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IASI INSTRUMENT ONBOARD METOP-A: LESSONS LEARNED AFTER ALMOST TWO YEARS IN ORBIT

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ABSTRACT

The Infrared Atmospheric Sounding Interferometer (IASI) is a key element of the MetOp payload, dedicated to operational meteorology. IASI measurements allow to retrieve temperature and humidity profiles at a 1 km vertical resolution with an accuracy of respectively 1 K and 10%. The aim of this paper is to give a status of the instrument and to present some lessons learned after almost two years in orbit. As the first European infrared sounder, the IASI instrument has demonstrated its operational capability and its adequacy to user needs, with highly meaningful contributions to meteorology, climate and atmospheric chemistry studies. The in-flight performance of IASI is fully satisfactory. The sensitivity to radiative environment seems to be higher than expected : several SEU related anomalies were recorded, without any consequence on the instrument's health. The first decontamination since the commissioning phase was successfully performed in March 2008. The instrument globally shows a stable behaviour.

1. INTRODUCTION

MetOp-A was launched from Baïkonour on October 19th, 2006. Following a successful in-orbit commissioning phase, which included in-orbit functional validation (2 months) and calibration/validation (6 months), the first IASI instrument (FM2 model) has been in routine phase since July 2007. The instrument is designed for five-year lifetime. Two other IASI flight models, PFM-R and FM3, will be flown respectively on MetOp-B and MetOp-C.

The IASI instrument is a Fourier Transform spectrometer based on the Michelson interferometer principle, operating in the 3.7 – 15.5 µm spectral range, associated with an integrated imager (10.3 – 12.5 µm) allowing coregistration with the AVHRR imager onboard MetOp [1]. The onboard processing subsystem allows to obtain calibrated spectra which are transmitted to the ground segment.

The IASI program is a cooperation between CNES and EUMETSAT. CNES has the technical overview responsibility for the instruments development, is in charge of the development and maintenance of the level 1 processing software, and operates the Technical Expertise Centre (TEC). The instrument development was carried out by Thales Alenia Space as industrial prime contractor. EUMETSAT is responsible for operating IASI, archiving and distributing IASI data to the users.

2. INSTRUMENT STATUS

The IASI FM2 instrument is fully operational. Its in-flight performances entirely meet users' and designers' expectations [5].

The instrument configuration is the nominal one. No changes were made in on-board software configuration after the calibration/validation phase. At the end of the calibration/validation phase, it was decided not to release the Locking and Filtering Devices (LFD) which are the mechanical interface between IASI sensor and MetOp platform, designed to ensure IASI protection from external microvibration perturbations potentially coming from other instruments. The release of LFDs was not necessary on IASI FM2, however the possibility to release them on IASI PFM-R and FM3 will still be available if necessary.

The main events that can be noted are the IASI internal anomalies due to radiation effects (see section 3) and the ice decontamination phase that was successfully performed in March 2008 (see section 4).

3. SEU ANOMALIES

3.1. IASI sensitivity to SEU (Single Event Upset) anomalies

SEU anomalies are the consequence of charged particles impacts that can cause a bit corruption on memory areas used by onboard software. Since the beginning of its in-orbit life IASI has experienced an unexpectedly high number of SEU anomalies. Between

January 2007 and September 2008, eight SEU-related anomalies were recorded, six of them concerning one subsystem which is the Data Processing Subsystem (DPS).

The DPS is the most demanding subsystem in terms of memory resources. It processes raw interferogram data from the interferometer to obtain Level 0 spectra which are encoded and then transmitted to the ground. The DPS contains four processing chains associated to the four pixels of the sounder. The processing is complex, finely optimised in terms of time sequencing and uses a large amount of memory space (126 memories of 1Mb, without taking into account redundancy). During the development phase of IASI, it was decided to use radiation-hardened memory chips for the DPS RAM (they were also used in an other subsystem - the Cube Corner Electronics -but in a much lower quantity). The predicted rate of SEU anomalies was one over 4 years.

