

IASI-NG: Instrument in orbit calibration and validation

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ABSTRACT

IASI-NG is the new-generation Earth-observing instrument that will continue the legacy of IASI on the METOP series of polar-orbiting platforms. Operating in the thermal-infrared band (3.6 μm – 15.5 μm) and employing Fourier-transform interferometry, IASI-NG delivers operational meteorological products (temperature and humidity profiles) and global monitoring of key trace gases such as ozone, methane and carbon monoxide. Thanks to an innovative instrument concept: the Mertz compensated interferometer, it achieves a two-fold improvement in both radiometric signal-to-noise ratio and spectral resolution compared with its predecessor, while maintaining a swath width of roughly 2 000 km and a spatial sampling of 25 km.

To validate the performance of this complex system in the space environment, an eight-month in-orbit calibration and validation campaign (CALVAL) was conducted. The CALVAL program addressed more than 70 requirements using data coming from a set of dedicated operating modes as well as innovative activities. These activities enabled a thorough assessment of radiometric, spectral and geometric behaviours.

The results of CALVAL demonstrate that IASI-NG meets or exceeds its design specifications across all critical performance domains:

- NEDT in line, or better than the specification
- Very good spectral calibration
- High accuracy product registration between IASI-NG and METImage
- Successful radiometric comparison with IASI

Consequently, IASI-NG is poised to extend the IASI data record with markedly enhanced capabilities, supporting advances in three primary scientific fields: meteorology, atmospheric chemistry, and climate monitoring.

Keywords: Infrared, Spectrometer, CALVAL, Performances

1. INTRODUCTION

IASI-NG (Infrared Atmospheric Sounding Interferometer – New Generation) is the follow-on mission to IASI. Even though the objectives remain the same, the significant expected performance improvements have led to the use of an unprecedented instrument concept in orbit: the Mertz interferometer. Because of this innovative concept, a comprehensive in-orbit validation was required to confirm the overall system performance.

In this article, the instrument’s architecture will be briefly described, after which the objectives of the CALVAL and the data used for the validation activities will be summarized. Finally, the main results will be highlighted.

2. IASI-NG INSTRUMENT AND SYSTEM DESCRIPTION

2.1 IASI-NG instrument in a nutshell

IASI-NG (Infrared Atmospheric Sounding Interferometer – New Generation) is the follow-on mission to IASI. It provides operational meteorological data, such as temperature and humidity atmospheric profiles, and monitors trace gases (ozone, methane, carbon monoxide,...) on a global scale. The instrument performs spectral measurements in the infrared ($3.6\ \mu\text{m}$ – $15.5\ \mu\text{m}$) using Fourier-transform interferometry. A detailed description of the instrument and its operating principle is given in Ref. [1]; below is a summary of the main functions (see Figure 1).

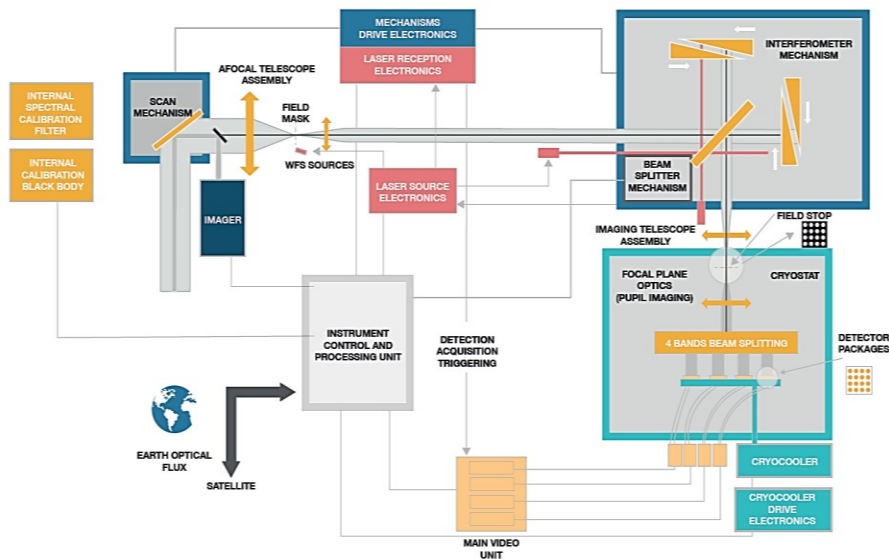


Figure 1: overall instrument functional description

The beam enters the instrument through a two-axis pointing mirror (the **SCAN**) that selects Earth views and compensates for satellite velocity. It then passes an afocal telescope that reduces the pupil size before reaching the interferometer. At the interferometer output, an imaging telescope focuses the beam onto a field mask located at the entrance of the cryostat, which houses the four detector arrays for the four spectral bands.

