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MSI (Multi Spectral Imager) performance check at integrated EarthCARE satellite system

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ABSTRACT

EarthCARE (Earth Clouds, Aerosols and Radiation Explorer) is the 6th Earth Explorer mission of ESA's "Living Planet Earth" Program. The EarthCARE satellite is about to start its environmental test campaign in autumn 2022. This Core Explorer mission (Core Explorer missions that focus on scientific objectives of a large scientific community) is a large and very complex Earth Explorer mission with 4 Instruments on board. It improves the representation and understanding of Earth's radiative balance for climate and numerical forecast models by advancing our understanding of the role that clouds and aerosols play in reflecting incident solar radiation back into space and trapping infrared radiation emitted from Earth's surface.

To achieve this goal, EarthCare is hosting a Multi-Spectral Imager (MSI), an Atmospheric Lidar (ATLID) and a Broad-Band Radiometer (BBR) under European ESA authority and a Cloud Profiling Radar (CPR) under JAXA (Japan Aerospace Exploration Agency) authority.

The EarthCare MSI Instrument consists in two camera units, the TIR (Thermal Infrared Radiometer) part with 3 channels (Band7 [8800nm], Band8 [10800nm] and Band9 [12000nm]) and an VNS (Visible, Near-infrared and Short-wave infrared) part with 4 channels (VIS [670nm], NIR [867nm], SWIR1 [1654nm] and SWIR2 [2214nm]) and by an overall weight of around 50kg (including control units, harness and thermal hardware).

The Instrument performance qualification consist in a full performance verification testing on instrument level and of regular instrument performance checks (IPCs) on Satellite level after Instrument integration. This performance checks for the MSI concentrate on a simplified test approach and are regularly repeated along the entire S/C AIT campaign until launch. The test results will be compared with first reference IPC measurements from instrument Level. MSI IPC definition does focus on radiometric key performance parameters as noise and responsivity to identify optical or detection chain degradations, as well as detector dead pixels.

This paper will present the MSI IPC approach for EarthCare and the first ambient results from S/C Level MSI IPCs performed so far. Furthermore this paper will show that the ambient S/C Level MSI IPC results are in line with the ambient IPC on instrument level but it will also shows good agreement with thermal vacuum results on Instrument level.

Keywords: EarthCARE, Multi-Spectral Imager, Performance Check, Ambient test results

1. INTRODUCTION

1.1 Earth Explorer Missions

Earth Explorer Core Missions are an element of the Earth Observation Envelope Program. They are defined as major missions led by ESA to cover primary research objectives set out in the Living Planet Program (ESA, 1998). The Earth Clouds, Aerosols and Radiation Explorer Mission (EarthCARE) has been approved for implementation as the third Earth Explorer Core Mission.

EarthCARE is a cooperative mission between ESA and JAXA, where JAXA will provide a Cloud Profiling Radar. ESA is responsible for the entire system including the Spacecraft, three instruments, the Launcher and the Ground Segment with the exception of the CPR data segment.

The EarthCARE Mission will help in determining the Earth radiation budget by providing global observations of vertical cloud and aerosol profiles. The mission is centered on the synergetic use of the data provided by an instrument suite consisting of an ATmospheric LIDar (ATLID), a Cloud Profiling Radar (CPR), a Multi-Spectral Imager (MSI) and a Broad Band Radiometer (BBR).

1.2 Scientific Objectives

The difficulty of representing clouds and aerosols and their interactions with radiation, constitutes a major source of uncertainty in predictions of climate change using numerical models of atmospheric circulation. Accurate representation of cloud processes is also critical for the improvement of numerical weather predication. A first step in gaining confidence in such predictions is to check that these models are at least correctly representative of the clouds and aerosols in the present climate. Unfortunately there are no global datasets providing simultaneously the vertical profiles of clouds and aerosol characteristics together with vertical temperature and humidity profiles and the top-of-the-atmosphere (TOA) radiance. Such datasets are crucial to validate the model parameterizations of cloud processes regarding both water and energy fluxes. The vertical profiles are important in controlling the radiative transfer processes in the atmosphere, and so affect the heating profiles, which then influence the dynamics.

Indirect aerosol effects on cloud radiative forcing as well as cloud parameterization are today the biggest sources of uncertainty in climate prediction. The critical cloud radiation feedback cannot be modelled without accurate cloud and aerosol parameterizations.

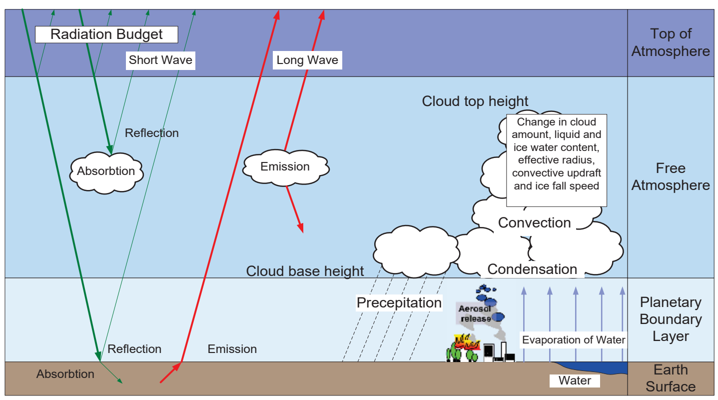


Figure 1. The scope of the EarthCARE mission. The objective is to retrieve vertical profiles of cloud and aerosol, and characteristics of the radiative and microphysical properties so as to determine flux gradients within the atmosphere and fluxes at the Earth's surface, as well as to measure directly the fluxes at the top of the atmosphere and also to clarify the processes involved in aerosol / cloud and cloud / precipitation / convection interactions..

For these reasons, EarthCARE has been specifically defined with the specific scientific objectives of quantifying aerosol-cloud-radiation interactions so they may be included correctly in climate and numerical weather forecasting models to provide:

- Vertical profiles of natural and anthropogenic aerosols on a global scale, their radiative properties and interaction with clouds
- Vertical distribution of atmospheric liquid water and ice on a global scale, their transport by clouds and radiative impact
- Cloud overlap in the vertical, cloud-precipitation interactions and the characteristics of vertical motion within

clouds

- The profiles of atmospheric radiative heating and cooling through a combination of retrieved aerosol and cloud properties

1.3 Instrument Compartment

The observational requirements discussed above indicate the need for measurements from a single satellite platform of the vertical structure of aerosols and clouds, plus complementary information on cloud-scale vertical velocities and precipitation, and of the corresponding broad-band and narrow-band radiances at the top of the atmosphere. The profile information can only be provided by active instruments, a lidar for aerosols and thin clouds and a high frequency (94 GHz) Doppler radar for clouds. These instruments can also provide the additional required information on discriminating absorbing from non-absorbing aerosols, on cloud-scale vertical velocities and precipitation (mainly drizzle) rates.

