

SpaceOps-2023, ID # 316

## IASI instrument: End of Life activities and Technology Tests

*Author:*

**Eleonora Bassi\***

*Co-authors:*

**James Miller<sup>†</sup>, Dorothee Coppens<sup>‡</sup>, Bertrand Theodore<sup>§</sup>, Olivier Vandermarcq<sup>\*\*</sup>, Laura LeBarbier<sup>††</sup>,  
Mathilde Faillot<sup>‡‡</sup> Jeremie Ansart<sup>§§</sup>**

This paper's objective is to describe the technology tests executed on IASI (Infrared Atmospheric Sounding Interferometer) in the frame of Metop-A EOL, with particular focus on the scheduling, planning and execution of the activities. The test campaign was the result of a collaboration among EUMETSAT, CNES, and TAS, involving a wide range of professionals and teams, from instrument and operations engineers, to mission planning and scientists. The goal was to gain better in-orbit experience on instrument equipment configurations and/or functions that are nominally not used but that could prove to be useful for the improvement of IASI operations and performances, as well as for other Eumetsat operated instruments and IASI-NG. At the same time, it was an occasion to execute particular tests that for various reasons were not performed in earlier phases such as SVTs or commissioning, and to verify actual operational lifetime and reliability of hardware/software like on board memories. The tests timeline was also based on operational constraints such as ground segment and teams' availability, system limitations, mission and flight dynamics' requirements, interferences with other instruments' EOL and routine operations, all in the frame of covid-19 restrictions. All of these aspects were taken into account during the actual planning and scheduling, a task that was continuously evolving due to contingencies experienced and unexpected operations' outcome, that changed the initial conditions of each test. The complexity of the project and the number of parties involved was such that valuable lessons were learned, not only from an engineering operational standpoint, but also from a human and manpower perspective, which will also be covered in this paper.

---

\* Flight Operations Division. *EXOSTAFF*, 64404 Bickenbach, Germany, [eleonora.bassi@exostaff.de](mailto:eleonora.bassi@exostaff.de)

† Flight Operations Division. *EUMETSAT*, 64285 Darmstadt, Germany, [james.miller@eumetsat.int](mailto:james.miller@eumetsat.int)

‡ Real Time Service and System Operations Division. *EUMETSAT*, 64285 Darmstadt, Germany, [dorothee.coppens@eumetsat.int](mailto:dorothee.coppens@eumetsat.int)

§ Real Time Service and System Operations Division. *EUMETSAT*, 64285 Darmstadt, Germany, [Bertrand.theodore@eumetsat.int](mailto:Bertrand.theodore@eumetsat.int)

\*\* DOA/MDA/TA CNES, 31400 Toulouse, France, [Olivier.Vandermarcq@cnes.fr](mailto:Olivier.Vandermarcq@cnes.fr)

†† DTN/CD/LOT CNES, 31400 Toulouse, France, [Laura.LeBarbier@cnes.fr](mailto:Laura.LeBarbier@cnes.fr)

‡‡ DTN/CD/SA CNES, 31400 Toulouse, France, [Mathilde.Faillot@cnes.fr](mailto:Mathilde.Faillot@cnes.fr)

§§ DTN/TPI/IN CNES, 31400 Toulouse, France, [Jeremie.Ansart@cnes.fr](mailto:Jeremie.Ansart@cnes.fr)

## Acronyms/Abbreviations

<i>AIT</i>	Assembly Integration and Testing
<i>AOCS</i>	Attitude and Orbit Control System
<i>AOS</i>	Acquisition of signal
<i>AVHRR</i>	Advance Hight Resolution Radiometer
<i>CAL/VAL</i>	CALibration/VALidation
<i>CBS</i>	Cold Box Subsystem
<i>CD</i>	Cube Direction / Compensation Device
<i>CNES</i>	Centre National d'Etudes Spatiales (French Space Agency)
<i>CS1</i>	Cold Space 1
<i>CS2</i>	Cold Space 2
<i>CSQ</i>	Corner Speed Quality
<i>DEF_LEOP</i>	Default LEOP TM acquisition mode
<i>DEF_PLM</i>	Default Payload TM acquisition mode
<i>DPC</i>	Data processing chain
<i>DPS</i>	Data processing subsystem
<i>EEPROM</i>	Erasable programmable read only memory
<i>EPS</i>	EUMETSAT Polar System
<i>EPS-SG</i>	EUMETSAT Polar System – Second Generation
<i>EOL</i>	End of Life
<i>EUMETSAT</i>	EUropean organisation for the exploitation of METeorological SATellites
<i>FDF</i>	Flight dynamics facility
<i>FDIR</i>	Failure detection isolation and recovery
<i>FMU</i>	Formatting and Multiplexing Unit
<i>FOM</i>	Flight operation manual
<i>FOV</i>	Field of View
<i>IASI</i>	Infrared Atmospheric Sounding Interferometer
<i>IASI-NG</i>	Infrared Atmospheric Sounding Interferometer – New generation
<i>ICU</i>	Instrument control unit
<i>IMS</i>	Instrument main software
<i>LEO</i>	Low Earth Orbit
<i>LEOP</i>	Launch and Early Orbit Phase
<i>LFD</i>	Locking Filtering Device
<i>LOS</i>	Loss of signal
<i>MAS</i>	Main Acquisition subsystem
<i>METOP</i>	METeorological OPERational satellite
<i>MPF</i>	Mission planning facility
<i>NEDT</i>	Radiometric noise
<i>NORMOP</i>	Normal Operation mode (with data acquisition)
<i>PLM</i>	Payload module
<i>RAM</i>	Random Access Memory
<i>RTTF</i>	Real time test format
<i>SATSIM</i>	Satellite simulator
<i>SET</i>	Single event transients
<i>SEU</i>	Single event upset
<i>SOI</i>	Special operations instructions
<i>SIOV</i>	Satellite In Orbit Verification
<i>SMA</i>	Shape memory alloy
<i>SNO</i>	Simultaneous Nadir Observations
<i>SVM</i>	Service Module
<i>SVT</i>	On-ground System Validation Tests
<i>TAS</i>	Thales Alenia Space
<i>TEC</i>	Technical Expertise Centre
<i>OOL</i>	Out of limit

## 1. Introduction

Before entering in the details of the IASI technology tests, an overview of the project will be given to understand the structure and the choices made in terms of preparation and timeline. As mentioned in the abstract, the objectives of these tests are multiple; from an engineering and operational perspective the final goal was:

- to acquire an in depth understanding of Metop-A instrument performances
- to acquire knowledge applicable to other LEO missions' instruments
- gain better in-orbit experience on instrument equipment configuration and on functions that are nominally not used but that could provide useful references for future or other in-flight missions
- assess the lifetime and correct functionality of redundant equipment
- test flying configurations that couldn't be tested by AIT tests, SVT or commissioning phase.

From a scientific point of view, the focus was mainly on:

- improving the instrument processing/calibration data
- test new on board configurations aimed to improve observability.

All these points had to be accomplished while keeping into account the project main requirements and constraints, like the need to be in line with Lifetime Extension Strategy to maximize Metop-A life, which requires:

- to minimize the outages before end of mission
- to place the tests with an impact on the data quality in the end, in order to not cause any risk for the spacecraft or other EOL activities
- to set up a flexible plan regarding the test and event dates, since the de-orbiting date wasn't initially known.

In terms of activities scheduling, another requirement was to avoid interference with Metop-C or EPS-SG ops prep, SVT, launch, SIOV and commissioning activities, and more in general to keep at minimum the resources necessary to plan and execute the tests.

The timeline was planned to start right after Metop-C end of commissioning, spread over 2 years' time, and divided in 4 campaigns, or phases, whose categorization allows the maximum operational utilization of the Instrument while minimizing the risks associated to them:

- Campaign I tests were deemed low-risk, with no impact at all or a small data outage, with possible early benefits that could be applied to the other flying IASIs, covering almost the entire Technology test timeline;
- Campaign II tests were also deemed low-risk with no big impact on data quality or outage. In this phase no IASI tests were present.
- Campaign III was containing tests with a possible impact at instrument level or outage, for a total duration of a month.
- In Campaign IV tests considered riskier at instrument level or with possible impact at system level.

External parties like CNES for IASI, have been involved in the project, by proposing technology tests and contributing to the test design and assessment. This required a high level of coordination and interaction, and from the initial timeline a lot has changed in terms of activities acceptance and operations design: this was mostly due to a continuous ongoing assessment of the resources needed, a continuous assessment of the workload required with respect to man power available, (most engineers and scientist were allocated as well on EPS-SG preparation or other projects) but also a continuous assessment of test outputs, to understand if the possible maximum time allocated per test was enough to collect the data needed to make it worth it.

For IASI tests, no big changes were introduced since the start of the project, tests were mostly moved from one campaign to another in order to fit into a continuously adjusting schedule, in order to optimize the waiting times or conflicts with other instruments, or for increased/decreased risk associated to a test after further assessment.

An important aspect in the detailed planning was to optimize the time by choosing the right order of tests such that the final conditions of one were good as starting conditions of the next, trying to avoid as much as possible ad-hoc reconfigurations to bring the instrument in the desired state.

## 2. IASI timeline: Test objectives and risks, benefits and costs predictions

Overall, many tests have been proposed by several parties, and in order to decide which ones to perform, a value was assigned to each test feature: cost (C), risk (R) and benefit (B). The risks were divided in 2 categories, internal and external: internal risks were those affecting only IASI, from the triggering of EQSOL (instrument switch off as implemented action in response to an anomaly) to the potential loss of the instrument, while external risks were

those activities potentially resulting in PLSOL (payload switch off as implemented action in response to an anomaly), with consequences at system level, affecting other EOL activities, or potential threat to the safety of the spacecraft.