A stabilized laser metrology source (LASE) is split into five sub-beams and injected into the interferometer; the beams are acquired and processed by the LARE electronics. The metrology serves two main purposes:

- Continuous OPD acquisition – the central metrology beam triggers the detection chain, ensuring a constant optical path difference (OPD).
- Interferometer geometry monitoring – the four lateral beams track geometric variations, enabling correction of the scientific data in the ground segment.

The scientific data are collected by four detectors (one per band), each containing 16 pixels. On-board analog and digital processing is performed by the Front-End Electronics (FEE), the Main Video Unit (MVU), and finally the Instrument Control & Processing Unit (ICPU).

All mechanisms (the SCAN and the interferometer mechanism) are driven by the Mechanisms Drive Electronics (MDE). The detectors are cooled by an active cryocooler.

The infrared imager (IMA) is also included on board IASI-NG; it is primarily used for the geolocation of the spectra.

2.2 IASI-NG operational acquisitions

The instrument performs continuous data acquisition throughout the mission lifetime. The swath is covered during a so-called Basic Repeat Cycle, which is repeated along the orbit. A typical observation sequence within this cycle consists of pointing the scan mirror successively toward the 14 Earth views to cover the required swath, followed by two successive radiometric-calibration positions: one aimed at a reference blackbody and the other at cold space. The entire sequence then repeats automatically.

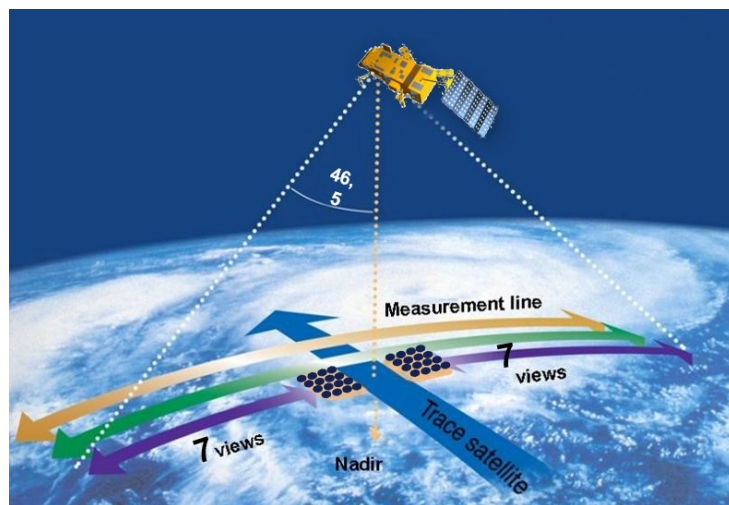


Figure 2: IASI-NG in orbit operational acquisitions

Each acquisition consists of:

- One interferogram per pixel (16 pixels) for each of the four detectors (B1, B2, B3, B4)
- One infrared image from the thermal imager

2.3 IASI-NG system

IASI-NG is a payload element of the second-generation European meteorological polar-orbiting satellites (METOP-SG), which are dedicated to operational meteorology, atmospheric chemistry, and climate monitoring. Consequently, the IASI-NG system is integrated into the overall EPS-SG (EUMETSAT Polar System – Second Generation) architecture.