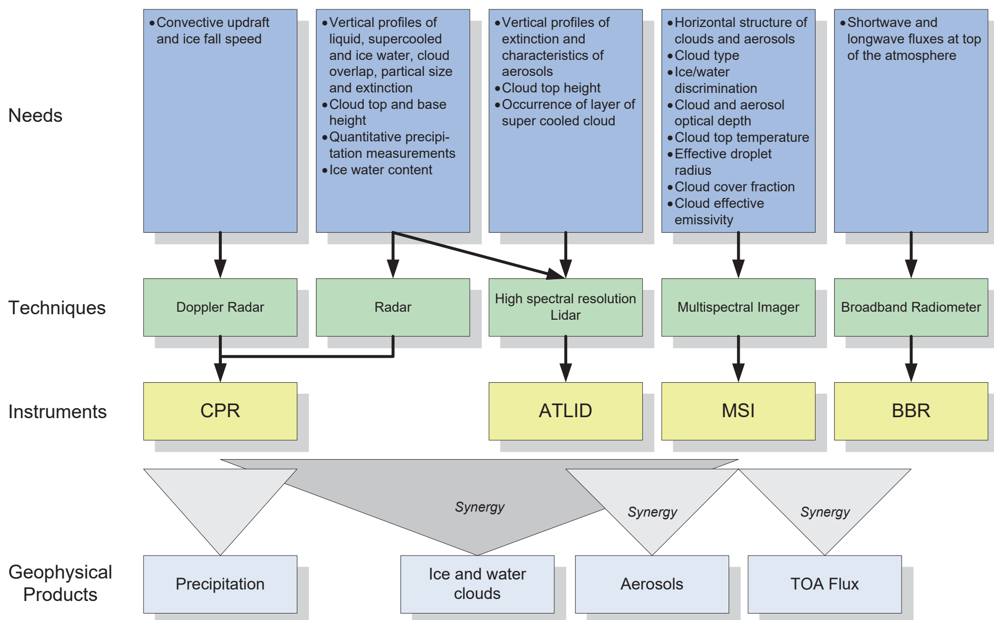


Figure 2. Summary of measurement needs, measurement techniques and the related EarthCARE instruments. The EarthCARE sensors as a complement will produce a set geophysical product for which again synergy is needed to perform the process studies of interest

A multi-spectral imager is required to provide additional geographical coverage of aerosol and cloud optical property retrievals, and a broad-band radiometer is required to measure radiances and to derive fluxes. These measurements need to be made for the whole globe and for a period long enough to ensure that all of the important climatic regimes are represented with the necessary statistical significance. This leads to the requirement for a single satellite mission with a lifetime of several years, in a Sun-synchronous polar orbit with an altitude as low as possible to optimize the performance of the two active instruments (lidar and cloud radar), which are supplemented by a multi-spectral imager providing cross-track observations and a broad-band radiometer for determining incoming and outgoing radiation simultaneously. Additional information on atmospheric temperatures and humidity can be obtained from other sources. The four EarthCARE instruments are listed with the corresponding observable parameters in the following table. The combination of passive and active instruments provides a unique set of vertical distributions of cloud and aerosol parameters.

Table 1. EarthCARE Payload and Observable Parameters

Instrument	Observable Parameters Single Instruments	Observable Parameters Instrument Combination
CPR Cloud Profiling Radar	- Vertical profiles of cloud structure (water / ice content) - Cloud top height - Cloud base height Quantitative precipitation measurements - Ice Water Content to a factor of 2	CPR / ATLID - Vertical profiles of the physical parameters of the cloud - Provide estimates of cloud particle size - Ice Water Content can be estimated to about 30-40% - Occurrence of layers of super cooled cloud
ATLID Atmospheric Lidar	- Vertical profiles of the physical parameters of aerosols - Cloud top height - Occurrence of layers of super cooled cloud	
MSI Multi-Spectral Imager	- Cloud horizontal structure / variability - Cloud type - Ice / water discrimination - Cloud optical depth - Effective droplet radius - Cloud top temperature - Aerosol optical depth - Cloud cover fraction - Cloud effective emissivity - LWP - All the above MSI measurements at cloud top only for thick cloud	MSI / CPR / ATLID - More accurate estimates of MSI observables MSI / BBR - Quantify variability within footprint of BBR
BBR Broad-Band Radiometer	- Short–wave and long-wave fluxes at the top of the atmosphere	BBR / ATLID / CPR - Constraint on the radiative flux derived from the cloud and aerosol profiles measured by the active instruments

The combined Radar and Lidar retrieval is extremely powerful. These two instruments have the unique property of penetrating clouds and providing vertical profiles of cloud and aerosol characteristics. The combination of the different instruments on board one spacecraft leads to additional observable parameters as the single instruments itself could provide, but leading to co-registration requirements between the different instruments.

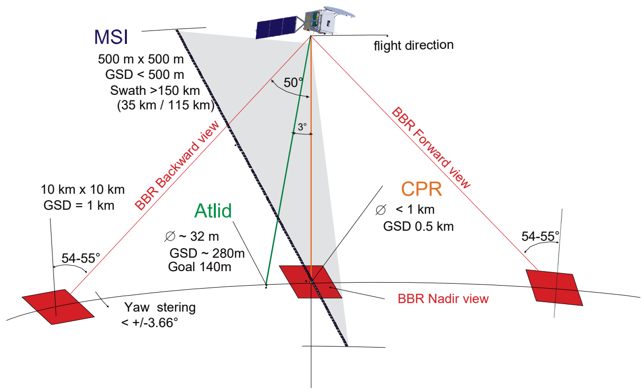


Figure 3. EarthCARE observation concept. The footprints of the nadir-pointing CPR and MSI, the 3° backward-looking ATLID, and the three BBR views

The EarthCARE mission is centered on the synergetic use of the data provided by an instrument suite consisting of active and passive sensors. This observation principle is depicted in Figure 4. All instruments observe the same volume of atmosphere, although at slightly different times, with the imager providing in addition across-track information. This principle allows not for only micro- and macro-level cloud and aerosol measurements to be taken as vertical profiles along the flight track, but also for acquiring horizontal bi-dimensional information by means of the across-track observations of the multi-spectral imager. The payload is accommodated on the satellite in a way that meets the viewing and alignment requirements, while the platform provides service functions like electrical power supply, data interfaces, attitude control and thermal control.

1.4 Current S/C status

Today, EarthCARE satellite build is complete and has been transported to the environmental test facility in Noordwijk (ETS). The environmental test campaign will start in October by satellite vibration and acoustic testing, followed by thermal vacuum testing and finished with EMC testing next year.

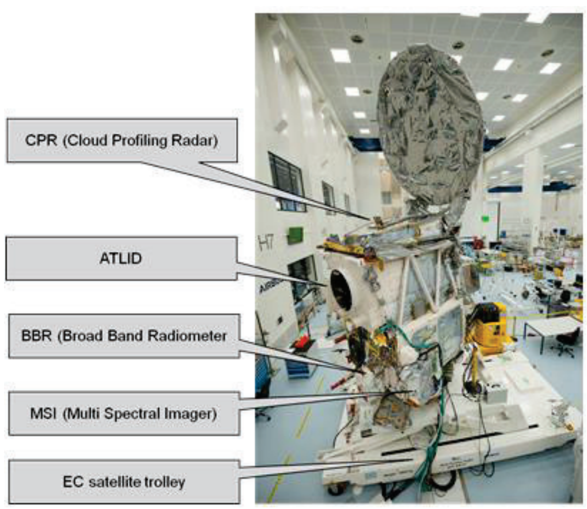


Figure 4. EathCARE satellite with all instruments integrated in Airbus Friedrichshafen cleanroom.

1.5 Multi Spectral Imager [MSI]

The MSI Instrument comprises the following entities housed on the space-craft platform:

- Optical Bench Module (OBM) fixed to the outside of the platform, itself comprising
  - Optical Bench (OB) "table" with a "down-sun tilt" (MSI looks "away" from the sun).
  - TIR Camera (three spectral bands).
  - VNS Camera (four spectral bands) with a prominent radiator to cool the SWIR-2 detector and a prominent diagonal "sun-baffle".
  - MLI and "beta-cloth" blankets (not shown) for thermal control.
- Front-End Electronics (FEE) module, fixed in close proximity to the OBM on the outside panel of the platform.
- Instrument Control Unit (ICU) housed inside the platform and connected by short harnesses to the OBM and FEE.