	<b>RISK<sub>ext</sub></b>	<b>COST</b>	<b>Category</b>	<b>Description</b>	<b>Importance</b>
<b>VERY HIGH (5)</b>	<ul style="list-style-type: none"> <li>Operations could <b>affect EOL ops.</b></li> <li>Operation can pose a threat to spacecraft <b>safety.</b></li> </ul>	<ul style="list-style-type: none"> <li>Complex Operation.</li> <li>Specific <b>Orbital Constraints/ Requirements.</b></li> </ul>	Cat1	Climate applications.	VERY HIGH
<b>HIGH (4)</b>	<ul style="list-style-type: none"> <li>Operations can result in or contribute to a very <b>serious mission capability loss.</b></li> <li>Operations can <b>pose constraints on EOL</b> operations.</li> <li>Risk of <b>RRM</b> and therefore <b>extended de-orbiting time.</b></li> </ul>	<ul style="list-style-type: none"> <li>Instrument <b>SW Patch to be developed.</b></li> <li>Ad-hoc tools required on ground.</li> <li>New <b>ground processing methods/SW</b> to be developed.</li> </ul>	Cat2	Metop-B&C meteorology applications.	VERY HIGH
<b>MEDIUM (3)</b>	<ul style="list-style-type: none"> <li>Operations can <b>affect other instruments/ subsystems</b> not related to the test.</li> <li>Potential <b>PLSOL</b> events.</li> </ul>	<ul style="list-style-type: none"> <li>As low, except <b>operations are beyond the scope</b> of what has been performed already in Routine, SIOV, Commissioning.</li> </ul>	Cat3	Understanding of Metop-A instrument performance.	HIGH
<b>LOW (2)</b>	<ul style="list-style-type: none"> <li>Operations <b>not done before</b> or not nominal.</li> <li>Risk of <b>EQSOL.</b></li> </ul>	<ul style="list-style-type: none"> <li>New <b>procedures/ Dastore</b> to be developed.</li> <li><b>More complex</b> operation to be run via <b>SOI.</b></li> <li><b>Within scope</b> of Operations already performed during Routine, SIOV and Commissioning.</li> </ul>	Cat4	Other LEO missions scientific applications.	HIGH
<b>VERY LOW (1)</b>	<ul style="list-style-type: none"> <li>Not further risk than <b>appropriate scheduling</b> of the test into the timeline.</li> </ul>	<ul style="list-style-type: none"> <li>Operations can be done with the <b>current FCP baseline.</b></li> <li>Short commanding operation.</li> </ul>	Cat5	Metop-B&C operations applications.	MEDIUM
			Cat6	Academic interest.	LOW
			Cat7	Redundant equipment assessment.	VERY LOW

	<b>RISK<sub>int</sub></b>
<b>VERY HIGH (5)</b>	<ul style="list-style-type: none"> <li>Operation could result in the <b>loss of the instrument.</b></li> </ul>
<b>HIGH (4)</b>	<ul style="list-style-type: none"> <li>Operation could <b>affect permanently</b> the instrument functionality.</li> </ul>
<b>MEDIUM (3)</b>	<ul style="list-style-type: none"> <li>Potential <b>EQSOL</b> events.</li> <li>Possible temporary modification of instrument performances.</li> </ul>
<b>LOW (2)</b>	<ul style="list-style-type: none"> <li>Operation <b>not done before</b> or <b>not nominal</b> (unforeseen issues during execution).</li> </ul>
<b>VERY LOW (1)</b>	<ul style="list-style-type: none"> <li><b>Routine</b> operation.</li> <li>Accommodate the test in the schedule.</li> </ul>

Figure 1 - EOL definition of Risks, Costs and Categories

The Acceptance criteria considers mainly the External Risk (on the system). The Internal instrument risks will mainly drive the position of the test in the test timeline. In this context also the expected outage duration was used as a defining criteria

- $R_{ext} = 1,2 \ \& \ C = 1,2 \ \rightarrow$  accepted
- $R_{ext} = 3 \ \parallel \ C = 3 \ \rightarrow$  assessed informally
- $R_{ext} = 4 \ \parallel \ C = 4,5 \ \rightarrow$  official review board
- $R_{ext} = 5 \ \rightarrow$  rejected
- $B = 4,5 \ \rightarrow$  becomes important during the official review board.

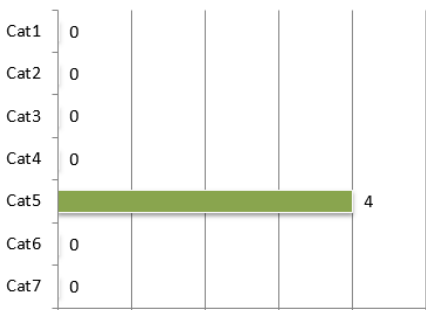
The first assessment done was a risks and costs analysis of each test, in order to plan in which campaign to place it. This was integrated with CNES’s priority inputs based on users’ and industry’s needs. In the frame of the test design review, risks, benefits and costs factors were assigned to each test.

Also, the benefits coming from every test have been specified and detailed within the 7 categories. The 7 different categories have a different weight in the assessment: for example, applications for Metop-B and C are more valuable for EUM than just academic interest and serve as a stronger test justification. Numeric values from 0 to 5 can be assigned to every category to produce a visual bar graph which gives immediately an idea of what every test “brings to the table”. The likelihood of obtaining valuable/useful test results is combined with the final result. In this chapter an overview of these factors in the frame of each tests will be given to understand better the decision making process to allocate these tests in the timeline.

## 2.1 Campaign I

### 2.1.1 IASI-EOL-12: IASI EEPROM PATCH

After every power cycle, software patches are applied to IASI-A IMS. In fact, operationally IASI uses the RAM, which content is loaded directly from the EEPROM image, outdated due to software updates throughout its lifetime. This activity requires 4 passes due to “space” limitation in the on-board queues, for the total duration of about 6 hours, since the daytime visibility is about 14 min every orbit of 1h 40min, with the consequent loss of the instrument thermal stability. The objective of the test was to copy these patches into IMS EEPROM in order to avoid losing them in case of power cycles, saving this way multiple passes and hours of outage during contingency recoveries or planned operations requiring IASI switch off, as well as saving time due to the loss of thermal stability – which itself adds hours to the recovery. The reason for the patches to take such long time, is because a complete image upload was performed, and although the source code updates were quite small, it induced modification on the memory mapping and big parts of binary image were impacted.



**Figure 3 - IASI-EOL-12 Test category vs. value assigned**

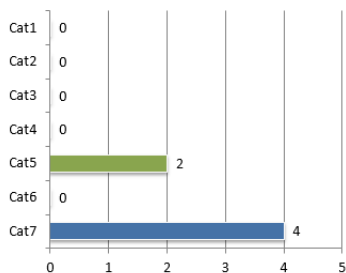
upload was performed, and although the source code updates were quite small, it induced modification on the memory mapping and big parts of binary image were impacted.

Despite considering the test safe, the on-board EEPROM expected operational lifetime was overdue by 5 years, with the associated risk of failure of the copying function or increased possibility of SEU/SET corruption during the writing process. This is why at first this test was scheduled for campaign III, along with the fact that at the beginning it was still to be assessed how long would the copy take, as the FOM was not specifying it. In case of EEPROM corruption, the mitigation would be to patch again the entire IMS, with the only inconvenience of having to use multiple passes. It’s worth mentioning though, that the EEPROM Image is anyway not currently used, procedures to update the Image in RAM are well validated and the Boot Software is not affected, so there was no reason to believe that the activity was so risky. An initial doubt was coming from the fact that SEU could affect specific registers prohibiting the upload but no realistic cases were really known.

This test was considered initially low priority for CNES, but eventually presented higher importance in the understanding of memories performances. The graph shows indeed that the main application is for Metop-B and C operations. For this reason, it was desirable to perform it as soon as possible in order to apply the results to IASI-B and drastically reduce the outage in case of anomaly. The probability of having a corruption of the memory due to a SEU were considered medium, but the severity itself, low. Eventually the risk associated would be low (EQSOL) as the recovery was considered easy to plan and execute.

## 2.2 Campaign III

### 2.2.1 IASI-EOL-13: IASI REDUNDANCIES TEST



**Figure 4 - IASI-EOL-13 Test category vs. value assigned**

The purpose of the test was to check the remaining redundancies of the instrument that have never been exercised in space before, with the objective of gaining some knowledge about the ageing effect after a long stay in space in cold configuration (non-powered). What was going to be measured in the end, was the functional status of Laser 2, stability, amplitude of the metrology signal, the DPC 5 functional status, the aging effects, and the possible applicability of the test to IASI-B or IASI-C. The benefits were considered overall low, but so were the risks associated to it. The limited amount of outage foreseen for the operations as well, made it possible to insert this test in campaign III, where IASI was still expected to provide data, just before IASI-EOL-16, as the final conditions were

The limited amount of outage foreseen for the operations as well, made it possible to insert this test in campaign III, where IASI was still expected to provide data, just before IASI-EOL-16, as the final conditions were

<b>RISK (int)</b>	MEDIUM	3
<b>RISK (ext)</b>	LOW	2
<b>COST</b>	MEDIUM	3
<b>BENEFITS</b>	MEDIUM	3

**Figure 2 - IASI-EOL-12 Risk, Cost, Benefit Assessment**

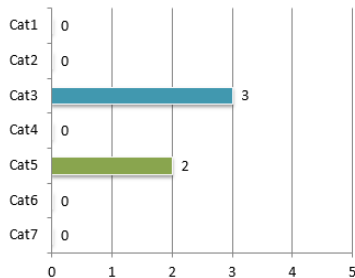
<b>RISK (int)</b>	LOW	2
<b>RISK (ext)</b>	VERY LOW	1
<b>COST</b>	LOW	2
<b>BENEFITS</b>	LOW	2

**Figure 5 - IASI-EOL-13 Risk, Cost, Benefit Assessment**

good to start the new test. As it can be seen from the table, despite the benefits were considered low, the likelihood of obtaining good results in case of performing the test successfully, were considered “medium”. To wrap up, the graph shows that the test had two main purposes: to benefit Metop-B and C operations, and for redundant equipment assessment. No impact was foreseen on other subsystems, and in case of failure, a swap back to nominal equipment was considered easy by using the default datastores.

**2.2.2 IASI-EOL-16: INVESTIGATION ON CSQ ANOMALY**

Since September 2014 an increased rate of the Corner Cube Speed Quality errors had been observed on IASI-A. This is a minor error that IASI throws when the corner cube speed is not in the expected range and the position error is >6µm. It is accompanied with an IASI Anomaly counter increase by 1 and a Report type 14 Complementary Failure. As a result, the science data is flagged as invalid. Until April 2015, the daily rate of CSQ errors increased quite rapidly with more than 2000/day. As a mitigation action, the IMS was switched-over to IMS-B and this brought the number of error events to a nominal level of in average one event every 14 days. The objective in this case was to characterize more finely the CSQ (Cube corner Speed Quality error) anomalies on nominal and on redundant sides, by testing several values for the



**Figure 6 - IASI-EOL-16 Test category vs. value assigned**

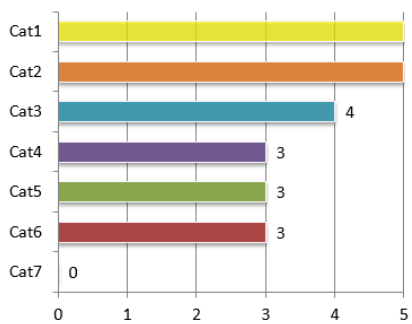
low and high CSQ detection thresholds, in order to gain a more precise idea of the amplitude and sign of position errors causing the appearance of CSQs and to provide work around solutions for IASI-B or IASI-C in case of similar anomalies.