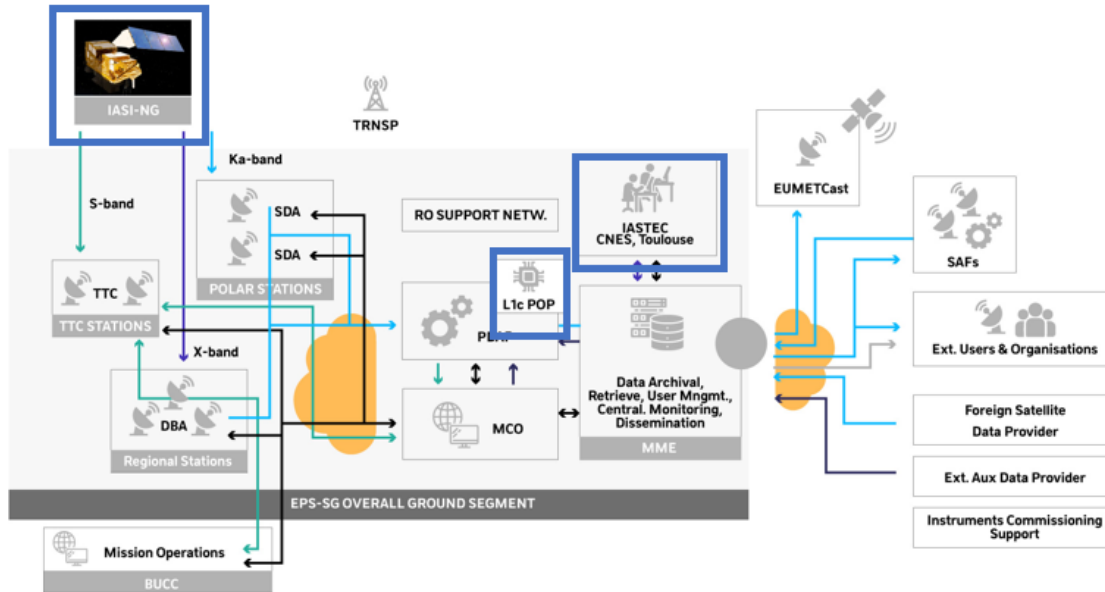


Figure 3: IASI-NG in the EPS-SG system

The IASI-NG system consists of:

- A space segment installed on each Metop-SG A satellite (described above).
- A ground segment, which includes:
 - The IASI-NG Level-1 processor (L1C POP) – integrated into the EUMETSAT EPS-SG ground system for processing and delivering Level-1 products. A local version of this processor (L1C LOP), dedicated to centers that perform direct broadcasting and in-situ data processing, is also provided and can operate independently of the PDAP (EUMETSAT operational processing infrastructure).
 - The IASI-NG Technical Expertise Centre (IASTEC) at CNES, Toulouse. This center has several responsibilities:
 - Ensuring the health of the instrument.
 - Monitoring instrument performance.
 - Monitoring Level-1 performance.
 - Calculating and updating instrument and Level-1 tuning parameters.

2.4 IASI-NG objectives

Compared with the IASI first-generation specifications, IASI-NG system will improve the radiometric signal-to-noise ratio and the spectral resolution by a factor of two. Figure 4 shows the main instrument requirements:

Geometry	Sounder pixel size	~12 km	same as IASI
	Spatial sampling	~25 km	
	Geolocation error	0.5 km	
Spectral	Band	645 cm ⁻¹ to 2760 cm ⁻¹	2 times better than IASI
	Resolution	0,25 cm ⁻¹	
	Sampling	0,12 cm ⁻¹	
	Calibration error	$d\sigma/\sigma = 5 \cdot 10^{-7}$	
Radiometry	Calibration error	0,25K @ 280 K	2 times better than IASI
	NedT	NedT ~0.1 K to 0.4 K within spectrum	

Figure 4: IASI-NG system objective performances

Because of volume and mass constraints, the radiometric performance of IASI could not be improved simply by enlarging the pupil. The chosen solution was to increase the field-of-view (FOV) and, consequently, the integration time. The resulting FOV is on the order of $100 \times 100 \text{ km}^2$, with a swath width of roughly 2 000 km and a spatial sampling of 25 km.

To compensate for the associated field effects, such as a marked loss of radiometric contrast and spectral resolution, a correction is applied directly in the pupil. This is the first time that a so-called Mertz-Concept Interferometer is used in space. The correction is achieved by inserting a dynamically varying glass thickness into the interferometer while it swings, thereby correcting the off-axis optical-path-difference (OPD) variations. In practice, two pairs of KBr prisms are moved synchronously with the interferometer mirrors by a patented “dual-swing” mechanism driven by a single motor.

