classical image quality loop was then applied to assess the new multi-spectral registration performances. It can be noticed that, in this specific case, the image quality loop between VIQ and VIP had been enriched with the use of AOC XML files (Fig.16), additionally to GIPP

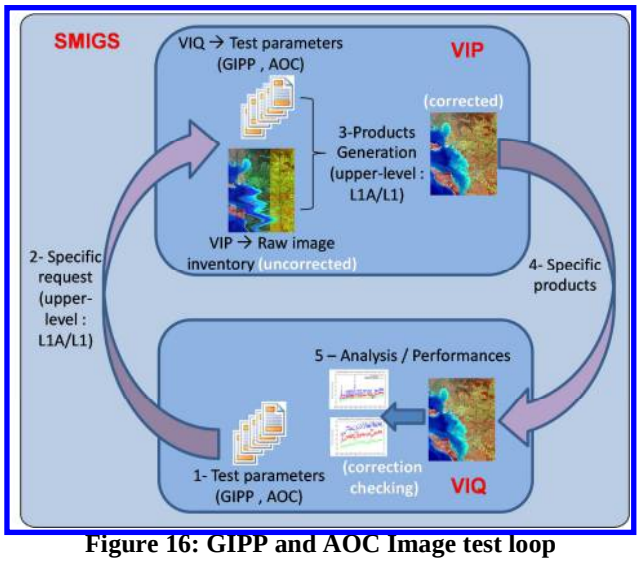

Figure 16: GIPP and AOC Image test loop

files. Indeed, as explained in Fig.11 detailing the classical image quality loop, a specific GIPP loop existed in SMIGS system. It consisted in a VIQ specific demand: to produce from an inventory product, on VIP side, a dedicated upper-level image using specific GIPP (to be tested on VIQ side). This loop had been extended, in this context to AOC corrected data file. Indeed, the various "GAE-processed" accurate attitude data (AOC XML data), provided by IAI, were ingested in VIQ database (Fig.16-point1), and were integrated in specific requests (Fig.16-point2) addressed to VIP (as if they were GIPP files). The VIP generated upper-level products (Fig.16-point3), using these corrected attitude XML files, and sent back to VIQ the new products (Fig.16-point4). Therefore, the VIQ could have access to the same level of product, generated with classical or with accurate AOC data, which is extremely convenient to exactly compare the geometric performances reached (Fig.16-point5).

Last, but not least, it can be noticed that this GAE processor is constituted by an executable delivered by MBT, which should run operationally in CNES premises. For security reasons, such a situation must be specifically handled in CNES system. A dedicated machine should be used to host this GAE processor. The only authorized information fluxes between this machine and the SMIGS would be the needed interfaces (as inputs) and the nominal output of the GAE processor.

Unfortunately, at the time when this paper has been written, very few results were available thanks to these corrected attitude data. On a unique site, at a unique date, an XML file of "GAE-corrected" attitude data had been delivered by MBT, and tested in CNES expertise center. The geometric performances assessed on the L1 products generated with these GAE data were certainly better that the initial ones, but were clearly showing that some parameters had still to be tuned accurately on MBT side. This task needed time, and the complementary checking tests in CNES (SMIGS data ingestion and processing) increased the time consumed in the total validation loop. Moreover, on CNES side, to be able to guarantee the reliability of the geometric performances, a complete validation of the process should be executed on many sites, distributed in a homogeneous way in latitude. All these different reasons explained that no conclusion could be given in the frame of this paper.

E. Image Quality special programing: the Moon

The moon acquisitions are dedicated to radiometric analysis. They can be used to assess and monitor the absolute radiometric calibration of each spectral band of the camera, and can also help in characterizing the straylight impact thanks to the strong transition between the dark space and the bright moon surface. An interesting story concerned Venμs moon acquisitions, illustrated with Fig.17 and discussed hereafter.