This test was considered low priority. The risks associated to this test were very low, since the IMS swap has already been performed in the past and the parameter upload didn't present concerns per se, but so were the benefits, which is the main reason why it was performed in campaign III, despite 7 days of outage.

If initially the test benefits were medium, the likelihood of obtaining good results in case of successful test, were deemed low: the CSQ error problem could be again investigated, but it is not stated that useful results will be obtained to get to a valid conclusion. Therefore, the total benefit level was degraded from medium to low.

**2.2.3 IASI-EOL-15: LOCAL IMPROVEMENT OF SPATIAL SAMPLING**

The objective of the test was to reduce the swath and increase the spatial density of the soundings. The purpose of the test was to study the possibility to improve the



**Figure 9 - IASI-EOL-15 Test category vs. value assigned**

spatial resolution by ground processing of overlapping acquisitions. In this case the test was of scientific interest, aiming to increase the number of soundings over an area of interest in order to measure the chemistry of the atmosphere, and pollution over the cities. Based on the results, an application could be considered for future Metop-B and C operations, as well as for MTG-IRS and IASING. the graph shows that the final applications are covering all the categories except the redundancies one, which raised the importance of the test to very high, reflected by the likelihood of obtaining valuable results in case of successfully executed test. In terms of internal risks, a modification of  $\alpha_1$  parameter could lead to a degraded positioning or stability of the scan, since the scanning law is not optimized for the new  $\alpha_1$  parameter. With the modified scanning law, the performances of the instrument and the data quality could be influenced, however, as the distance between views will be smaller than the nominal ones, it is not expected to degrade the scan performances: on these premises, it was then safe to assume that the 29 days of test would produce usable data, leaving the outage to few orbits, which

<b>RISK (int)</b>	VERY LOW	1
<b>RISK (ext)</b>	VERY LOW	1
<b>COST</b>	VERY LOW	1
<b>BENEFITS</b>	LOW	2

**Figure 7 - IASI-EOL-16 Risk, Cost, Benefit Assessment**

<b>RISK (int)</b>	HIGH	4
<b>RISK (ext)</b>	LOW	2
<b>COST</b>	MEDIUM	3
<b>BENEFITS</b>	HIGH	4

**Figure 8 - IASI-EOL-15 Risk, Cost, Benefit Assessment**

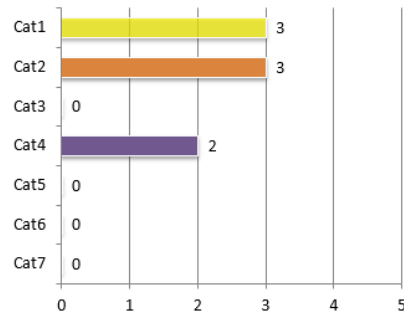
was a factor in deciding to place the test in campaign III. If the internal risks were considered high, no impact was foreseen on other satellite subsystems. As it will be shown in the next chapter, the costs of preparations were mostly on ground side, while on spacecraft side new procedures and DS had to be developed, but with existing commands.

### 2.3 Campaign IV

#### 2.3.1 IASI-EOL-18: NEDT IMPROVEMENT IN B1 ON 1 SOUNDER PIXEL

The purpose of the test was to improve the radiometric noise performance in spectral band B1 on one of the four IASI sounder pixels by switching off the other pixels, with the objective of reducing the radiometric noise by decreasing the detector’s temperature. The outcome data was going to be an asset for the preparation of IASI-NG. The testing of the 1-pixel configuration was not considered particularly risky for the instrument and the satellite. At instrument level, a 3-pixel configuration (3 pixels ON and 1 pixel OFF) was already functionally validated in Optical Vacuum Test for all IASI FM models, but no performance assessment was made for this configuration. Configuration with no pixels ON is also often used during on-ground tests, and can be done on any side of the instrument. Despite the risks were deemed low due to the previous test of such configurations on ground, the impact on IASI spectral calibration had to be assessed since the test was never performed before in flight. Despite no impact was foreseen on other satellite subsystems, this risk associated to the performances and the extended outage were main drivers to the placement of this test in campaign IV, were data would be stopped from dissemination. As it can be seen from the graph, the benefits were deemed high, but the complexity of the test from an operational standpoint set the costs even higher. This test was decided to be the one opening campaign IV, placed in the timeline just before IASI-EOL-01, also because the ending conditions could have been a good starting point for the following test.

**Figure 11 - IASI-EOL-18 Test category vs. value assigned**



<b>RISK (int)</b>	MEDIUM	3
<b>RISK (ext)</b>	LOW	2
<b>COST</b>	VERY HIGH	5
<b>BENEFITS</b>	HIGH	4

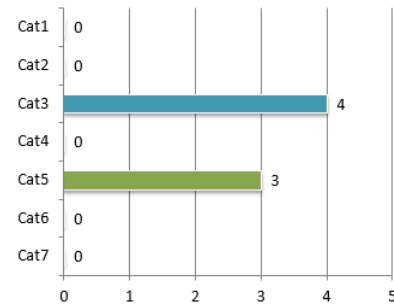
**Figure 10 - IASI-EOL-18 Risk, Cost, Benefit Assessment**

deemed low due to the previous test of such configurations on ground, the impact on IASI spectral calibration had to be assessed since the test was never performed before in flight. Despite no impact was foreseen on other satellite subsystems, this risk associated to the performances and the extended outage were main drivers to the placement of this test in campaign IV, were data would be stopped from dissemination. As it can be seen from the graph, the benefits were deemed high, but the complexity of the test from an operational standpoint set the costs even higher. This test was decided to be the one opening campaign IV, placed in the timeline just before IASI-EOL-01, also because the ending conditions could have been a good starting point for the following test.

#### 2.3.2 IASI-EOL-01: LFD RELEASE

The Locking Filtering Device (LFD) was implemented on IASI to ensure a decoupling between the platform and the instrument in order to prevent micro-vibrations coming from the METOP platform and impacting the quality of IASI data. However, this option was never exercised during CAL/VAL and there is no in-orbit experience of IASI in this configuration. With the passing of time, there was also concern about the risk of cold welding of components which would prevent the release of the LFDs, slower it, or have only a partial one.

**Figure 12 - IASI-EOL-01 Test category vs. value assigned**



<b>RISK (int)</b>	HIGH	4
<b>RISK (ext)</b>	LOW	2
<b>COST</b>	LOW	2
<b>BENEFITS</b>	MEDIUM	3

**Figure 13 - IASI-EOL-01 Risk, Cost, Benefit Assessment**

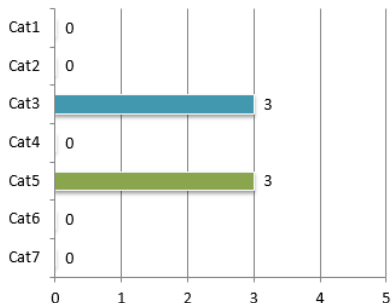
vice versa with a consequent improvement of the products. Another indirect benefit would be in terms of impact on Metop AOCS and efficiency in terms of noise compensation: in fact there was no direct way to validate the success of the release of the LFD and after a long stay in space if not through indirect observations on the AOCS itself. There was a risk that the instrument performances would have been irreversibly degraded after this operation, either due to incomplete release of the LFDs or due to unforeseen issues with this untested configuration. However, this risk is internal to the instrument and was mitigated by scheduling it as late in the Technology Test Campaign as

possible. From a Cost point of view, the test requires only to re-validate and roll out again procedures used for the same task during SIOV/CALVAL, therefore there is no particular development necessary.

The operation of IASI with LFD released nominally requires the activation of CD. The CD will have to be reactivated just after LFD release, before going to operational mode. After a first assessment of IASI performance in this configuration, the stop of CD with LFD release was planned to be performed in the following test IASI-EOL-02, scheduled for this purpose right after IASI-EOL-01. Eventually successful results would help not only to understand the instrument performances but also but also to improve those of Metop-B and C.

**2.3.3 IASI-EOL-02: CD STOP**

IASI-EOL-01 was followed by IASI-EOL-02, as a complementary test: after the release of the LFDs, the CD is now stopped. The CD was introduced in the IASI design to compensate the dynamics perturbations generated by the CCFD in the configuration where the LFD are deployed; in this configuration, the interface between IASI and the satellite PLM is non-rigid. The purpose of this second part of the test, is to check how much the CD can compensate the dynamics perturbations generated by the CCFD in the LFD (assumed) deployed configuration and



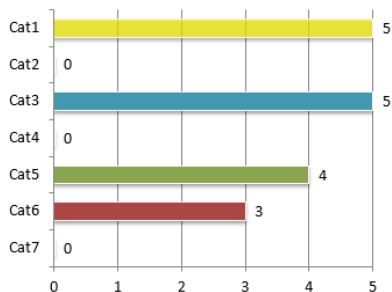
**Figure 15 - IASI-EOL-02 Test category vs. value assigned**

IASI LFDs are released, to be compared with the different configurations already tested. In this LFD released configuration the impact on satellite AOCS performance is expected to be more significant than the CD stop operation already performed with the LFD locked. Therefore, it was interesting to see how the two different mechanical configurations affect the products quality and the satellite platform. Operations to stop the CD have already been successfully executed and re-enable CD movement is supposed not to produce unexpected error. However, it has never been tried in a configuration with the LFDs released; hence risk went from very low to low. This test also seems to present very low risks at system level: the CD stop is an already proven operation and, in the case of too degraded AOCS performances, to restore the CD device to the running configuration is a simple operation. Also, procedures to be used are already developed since the operation stop in October 2015. Anyway, in case of fail, the risk at instrument level on this operation is considered high as major issues can lead to a permanent CD failed.

