“MAJIS performances in the infrared during the JUICE 2024 Earth fly-by: comparisons with IASI measurements and sensitivity to trace species”

Response to comments from both referees

General comments:

We thank both referee for their thorough review of our manuscript.

We reply to all their comments below (answers in red). The last 8 pages report on a more in-depth analysis of the radiometric biases based on comparisons with co-located MAJIS and IASI measurements. This part can be easily edited and implemented in a revised version of the manuscript.

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Referee #1
Comments in detail:

I would suggest a slight rephrasing of the title: "MAJIS infrared performance during the JUICE 2024 Earth flyby: comparison with IASI measurements and sensitivity to atmospheric trace species".

To address also another comment by referee#2 (regarding the choice of word “sensitivity”), we will change the title to “MAJIS infrared performances during the JUICE 2024 Earth fly-by: comparisons with IASI measurements and detection of atmospheric trace species”

page 4: "We did not perform any retrievals in this paper" - a few lines below the authors state "For CO, CH4 and N2O, we .... scaled these profiles in order to obtain a best fit". These are somewhat contradictory statements.

We did not do any retrievals in the sense that no inverse retrieval algorithm was used to minimize a cost function ; only direct calculations were done for different multiplicative factors to trace species profiles and we stopped the analysis when the residuals were at the order of the noise level. Our goal was to get a set of atmospheric profiles that match the data well in order to have a good baseline for our future sensitivity analysis, without seeking optimization (that is outside the scope of this paper). We agree that this could be confusing, especially where we employed the term “best fit”. For clarity, we can remove the term “best fit” and that part of the sentence that described what we did not do (remove “We did not perform any retrievals in this paper; rather”) and change a bit the text to:

“Other trace species were set to typical vertical profiles found in the tropics; however, some IASI-4A/OP mismatches were found in the spectral ranges corresponding to the signatures of CO, CH4 and N2O. We thus also scaled these trace species profiles until we obtained a good match of these spectral features (with residuals of the order of the noise level), resulting in the spectrum shown in Fig. 1."

page 5, cloud filtering: The MAJIS cloud filtering via a 4.64 um brightness T threshold appears not to be the optimal choice. Would the addition of a VIS/NIR brightness value further improve the recognition of clouds? (See Fig 3, where in the right panel more filigrane cloud structure tend to be lost.)

We argue on our side that the cloud filter works well enough: even if there seems to be a few filament clouds not captured by the BT flag, the correspondence seen in Fig. 3 is satisfactory enough to be comparable to the "less than 5% cloudy" at the scale of the wide IASI field of view. In addition, in Fig. 5, we see that all IASI data that were independently flagged as "cloudless" from a high resolution onboard camera (<5% cloud contamination) also have a BT at 4.64µm > 290K. Of course it does not mean that all data that have a BT > 290K are cloud free, but that is already half of a validation.

The reason for not choosing a MAJIS VIS radiance threshold value for the cloud filter is that the IASI/MAJIS comparison exploits the MAJIS NIR channel, and that there is not a perfect geometric correspondence between VIS and NIR MAJIS pixels. We found it simpler to base our cloud filter on the NIR channel itself, while checking the validity of our filter with this visual inspection of clouds in the VIS channel, as reported in the manuscript.

page 13, line 193ff: if the discrepancy is induced by differences in H2O as claimed by the authors, I would expect that the quite pronounced spectral patterns shown in Fig 10 at wavelengths beyond 4.6 um correspond to H2O spectral signatures. Adding some further simulations using 4A/OP should allow to verify this claim more explicitely.

We did make these calculations for different water vapor profiles as retrieved by IASI (all other variables such as surface and atmospheric temperatures held constant), as already state lines 199-201. To limit the number of figures we had not shown it. From these spectra, we found a positive correlation between the position of water lines and IASI-MAJIS differences. Our conclusion at submission time was that the IASI-MAJIS mismatch could be explained by a combination of a ~5% radiometric bias in the MAJIS calibration (as far as co-locations from swath"C15" are concerned) and of some changes in water vapor between the scenes.

However, since submission, we have done more sensitivity studies with 4A/OP to changes in surface temperature, emissivity and atmospheric temperature, and our conclusion slightly changed. Indeed, a +1K in atmospheric temperature results in a similar signal as a 10% decrease in atmospheric water vapor, so that we cannot disentangle the two contributions. Furthermore, we have led a better analysis and now characterize the radiometric MAJIS bias to be of -7.5% (instead of -5%) for these left-edge pixels. The full study is detailed at the end of the "reply to comments".

page 15, line 239: "potential variations in meteorological conditions". This seems a persisting problem for the whole comparison, especially when it comes to the H2O profile. I wonder whether the ERA5 hourly data combined with 4A/OP runs for estimating the resulting effects on radiances would help to further substantiate the conclusions and perhaps narrow down the residual uncertainty of the MAJIS radiance calibration.