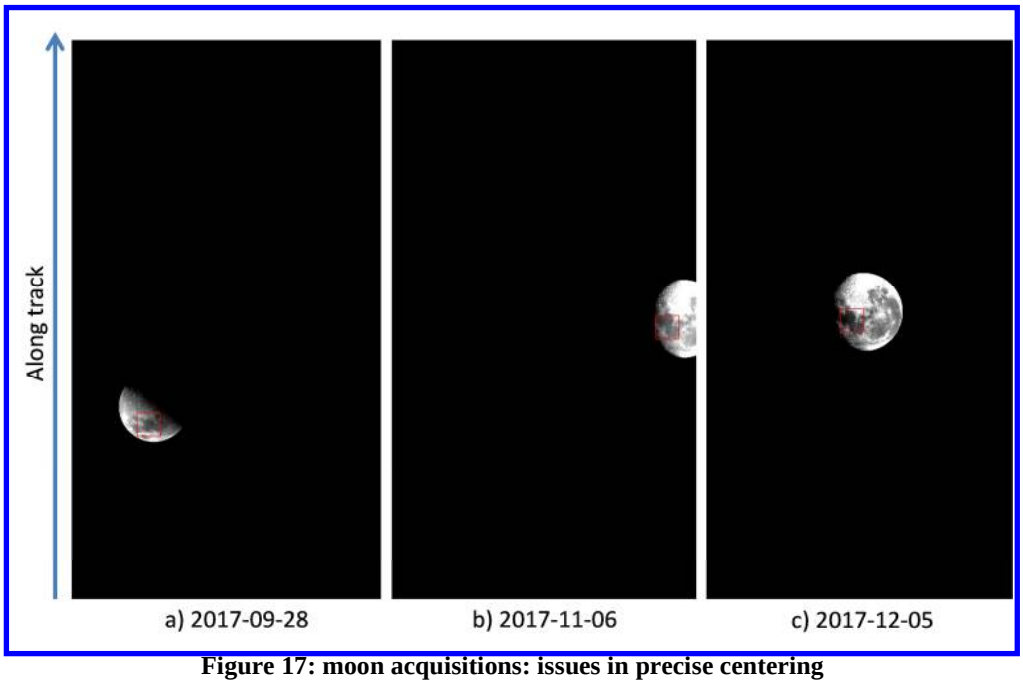

Figure 17: moon acquisitions: issues in precise centering

Moon acquisitions were attempted since September, but in November, despite the analysis on both CNES and IAI side, they were still not centered. Actually, this issue was complicated because of the special type of

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programming and since there were little opportunities (due to new and full moon constraints, delays in ASRequest posting…). At the end of November, only 9 moon products were available, and none of them was centered (Fig17 left). In some extreme cases (Fig.17 center), some part of the moon was outside the field of view, making the acquisition useless from a radiometric point of view. The moon being essentially used for radiometric calibration, the only advantage of these non-centered moon products was to assess, in different focal plane positions, some radiometric parameters. Nevertheless, GCS and CNES went on working together to check the global command chain leading to a moon programming.

Finally, in December, the GCS found that the telecommands computation considered a moon pointing from the center of the earth, and not from the satellite position. Once the problem solved, at the beginning of December (Fig.17 right), moon was successfully centered in each acquisition.

F. Image Ground Segment Evolutions

During the commissioning phase, the image ground segment (SMIGS) also experienced various phases. Some software and hardware evolution have been implemented to follow the IOT events.

1. Software evolutions

First of all, at the very beginning of the image production on VIP side, a global limitation was discovered: the coding of Level1A was in 8bits, which was not sufficient for the required precision on some radiometric performances. A quick modification of the SMIGS was then been necessary to be able to generate products in floating point on the VIP side, and to process them through the VIQ.

In the frame of the AOCS campaigns, many analyses have been made on VIQ side, based on the products received from VIP. Especially concerning the geometric processing activated while producing a Level1 image, the experts have noticed that the amount of information logged during the production was not accurate enough to carry out investigations. Some evolution was thus developed on SMIGS side to deal with more detailed geometric information (both in VIQ and VIP systems).

In VIP system, GPS and AOCS files selection was based on validity start and stop times. The problem is that, in some cases, these times values for GPS files were wrong due to the existence of outdated packets in the auxiliary telemetry. The consequence is that the VIP could trigger automatically image processing with GPS and AOCS files that did not have data covering the acquisition, which led the process to fail. This was worked around by patch a while ago and then solved by adding a filtering module in the auxiliary data processor to get rid of these outdated packets.