Compared with the first-generation IASI, the instrument’s spectral resolution and sampling are improved by a factor of two, obtained by doubling the interferometer’s total OPD to about 8 cm (± 4 cm).

3. CALVAL

3.1 Objectives of the CALVAL

The objectives of the CALVAL are to verify the system requirements related to:

- Radiometric performances of the sounder
- Spectral performances of the sounder
- Comparison with other sounders
- Imager performance
- Geometric performance
- In-orbit behavior of the instrument

The campaign covers roughly 70 requirements that must be validated over the eight-month CALVAL period, using more than 50 separate analyses.

3.2 CALVAL classical activities

IASI-NG has been designed with a variety of operating modes that allow us to validate the instrument's performances while it is in orbit. These modes are readily accessible and can be used at any point during the instrument's on-orbit life. All of the following modes were exercised during the CALVAL campaign:

- **OPER (Nominal operational mode)** – Used throughout CALVAL to assess the majority of IASI-NG's performance, especially its spectral characteristics.
- **OPER_EXTCAL BB** – Only the internal hot blackbody and the cold-space view are presented to the instrument. This mode is primarily used for radiometric-performance studies, in particular the NEDT (for both the sounder and the imager).
- **OPER_EXTCAL CS1 and CS2** – Only one of the two cold-space views is visible. The purpose is to evaluate the stability of the cold-space view, a parameter that is critical for radiometric performance.
- **OPER_EXTCAL Nadir (or Around-Nadir)** – The instrument sees either the nadir view alone or the three views surrounding nadir (the calibration views remain unchanged). These acquisitions are used to estimate inter-pixel performance.
- **OPER_EXTCAL Back Scan** – All Earth views are replaced by a view of the back of the scan mirror. These special measurements are employed to study the thermal behaviour of the scan mirror; the resulting model is needed in L1 processing to correct temperature-induced effects.
- **OPER_EXTCAL FPI** – The instrument looks at the Fabry-Perot interferometer (FPI) instead of Earth scenes. The FPI provides a spectrum rich in regular, well-defined, lines that together with atmospheric lines, are used to assess spectral performance.
- **WFS_ISRF** – An investigation mode in which a dedicated laser source is used to establish the Instrument Spectral Response Function (ISRF) while in orbit.
- **WFS_WFS** – An investigation mode that employs a specific laser source (same as WFS_ISRF) to determine the wave-front shape across the instrument.
- **CHECK_MEC_MET** – An investigation mode that records high-frequency metrology (LASE) and mechanism (SCAN, IFM)-state data, allowing a very precise study of the in-orbit behaviour of these critical components.

In addition to the activities performed with these “standard” instrument modes, several supplementary investigations were carried out during CALVAL

3.3 Particular CALVAL activities

During CALVAL a number of special activities were carried out that will not be repeated during nominal operations.

- **Moon acquisitions** – Because of orbital geometry, the Moon sometimes enters the field-of-view of the cold-space view CS2 (about once per month) and of CS1 (twice per year). In nominal operation we will avoid this by changing the cold-space view, but during CALVAL we deliberately used the OPER_EXTCAL scenario so that the Moon was visible during every Earth-view step. This allowed us to investigate:
 - inter-pixel radiometric performance,
 - radiometric calibration,
 - the imager (IMA) field-of-view,
 - radiometric comparison between IASI and IASI-NG.

- **Roll manoeuvres** – Three roll manoeuvres were performed during CALVAL. These maneuvers are performed to change the attitude of the MetOp satellite so that the scientific instruments can point toward deep space instead of Earth (during this maneuver the MetOp spacecraft is positioned on its “back” side). They were originally requested by other instruments on the platform, but we used them in orbit to:
 - compare vignetting effects on the Earth-view steps (by keeping the same cold-space view),
 - refine the reflectivity model of the scan mirror.
- **Tandem flight with IASI** – To support performance analysis of IASI-NG and to achieve a precise assessment relative to the IASI first-generation, a two-month tandem flight was carried out. During this period IASI and IASI-NG followed the same ground track with only a 30-second offset. The tandem operation enabled direct, spectrum-by-spectrum comparisons:
 - covering all parts of the Earth and a wide range of surface and atmospheric conditions,
 - providing not only statistical validation but also point-wise spectral matching.