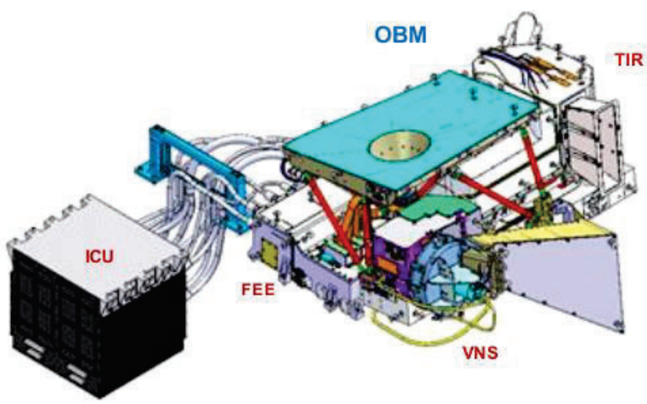


Figure 5. MSI Instrument with all higher level components.

The EarthCARE MSI spectral bands can be found in the figures below for the VNS and TIR.

Band Number	Band Name	Centre Wavelength	Band Width
1	VIS	670nm	20nm
2	NIR	865nm	20nm
3	SWIR 1	1650nm	50nm
4	SWIR 2	2210nm	100nm

Figure 6. VNS spectral bands.

Band Number	Band Name	Centre Wavelength	Band Width
7	TIR 1	8800nm	900nm
8	TIR 2	10800nm	900nm
9	TIR 3	12000nm	900nm

Figure 7. TIR spectral bands.

1.6 VNS-Camera

The optical concept [1] for the MSI VIS/NIR/SWIR channels consists of four telescopes that are distributed over two separated apertures. One common entrance aperture is used for VIS (Channel 1), NIR (Channel 2) and SWIR 1 (Channel 3) operating around +26degC and an independent aperture for SWIR 2 (Channel 4) as the operating temperature is around -50degC to reduce dark leakage current and noise. Band filters are used to define the spectral response of each channel. The system has four linear array detectors with the same geometric pixel configuration, thus the effective focal length of all channels is the same.

Furthermore the VNS has a calibration carousel in front which allows data collection from

- Earth View
- Calibration diffuser 1
- Dark View
- Calibration diffuser 2

Sharing the calibration optics is an important characteristic of this concept as it allows simultaneous calibration with the same equipment for the four channels.

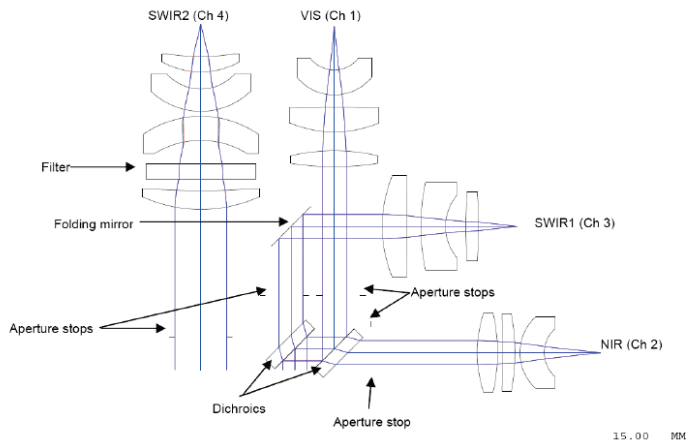


Figure 8. VNS Optical Schematic. SWIR-2 (left) has its own entrance aperture, whilst VIS / NIR / SWIR-1 share a common aperture and receive their light via dichroic filters.

1.7 TIR-Camera

The TIR will use a single micro-bolometer area array detector within a two-stage imaging system. In the first stage, an image of Earth will be formed at relatively long focal length by a simple lens system. The beam will be split by two dichroic beam-splitters located near the large primary image, and optical filters in the three separated beams will define the required TIR spectral response functions. The three beams, folded by mirrors onto parallel paths, will then be re-imaged onto the area-array with a substantial de-magnification. Absolute calibration for the TIR will be provided using a rotatable mirror in the incident beam path, allowing the instrument field to be switched between

- Earth View
- Cold Space View
- Calibration Blackbody

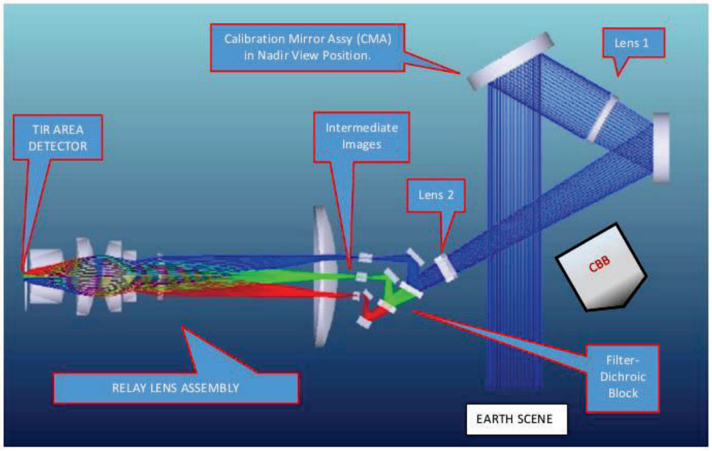


Figure 9. TIR two-stage optics. Telescope (Lens 1 and Lens 2) and filter-dichroic block form three spectrally filtered intermediate images which are de-magnified onto the area detector using the Relay lens. For simplicity, the rotating calibration mirror is shown fixed in the "nadir view" position, and the cold-space port is omitted. The CBB position is indicated.

1.8 MSI Flight Calibration Concept

Both cameras (VNS and TIR) will undergo regularly calibrations in orbit. For this purpose the calibration mechanisms will change the view scene for the cameras.

During the dark view scene of VNS a so called "Flat Field" is generated as background offset measurement which is subtracted onboard from subsequent data acquisitions. Similar "Flat Field" concept is in use for the TIR camera, the TIR offset measurement is acquired during the cold space view scene.

A second view scene, a "known" scene is uses during the calibration for both cameras. In case of the VNS camera it is a view through a sun-illuminated Quasi Volume Diffusers for which the BSDF is known and the Earth reflectance can be correlated. To overcome potential diffuser degradation a second diffuser is installed and both diffusers will be compared on a regular base. For the TIR camera an internal Blackbody (equipped with high quality thermometers) is the "known" view scene which readings will be correlated during ground processing.

2. MSI INSTRUMENT PERFORMANCE CHECK (IPC)

2.1 Main Goal on Satellite Level

The MSI instrument was fully qualified and tested at supplier Level including ground calibrations and performance characterization but the time between instrument delivery and the start of nominal operation of EarthCARE satellite in orbit comprise a few years. In these years the instrument will be functionally tested and contribute functionally to Satellite Level tests and test campaigns (e.g. thermal vacuum test, emissive/radiative electromagnetic compatibility tests, etc.) but it will normally never see again a performance test as on supplier level due to feasibility, complexity and or accessibility.

Therefore the main question on satellite level is how to ensure that the instrument still works until launch.