2. System evolutions

An important evolution was identifiedat the beginning of the commissioning phase. Indeed, at this stage (Phase A and B), the system allowed only few telemetry data to be transmitted by network. This is a heritage of the first conception design which prioritized postmail over network data transmission. As a consequence, a special organization had been established on VIP side, based on two different contexts. On one hand, during each Kiruna pass (8 times a cycle), some raw data (image and auxiliary, corresponding to specific geographical sites) were automatically transmitted from VRK to VIP, processed on VIP side, and were made available on VIQ side. On the other hand, manually, once a week, a huge amount of data was received on VIP side, and ingested in the SMIGS. These two different policies brought in additional work within the SMIGS to fulfill the image quality loop between VIQ and VIP on the total amount of available products. Fortunately, this tricky organization was stopped at beginning of October. A special internet link was set up between Kiruna and CNES, and all the raw data downloaded at VRK was entirely transmitted by network since that moment.

In December, the lack of new image acquisitions gave a chance to make some suitable changes to optimize the VIP hardware. Indeed, the total disk space available for production was regularly considered as too limited (in case of problems in archiving, of necessary reprocessing in relation with the AOCS issue…). The global disk space was increased during this phase, to make it more comfortable for nominal processing and reprocessing.

G. Kiruna downloading

During all Venµs mission life, scientific and technological data are downloaded at Kiruna, Sweden. Consequently, the VRK (located at SSC, Kiruna) is a key-element in the ground segment.

Concerning the IOT period between launch and VM1 start (end of January), more than 400 passes took place at VRK for the scientific mission, corresponding to around 4800 images.

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As shown in Fig.18, overall, around 30% of the passes (named DLREPT for Downlink Reports) were considered partial or failed, which caused the loss of 600 images.

Various explanations have been raised to understand these issues, mainly

- on GCS (downlink plan inconsistent with the orbit at the end of IHET periods…)
- or SSC side (anomaly relative to either a technical issue or an operator error).

At the end, only 2% of all the lost images were due to unknown anomalies.

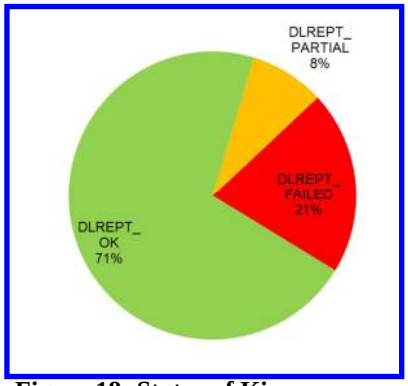

Figure 18: Status of Kiruna passes

V. Lessons learnt:

The Venμs scientific and technological commissioning phase was very intensive. Nevertheless, despite the problems encountered, many positive points must be mentioned: the whole ground segment successfully worked, the French and Israeli teams jointly worked efficiently, as well as the expertise and exploitation teams. This in orbit test phase naturally led to some lessons detailed below.

A. Venμs image quality: an inheritance of previous in orbit tests phases

Since many years, CNES has acquired a huge experience in image quality monitoring. Various IOT phases have been successfully carried out, often in international cooperation contexts. Each satellite qualification has been both challenging, an also rewarding. Consequently, little by little, the issues faced during these intense phases have constituted feedbacks for the next qualifications. From an image quality point of view, the first lesson learnt from Venμs commissioning phase is that every image quality system should inherit from its predecessors. It has clearly been the case for Venμs expertise center (as detailed below) and these feedbacks made the VIQ more efficient during the in orbit test period.

1. Global re-use of central framework

In CNES premises, a wide pool of different Earth observation satellites are monitored (at different levels) to maintain an optimal image quality. Pléiades, IASI (Interféromètre Atmosphérique de Sondage dans l'Infra-rouge – Infra-red atmospherical sounding interferometer), Megha-Tropiques are some examples of satellites/sensors for which CNES is in charge of the health instrument monitoring, or guarantees the quality of upper level products. For this, CNES is responsible of the development and the operation of image quality expertise center, specially designed for each satellite. Since Pléiades in orbit test phase, many efforts have been done to keep and expand the experience acquired during each satellite qualification. The result of this approach has been the development of a generic software framework SAG (Structure d'Accueil Générique – generic host structure [6]). Almost all the recent expertise centers currently managed in CNES Earth Observation department are based on such a framework.

The expertise centers of Sentinel2 and Megha-Tropiques are in this category, as well as Venμs expertise center VIQ. Figure19 shows the similarities of the software environments of Sentinel2 technical expertise center and VIQ.