4. CALVAL MAIN RESULTS AND LESSONS LEARNED

4.1 Radiometric main results

During CALVAL, 27 individual activities were carried out to satisfy 12 specific radiometric requirements. The most significant outcomes pertain to the NEDT and the radiometric calibration. The NEDT measured in orbit is of very high quality, in fact it is even slightly better than the values obtained during ground testing.

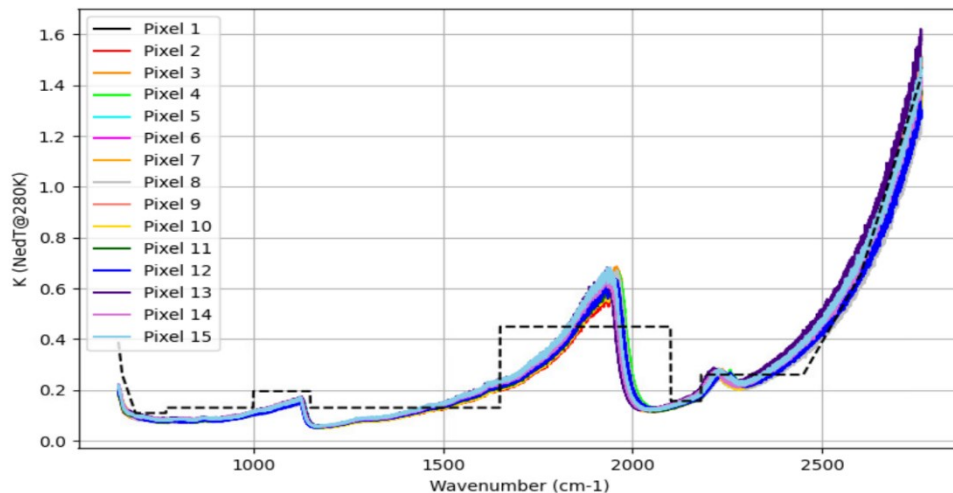


Figure 5: IASI-NG in flight NEDT

In parallel, a radiometric-calibration effort was conducted using in-orbit data. Although absolute performance could not be quantified, due to the absence of truly calibrated reference sources, comparisons with IASI data enabled a thorough assessment. These analyses demonstrate that IASI-NG’s absolute radiometric accuracy meets the required specifications.

4.2 Spectroscopic main results

During CALVAL an assessment of the spectral performance was carried out. This work was essential because the ground-based validation, performed with a gas-cell test, was not sufficiently accurate to verify the demanding 5×10^{-7}

requirement. In orbit we selected a representative set of atmospheric spectra and then evaluated the instrument's performance by analyzing the atmospheric absorption lines present in those spectra. The results confirmed that the spectral specifications are satisfied.

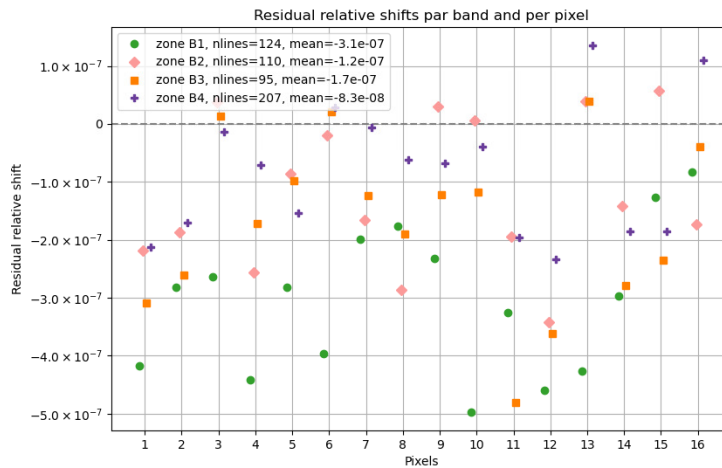


Figure 6: In flight Spectral shift estimation

This plot shows that the requirement is satisfied for every pixel and across all bands. During CALVAL, this evaluation was repeated across a variety of orbits, confirming the good stability of IASI-NG spectral calibration.