<b>RISK (int)</b>	LOW	2
<b>RISK (ext)</b>	LOW	2
<b>COST</b>	VERY LOW	1
<b>BENEFITS</b>	MEDIUM	3

**Figure 14 - IASI-EOL-02 Risk, Cost, Benefit Assessment**

**2.3.4 IASI-EOL-03: INTER CALIBRATION OF METOP-A, B & C**



**Figure 16 - IASI-EOL-03 Test category vs. value assigned**

The purpose of the test was to use the opportunity given by the deorbiting of Metop-A and the change of the geometric configuration of the METOP constellation, to acquire Simultaneous Nadir Observations (SNO) data by IASI-A and IASI-B or by IASI-A and IASI-C over the Earth poles. Since in the current geometric configuration of Metop-A and Metop-B, the nadir Observations by IASI A and B are not simultaneous but 50 minutes separated, this test had to be placed in Campaign IV in the point where IASI-A wouldn't be in its nominal orbit: indeed, it is possible to have SNOs during

<b>RISK (int)</b>	VERY LOW	1
<b>RISK (ext)</b>	MEDIUM	3
<b>COST</b>	MEDIUM	3
<b>BENEFITS</b>	LOW	2

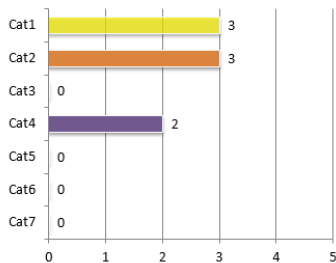
**Figure 17 - IASI-EOL-03 Risk, Cost, Benefit Assessment**

EOL operations, when the orbit of Metop-A is lowered and there is a chance of naturally achieving SNOs without

dedicated orbit modifications. Satellite Inter-calibration is very useful to identify problems and increase the confidence in the operational calibration of individual instruments, it's also useful for climate quality measurements since it provides a more accurate calibration of the products. Lastly, it provides knowledge on instrument degradation that may be useful for the operations of METOP-B and C. From IASI OPS perspective the cost was very low as no direct operation on the instrument was foreseen. But due to the complexity related to the simultaneous acquisition of the data, the cost was considered medium. In terms of risks, at instrument level, IASI Measurement or EXT CAL mode and the dumps operations are all nominal operations, hence major issues are not expected, while at system level, the risks were related to having IASI on during EOL operations, posing requirements to the procedure to switch off the payload in the end of Phase 1 of EOL. While the test itself has no impact on the rest of the spacecraft, there was a certain complexity in having three satellites flying and performing operations which have to be combined according to the ground station availability.

**2.3.5 IASI-EOL-17: IASI LIMB POINTING**

The backflip manoeuvre of METOP-A planned at the end of the EOL test campaign, gave the opportunity to acquire measurements of the atmosphere in Earth Limb directions that has a potential scientific interest and can provide a comparison between IASI and other limb atmospheric sounders. Initially an ad-hoc test was proposed to try to get limb views, but it was discarded because too risky. Fortunately, the configuration of the deep space manoeuvre will allow some limb measurements. This test is also less demanding from the platform point of view and, even if it consists in a quite complex attitude manoeuvre, it is already used by many other instruments, making the benefit coming from the test increase substantially balancing the high risk and development cost. The risk for IASI is very low, since the test is going to be performed right in the end of the life of the instrument, shortly before de-orbiting and it consists in keeping the instrument in its nominal scanning mode. From the point of view of external risks and costs, the high comes from the assessment associated to the Deep Space Manoeuvre itself, quite dangerous since the satellite was never designed for such an attitude manoeuvre.



**Figure 18 - IASI-EOL-17 Test category vs. value assigned**

<b>RISK (int)</b>	VERY LOW	1
<b>RISK (ext)</b>	HIGH	4
<b>COST</b>	VERY HIGH	5
<b>BENEFITS</b>	MEDIUM	3

**Figure 19 - IASI-EOL-17 Risk, Cost, Benefit Assessment**

In terms of risks, there's no risk for IASI as the tests consists only in a nominal acquisition, and does not pose specific risks on the system or on the other instruments. However, the "High" comes from the risk related to the Back-flip Manoeuvre, which has never been performed before on a Metop spacecraft, has unpredictable risks and could impact EOL operations: in fact, if a transition to Safe Mode/RRM is executed, there will be an impact on EOL operations in terms of re-entry time due to the fuel spent on the recovery operation. The costs are as well very high: not only for the manoeuvre itself, but for the effort on CNES side to produce a dedicated table, as well as a joint effort with the flight dynamics team to provide the timeline of all the manoeuvre: when the EW FOV sees the earth and when the CS2 view start to see the earth as well.

After understanding the structure and management choices that defined the Technology test timeline as a project, this chapter will deal with the operational aspects of each test, describing not only the initial plan and foreseen workload but also the actual development.

**3. Operations preparation, execution and analysis**

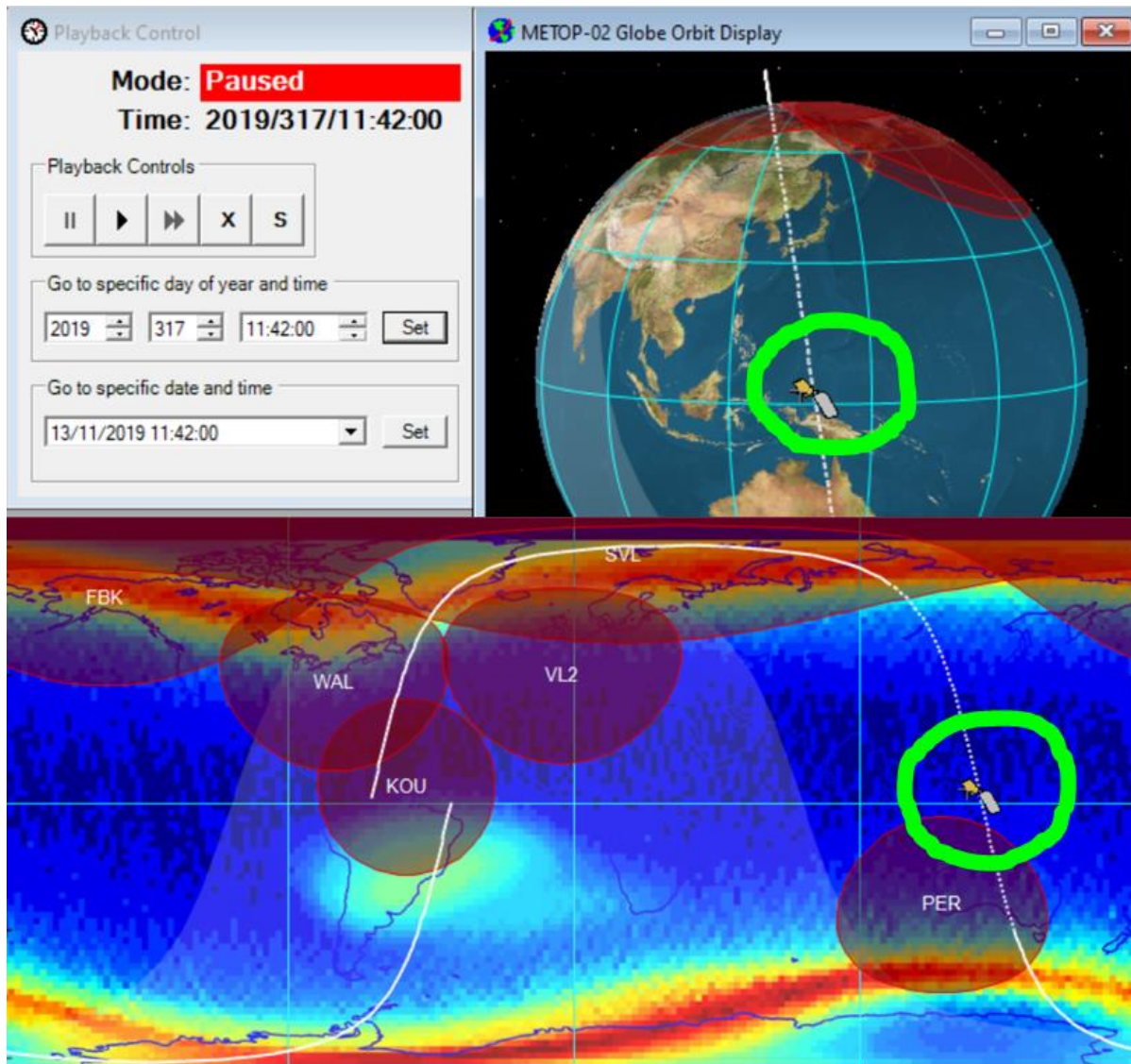
After understanding the structure and management choices that defined the Technology test timeline as a project, this chapter will deal with the operational aspects of each test, describing not only the initial plan and foreseen workload but also the actual development.

**3.1 Campaign I**

**3.1.1 IASI-EOL-12**

As previously mentioned, this test purpose was to copy the ICU RAM content into the ICU EEPROM thanks to a copying function that allows OPS to mirror the content in EEPROM without having to patch it "manually". From a

scheduling standpoint IASI-EOL-12 didn't require coordination with other IASI tests because it was the only one executed in campaign I. In order to avoid conflicts with routine activities, some tasks like SVM reports and reports dump were suspended at PI/MPF level, while the test was carefully planned away from external calibrations. A bit more of coordination was required with other instruments tests, making sure that there were no overlaps in commanding passes and impact on each other's data generation. The biggest part of the coordination and planning was with the users due to the outages generated by several power cycles, being the test executed in Campaign I were outages had to be minimized. Particular attention was paid to patch command scheduling to avoid areas of known high radiation activity (polar belt and south Atlantic anomaly regions) as the EEPROM would be un-protected for the 5 minutes with write-enabled during the patch commands.



**Figure 20 - Metop-A position during memory patch into EEPROM: the spacecraft is far from high radiation areas**

Another aspect to take into consideration in the planning was the time dedicated to production and validation of a new OPS procedure, which couldn't be completely validated due to the non-representativeness of the SATSIM in respect to the on board memories. On the other hand, in case of anomaly, the patch itself was already present in EUMETSAT' system, with no need to ask for further patch developments to CNES.

As previously mentioned, the biggest risk associated to this test is related to a potential EEPROM corruption due to a Single Event Upset during memory writing, being the EEPROM is SEU-sensitive in Write mode. This would be leading to, in the worst scenario, an impossibility to reboot the instrument on the B-side, being IASI already on the redundant chain due to another anomaly. As contingency scenario, OPS team prepared in advance the operations to re-upload the full RAM and trying to mitigate the issue by scheduling the activity over safe areas of the globe, trying to avoid those with high particles activities. To rewrite only part of the memory would be less effective, because the content of the other part would be unknown (old SW version or corrupted SW). In addition, there was no way to perform a comparison of the EEPROM image to detect which areas have been corrupted. Assuming that the new SW version was fully correct then a possibility would be to re-apply the latest version in EEPROM. This activity was particularly relevant for the following EOL activities and in case of future anomalies on IASI-B, since both instrument required 3-4 passes each just to re-upload dedicated patches each time a power cycle was needed, resulting in a lot of outage time avoided.

Initially the test was supposed to perform also the writing of the current DPS/DPS RAM patches into DPS/DPC EEPROM, which was eventually de-scoped since support by the industry supplying the DPS memory was not foreseen as it would have implied additional costs. Also, in case of anomaly the patch of DPS boot area were not recommended by TAS.