The answer is called instrument performance check which needs to be defined as a compromise of possible performance data acquisition by minimizing the complexity and effort. A good IPC test should generate the required performance measurements without long preparation time, without hard constraints or boundaries on environmental conditions (e.g. temperature) and it should be feasible to perform and evaluate the results in short timeframe (days).

If these criteria a met, the test can be placed several times along the Satellite Level AIT campaign to ensure a healthy instrument until launch and to generate data which could be trended as it should always the same.

2.2 MSI IPC Definition

The MSI supplier SSTL has developed the MSI instrument performance check in close cooperation with the satellite team, in order to make sure compatibility with reasonable execution in Satellite Level AIT.

The MSI IPC seeks to operate the instrument under defined, stable, reproducible conditions, and then to extract processed science data via ISPs (Instrument Source Packets) from the MSI from which performance information can be extracted (with suitable post-processing). In ambient (clean-room) conditions, it is expected that the distribution of temperatures around the instrument will NOT be flight-representative, and that active thermal systems will be operated with modified parameters (especially set-points). Nevertheless apart from the SWIR-2 detector, all Instrument detectors will work at or close to their in orbit temperatures.

The IPCs focus upon obtaining science data from all detectors (VNS and TIR) with a view to measuring both "dark noise" and "responsivity", and thereby verifying the continuing good health of the MSI.

IPC-1:

"Dark Response/Noise" for the VNS represents the temporal noise associated with any individual detector element which is presented with a "dark" target; for the purposes of IPCs, the dark target shall be the view obtained when the VNS calibration mechanism is commanded to "Dark" (or "closed").

It is expected that the noise levels obtained from the SWIR-2 detector will be higher in all ambient tests due to the fact that it will be operated around room temperature instead of -50degC.

IPC-2:

"Dark" noise for the TIR is similarly defined as the temporal noise associated with one detector column in one particular spectral band that is observed when the TIR camera is presented with a "cold" black target at the cold space port. In this context, a "cold" target means colder than the internal "hot" BlackBody. For IPCs carried out in "ambient" conditions, a black target which "floats" near ambient temperatures is acceptable.

IPC-3:

Responsivity of the VNS will be judged in a relative manner by using a reproducible but non-calibrated light source which will be presented to the "sun-baffle" port and viewed by the VNS via the diffusers (one at a time).

IPC-4:

Responsivity of the TIR will be measured by acquiring signals from targets at two different temperatures. These targets are the cold-space reference and a separate temperature-controlled target presented to the TIR Earth-view port.

IPC-5:

A test is defined for detecting un-responsive detector elements (Dead pixel map) in the TIR. The efficacy of small deviations/degradations is limited in ambient since it must deal with "raw" data where the signal is small and the noise is relatively high, but dead pixels would be detected.

The next figure shows the MSI with all IPC covers attached. The IPC test makes use of 4 covers:

- TIR Cold Space (CS) OGSE: Black Cover with temperature sensor attached.
- TIR Earth View (EV) OGSE: Black Cover with temperature sensor and regulated heater attached.
- VNS Optical Unit (OU) OGSE: No specific cover only to protect the baffle from light.
- VNS Sun Baffle (SB) OGSE: Reproducible non-calibrated light source cover.

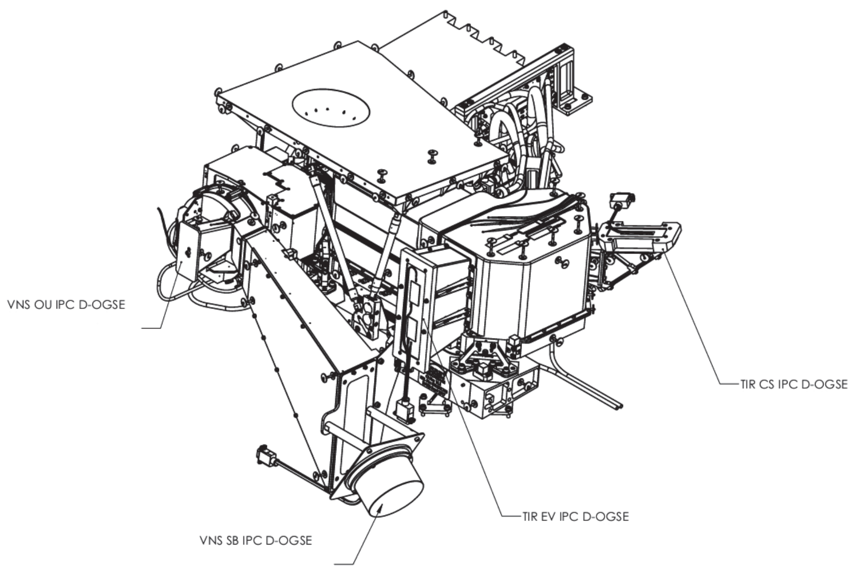


Figure 10. MSI Instrument with all Instrument Performance Check OGSEs attached.

2.3 MSI IPC repetitions along Instrument and Satellite Level AIT

The IPC described above has been performed several times already at Instrument Supplier Level. A similar strategy is and will be followed during the Satellite Level AIV campaign until launch. All 5 IPCs described above will be always executed. The following table shows the repetitions along instrument AIT and satellite AIT.

AIT Level	AIT Phase	Dates
MSI Instrument AIT	Before environmental test campaign	Apr. 2018
	During TBTV campaign	Jun. 2018
	Incoming test in satellite AIT	Oct. 2019
EarthCARE Satellite AIT	Post MSI integration on Platform	Dez. 2019
	Post MSI Hardware modifications*	Aug. 2021
	Post satellite mechanical campaign	Nov. 2022
	During Satellite TBTV campaign	Jan. 2023
	Post Satellite EMC campaign	Apr. 2023
	Launch site (TBC)	TBC

Figure 11. MSI IPC repetitions along instrument and satellite AIT

*The MSI Hardware modifications contain a replacement of Instrument TIR EarthView and ColdSpace Baffle together with an additional heater on the TIR Housing seen in Figure 10. These modifications were performed to reduce Straylight impact on the TIR camera found during the instrument calibration at supplier Level.

3. MSI IPC RESULTS AT SATELLITE LEVEL

This chapter will show the test results of the first MSI IPC after integration into the Satellite before the Satellite environmental test campaign has started. To complete the picture it shall be noticed that there have been two IPCs at Satellite level performed before environmental test campaign due to a hardware modification of MSI which is not part of this paper. The first Satellite Level MSI IPC in 2019 which is reported in this paper and a second in 2021. Only the first IPC results are presented. Nevertheless there was negligible impact of the hardware modifications for the ambient IPC and therefore both IPCs shows similar results. One example of VNS responsivity will be demonstrated below.

3.1 IPC-1 VNS Noise

The noise is measured in the spectral bands VIS, NIR, SWIR-1 and SWIR-2 in flight-representative operating mode, but non-flight temperatures. The signals are evaluated in the DarkView where the shutter is closed, in the EarthView which is closed with a dust cover and should be similar to the DarkView. The DarkView and EarthView are evaluated twice due to the fact that after each diffuser calibration the VNS mechanism orientation is in DarkView and after calibration back in EarthView. In fact there is no reason to evaluate it twice because there should be no different except noise but the data are in any case available. In addition both diffuser views are evaluated.

The following figures show the noise response as output in ADUs measured at each view target.