4.3 Radiometric comparison main results

To ensure continuity of the temporal studies between the first- and second-generation IASI instruments, a tandem period was established during which IASI and IASI-NG operated side-by-side, with the two MetOp satellites trailing each other by only 30 seconds. This configuration enabled the following comparison:

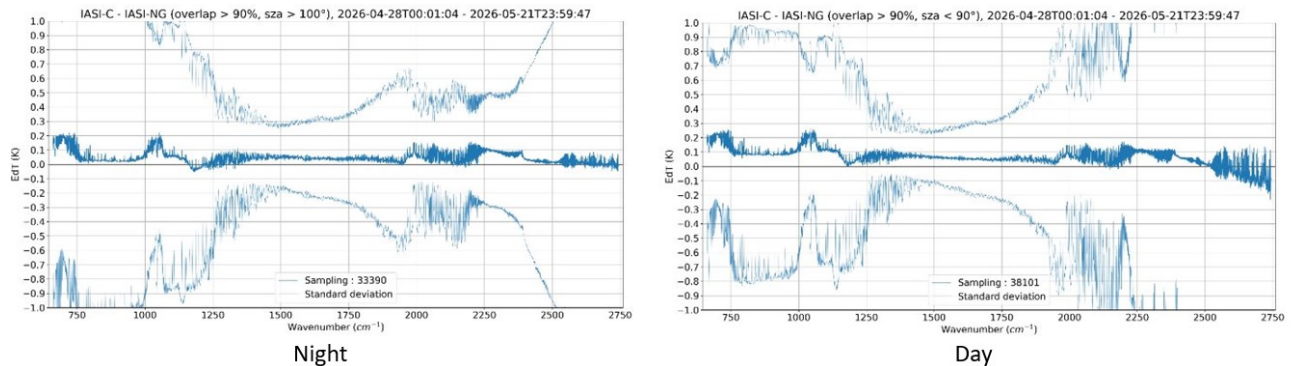


Figure 7: In flight IASI and IASI-NG intercomparison (mean and standard dev.)

These results demonstrate good agreement between IASI and IASI-NG and indirectly confirm the quality of the IASI-NG radiometric calibration.

4.4 IMA main results

An assessment of the in-orbit behaviour of the IASI-NG imager has been done. The main objectives were to evaluate the stability and quality of the measurements. The results obtained show an NEDT lower than the specification (0.5 K) and very good stability of the radiometric calibration.