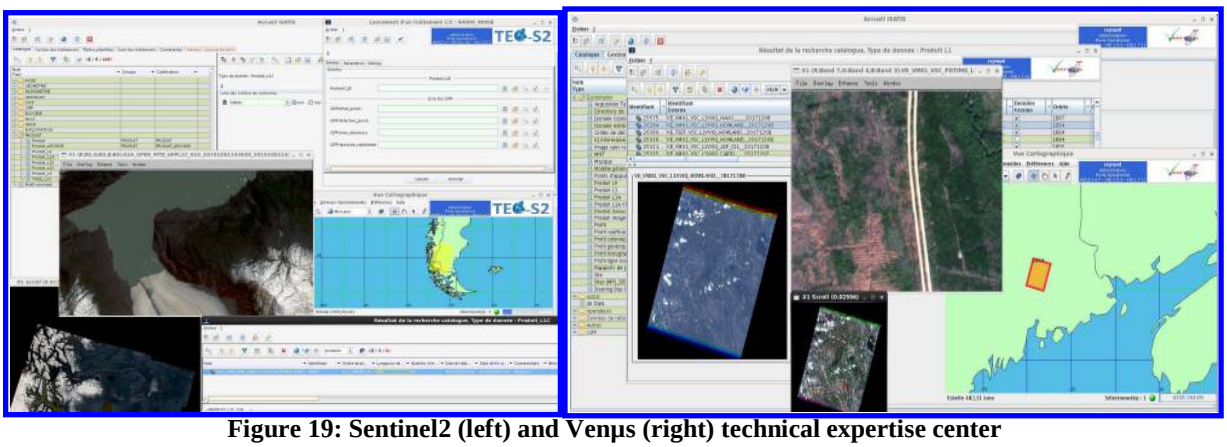

Figure 19: Sentinel2 (left) and Venμs (right) technical expertise center

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The re-use of SAG framework for each image quality technical center is extremely useful to easily maintain the different systems, due to the similarity of the architecture and the computer languages implemented [7]. Moreover, it allows operators to carry out almost the same monitoring activities (with similar procedures) on different satellites. Eventually, it is a great advantage to have a solid basis of global management procedures, which can be improved from one system to another. Naturally, in that domain, the lessons learnt before have been applied to VIQ system, which has inherited from Sentinel2 expertise center (last one to be qualified).

One typical example is the management of the processing in error. Indeed, every day, many processes are automatically triggered within the expertise center (archiving, automatic database interrogations, computations… etc…). In Sentinel2 expertise centers, an automatic monitoring of all the processes in error have been implemented in order to receive an email listing the potential problems on the system. The same email monitoring has been successfully used on VIQ.

Another case is the global disk space supervision. On Sentinel2 system, because of the huge size of the products, some disk spaces were critically monitored (the online products for examples) in order to anticipate disk saturations. The goal was to discuss with experts about deleting useless data, to have enough disk space to carry out the nominal global monitoring. On Venμs, even if the products are smaller, the disk spaces available are smaller too. Thus, some internal subdirectories were accurately checked to prevent from dangerous saturations.

2. Similarities of Sentinel2 and Venμs

Venμs mission was preliminarily designed to be a demonstrator to prepare COPERNICUS operational system. But being delayed, it has finally been launched after its ESA/European Union corresponding project Sentinel2. In turn, it will help to shape the future for the next COPERNICUS satellite, highlighting the benefit of short revisit time. Nevertheless, on CNES side, many activities have been (and still are) carried out in the frame of Sentinel2 image quality monitoring (to support ESA, in charge of the routine monitoring). In this context, specific tools had been developed within Sentinel2 expertise center, and have now been adapted to Venμs image monitoring. The lesson learnt in this case is that these adaptations (some examples are provided below) have been extremely precious to optimize the operations.

Concerning the geometric activities dedicated to assess the Venμs performances, the various processing chains implemented within the VIQ are based on a pool of tools also used in Sentinel2 expertise center. This similarity has been very interesting to transfer some procedures (activated during Sentinel2 IOT phase) to Venμs center. One typical case is the procedure to aim at monitoring the disk space occupation of geometric tools execution subdirectories. Indeed, many geometric processing chains need to keep the execution directories for further analysis (due to the existence of intermediate results). This can cause an increase in disk space occupation, potentially harmful for the rest of the processing executions (especially the radiometric ones). For this purpose, some Sentinel2 tools have been updated in Venμs context: the subdirectories are listed (included the users and the disk space occupied) and the information is sent to the concerned users (Fig.20). In return, the experts choose the subdirectories which can be deleted.