Operations went without errors, except issues in importing the needed procedures in the system. This caused a commanding delay of 1 orbit without impact on the timeline, since 1 pass of margin was already taken into account. In conclusion, the test was performed successfully in November 2019, illustrating also the capacity of the EEPROMS components to support a rewrite after more than 10 years in space. The interest of the operations was later demonstrated in June 2020 when a fast power cycle was performed to recover from a SEU affecting Active Thermal Control lines. The same operations of EEPROMS rewriting were performed successfully on IASI-B, in October 2020.

### 3.2 Campaign III

#### 3.2.1 IASI-EOL-13

The test was focused on switching to Laser 2 and DPC5 equipment on the redundant side configuration of the instrument. This test didn't present any issue in terms of planning and execution, no big changes were required in the documentation, and test execution could be easily allocated within normal working hours. With respect to the first draft of the test, the activity was performed from HEATER 1 and both changes could be performed in one operation. With this new approach, the development of a monitoring procedure and a datastore was needed, in order to reflect the monitoring on the redundant side, and a final SOI had to be created.

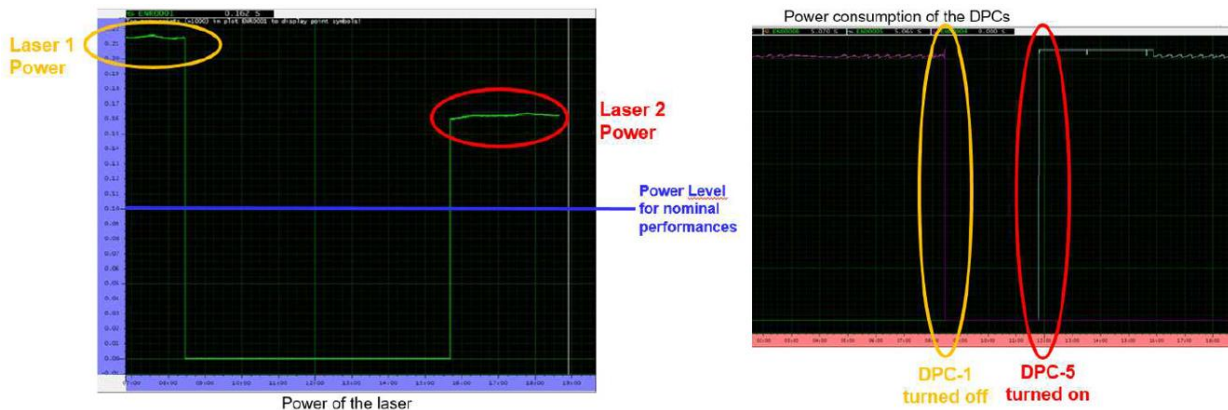


Figure 21 - Successful switch of IASI units to the redundant side

The configuration was then maintained to start the next EOL 16 test (CSQ) on the operationally active side, with IMS B, FMU B, Laser2, DPC 2/3/4/5. In case of failure, the fallback scenario to the nominal configuration wouldn't have taken more than a few passes with no real impact on the timeline.

The test results show that the redundant equipment performs as well as the main one after more than 10 years in flight, and that there were no major effects of the switch to the instrument redundancies on the spectral calibration.

### 3.2.2 IASI-EOL-16

This test was intended to be performed in 2 phases: first, a set of operations on the B-Side of the instrument was performed, to assess the limit of appearance of the CSQ by reducing the values of the threshold by applying four values,  $\pm 6$ ,  $\pm 5$ ,  $\pm 4$ ,  $\pm 3 \mu\text{m}$ . In the second phase, different thresholds were applied to the A-side of the instrument after a power cycle, to assess the limit of disappearance of the CSQ, this time by increasing the values of the threshold:  $\pm 7$ ,  $\pm 7.5$ ,  $\pm 8$ ,  $\pm 8.5$ ,  $\pm 9 \mu\text{m}$ .

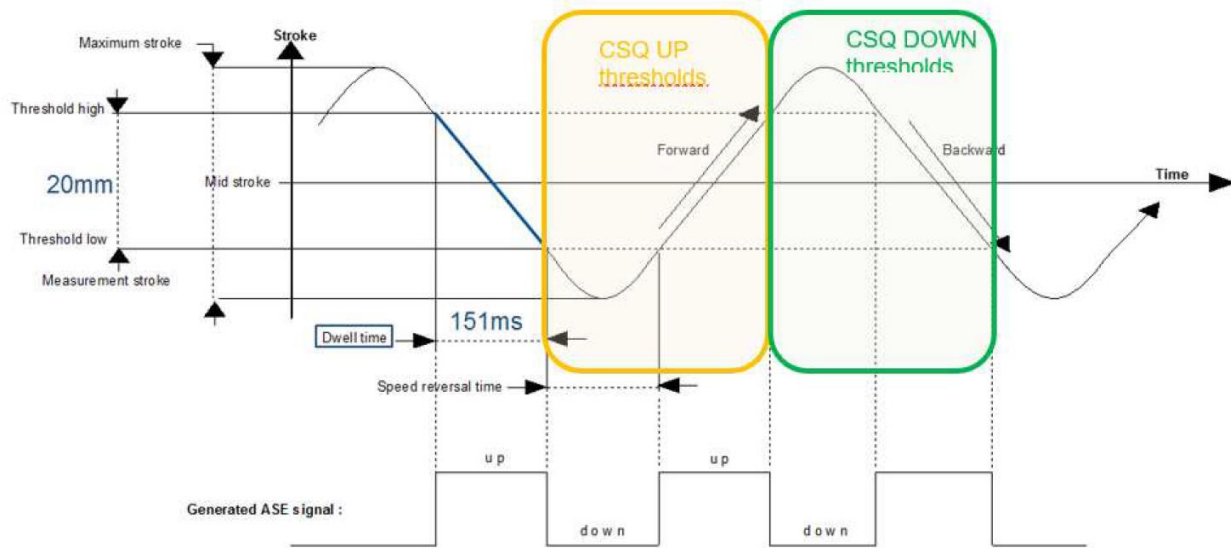


Figure 22 - CSQ thresholds vs. instrument ASE signal

This test presented many challenges from a planning perspective because the test was repeated multiple times due to issues of different nature: the first test attempt worked as planned on B-side but failed on A-side due to wrong FMU selection that prevented IASI from producing data. As a result of this test the operational procedures for IASI were reviewed and updates made to mitigate the FMU selection error. The selection logic was indeed straightforward on the nominal side, but quite complicated in case of redundant chain selection.

A second attempt was then made after IASI-EOL-18 since the timeline allowed it, but despite the right setup of the instrument, the test on A-side failed on first day due to a possible SEU during the patching phase, such that an FDIR triggered during post-patch step with SW failing to restart. Test have been then aborted for lack of time. Additional information on the failure were missing due to TM being in DEF\_LEOP instead of DEF\_PLM, which couldn't be easily avoided due to possible conflicts with other EOL activities. Initially the timeline didn't give the opportunity to schedule a 3rd attempt, but a simple Switch-ON on the A-side was performed right before the payload deactivation to rule out the possibility of a permanent anomaly in the IMS SW. This activity although simple, had to be carefully plan as OPS team could not allow the triggering of PLSOLs that could potentially leave the payload in an unwanted status before the final deactivation. Also, the Switch ON of IASI requires per se several minutes, which was time critical since the activity was supposed to be executed and completed during the pass, where the pass had a duration of 5-6 minutes being during night time. In addition, to reduce the maximum commanding time per pass, SVM commands had to be performed at AOS, with precedence over IASI commanding.

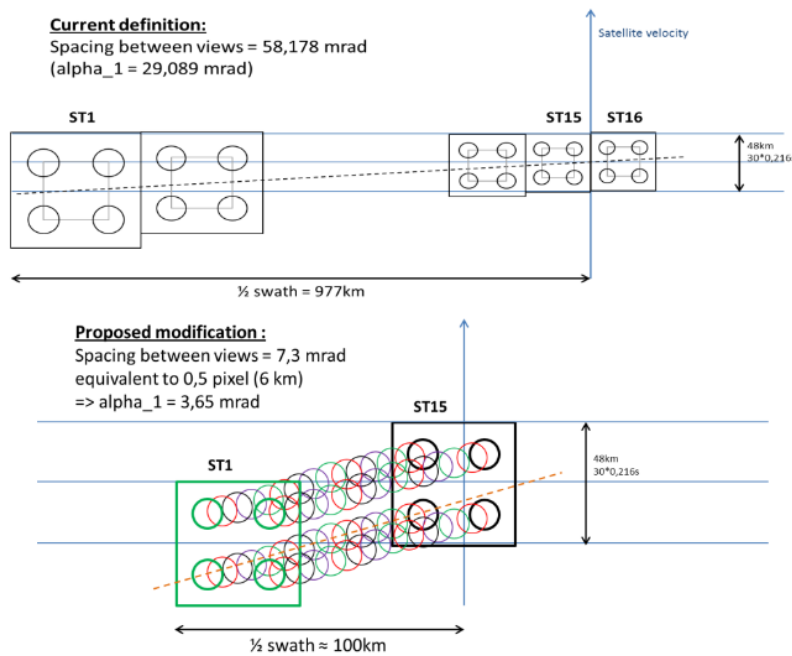
The planning of this activity presented different obstacles and high effort on many levels: first, the change of operational approach with respect to the first draft of EOL tests agreed in early stage meetings, brought to a major re-writing of the documentation and to a manual creation of 56 datastores. Another problem to overcome was an MCS related limitations leading to possible risk of system crashing due to the number of directories needed to be sent in every pass. Complexity of the instrument set up at every power cycle with ad hoc manual adjustment of the datastores used. Specific EOL datastores couldn't be created without having to create also ad hoc switch on

procedures, since the names of the DS were hardcoded, leading to a manual editing of the datastores directly in the operational environment.

Also in terms of execution the efforts turned out being higher than expected, in fact in case of anomalies, long recovery times due to loss of thermal control after power cycle were needed, resulting in long working hours and commanding over the weekend. On top of that, each attempt required extended time allocated, in an already tight schedule. The impact of a variation of CSQ threshold modification on IASI-I6 data remains inconclusive. Due to errors, the test was interrupted and not enough data could be collected for a meaningful statistic.