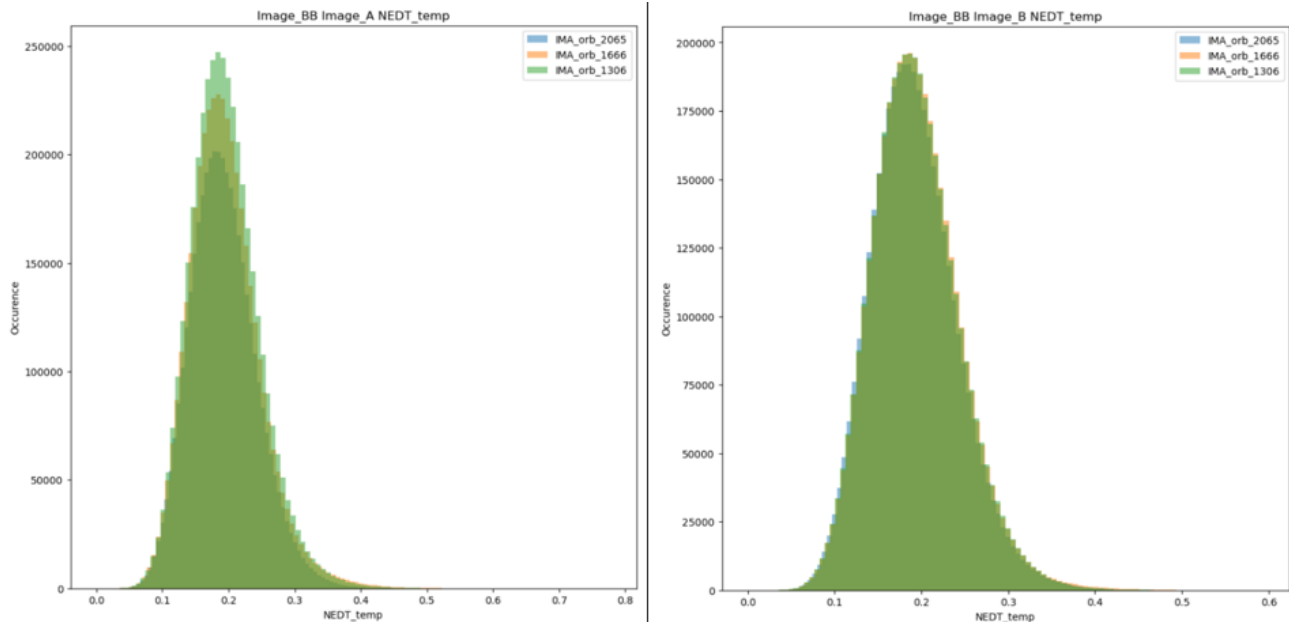


Figure 8: Comparison of imager A and B NedT reached values (in K) in terms of occurrences

4.5 Geometric main results

The geometric performance is established through two activities:

- Determination of a static bias between the IASI-NG IMA and the IASI-NG sounder.
- Evaluation of the coregistration performance between the IMA and METImage (the imager aboard MetOp-SG). This coregistration is performed dynamically to compensate for thermo-elastic effects.

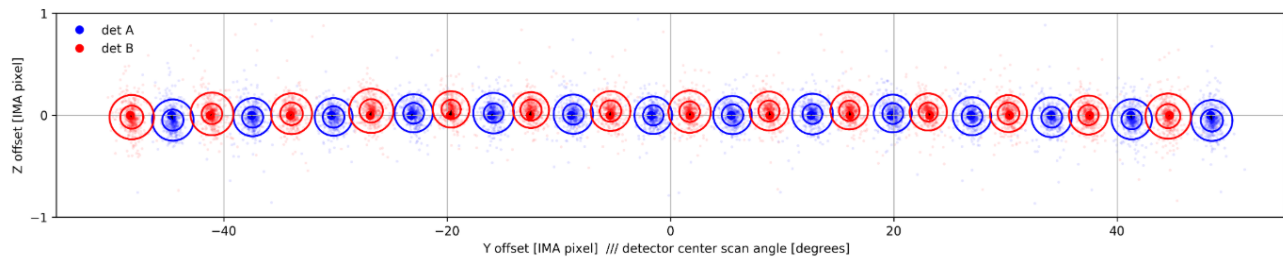


Figure 9: IMA / METI coregistration

Thanks to these two activities, it has been demonstrated that the coregistration between the IASI-NG sounder and METImage is better than the specification.

4.6 Instrument behavior main results

During CALVAL a comprehensive monitoring of the main instrument components has been done:

- Thermal evolution (critical for radiometric stability). This study showed that the on-orbit temperature variability was larger than expected, so the SCAN thermal model had to be updated to improve the correction of this variability in the L1 processing chain.

- Geometrical stability of the beam splitter alignment (a parameter that must be closely watched because the interferometer's reflective surfaces are flat). Monitoring showed that the interferometer was well aligned after the SIOV, followed by a gradual evolution in alignment during the first few months in orbit. This evolution stays within the specified limits and now appears to have stabilized.
- Mechanism behavior: throughout CALVAL the mechanisms performed flawlessly.
- Metrology-system performance: the very good stability was verified and demonstrated during the first months in orbit.
- Micro-vibrations: this was a major focus during instrument development because the active cryocooler and other mechanisms can be a source of micro-vibrations. In orbit, however, the behaviour is entirely satisfactory.

5. CONCLUSION

Thanks to the 8 months of CALVAL activities the very good performances of the IASI-NG instrument have been demonstrated. IASI-NG will be able to continue the IASI legacy with significant improvement of the key performances. These improvements make it possible to envisage progress in the three scientific domains that will use IASI-NG data: meteorology, atmospheric chemistry, and climate monitoring.

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