We did try earlier to use ERA5 (3-hourly, not hourly) but the spatio-temporal variability in either atmospheric temperature or water vapour was small compared to the observed natural variability (as retrieved by IASI for instance), so that the resulting synthetic spectra also showed little variability and did not help in finding where the IASI-MAJIS mismatch came from. However, as said above, we refined our analysis since this Discussion was opened, and this part will be edited accordingly.

Conclusions: Here, a coincidence interval of 2 hours is mentioned, while the reader would expect (based on section 4.3 and table 1) 2.5 hours?

Indeed our criterion was 2.5 hours (in order to get co-located data for C10 and C9); we will correct this text.

Further down, the conclusion discusses in length (lines 286 to end) items which have not at all been treated in the paper. Either this part should be removed or an additional section needs to be added which makes the claims of the conclusions explicit.

Agreed; we can move this part to the end of the discussion before the conclusion.

Data availability: I find an embargo period of about 5 years after data collection of the flyby data (this would imply data accessibility three years after publication of this study) inacceptable, roughly as distant from any contemporary FAIR principles as Jupiter is from the sun. It would appear to me that the minimum requirement from the viewpoint of a study publication would be a release of at least the subset of MAJIS spectra actually used in the form of an electronic supplement.

That was not our choice but the policy (from ESA) at the time of submission, but since then they agreed to archive the MAJIS calibrated data used for the LEGA papers. We will thus add the following data availability statement:

MAJIS calibrated data acquired during the JUICE Moon–Earth flyby in August 2024 are available through the following Guest Storage Facility: European Space Agency, 2026, ESA-JUICE_LEGA-Special-Issue_v1.0, https://doi.org/10.57780/esa-2bb387d.

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Referee #2

General comments: This is an interesting cross-comparison for the first in-flight characterisation of the MAJIS IR channel against a reference sounder (IASI), applied through an established methodology (4A/OP). The data is well studied and the study merits publication after revision. My main concern is that the authors tends to state the central calibration results more firmly than the actual data support: The comparison uses limited data subset rather than statistics over the full data set, The differences are attributed mainly to water vapor when other effects such as those from calibration bias, pixel-position effects and a high-angle emissivity assumption are omitted. I recommend publication after revision, contingent on the four major comments below.

We thank the referee for his review that motivated us to refine our analysis and sensitivity studies.

However we tend to disagree with that sentence: “ ...when other effects such as those from calibration bias, pixel-position effects and a high-angle emissivity assumption are omitted”

as calibration bias are at the center of our work (this is precisely what we want to bracket); as pixel-position effects are also mentioned (that is why we did not do a global statistical analysis but separated case studies for the middle, left or right edge of the MAJIS array); and high-angle emissivity are not a concern here (the largest value is 50°).

Statistics over the full dataset were initially done but given the range of different observing conditions (such as viewing angles or local times gaps between IASI and MAJIS) and different parts of the MAJIS array for different swaths, we preferred to take a closer look at co-locations from different MAJIS swaths. Not showing a global statistical analysis was thus motivated for scientific reasons.

Major comments

1. The calibration conclusions come from on one example (C15), + some limited C10/C11 yet there are 36 co-locations, each with tens–hundreds of MAJIS spectra. Why do authors do not want to show the mean and scatter of full data set; (MAJIS−IASI)/IASI as a function of wavelength across all 36 co-locations, with error bars? Without this, “better than 10%” remains unsupported. When the authors show the difference, they can add a %-difference plot or curve secondary axis to Fig. 10b.

We did such plots early in our analysis to look at statistics over hundred of co-located data (mean and scatter), just as the referee suggests. This highlighted the spectral shift issue (detailed in Langevin et al., same issue). Once corrected for, the scatter between IASI and MAJIS remained quite large, and we then turned to more focused comparisons, swath by swath. The reason behind it was to try to disentangle potential biases that would not be global, but dependent on the position of the pixel on the array; or depending on the varying “quality” of the co-location criteria. For instance, there were only a 3° difference in emission angle between IASI and MAJIS for swath C11, but a 15° difference for swath C10.