### 3.2.3 IASI-EOL-15

The test itself although not difficult in preparation, needed to be restarted a day after the scheduled time, due to an error in the selection of the Alpha and Beta datastores. The datastores were applicable in fact for IASI-A side A instead of side B. The effort in recovering was very low as well, since the issue was detected immediately by CNES



**Figure 23 - Nominal and modified IASI scanning law**

and fixed the following day in 1 pass, with no further deviation from the scheduled test. The only effort required was to re-deploy to the operational environment the right datastores, as they were already used in the past, as well as adjusting the on-ground configurations a few days after the beginning of the test to improve the L1 data quality. The test presented nevertheless challenges due to a transition to HEATER REFUSE triggered right after the test commanding, due probably to a SEU at the level of the DPS RAM memory, which was recovered in the shortest time possible due to the presence onsite of IASI engineer at the time of the occurrence. To be noted that while a SEU recovery would be considered routine, and could be executed by any engineer, in this case IASI expert was needed due to the deviation from routine in the upload of the datastores needed

when transitioning to NORMOP. If such anomaly happened outside working hours, the test would have been affected by a way bigger outage leading to delays in the timeline or de-scope of the test. Another (this time foreseen) deviation was due to a moon avoidance activity, which had to be executed manually due to the use of specific datastores not selectable on MP level. In terms of activity scheduling, a duration of 1 month was considered the minimum time for which the test would have made sense, in order to collect enough data to be analyzed. If this wasn't going to be feasible, the test would have been cancelled. This concept was applicable to other tests too, fortunately in this case no commanding was foreseen in the whole month and this test was in no way a potential obstacle for other instruments tests performed at the same time, at the condition of keeping IASI in NORMOP. Additional coordination was needed due to an overlapping with an AOCs activity foreseeing a change of satellite attitude: the yaw steering control of the satellite was changed for 2 days with a potential impact on the spectral calibration. This caused nevertheless no interference from an OPS perspective.

## 3.3 Campaign IV

### 3.3.1 IASI-EOL-18

In order to reduce the temperature of the detectors and check the improvement of radiometric noise in spectral band B1, a decrease of temperature is needed and obtained by switching off 3 of the 4 pixels of the sounder. This test's

operations required a quite complicated series of steps consisting in changing the MAS HAU configuration to select only 1 pixel, and adapt the monitoring to this configuration. Then, the CBS 3rd stage temperature target had also to be changed, first by changing a priori setting then refined after stabilization and observation of thermal line regulation power.

After optimization of the temperature, the instrument was supposed to be switched to NORMOP mode to acquire verification interferogram, similarly to the DPS initialization phase done in SIOV. As the new temperature was a few degrees away from the nominal one, the settings of MAS gains and offsets for B1 were supposed to be updated as well, requiring a new MAS table to be delivered by CNES and uploaded by OPS team. The non-linearity response of the B1 detectors were expected to be re-assessed and new coefficients uploaded if needed. An external calibration would follow before remaining in NORMOP, for a total test duration of 12 days.

This test, like for test IASI-EOL-16, was repeated due to an anomaly triggering: A STANDBY REFUSE was triggered during the transition to HEATER 2. IASI was taken to HEATER 2 with routine settings after power cycle, while waiting for the anomaly to be investigated. After several ARBs, it appeared that the on board monitoring of the DPC was not consistent with the status of the DPCs, the DPC1 still being ON and not OFF as expected and written in the FOM. After an update of DPC monitoring, the transition to HEATER 2 was achieved successfully with 3 pixels Off and a target temperature of the CBS at  $-187^{\circ}\text{C}$ . The final target of  $-185.3^{\circ}\text{C}$  was set up on-board and MAS parameters (gain and offset) were adjusted right after. This required quite some effort, as CNES had to send new inputs to be modified in monitoring procedure, new CBS temperature targets, with a consequent de-scoping of TOP-18 uplink, and an agreement to stay in NORMOP less time than planned in order to give priority to IASI-EOL-16 reattempt. Since the second attempt of EOL-16 was not successful, it was agreed with CNES in an ARB to go back to IASI-EOL-18 in order to perform an External Calibration and a MAS table update that was removed by mistake in the second attempt.

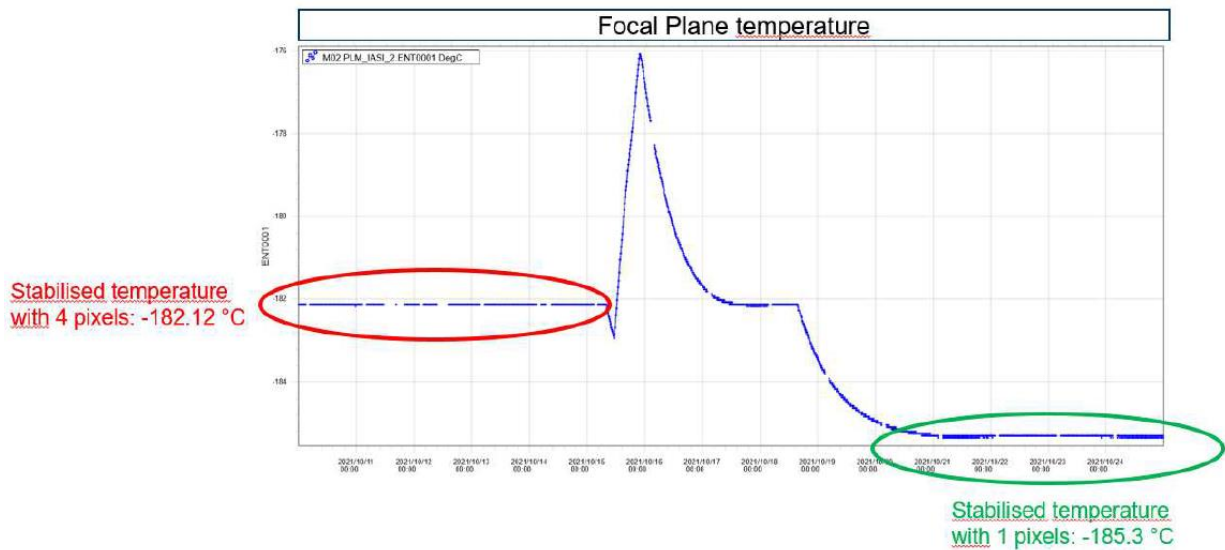


Figure 24 - Temperature stabilization with only 1 pixel ON

This anomaly had a high impact on the rescheduling of the activities as well as requiring long commanding time. CNES had to recreate the configuration tables to be uploaded, an activity that took itself time and impacted the test rescheduling. In order to re-perform the test in the little available time, operational procedures and datastores have been manually updated directly from the operational environment, adding risks of errors and without the possibility to revalidate the new products, nor to have a final feedback from industry after making important changes in the test timeline. This level of risk was accepted as considered still safe for the instrument, being IASI-EOL-18 the first on a list of tests in campaign IV. At the same time, the only time constraint presented was related to the schedule, while the outage created by the additional testing was irrelevant for the users, having declared end of mission right before its execution. In preparation phase the effort was quite high, mostly in planning the activity and foreseeing the temperature evolution, but also datastores for monitoring needed to be created as well as ad-hoc datastores whose inputs could only be given by CNES moments before their foreseen uplink: lots of flexibility on OPS/CNES teams

was required because of this, and because of a certain degree of impossibility to predict the outcome timings required for some steps. In execution instead high effort was required due to anomaly triggered by wrong input in the monitoring procedure, limited CNES availability during the time of anomaly, limited time to reschedule the activity. Overall the lesson learned was to leave more spare time in the EOL timeline and to identify high risk steps and ensure industry real time support to react quickly to possible issues.

To be noted that in this frame, IASI-EOL-16 and IASI-EOL-18 were re-performed multiple times one after the other, with a mutual impact in terms of operations preparation and execution: during the second attempt of the IASI-EOL-16 test, the MAS parameters were those used during IASI-EOL-18 and at the end of the IASI-EOL-16, MAS default parameters were reloaded after the switch off, all steps that needed additional time in preparation and execution. In conclusion, the results of the test were very close to the expectation as they brought new elements of validation of the thermal instrument and detector models, but the multiple anomalies occurred highly impacted the initial plan.

### 3.3.2 IASI-EOL-01/02

The preparation and execution effort for these tests was very low, requiring only a re-deployment of old procedures used during Metop-C SIOV, with minor modifications. The time consuming part would be the post-test analysis: if a first feedback could be given after a week, a further and deeper analysis from CNES and TAS would require months. The release itself took approximately 35 minutes (for each LFD), however approximately 1-2 orbits of product monitoring and AOCS performance monitoring was required to assess the instrument performance.

A minimum of 4 days in NORMOP mode were also needed to acquire data, and were possibly the only operational constraint of the test. The overlapping with other tests was instead minor with flexibility in commanding.

After such a long period in space in a locked configuration, the deployment of the LFD might exceed the duration in NORMOP of test IASI-EOL-01. This is why, it was proposed to stay in NORMOP for a while during IASI-EOL-02 to gain more confidence in the success of the LFD deployment by monitoring the stability between IASI and AVHRR. After the release of the LFDs and when IASI was in NORMOP, a STANDBY REFUSE was triggered due to a DPS RS422 dialogue error. The routine contingency procedure to recover from STANDBY REFUSE to NORMOP was applied, which brought IASI back to NORMOP the day after. The default TOP had to be uploaded since the ad-hoc TOP for test IASI-EOL-18 was eventually not uplinked due to the anomalies previously described: this was done afterwards and was followed by the transition to NORMOP the same day. Another deviation from the initial plan, was to start the test with a power cycle in order to reset the configuration and start from a clean slate.

The first part of the LSD release was too time consuming to be executed entirely within 1 day working hours: the third release was then planned the following day, by leaving the instrument overnight in HEATER warm up, as leaving it in heater deployment without direct monitoring wasn't recommended by industry: a small deviation that had no impact in the schedule. IASI-EOL-02 went without issues and required almost no preparation time, as the external calibration were performed with tables already used in the frame of other activities.

In the aftermath of the test, one of the conclusions showed that the duration of the experiment was not long enough to draw any conclusions regarding a potential detrimental effect of the ghost effect on the L2 retrievals of temperature and water vapor. This means that to obtain some results more time spent in NORMOP to acquire data was needed. This was impossible with the final schedule, but would have been if no additional time was allocated to re-do failed tests. Nevertheless, the release of the LFD SMA ran as expected and the variation of the SMA temperature showed the plateau confirming the phase transition and therefore the elongation of the material, as it can be seen in the picture below.

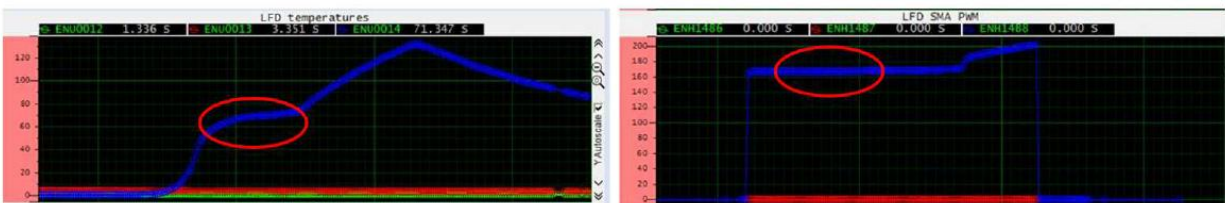


Figure 25 - LFD temperature (left) and LFD SMA (right)

At AOCs satellite level, the only dynamics effect noticeable, was the restart of the CD mechanism which motion compensates for the motion of the CC mechanism. It can be observed that the level of perturbation was similar to the one observed in Normal OP before 2015, with the configuration LFD not released, CD ON.