ID_PROCESSING	RUN	TO PURGE ?	DISK SPACE	USER	COMMENT
AGILEIMPORTDONNEES_251405	251405	DELETE COMPLETLY	5,7G	rollanda	L1A-ES-TERA-20171128---POL3-neige
AGILEFILIERECARTOPLANFOCAL_SPATIO_251520	251520	RERUN	1,6G	languillef	SAOP-poly8
AGILEFILIERECARTOPLANFOCAL_SPATIO_243717	243717	AD	654M	dicka	Test-SNO-Arthur-B00-B02
AGILEIMPORTDONNEES_253735	253735	AD	131M	dicka	SNO-Kentucky-2018-01-28-S2
AGILEFILIERECARTOPLANFOCAL_SPATIO_251425	251425	DELETE IMAGE	1,7G	delussyf	SO2-28-11-ref-pol7
AGILEFILIEREPERFOLOCSPATIO_238980	238980	AD	1,8G	binetr	CORR16-08-10-EVA-decal-1.04s
AGILEFILIERECARTOPLANFOCAL_SPATIO_243716	243716	AD	653M	dicka	Test-SNO-Arthur-B00-B01
RECUPERATION_FTP_ET_IMPORT_253743	253743	AD	2,6M	oper1	RA5
AGILEFILIEREPERFOLOCSPATIO_243367	243367	RERUN	615M	binetr	GERARD-29-11-B05-Pollux
AGILEFILIERECARTOPLANFOCAL_SPATIO_251411	251411	DELETE COMPLETLY DELETE IMAGE RERUN	1,8G	languillef	SNORussie-ecarttypevignette0.2
AGILEFILIERETRACECARTO_239364	239364		100K	rollanda	corr16-17-11
AGILEFILIERECARTOPLANFOCAL_SPATIO_243726	243726	DELETE COMPLETLY	536M	languillef	RA5
AGILEFILIEREPERFOLOCSPATIO_242447	242447	DELETE IMAGE	475M	binetr	GERARD-29-11-B06--74lig
AGILEFILIERECARTOPLANFOCAL_SPATIO_251522	251522	AD	530M	languillef	SNO-russie-sanspatch
AGILEFILIEREPERFOLOCSPATIO_243420	243420	AD	154M	binetr	GERARD-29-11-B5-B6-patch-bloc-spatio-B5
AGILEFILIERECARTOPLANFOCAL_SPATIO_251573	251573	AD	1,2G	languillef	DESNIGE1-nuages-pol3-parfait
AGILEFILIERECARTOPLANFOCAL_SPATIO_243718	243718	AD	655M	dicka	Test-SNO-Arthur-B01-B03
AGILEFILIEREPERFOLOCSPATIO_242029	242029	AD	732M	binetr	GERARD-29-11-B6
AGILEFILIERECARTOPLANFOCAL_SPATIO_251526	251526	DELETE IMAGE	1,7G	rollanda	SO2-pol7-test-GLOBE
EXPORT_IMPORT_L1_AGILE_253219	253219	AD	36K	languillef	CREDO-L1-affine-mod1+mod2

Figure 20: execution subdirectories : monitoring and deleting choice

On a radiometric point of view, it should also be noticed that the spectral bands of Venμs and Sentinel2 are relatively close. This feature has naturally led to a homogenization of the radiometric calibration data computed by each expertise center, and measured on dedicated sites (deserts, ocean, snow…). This aspect was all the more important since a cross-calibration center is operated and maintained in CNES Earth observation service. In such a tool, the Sentinel2 and Venμs calibrations data, almost identical in their format, can therefore be easily ingested and compared.

3. Automatic monitoring of events

In another completely different sector, Megha-Tropiques mission (INDO-FRENCH project dedicated to study atmosphere in the tropical regions) is monitored in a dedicated expertise center located in the CNES Earth Observing department. For this program, CNES is responsible both for the monitoring of the health instrument and of the data production quality. For that goal, specific tools have been implemented in this expertise center (also built

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around a SAG framework) to gather information related to these monitoring. Typically, every day, an e-mail (Fig.21-left) is automatically sent to a dedicated diffusion list (experts, operators...), listing the anomalies raised during the last 24 hours. By checking this email, operators and experts can have a first idea of the status of the instruments or the ground segment.