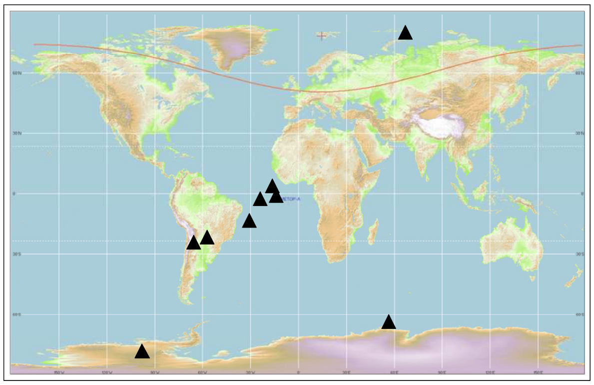

Fig. 1: IASI SEU/SET anomalies geolocation

Fig. 1 shows the geographical repartition of SEU anomalies (plus an SET – Single Event Transient – that occurred on a DPS power converter).

The SEU anomalies appear over the South Atlantic Anomaly area and in polar regions. This location tends to show that those memory chips are sensitive to protons as well as heavy ions. At the time of IASI design choices, no proton sensitivity was known for this kind of memory chips.

3.2. Operational impact

This kind of anomaly does not have any functional after-effect on the instrument, but causes unwanted mission outages. SEU impacts on IASI usually trigger a mode transition consecutive to error detection on the impacted subsystem : the onboard management software switches the instrument to a safe mode. Then, considering the anomaly signature, the ground can command the reload of the memory and put the instrument back into nominal mode.

SEU anomalies have involved approximately 1% unavailability of IASI instrument between January 2007 and September 2008. Thanks to joint efforts from EUMETSAT, CNES and Thales Alenia Space teams to reduce both investigation and recovery time after anomaly, the cumulative interruption time due to SEU for this period was eventually quite low regarding the number of anomalies.

3.3. Actions taken

After the first SEU anomalies, two kinds of actions were initiated. The first one was to minimise the mission outage in case of SEU anomaly. Specific signatures associated to SEU anomalies were identified and a "turbo procedure" was implemented at EUMETSAT to have a quicker recovery. The mission outage time is now very short (between 2 and 5 hours) compared to the first anomalies (more than one day). The second one was to find solutions to avoid triggering anomalies in case of SEU hits, via onboard software modifications, and consequently to reduce ground intervention and to stop mission outages due to SEU. The solutions were either to implement error detection/correction algorithms in the DPS, or to modify the onboard management subsystem in order to autonomously reinitialise the DPS in case of anomaly. The preferred solution was the autonomous onboard reinitialisation, which is currently under development by Thales Alenia Space. This solution will be implemented on IASI FM2 and on IASI models on ground.

These anomalies raised questions on the immunity level of the radiation-hardened memory parts to different kind of particles, and on the scope of tests that have to be required from the manufacturer at delivery. Additional radiation tests will be conducted by CNES, for both protons and heavy ions, in order to have a complete evaluation of the sensitivity of the parts used on the three IASI flight models.

The IASI experience highlights the importance, in terms of operational consequences, of a proper evaluation of RAM sensitivity to radiations. This has to be considered when during design phase a choice must be made between EDAC protected and rad-hard memory parts. This concern is especially relevant for future sounder instruments that may, even more than IASI, need heavy onboard data processing.

4. DECONTAMINATION

4.1. Need for decontamination

The IASI interferometer and optical bench are regulated at 20°C temperature, while the cold box containing cold optics and detection subsystem is at about -180°C. Water desorption from the instrument causes ice formation on the field lens at the entrance of IASI cold box. This desorption phenomenon is particularly important at the beginning of the instrument in-orbit life. That is why one of the very first activities of IASI in-orbit commissioning was an outgassing phase consisting in heating the cold box up to 300 K during 20 days. This operation allows to remove most of the initial contaminants coming from IASI and other MetOp instruments. A routine outgassing (which is much shorter and at 200 K instead of 300 K) is then needed from time to time to remove ice contamination, but less and less frequently as the desorption process becomes slower. A first run of this routine outgassing procedure was done for validation purpose during commissioning phase in December 2006. The second one, which was actually the first in routine phase, was done in March 2008.