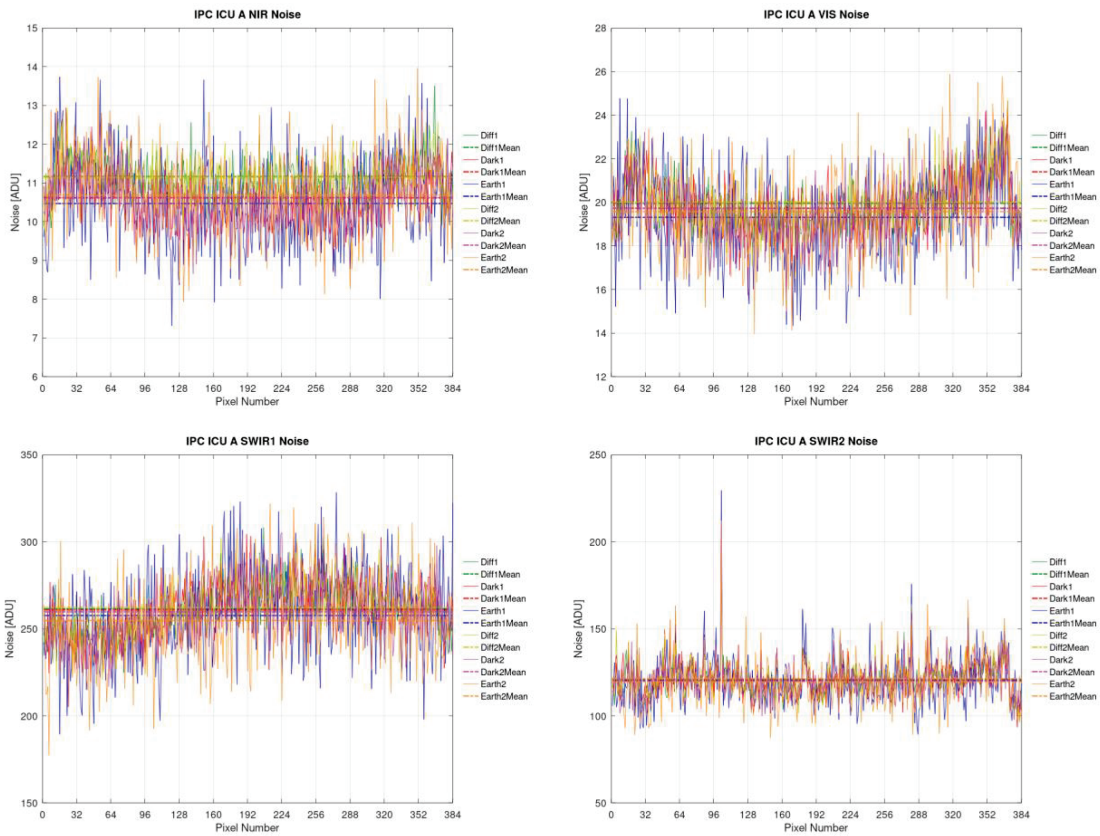


Figure 12. VNS Noise measurements for spectral bands VIS, NIR, SWIR-1 and SWIR-2 during post MSI integration on Platform IPC.

The presented VNS noise response in level and shape is fully in line with tests in ambient conditions performed at supplier level. The noise average of all bands is very similar for all view scenes. In SWIR2 measurements a noisier pixel can be clearly identified, identical to supplier level tests.

3.2 IPC-2 TIR Noise

The IPC measures noise for spectral bands 7, 8, 9 in flight-representative operating mode, but in non-flight temperature settings. The settings need to be adapted for ambient testing. Main test goal is the acquisition of science data for different temperature target scenes as the in-flight calibration concept. For simplification and a higher contrast, this will be realized by moving the calibration mechanism instead of changing the OGSE temperature. The test acquire science data from the heated TIR earth view cover, the temperature floating internal black body and as a third temperature target the temperature floating TIR cold space cover. In ambient conditions the internal black body and TIR cold space cover will have only a small difference in temperature. The following figures show the noise response as output after some post processing in ADUs for Band 7, 8 and 9 at all three view targets (ColdSpace, BlackBody and EarthView).The currently defined 14 side pixels on both detector sides (8 reference + 6 guard pixels) are not taken into account for evaluation and therefore is the mean value calculated from pixel 15 to 370.

The view scene temperatures during the test were around:

- ColdSpace = 295.7K
- BlackBody = 297.8K
- EarthView = 310.1K

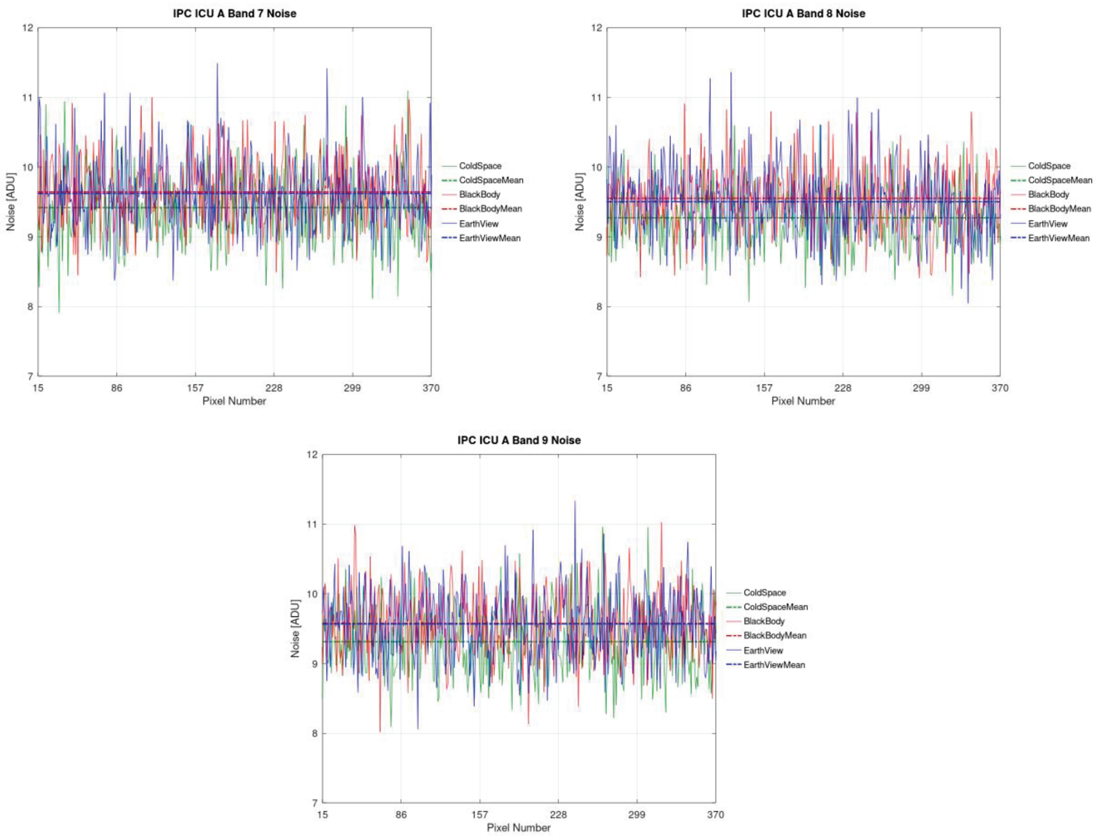


Figure 13. TIR Noise measurements for spectral bands 7,8 and 9 during post MSI integration on Platform IPC.