Collecting all co-located data was thus not very informative, and we instead choose to show these comparisons separately in the manuscript for C10, C11 (7 IASI spectra for each case, for the sake of clarity) and C15. To limit the number of figures we have not shown C9 but did perform the same analysis.

For this revision work, we still focus our analysis for swath C10, C11 and C15 separately but we have updated our plots to include all the co-located data for each swath; the median of the difference; and show both the relative (in %) and absolute differences (see at the end of the reply to comments for updated plots and a detailed description). We hope this will convince the referee that based on comparison with IASI, we find that MAJIS radiometric calibration is indeed within 10%, over most of the considered spectral range.

2. The “best case” is C15 (L176), itself flagged as glint-affected and corrected; C15 is then reused in Section 5 for the SNR and trace-species analysis despite being among the poorer matches. Using

a contaminated swath as the radiometric reference, and again as the trace-species testbed, should be justified or replaced with cleaner swaths.

While that swath is largely glint-contaminated, the upper part of the array is not. We used a very stringent filter for glint on purpose and we are confident (based also on an analysis on the VIS channel where glint is also obvious) that the remaining MAJIS spectra that pass our filter are not contaminated. There is no correction applied (we do not know to which correction the referee is referring to). In the submitted version, we chose these spectra as our benchmark test case because they are the closest in space and time to IASI spectra (acquired only 20 minutes earlier than MAJIS, versus ~2 hours for the C10 and C11 cases); hence we found it the best case to perform a sensitivity analysis on trace species as we could start from a reference atmospheric state (temperature and composition) taken from IASI retrievals. The SNR and trace species analysis from other swaths yield extremely similar results anyway; hence we argue to keep our test case in the manuscript.

3. The fact that C10/C11 agree well without correction while C15 needs +5% does not confirm the influence of the water-vapour story.The water-vapour attribution, and the +5% bias, should be presented as cpossible hypotheses , not as established. The abstract and conclusions currently overstate this.

We agree; this is why we presented two hypothesis: a radiometric bias that depends on the detector's pixel position, and an effect of different meteorological conditions between IASI and MAJIS times of acquisitions (as there was a ~2h gap in local time for swath C10 and C11, but only 20 min gap for swath C15). We precisely presented these in those terms (line 223-229) "One hypothesis is that…The other hypothesis is that…", s while our conclusions was also cautious ("we suggest that...") so that we find the referee's comment somewhat a bit unfair.

We will anyway re-write the whole section and conclusion in a revised manuscript, based on the more extended sensitivity studies (see text and figures at the end). We feel that we now have more elements pointing towards a pixel-dependent radiometric bias (left versus right edge of the detector) but will continue to remain cautious throughout the manuscript, as more data are needed to confirm these results.

4. The flyby geometry is ~50° emission angle, yet 4A/OP uses a fixed emissivity of 0.98 across the whole range. At ~50° the sea-surface MWIR emissivity departs measurably from 0.98 and becomes angle- and wavelength-dependent, and the reflected term grows, wavelength-varying effect of the same magnitude attributed to water vapour. An angle-dependent emissivity should be tested before the residual is assigned to water vapour.

The referee is right that emissivity will vary with emission angle and wavelength (and windspeeds), however we argue that these changes are very small.

Firstly, according to Masuda et al., 1988 (Remote Sensing of Environment), the emissivity of sea water is expected to lie in the range 0.963 – 0.977 at a wavelength of 4 µm for emission angles between 0 and 50°, with amplitudes of wavelength-dependencies of 0.015 at maximum between 3.5 and 4.1 µm. For instance, at a 50° emission angle the emissivity of sea water varies between 0.9559 at 3.5 µm to 0.9637 at 4.1 µm. [We checked our program and actually used a constant value of 0.97

in the results presented in the manuscript, not 0.98 (that was used for preliminary tests; this error will be corrected in the revised manuscript)].

Secondly, while we note from Masuda et al. that emissivity values depart significantly from 0.97 at high emission angles (~0.94 at 60°, 0.86 at 70°, and so on), the highest emissivity value in the whole IASI data set is 53°, and 50° for MAJIS case, so that we should not be concerned by any significant variations.

Thirdly, it is important to note that while changing the emissivity will have a small impact on the measured spectra in the range 3.5 -4.1 µm, it does not significantly impact the outgoing thermal emission in the range 4.1 to 5.5 µm, dominated by atmospheric (gaseous) absorption. Hence, in the spectroscopic range of water vapor, changing the emissivity has no noticeable effect on the spectra, and we disagree with the referee remark that the emissivity could have a " wavelength-varying effect of the same magnitude attributed to water vapour" and that "An angle-dependent emissivity should be tested before the residual is assigned to water vapour.".