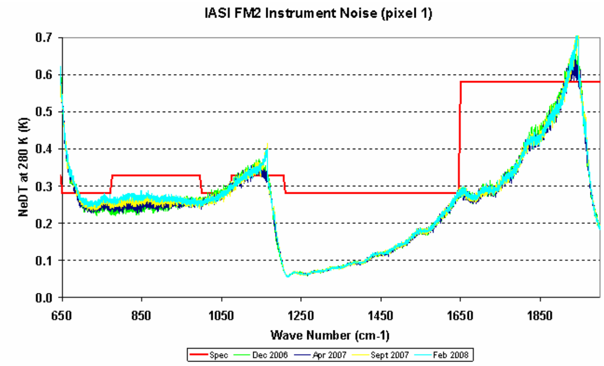

Fig. 2: FM2 instrument noise (NEdT @280K) between December 2006 and March 2008

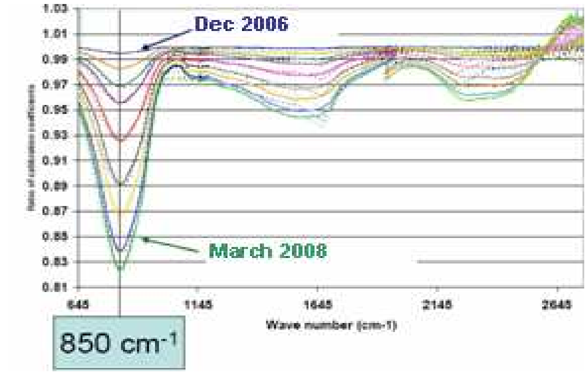

Fig. 3: FM2 transmission loss due to ice contamination

The ice contamination decreases the instrument transmission and thus degrades the radiometric performance. The spectral signature of the degradation is characteristic of the presence of ice. The maximal degradation is observed in band B1 around 850 cm^{-1}. Fig. 2 shows the evolution of radiometric noise between end of 2006 and early 2008, Fig. 3 shows the evolution of the instrument transmission.

The maximum acceptable degradation of transmission is a 20% loss at 850 cm-1 (which corresponds to an ice thickness of about 0.5 µm), so decontamination must be done before reaching this limit. The transmission degradation rate is regularly monitored by CNES TEC through gain measurements given by calibration coefficients ratios. This monitoring allows to extrapolate about six months in advance the date when the 20% limit is reached. This limit was predicted for July 2008. The decontamination was done in March 2008, in conjunction with an operational opportunity. The transmission loss was then about 17%.

4.2. Decontamination procedure and results

The decontamination lines heat the different parts of the Cold Box Subsystem (the three passive radiator stages and the sunshield) up to a temperature of 200 K (-73°C) for a duration of 4 hours (see Fig. 4). Then during the cooling down of the first and second stages, the third stage is maintained at -93°C in order to avoid re-deposition of ice on the cold optics. About 1.5 day later, when the second stage reaches -131°C, the third stage decontamination line can be switched off and the cooling of the first stage begins. It takes about 4 days to cool down the CBS third stage from -73°C to -181.8°C, the final temperature being exactly the same as before the outgassing phase. Once the temperature is stabilised, IASI can be put back into normal operational mode. The total duration of the mission interruption for a decontamination is about 6 days.

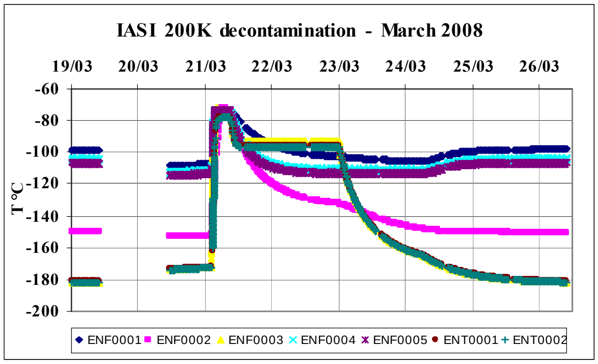

Fig. 4: Cold box temperatures during 200 K decontamination in March 2008

The data interruption on March 20th was due to a MetOp anomaly which caused a complete payload switch-off (see Fig. 4). Following that event, considering that for IASI the whole recovery from the anomaly would have taken 2 days for the temperatures stabilisation, the decision was taken to engage the decontamination process immediately after IASI was on in order to minimise overall mission interruption (considering that anyway it was mandatory to perform the decontamination before July 2008).