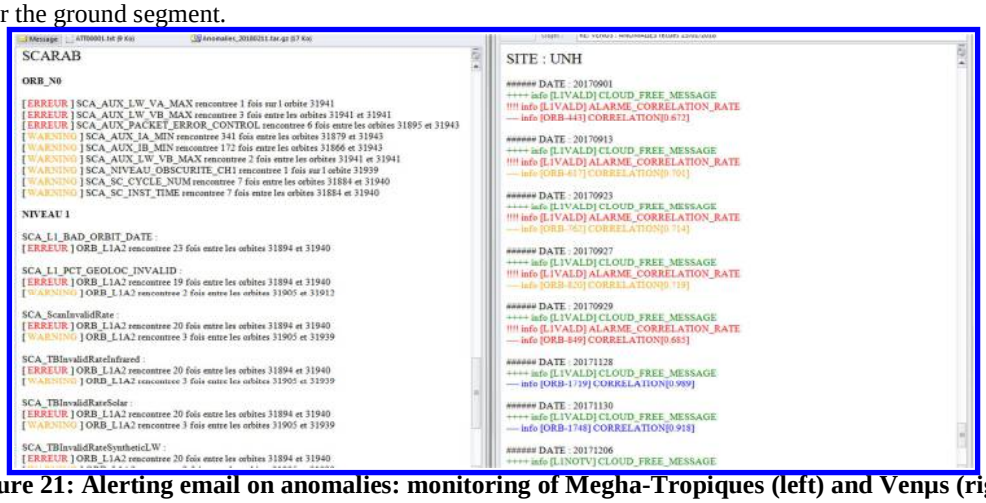

Figure 21: Alerting email on anomalies: monitoring of Megha-Tropiques (left) and Venμs (right)

Such a mechanism can also be useful in Venμs context. Indeed, the multi-temporal registration of data is extremely important for Venμs scientific use. The consistency of the reference image (specific to each acquired geographical site) with the current acquisitions is thus an important criterion to be monitored. In Venμs expertise center, like for the Megha-Tropiques one, anomalies are raised when correlation rate between acquisition and reference are less that a specific threshold. Consequently, the same tool operated on Megha-Tropiques expertise center has been adapted to Venμs expertise center. The result is that, every day, operators and experts receive email (Fig.21-right) listing information related to the last acquisitions produced on VIP side. Such messages bring information on the ground segment behavior (if no product is listed in the email for example), or on the quality of the correlation between reference image and acquired product (if some anomalies is raised). The monitoring information provided can thus lead, for some geographical sites, to an update of the reference product to maintain an optimal image quality. Again, in such a context, the previous experiences in IQ commissioning have allowed to save time in exploitation.

B. Communication and cooperation

The Venμs commissioning phase was handled in a context of international cooperation. Communication was clearly a key-element to manage to deal with the issues encountered during the project. One important lesson learnt is that the human exchanges should not be under estimated in such a context (international cooperation, intensive test period…). Along the same lines, email discussions show sometimes their limits and meetings are then necessary to gather appropriate information in such complex systems. The following practical exchanges illustrate the importance of communication in dedicated meetings.

For the global Venμs system, many discussions took place between IAI(GCS) and CNES(SMIGS) to be able to facilitate the sequencing of IHET cycles and imaging cycles, to be able to plan moon acquisitions, and to implement and validate the GAE correcting processor. For this latter example, a 2-days meeting finally took place in CNES premises to put everything in common and establish practical solutions.

More specifically, from an image quality point of view, the CNES internal communication was essential to elaborate the radiometric and geometric performances of VSSC camera, and to participate in the GAE validation operations. Some successful exchanges can be highlighted in the Venμs commissioning phase (during so called GEPO meetings):

- between radiometric and geometric experts : indeed the radiometric and geometric image quality performances are linked. The various radiometric GIPP were important to improve the radiometric quality of the upper-level products. In return, thanks to these radiometric improvements, the geometric performances assessed were more accurate, which was important to characterize the multi-spectral registration performances. Exchanges between experts were then necessary to know the current status of the image quality of products.
- between experts and exploitation team : one of the exploitation team tasks was to generate the appropriate data in order that experts can easily compute the new correcting parameters and validate their effects on

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radiometric and geometric performances. Thus, a clear communication should exist between experts and exploitation to optimize the data availability in a context of image quality loop.