It can be seen that the noise in all bands is around 9.5 ADUs which is after temperature calibration between 0.9 Kelvin and 0.15 Kelvin pending on the spectral band. This is similar to the IPC results acquired at supplier Level and in line with all expectations. The Noise in all bands is close to each other and independent from the view scene temperature. The MSI was tested in TBTV conditions during the Instrument calibration campaign on supplier Level in flight representative temperatures. In front of the EarthView was a variable black body positions to scan the entire temperature range specified for the TIR camera. It was observed that the average noise is as well around 9.5 ADUs for all three spectral bands at a view scene temperature of 220K.

3.3 IPC-3 VNS Responsivity

The VNS responsivity is evaluated during both diffuser views while the VNS OGSE lamp is attached and active. The easiest way to judge the success of this test is a comparison of VNS plots captured in the past by the supplier SSTL with the acquired responses during the first IPC at satellite due to the specific shape of some response curves.

The following figures show the VNS response as output in ADUs measured at each view target after post processing.

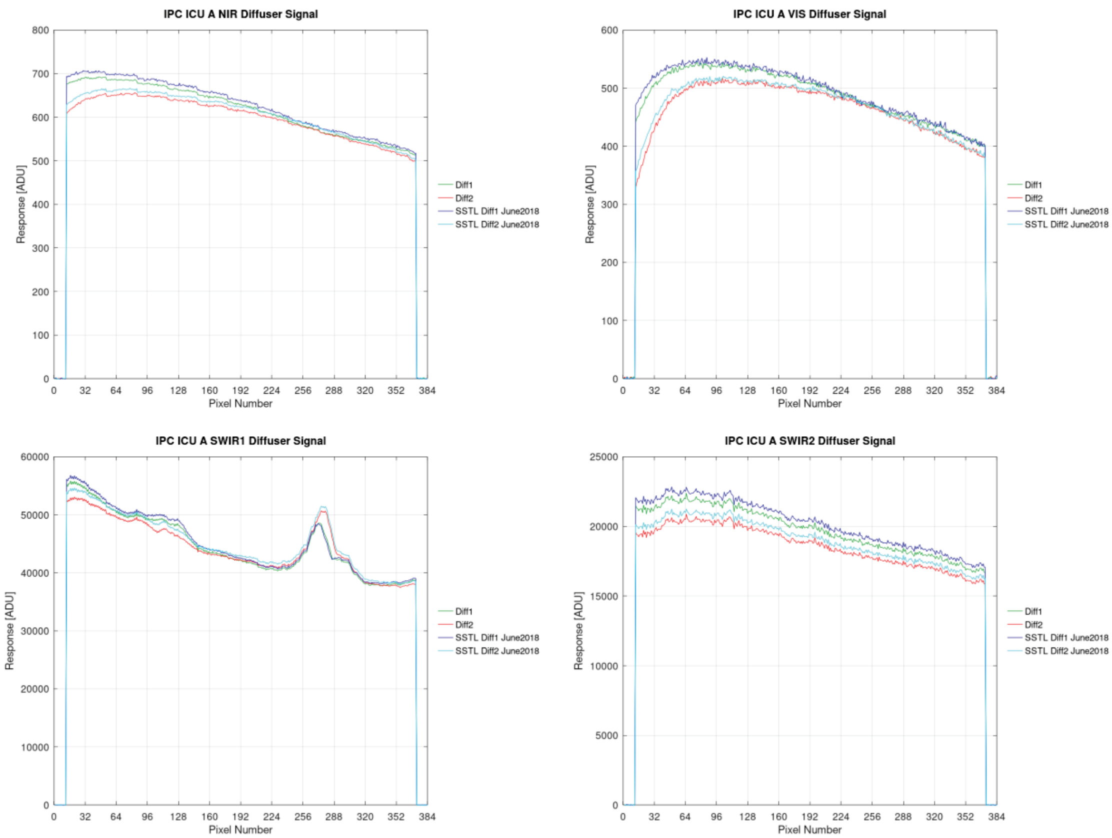


Figure 14. VNS response measurements for spectral bands VIS, NIR, SWIR-1 and SWIR-2 during post MSI integration on Platform IPC in comparison to supplier level measurements during TBTV campaign.

It can be seen that the curves between the VNS response at satellite level and supplier level matches well but are not fully overlaying each other. This can be caused by slight changes in the VNS sun lamp due to exact control parameters, set points or also operating time of the lamp. These influences has been tried to be negligible at satellite level by an automated procedure including the OGSE settings. Therefore the next figures show the comparison of the first satellite IPC 2019 with the second satellite IPC 2021 for the VNS response. The comparison is performed at unprocessed VNS data to also eliminate every deviation by a change in post processing code.

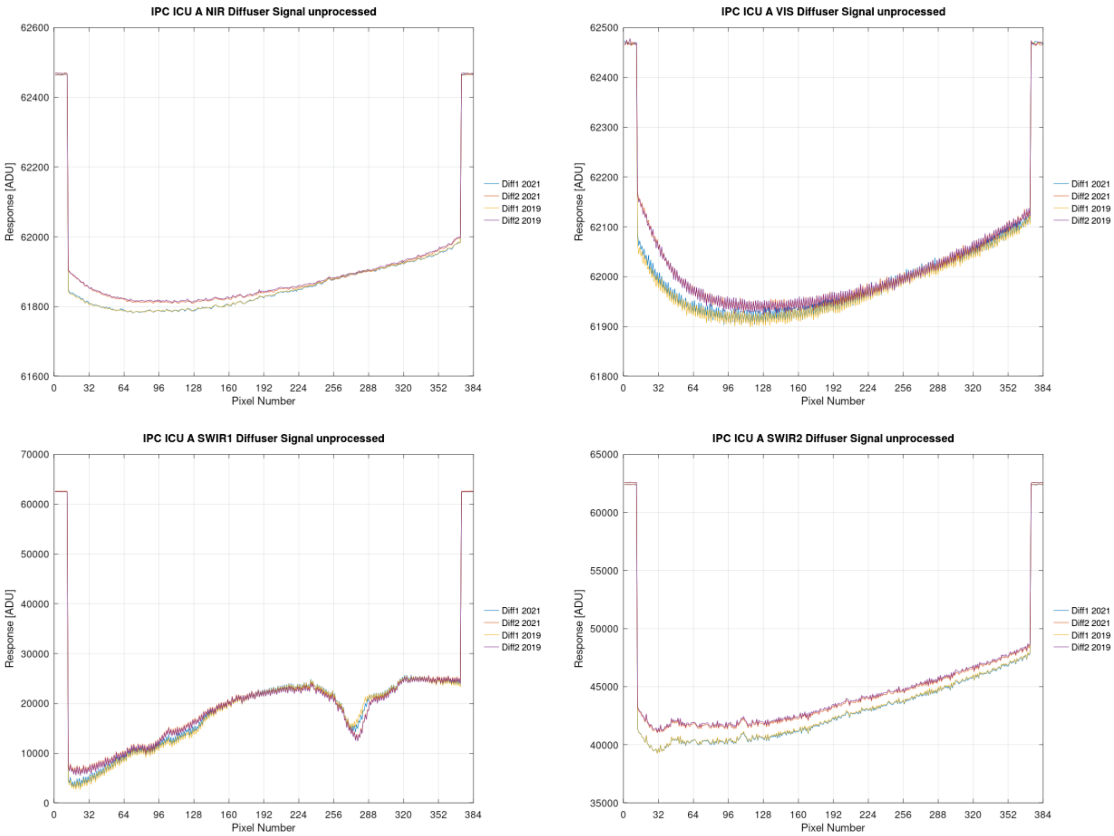


Figure 15. VNS unprocessed response measurements for spectral bands VIS, NIR, SWIR-1 and SWIR-2 during post MSI integration on Platform IPC in comparison to post MSI Hardware modification IPC.