The radiometric performance after that decontamination was back to the level measured in December 2006 (see Fig. 5), showing that all the ice had been removed from the cold optics.

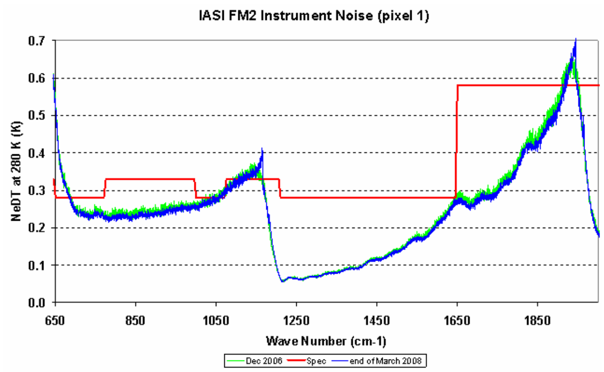

Fig. 5: FM2 instrument noise (NEdT @280K), 12/2006 (green) and 03/2008 after decontamination (blue)

CNES monitoring of the transmission evolution after the decontamination shows that the contamination rate is lower now than after the previous decontamination (December 2006) as shown in Fig. 6, which was expected as it indicates that water is efficiently evacuated outside the instrument during the outgassing phases. The current estimation is that the next decontamination will not be needed before 2010.

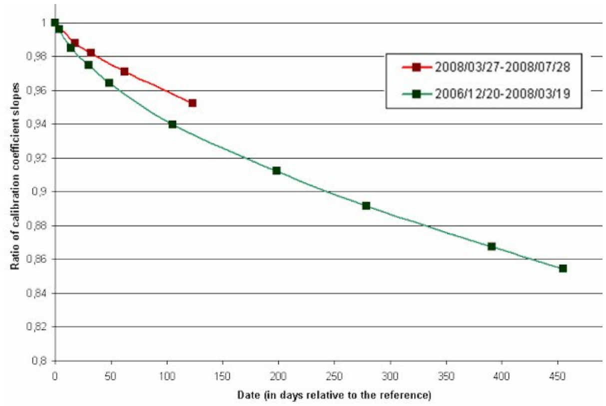

Fig. 6: Evolution of the transmission ratio at 850 cm^{-1} since previous decontamination

By now the decontaminations on IASI are less frequent than expected before launch. The actual contamination rate is slower than the predicted rate based on optical vacuum test results. This highlights the difficulty to create on ground for instrument testing an environment similar to the in-flight conditions (platform environment and space environment), considering also that we cannot have long term data until the instrument is flying. The on ground uncertainty has finally leaded to a robust design of the instrument in terms of contamination prevention. The flight data now provide new inputs to improve contamination prediction models, this will be useful for the two next IASI flight models and for future instruments.

5. INSTRUMENT STABILITY

5.1. General behaviour

The instrument's health is monitored via on-board and on-ground parameters. After 23 months in operation, IASI globally shows a very stable behaviour, regarding temperature, power consumption of the different subsystems, and motion of the mechanisms. Some examples particularly representative of the instrument’s good health are presented hereafter, plus a particular trend concerning the imager focal plane temperature.

5.2. Focal plane thermal control

The different IASI subsystems are regulated in temperature via 14 active thermal control lines. One of theses regulation lines controls the temperature of the detectors inside the CBS, via platinum sensors located near band B1 detector. The regulation maintains a very stable temperature on the detectors, compensating for environmental thermal variations. This stability is fundamental to guarantee the instrument performances.

The CBS thermal efficiency is monitored through its regulation line power. Fig. 7 shows small orbital and seasonal variations, and a very good stability on the long term. This stability shows that there is no need to increase the detectors target temperature. Keeping a low temperature is particularly important for the radiometric performance in band B1.