- between VIQ and VIP exploitation team: the data analysis was made on VIQ side, and the image production was carried out on VIP side. Therefore, these two entities were central in the image quality process and the communication between them was crucial. The availability of data for experts depended on many factors on both sides of the SMIGS: format of the interfaces, correct values of parameters, choice of the test images, database ingestions and processing of the adequate product level, hub transfer of data, correct chains of monitoring and analysis… All these steps were daily discussed to be able to provide the maximum of data in order to fulfill all the performances assessments.

C. System specificities

Venµs global system has certain specificities coming from its design. Indeed, preliminarily designed to be a demonstrator to prepare COPERNICUS operational system, Venµs had some budget constraints. Moreover, because of its mission characteristics (to permanently acquire the same geographical areas every 2 days), the ground segment was not intended to evolve during the 2.5 years of the nominal scientific mission. For all these reasons, the programming was very simple, but also very rigid (some orbits were excluded from any programming, the slightest modification on a site definition necessarily triggered important modifications in the whole programming chain …). The lesson learnt from Venµs IOT is that, even if routine acquisitions are fixed during the mission life, flexibility is essential during the commissioning period. This aspect should be considered during the elaboration of the ground segment: to be able to combine flexibility and rigidity, depending on the phase of the mission.

From a hardware point of view, there is also another lesson that can be highlighted: to study carefully the needed space disk in the conception of the ground segment. In Venµs SMIGS context, this has been an important point. Indeed, on VIP side, some adjustments were to be done in global disk space during the IOT phase and, on VIQ side, some disturbances appeared (in processing or in team organization) due to a lack of margin on this same disk space. This aspect should thus be taken into account carefully, since it is central in the ground segment. Margins should be considered during the development taking into account the experience of previous in orbit test phases and the possibility of issues during the commissioning phase.

Information traceability has been a key-point in Venµs IOT. Indeed, in such a "locked" system as Venµs (where the same images are repetitively acquired), all the VIP production steps should be carefully followed on VIQ side (with suitable analyses). Moreover, some issues occurred during the commissioning phase (straylight, AOCS…), which made necessary the ingestion of a lot of products and information in VIQ expertise center. As the required analysis on these topics were carried out, it was crucial to be able to gather, on VIQ side, new production information coming from the VIP (which had not been foreseen during SMIGS conception). The lesson learnt, in this frame, is that data traceability (image information, log files, auxiliary data, intermediate results…) is very important in complex systems and should be precisely designed during the conception of the system, taking into account production and expertise needs. Besides, the way information are transferred from the production center to the expertise center must be conceived to be open enough in order to make possible an easy addition of new information during the mission life.

VI. Conclusion:

As a conclusion, Venµs in orbit test period has been a very complex and instructive period! Israeli and French teams have to carry out a multi-phased commissioning period, and to face image quality issues that altered radiometric and geometric performances. However, every time, correction or workaround have been implemented successfully to guarantee routine image quality monitoring, thanks to CNES and IAI experience and cooperation. Only one open point remained at the end of this IOT phase: some geometric performances altered by the lack of accuracy of the attitude data.

Being confident with a future complete consistency of image quality performances, Venµs clearly opens up new horizons for scientists, combining unique features within one satellite (constant viewing angle, high resolution, high revisit and spectral richness), which will foster the capability of the scientific community to use such new datasets and to develop innovative methods and applications.

It is now up to the scientific community to use Venµs datasets so that this mission could contribute to shape the future of Earth observation satellites definition.