These plots show clearly that the signal shape and signal values are well comparable which demonstrate that the MSI VNS is operating as before.

3.4 IPC-4 TIR Responsivity

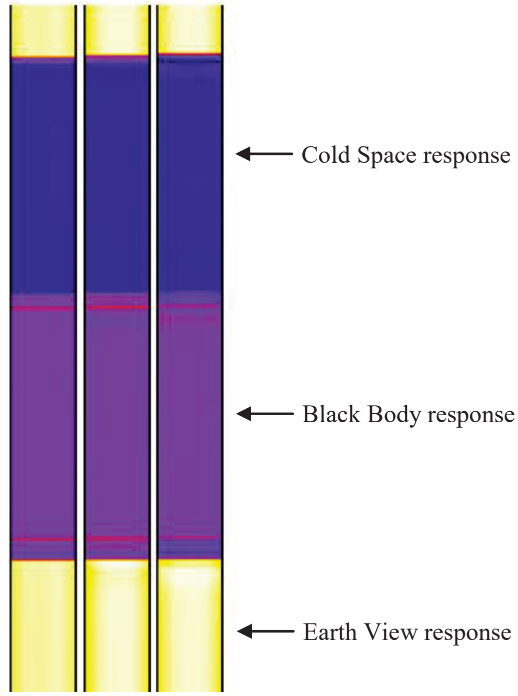


Figure 16. TIR calibrated response measurements for spectral bands 7, 8 and 9 in false coloring.

The response is captured in parallel to the noise measurements above. After acquisition the science data are post processed and a generic TIR Calibration curve for all pixels is applied (Instead of an individual temperature calibration curve per pixel as used in flight). The calibrated response should match the measured target views. The next figures show the TIR responses after applying the generic temperature calibration with respect to the measured target temperatures indexed by reference. In addition the range of ±1K around the measured target is visible.

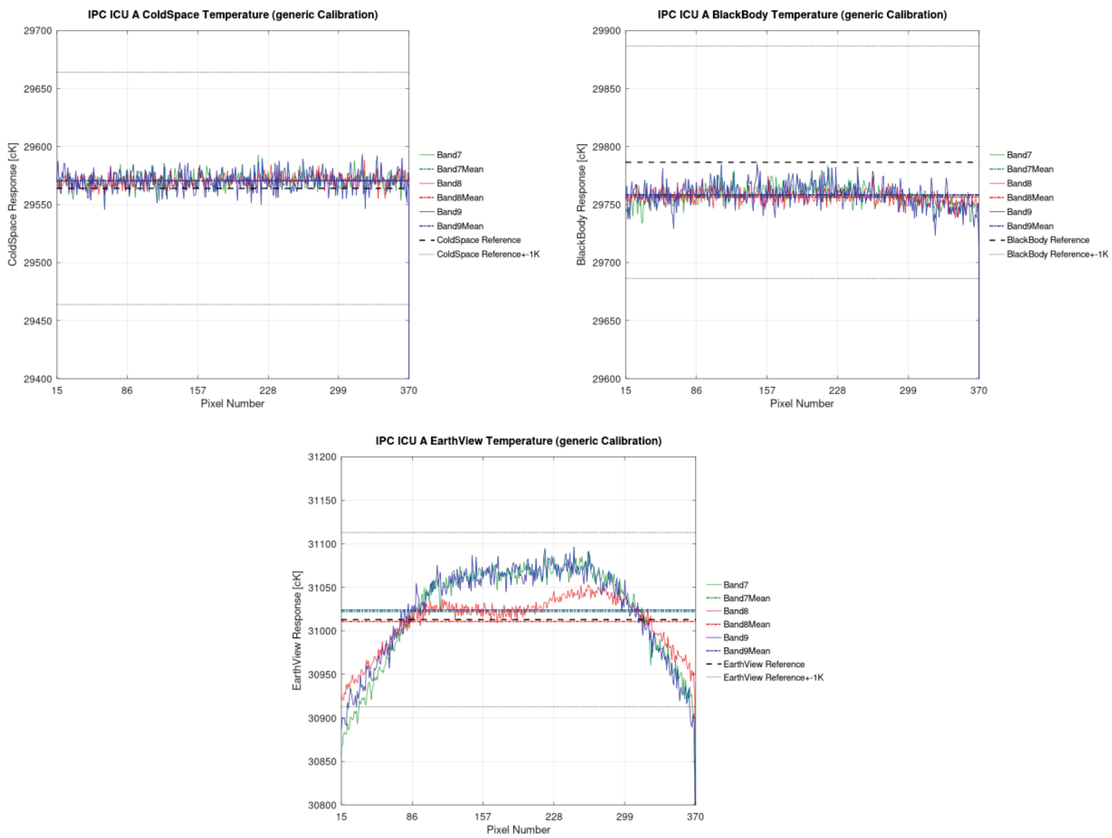


Figure 17. TIR calibrated response for spectral bands 7,8 and 9 in centi kelvin for all view scenes during post MSI integration on Platform IPC.

The averaged values are matching the measured response overall even with a generic temperature calibration. The EarthView response is in shape and level as expected, the Earth View IPC cover gives a non-uniform response because it is fitted with two small heaters. The “double-hump” profile is most obvious in band 8 response whereas for bands 7 and 9 the responses are slightly more curved at the edges of the field. All these measurements are in line with previous ambient tests at supplier level but even more it proves the good health of the MSI TIR camera after integration into the EarthCARE satellite.

3.5 IPC-5 TIR Dead pixel/responsivity map

The TIR dead element test is based on the RAW image. This RAW image needs to be further processed manually to achieve the required results.

At entering the MSI RAW mode the instrument rotating mirror was faced to the ColdSpace port, this port is the "cold" reference for this test. During the test the TIR view direction is changed to EarthView. At time when the MSI leaves the RAW mode the instrument rotating mirror was facing the EarthView port, this port is called the "hot" reference for this test.

As a next step the entire TIR RAW image needs to be cropped into an image consisting of all 3 TIR Bands at the beginning of the test, referenced in the following as TIR RAW COLD image. The same entire TIR RAW image needs to be cropped into an image consisting of all 3 TIR Bands at the end of the test, referenced in the following as TIR RAW HOT image.

The last processing step is to subtract the TIR RAW COLD image from the TIR RAW HOT image, at places where the values deviate from the surroundings a noticeable pixel is found with a "problem". Problem is a subjective category but if all pixels would respond in a similar manner, the sum between HOT and COLD would be equal for all pixels. A lower pixel value indicates less responsivity but not necessarily mean dead/defect.