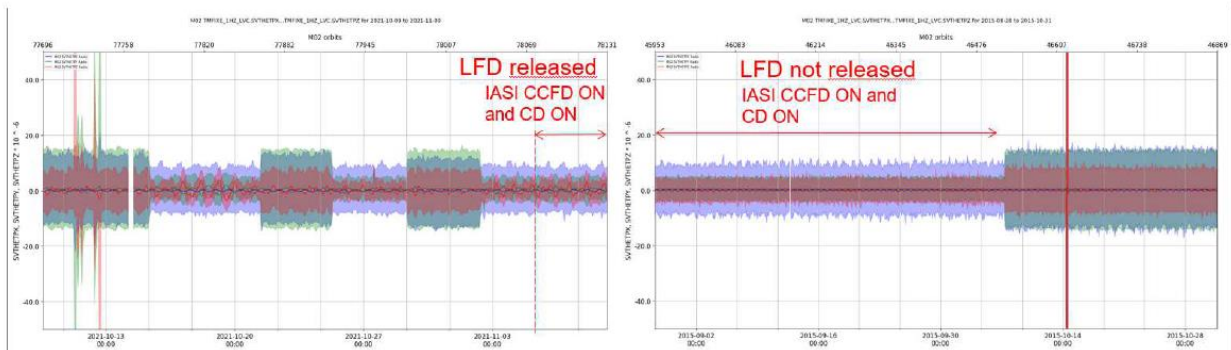


Figure 26 - LFD released (left) and LFD not released (right)

For what concern the second part of the test (IASI-EOL-02) it can be seen that the CD was stopped successfully in the configuration of LFD deployed, and this test has proven that the CD OFF/LFD unlocked configuration is possible for IASI instruments in flight, if the release of LFD turns out to be necessary due to unacceptable new perturbations from other instruments on MetOp platform.

### 3.3.3 IASI-EOL-03

In this test, there were no configuration constraints on the instrument, only on the satellite AOCs. The intended operation itself (keeping the instrument switched on) does not imply a high risk but the complexity arises when it is necessary to perform the science dump: the chance to inter-calibrate IASI-A and -B would present mostly over the poles, but executing a simultaneous dump of the two spacecraft is not feasible/possible over SVL alone. Moreover, the flight path of the two spacecraft would be different, leaving the overlap of the swaths reduced. Operations were then quite complex, mostly in terms of preparation involving the flight dynamic team: three satellites flying, phase between satellites changed, EOL operations started and limited time of the ground station availability to dump the data (due to the use for Metop-B and Metop-C).

Nevertheless, from IASI perspective no extra procedures have to be developed and no operations involving instrument mode change were foreseen. Once a dump strategy has been developed, there was no additional complexity in keeping an additional instrument ON during Phase 2 of EOL.

### 3.3.4 IASI-EOL-17

No special operations on IASI were necessary for this test, except the uplink of new tables to allow the particular acquisition. A dedicated coding table was built, adapted to limb acquisitions and based on simulations of limb measurements between 20 to 100 km height. The coding table was applied to both Nadir Earth View and CS2 targets.

A dedicated external calibration was also tuned to optimize limb measurements during the test using both Nadir Earth View Target and CS2 target. The test was composed with 2 phases of 2 consecutive sequences using the Earth Nadir and the CS2 views. Data were acquired in External calibration mode. The duration of IASI-EOL-17 was of less than one day, but it required great coordination and flexibility from different perspectives: the OPS team had to manually upload all the TCs with a visibility window of

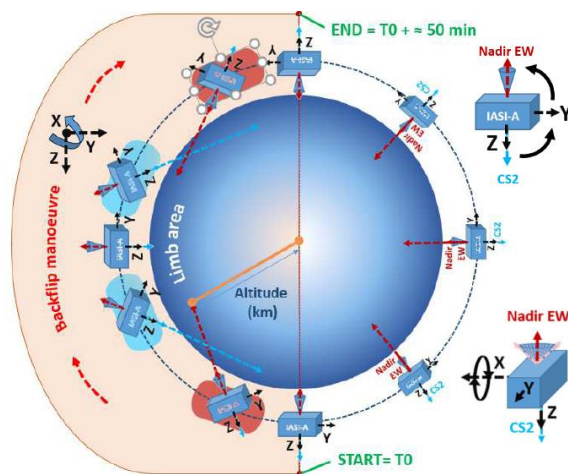


Figure 27 - Graphic of the EOL-17 test using alternatively Nadir views and CS2 views

only 250 minutes in the future, as with the approach of the PL deactivation and final maneuvers, the flight dynamics team had to recalculate the events with little anticipation, reflecting this aspect with a short timeline on MPF. Because of this OPS team had to watch out very carefully for overlapping of time tagged TCs with routine commands and other tests performed in parallel. The time tagged commands had to be uploaded onboard 2 days before the actual execution for lack of commanding slots close to the target time, the time of the backflip maneuver. The only procedures that had to be uplinked few hours before its execution were the ones related to the update of IASI coding tables, for which a slot on the Mission timeline was reserved. This was necessary because CNES would have been able to decide the necessity of them only on the same day. The coding table was perfectly adapted and so was the timeline of the external calibration.

The results from the test show exploitable spectra for the first Nadir Earth view acquisition sequence. Because the detector temperature of SB1 increased very quickly, the SB1 data acquired 10 min after the beginning of the test cannot be exploited. Therefore, the last Nadir Earth view sequence is likely to be exploitable for SB2 and SB3 only. The CS2 L0 data acquired during both phases will be reprocessed to provide additional limb measurements to the users.

#### 4. Fallback plans and contingency handling

The project presented an exhaustive analysis of potential contingencies and their mitigation, covering unforeseen delays in the schedule and related mission planning rescheduling, spacecraft anomalies and related priorities for the team in case of Metop-B or Metop-C issues, ground station contingencies, control centre contingencies, evacuation to back-up control center (BUCC). In the frame of IASI Tech and EOL test, no specific ad-hoc fallback plan was prepared in advance, mostly due to the high number of possible contingency scenarios that could happen. Especially in campaign I and III each test presented the option to re-apply the original settings in case of failure, while toward the end of campaign III and IV as the risk increased, some failure scenarios could have been not reversible, like in case of LFD release failure or errors in the manoeuvre in Campaign IV. The risks associated to each test have been shown and analyzed in chapter 2 as one of the main drivers to the test allocation in the timeline, nevertheless other types of contingencies not associated to the test can affect the plan at any time, like SEU or SET due to radiations, which can be quite common events.

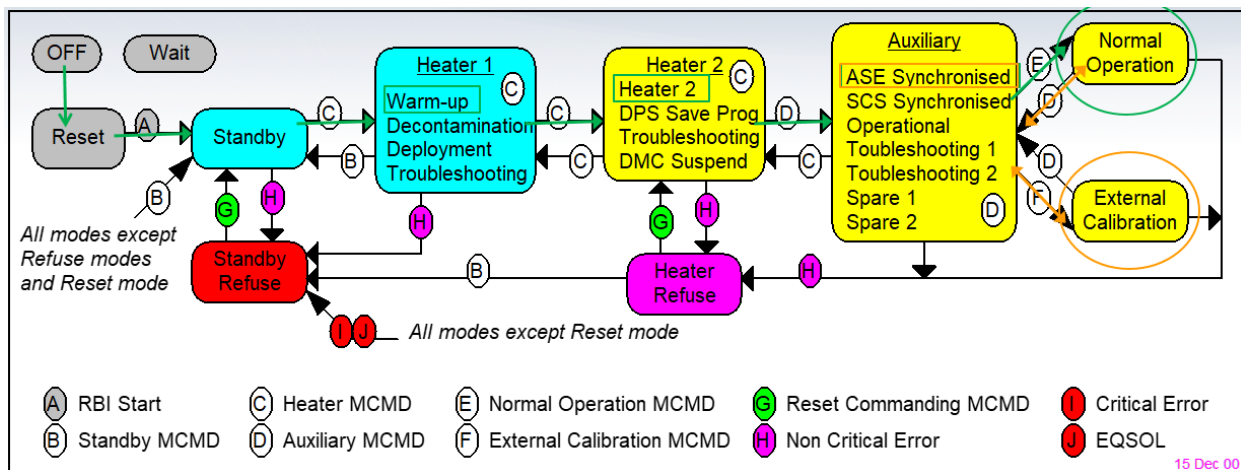


Figure 28 - IASI Nominal and contingency modes

These errors can bring in fact IASI to STANDBY REFUSE or HEATER REFUSE, adding time to the recovery – not only for the recovery itself but for the consequent loss of thermal stabilization that comes with a mode change to a lower state. This was the case of IASI-EOL-15 and IASI-EOL-16. In preparation for such routine anomalies the on-call engineer was instructed on a daily basis by the IASI FCT engineer when they would be able to recover the instrument following the baseline documentation, and when an ad hoc SOI was needed. The first case applies when IASI was in NORMOP with default configuration, or when in a lower mode where such FDIR couldn't trigger.

Most of the times though, since a lot of tables were uploaded from HEATER 2 or AUX ASE mode, this would require the instrument to be properly reconfigured and brought to NORMOP by IASI expert. When possible, especially in cases where IASI was supposed to be in NORMOP for long like for IASI-EOL-15, a fallback SOI was prepared along with a re-deployment of old procedures so that the on-call engineer could safely recover the instrument outside working hours. This was though a very rare case, as the fast pace of the schedule and the high rate of contingencies made it difficult to prepare recovery procedures during the EOL tests phase, resulting in the IASI expert being available on best effort outside working hours or accepting longer outages.

A different approach was to be taken when a non-routine anomaly would happen, either in relation to the test performed or something unexpected at payload or platform level switching off IASI. This latter case would have presented longer waiting times with consequent impact on the timeline, but no additional effort from IASI team being the anomaly affecting another subsystem. More frequent was the first scenario instead, and a good example was IASI-EOL-18: the anomaly was triggered due to the upload of a wrong configuration datastore bringing IASI to STANDBY REFUSE. In this case 3 days were needed to sort out the reason and the way forward, new configuration tables were delivered and uplinked cutting through the formal process in order to save time, and operational datastores were manually updated directly in the operational system, adding a certain level of risk, but mitigated by multiple members of the operations team carrying out checks. It's worth mentioning anyway that this operational approach was not the routine one, it was just an option agreed for EOL non-destructive tests.