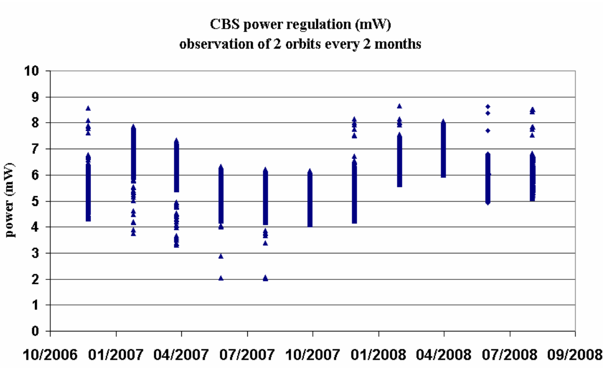

Fig. 7: CBS regulation power

A change of the target temperature would be necessary in case of a drift of the CBS third stage temperature, which may happen with ageing and contamination effects on the sunshield or on the CBS radiator stages. It is currently impossible to predict a possible degradation for the next years. The hypothesis made before launch indicated a maximal temperature increase of 7,8°C from beginning of life to end of life. The in-flight evolution is now expected to stay well below this hypothesis.

5.3. Mechanisms

The motion of the mechanisms is periodically recorded onboard IASI via the Position Data Diagnostic (PDD), which allows monitoring their regularity. The IASI mechanisms are indeed in a very good health after almost two years of continuous operation.

The cube corner mechanism realises during each interferogram acquisition a 2 cm trajectory with a constant speed of 132 mm/s. The regularity of this trajectory is important for the quality of interferograms. The long term stability of the cube corner motion is an indicator of the mechanism's good health. Fig.8 shows a superposition of several cube corner speed acquisitions illustrating this stability.

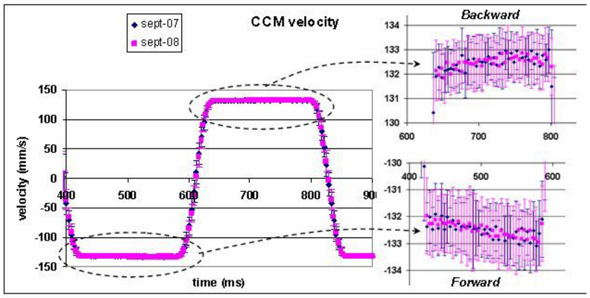

Fig. 8: IASI cube corner mechanism motion

The scanning mirror mechanism ensures pointing precision and stability. It realises for each viewing position (30 Earth targets and 2 calibration targets in normal operational mode) two rotation motions : the first one is the scanning angle α around satellite track direction, the second one is the satellite motion compensation angle β. The α and β monitoring also shows a very good repeatability of the motion in the long term.

5.4. Unexpected trends

One parameter shows an unexpected behaviour : the integrated imager (IIS) focal plane temperature telemetry, measured by an internal sensor on the microbolometer, is slightly drifting with an average slope of +0.12°C/year (see Fig. 9). The short term stability of this telemetry is still very good. Such a long term drift is not critical. No impact is foreseen on the instrument performance.

This trend may be explained by a drift of the temperature sensor and thus may not reflect the actual temperature of the microbolometers. The same behaviour has been observed on the Calipso IIR imager, which is similar to IASI IIS. Calipso, part of the French-American A-train, was launched in April 2006. We can expect to have the same trend in the future for IASI PFM-R and FM3 models.

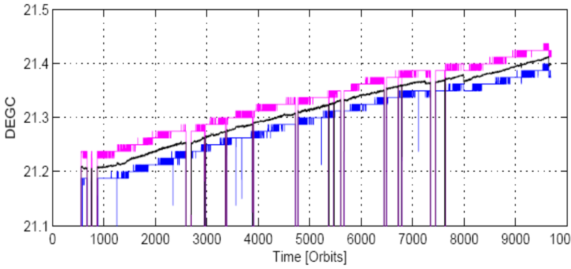

Fig. 9: Imager focal plane temperature : orbital average (black), minimum (blue) and maximum(pink) from end 2006 to mid 2008

6. CONCLUSIONS

Since the first series of IASI data, the scientific users have given a very positive feedback on the instrument performances. IASI data are now operationally used by many meteorological agencies (e.g. Meteo France, ECMWF, UK MetOffice). The instrument shows a very good health after almost two years of exploitation. Maintaining a high level of users' satisfaction also means according a high priority to the operational constraints in order to maximise the instrument availability, including efficient management of occasional anomalies and necessary interruptions like decontaminations and external calibrations.

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