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Appendix

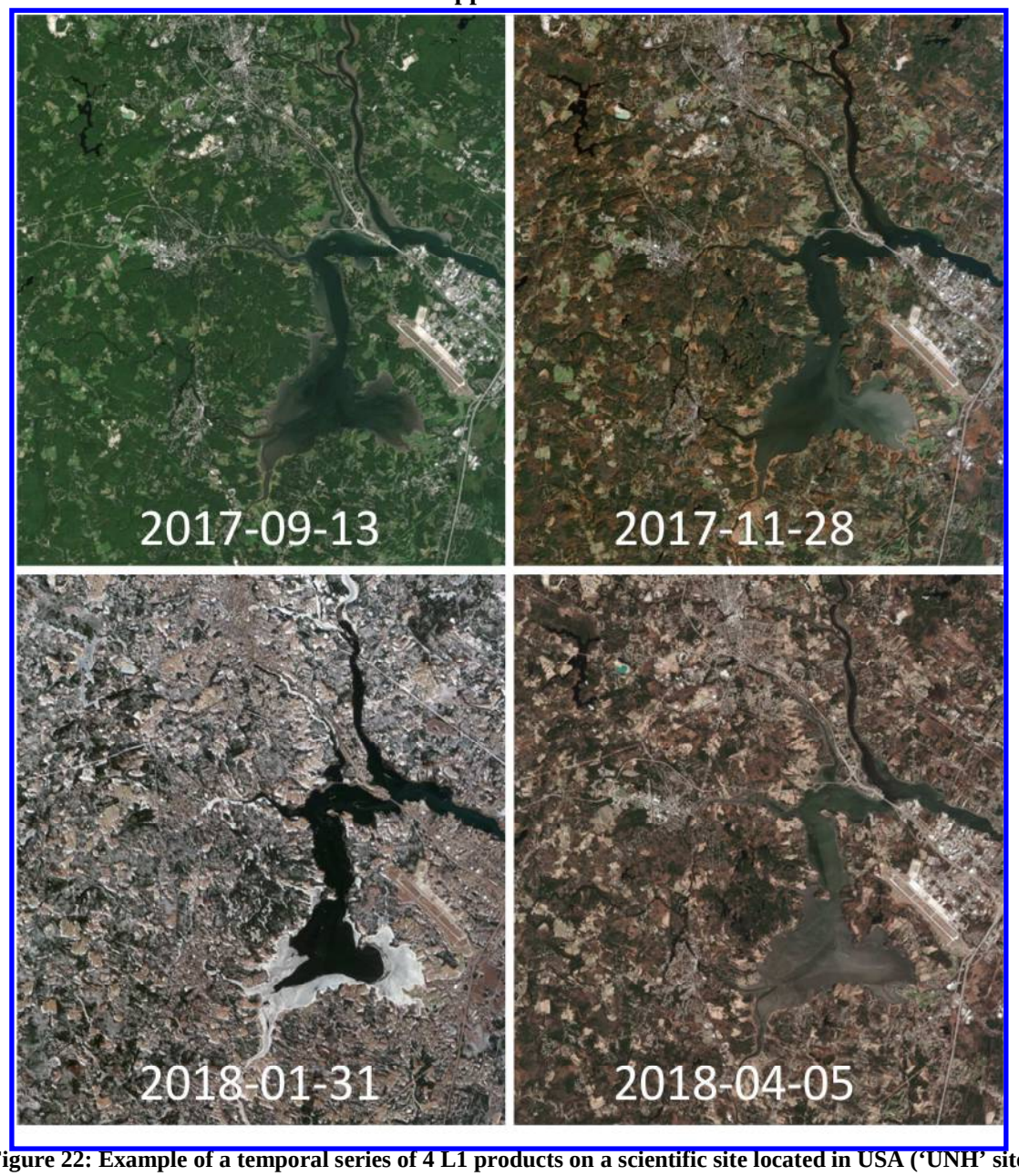

Figure 22: Example of a temporal series of 4 L1 products on a scientific site located in USA ('UNH' site, near Portsmouth, New Hampshire)

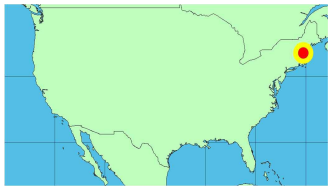

Figure 23: UNH site, geographical location

Figure22 shows a collection of 4 different acquisitions of a site located in USA (location in Fig.23). Each image is an extract of the full footprint of the site, acquired at a specific date (indicated at the bottom of each picture). A selection of three spectral bands has been chosen for the display: Band 7 in red, Band 4 in green, and Band 3 in blue.

During the illustrated period between September and April, the evolution of growing cycle can be emphasized trough visual evolution of global landscape (greener in the beginning of the series, with an icy stage in January).

All the products are available at https://theia.cnes.fr/atdistrib/rocket/#/home.

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