That being said, we do now include a sensitivity test on the influence of emissivity in our revised analysis (see plots at the end of the replies). We find that small emissivity variations in the range +/- 0.01 or 0.02 could help fill the gap between IASI and MAJIS at wavelength shorter than ~4µm for some swaths, and confirm that it has no significant effect in the range 4 -5.6µm.

IASI and MAJIS being taken at similar emission angles, we argue that such small changes in emissivity could be rather attributed to change in wind speeds.

Minor comments

Abstract

- Abstract can be slighly misleading since it may imply IASI and MAJIS share similar local times, locations and footprints, whereas all differ and effectively only three IASI spectra are truly comparable. Please state this clearly.
  We can rephrase these sentences by removing the term "co-located" and write instead "...acquired very close in space (<0.1°) and less than 2.5 hours away in time". We consider the difference in footprint size to be too much a detail for an abstract (it is stated clearly enough in the manuscript).
- The "Excellent" is contradictory with "better than 10%" Considering it is an instrument designed for other objectives yes the comparison is indeed impressive but either name the benchmark or soften the sentence.
  We will remove the term "excellent" that was indeed subjective.
  In Abstract "~15%" beyond 5.25 µm is menstioned here, however in the text and conclusions "~15–20%" — is stated.
  These parts will be edited according to the updated analysis.
- For the trace species the authors use uniform capability. The detection significances show each gas is detectable above the noise. The retrieval precisions (Table 2) are a different, theoretical quantity: the minimum column uncertainty achievable if noise were the only error. Usefulness depends on comparing that precision against each gas's natural variability: CH_4 is unusable, CO marginal. The abstract and Section 5 should therefore not present a uniform "sensitivity to trace species.

We agree and we did include a comparison with each gas natural variability in the submitted manuscript (see Table 2) and already emphasized in Section 5 that CH4 is useless (line 264: "Hence, no useful information on the CH4 spatial variations can be derived from MAJIS spectra"). We will make this point clearer in the abstract in the revised version.

- Minor: "carbone monoxide" → "carbon monoxide."

We will change this in the revised manuscript.

Introduction

- State briefly here the spectral resolutions of both MAJIS and IASI (currently mentioned only later), and note the observations are close but not exactly co-located in local time.
Goo idea; we will add a mention of the differences in spectral (and spatial) resolutions of the two instruments in the introduction.
However, we already used the term "similar locations, local times and viewing angles"; we did not say it was exactly the same. While we agree this is not very precise, we find it is appropriate for the introduction - there is a full section dedicated on the choice of co-location criteria.
- For description o Majis observations the authors move too fast and rely heavily on forward references to companion papers (Poulet 2025, Langevin 2026, Oliva 2026); some data and figures must stand on its own.

We will remove from the introduction that sentence referring the reader too quickly to companion papers for detailed description of MAJIS and change section 3 to "Characteristics of IASI and MAJIS observations".

Section 3 — IASI characteristics

- Drifts into describing MAJIS co-located measurements; comaprison of the footprint, local-hour mismatch and comparability should be addressed may be in other sections.?.

We feel this can be solved by changing the section to "Characteristics of IASI and MAJIS observations", so that we will describe the two instruments in parallel, including a comparison of their footprint sizes etc.

Section 4 — Timing & co-location

- Provide a table of the time and local time of each observation actually used (currently deferred to other papers).
Rather than repeating here a general table for all MAJIS observations, we have prepared this table below, focused on characteristics of co-located MAJIS and IASI datasets, showing the ranges in local times and emission angles of both datasets, and latitude/longitude ranges to help locate them on the map.

Swath number	Number of co-located IASI obs.	Longitude range (MAJIS and IASI together)	Latitude range (MAJIS and IASI together)	Local time range (MAJIS)	Local time range (IASI)	Emission angle range (MAJIS)	Emission angle range (IASI)
C08 right	1	140.5-140.55	20.6 – 20.8	6h57	9h23	19.3	37.3

edge							
C09 left edge	8	140.7 – 141.9	17.7 – 18.8	6h59 - 7h03	9h24 – 9h29	17.0° – 18.8°	25.5° – 33.3°
C10 middle	13	146.1 – 147.8	22.9 – 25.2	7h20 - 7h28	9h43 - 9h50	24.1° - 25.4°	4.9° – 10°
C11 right edge	14	153.2 – 154.6	25.6 – 27.4	7h50 - 7h58	9h18 - 9h23	32.4° - 33.7°	24.0° – 31.7°
C15 left edge	3	174.4 – 175.0	28.8 – 29.2	9h20 - 9h22	9h01 - 9h03	49.7° - 50.5°	52.2° – 53.8°