In these cases, the investigation phase could become even longer when anomalies happened outside working hours, as no industry support was foreseen. A particular contingency scenario happened in the frame of IASI-EOL-18: after the STANDBY REFUSE was triggered late on Friday for an unknown reason, the baseline plan would have been to leave the instrument as is until Monday, losing in this way thermal stability that would have taken several hours/days to re-gain on the following working day: IASI OPS team decided then to temporarily bring IASI to a thermally stable configuration with default settings bringing it to HEATER 2 mode. This prevented then an additional day of delay in the operations without endangering the instrument and without the need of CNES' support. A different contingency scenario happened in the frame of IASI-EOL-16, where due to a human error in the FMU configuration the instrument couldn't acquire data: being this a known tricky operation that created confusion in the past as well, and to prevent this scenario from happening again in the frame of future power cycles with cross strapped configurations, a different ad-hoc SOI with all the possible combinations was created in order to avoid similar mistakes – basically an SOI with extra notes on the line of a technical note, to be used as fallback scenario to cover every possible combination for whole IASI activation in cross-strapped configuration. This eventually ended up being very useful for the whole duration of EOL. One good example of fallback plan that brings along a valuable lesson, was in the frame of IASI-EOL-01, described in chapter 4, when a STANDBY REFUSE was triggered during the night. Despite the recovery being standard, the support of IASI expert was needed mostly for the short duration of the night passes, which have about half the duration of the day ones, with consequences on the standard recovery procedure which was based on day time passes of ~12 min. The recovery in this case was expected to last possibly 10-12h due to the reduced passes time which was not compatible with the previous 10 hours working day. In this case in the frame of the recovery, all the initial RTTF and memory dumps for anomaly investigation were skipped as the cause was most likely known and due to a SET. When possible, procedures have been uploaded with time tags in order to save execution time during the pass, and eventually in the transition to NORMOP, temperature stabilization period to allow data acquisition was skipped: once that the parameters with an FDIR implemented were inside the limits, a transition to NORMOP was commanded, with the only side effect of triggering ground OOL related to IASI performances without affecting its health status. This saved several additional hours of recovery allowing the on-call engineer and IASI expert to leave the control room.

To wrap up, while the creation of fallback scenarios didn't take too much effort in reparation phase avoiding a non-necessary time consuming activity, the attempted recovery from contingency scenarios during execution required much more effort than planned, as a campaign requirement was that failed tests wouldn't be re-run. This affected as consequence the precision and detail-oriented initial approach of these tests, which was required due to the unprecedented execution of them, as well as taking a toll on the parties involved. This aspect will be better analyzed in the next chapter.

## 5. Resources handling and the Covid-19 impact

The matter of the available human resources for the project, was one of the requirements of the Lifetime extension strategy, which was to exploit on best effort the teams involved while avoiding interference with Metop-C or EPS-SG ops prep, SVT, launch, SIOV and commissioning activities. These kind of points are often handled by ensuring no overlap on the scheduled activities, underestimating instead the preparation phases, sometimes quite difficult to quantify. While the workload prediction for the preparation of each test was more or less accurate despite a few exceptions due to last minute changes, the underestimation of human driven aspects had a higher impact than the workload during execution phase: the plan initially reported in the figure below didn't consider possible shifts of EPS-SG milestones due mostly to industry's delays which was more affected by Covid-19, made worst by the isolation that came with it.

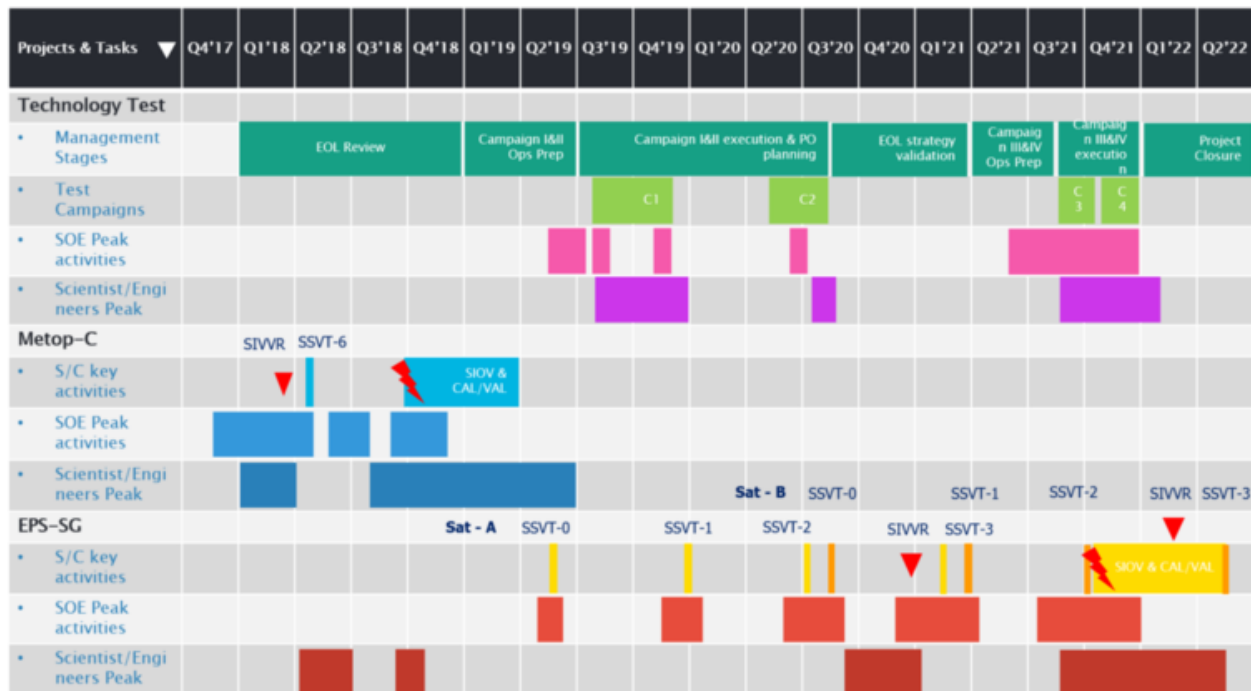


Figure 29 - Metop-C, Tech Tests, and EPS-SG activities timeline

This shifted as a consequence the workload peaks of the teams involved creating overlaps in tasks. Priority to Technology Tests and EOL were overall given by the feeling of urgency, and while there have been no visible effects on the readiness for EPS-SG SVTs, this took a toll on engineers' stress level and focus due to unplanned and extended working hours for extended periods.

In addition to the timeline reported in Figure 29, there was also to take into account the parallel work done to implement and execute the IASI Lunar acquisition in CS2 on Metop-B and C, a parallel project that was born at first as an EOL test, later discarded as such due to the magnitude of the work involved which required allocated resources, and the high level of interest from the users. The preparation and execution of this campaign, which required high preparation effort from both EUMETSAT and CNES, was done in parallel to the whole duration of Tech Tests and EOL. On both EUMETSAT and CNES sides, teams were involved and were carrying on tasks for EPS-SG in parallel, making members unavailable during important meetings, which was made worse by the impossibility to meet in person for the duration of 2 years, with an impact on the level of communication among teams. While on paper every milestone was reached and KPIs met with the production of the relevant documentation, the quality was impacted due to a waterfall effect of many factors, such as an overall underestimation of the workload required, high teams' member turnover with consequent loss of know-how, impossibility to meet in person and to access key facilities, absence of a synchronized coordination and teams'

involvement in other missions.. This was also reflected by the extra effort put in the tests execution, with multiple re-attempts of failed tests in an already very tight timeline. Working shifts have been set up to cover extended commanding passes, although with a change in the team leading to a new IASI engineer being appointed, only one could cover the most critical parts, since the new one had no time to get fully up to speed with the instrument to provide the expert level of support needed to react to certain contingencies. The overall sense of urgency and priority, along with the impossibility for the on-call engineer to recover the instrument from anomalies outside working hours, led the main IASI engineer to be practically on call for the instrument for the duration of 2 months, during campaign III-IV. In hindsight, a more efficient allocation of the resources and better coordination among teams was probably needed; also, a closer monitoring of the activities during tests executions could have prevented additional investigation time during the anomalies. In addition, it would have been an advantage to have experts' availability and live monitoring during key steps of the tests, either where the outcome was unforeseeable or the commanding was critical, as well as a more attentive scheduling of critical steps toward the beginning of the week, away from weekends/festivities and end of working hours.

On a last note, it's worth mentioning that there were a lot of unexpected and new factors, from covid-19 to the novelty of the tests themselves, so all the lessons learned during this campaign weren't necessarily addressable in advance, nor was possible to estimate or control the consequences of these many factors.

Covid-19 in particular, not only played a huge role on people's mental health by leading to isolation and forcing a change of habits, but also presented a huge challenge for every company and project, leading to the need to create specific contingency scenarios where teams wouldn't be allowed in the control room or other key facilities either due to a Covid outbreak within the team or by national regulations. When not forced to work from home, a specific setup based on teams' rotation was set in place, and controllers started to cover both Space and Ground segment to avoid cross-contamination, taking on them a higher workload with some side-effects on the monitoring and activities execution of Metop-A Tech Tests. One of the biggest consequences of this teams' rotation setup on OPS side, was the limited access to the Validation room (PSR) requiring very good organizational skills, in order to focus all the validations during the on-site week, or any other week. An exception was made during Technology tests execution, where the elaboration in PSR of last minute deliveries from CNES where considered priorities and access was granted. Also in these case though, the time was never enough to do proper product validations, the PSR was merely used to create the OPS product starting from CNES input files, but as a general rule a very small percentage of operational products were validated, most times impossible for lack of time between the delivery and the scheduled uplink.

## 6. Conclusion

As it was initially stated, the purpose of this paper was to describe in details the operations preparation and execution of IASI Tech Tests and EOL activities for Metop-A, with particular emphasis on the planning and scheduling. It is clear now that this aspect has been the more critical and challenging of the whole project, not just for the huge number of parties and facilities involved inside and outside Eumetsat, but for the unique conditions in which it was performed.

Nevertheless, despite the shortage of time available, every test was fully or partially successfully executed, bringing valuable results in each of the 7 categories shown in the first part of the paper. What made the difference despite all the obstacles, it was the team willingness to overcome them, a great teamwork and cooperation between EUMETSAT and CNES which led to find new and more efficient ways to communicate on a daily basis, the long hours spent in joint effort to solve anomalies and mutual availability beyond agreements and contracts.

## 7. Acknowledgements

No big project is the result of one-man job. A big acknowledgement and thanks goes to EUMETSAT OPS team, Flight dynamics team, Mission planning team, CNES and TAS for the hard work throughout the years. The picture below is a reminder of an intense journey that ended up in the best way foreseeable.