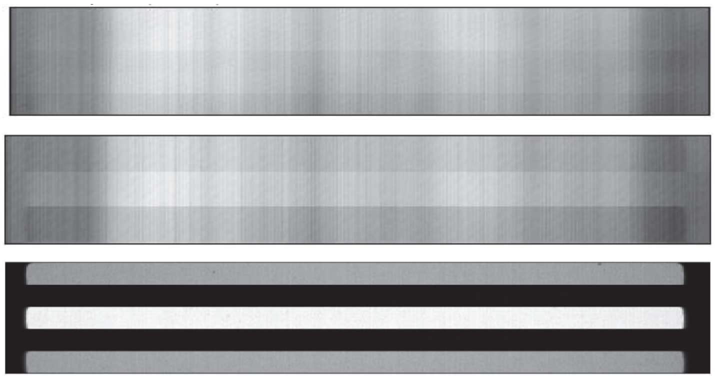


Figure 18. IPC processing for TIR dead element evaluation. (From top to bottom TIR RAW HOT, TIR RAW COLD and Responsivity map)

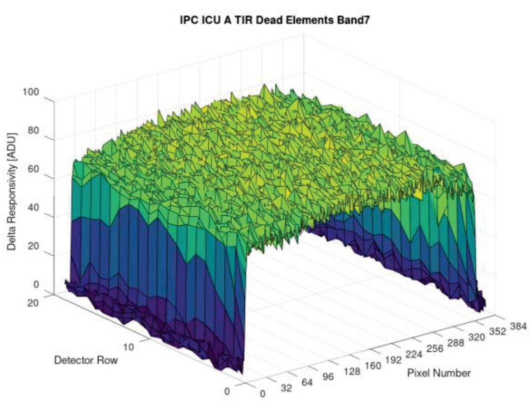
The normal operation of the TIR detector involves the use of TDI over columns of detectors spanning 19 rows; this makes the TIR relatively insensitive to the loss of individual detector elements, but by the same reasoning it is hard to detect individual “dead” elements. The check described below will permit “two-dimensional” data to be acquired from the TIR by utilizing a special “Raw Data” mode. Using these data it is possible to measure noise and response for individual detector elements (which is not possible for the flight data where TDI calculations are applied by the FEE).

This test is in ambient conditions very difficult to evaluate, the only constrain for this test is a maximum temperature deviation between two views.

In TVAC conditions the delta between a hot and cold target can be around 200 kelvin which provide a sufficient change in TIR response. The response change between two temperatures which deviate around 15 Kelvin in RAW mode is not that unambiguous during this ambient test.

The reader is warned that the dead element test in ambient conditions will result in several false friends based on the fact that there is no fully dead pixel visible. All pixels are responding up to certain amount, they only possible evaluation can be done by inspecting pixels where the response differs compared to others. The drawback is that all pixels are influenced by noise, therefore in ambient conditions it is close to impossible to distinguish if the deviation is caused by real response issues or by noise.

The following plots show the responsivity map per Band.



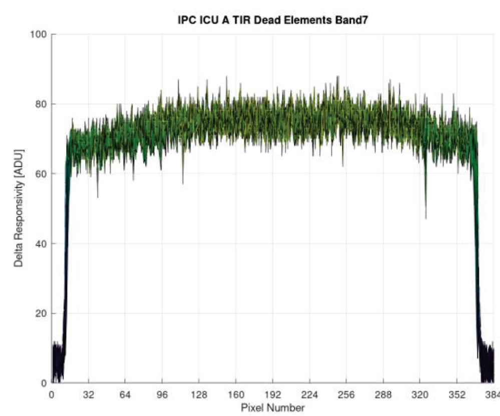


Figure 19. TIR Dead Element response map Band7 during post MSI integration on Platform IPC.

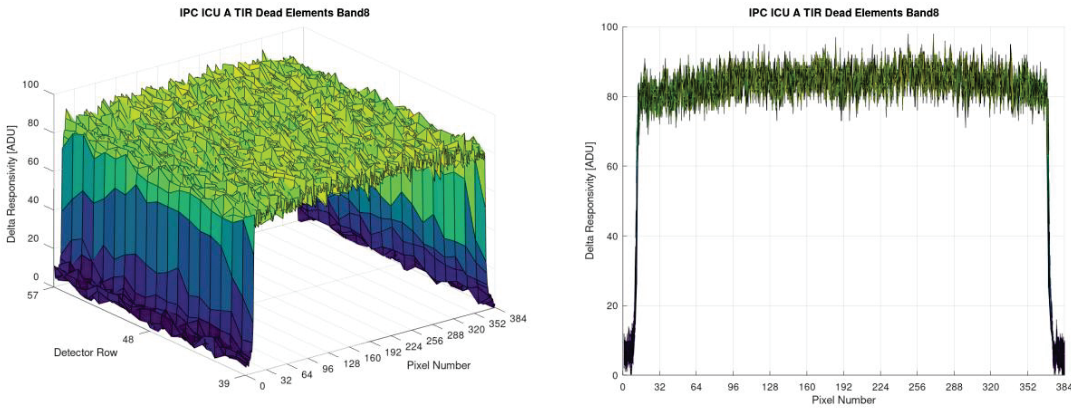


Figure 20. TIR Dead Element response map Band8 during post MSI integration on Platform IPC.

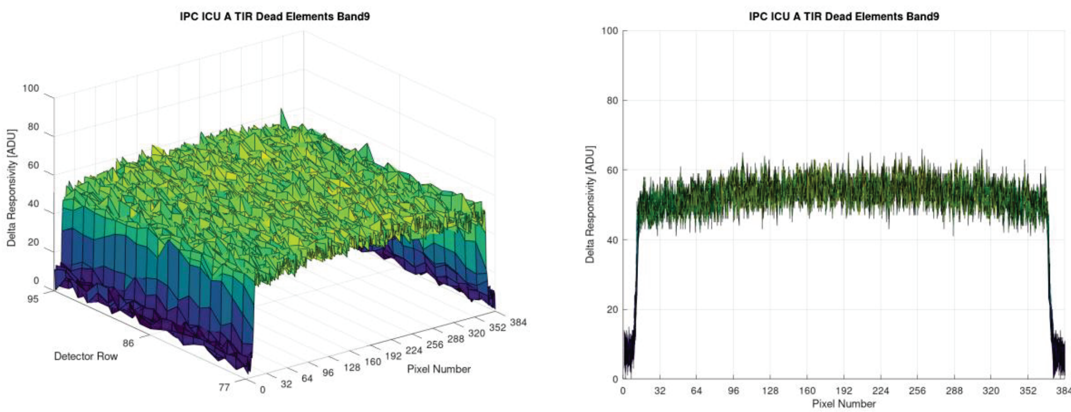


Figure 21. TIR Dead Element response map Band9 during post MSI integration on Platform IPC.

It is clearly visible that no detector element in all 3 TIR bands shows no response which confirms that no pixel is defect/dead but it can also be seen that a lot of noise is present. Therefore a identification of less responsiv pixels is very difficult in an ambient test where both view scene temperatures are not largly seperated. At least in band 7 at pixels 324/325 in detector row 2 (found by a detector line by line evaluation) a clear degradation in responsivity is observable. There are some more pixels in band 7 which have the potential to be less responsive but it is very hard to distinguish if it is real behaviour or an noise artefact. The pixels 324/325 in detector row 2 have been clearly confirmed during TVAC tests at suplier level.

4. CONCLUSION

The performed satellite level ambient MSI IPC has demonstrated good health and performance as expected, similar to demonstrations before on instrument Level. The IPC results show no pixel defects or degradation in both cameras. The future IPCs will monitor this behavior until EarthCARE is in orbit. The IPC results acquired during the satellite TBTV test will provide the best performance check results as the instrument will be operated at or very close to the in orbit temperatures especially for the detectors. Furthermore MSI IPCs definition has been found well suited for regular MSI IPC execution by satellite AIT team in satellite AIT environment, without the MSI instrument team present.

A similar IPC approach is available for all other EarthCARE payloads and will be repeated along the upcoming EarthCARE environmental test campaign [2].

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[2] Haas C., Belhadj T., Kruse K.-W, de Villèle G, Sauer M., Chassat, F., Corselle, B., Tzeremes G, Pereira do Carmo J., Ghose K., Wallace K.,ATLID (ATmospheric LIDAR) integration and initial test results on EarthCARE satellite, ICSO 2022