- The 06–10 h MAJIS scenes; are they within 3 h of IASI, or 2.5 h as in Table 1? Reconcile, and re-examine the loosened criterion.
  It is 2.5h as reported in the Table; we did not find a reference to "3 h" but we will double check.
- ±2.5 h at these local times is a large geophysical gap; quantify its expected radiance impact (linked to Major comments).

  Indeed, especially in the strong 4.2 µm CO2 band (probing the upper troposphere), we clearly start to see some departures between IASI and MAJIS observations that could be attributed to different atmospheric temperatures for the swath with a 1h30 gap, which increases for swaths with gaps of 2h or more.

  We note however that over the tropical ocean, where the surface temperature varies little (less than 1K according to ERA-5 data), this is not "that" large a gap.
  We wished we had more data closer in local time but restricting this criterion to only one hour leaves only the 3 IASI co-located observations in C15 (as said in the text around line 165). Our only strong conclusion is based on swath C15, precisely for this reason.
  In parallel we chose to loosened this criterion to get a larger number of co-located data and have more material for discussion. We do take into account potential changes in meteorological conditions in our discussions, supported by calculations of synthetic spectra with 4A/OP. While no quantitative analysis can be made due to this large gap, we do qualitatively find consistency among different swath (see text at the end).

  Another Earth fly-by is planned for September, 2026; hopefully this will bring complementary information (we will add this point in the conclusion).

Section 4.1 — Cloud filtering

- Excluding clouds is the good choice (cloud variability would affect the signal); the paper need only state this rationale in one sentence early also (also Table 1).
  Good idea; we will mention the challenges of intercomparison of two satellites datasets in the introduction, including the effects of clouds.
- For clouds VIS+IR is used on the MAJIS side (0.7 + 4.64 µm); IASI has limited range. Does it have a visible channel ? Figure 5 mentions an onboard camera. how is it used? Authors can discuss further?

Indeed, as IASI spectral range starts near 3.6µm, complementary information on clouds are obtained from a camera called the Advanced Very High Resolution Radiometer (AVHRR), mounted onboard METOP and NOAA satellites. It operates at 5 different channels simultaneously in the visible and infrared bands, at central wavelengths 0.63µm, 0.865µm, 1.61µm (only daytime), 3.7µm (only nighttime), 10.8µm and 12µm. It has an instantaneous square field of view of about 1.1 km near nadir and is used operationally by EUMETSAT to provide cloud coverage (among other data products). Cloud contamination within IASI, in % of field of view, comes as an operational IASI L1C data product.
Useful references are Guidard et al., 2011 and Farouk et al., 2019 that can be assed in the revised version.

- The <5% IASI cloud fraction is not a radiometric floor; The authors can quantify its actual radiometric impact and show it is negligible against the 10% claim.

The precise radiometric impact would depend not only on cloud fraction but also on the cloud type (low and thick cloud versus high and thin cirrus, for instance), but a 5% threshold was found by previous studies to be a good compromise between accuracy and number of co-locations, and is used as a standard in CAL/CAL IASI activities. Note that while a 5% threshold was used, most IASI data that we retain had a “0%” cloud contamination (according to this flag).

To convince the referee, we selected a large set of IASI data, all acquired at similar viewing angles, either flagged as “cloud-free” or 5% cloudy. The bias between the two ensemble of datasets is small : the “5% cloudy” data have a small positive +1.1% bias below 4µm and a small negative -0.4% bias between 4 and 5.5µm, with a standard deviation of 1.3%. The order-of-magnitude error due to possible different cloud contaminations between IASI and MAJIS is thus of typically ~1 %. We can add this piece of information in a revised manuscript.

Section 4.2 — Glint

- Justify the 3.9 µm glint proxy and the >301 K threshold; this explanation arrives very late (L155) and should move forward, next to Fig. 6 (which is vey helpful).
  We can improve a bit the clarity of this section by first showing the spatial distribution of the main signal of the glint spot (best seen in the visible/near infrared - eg. 2.35 µm and currently Fig. 7), and then mention its more subtle signal in the range 3.4 - 4µm – currently Fig. 6 – to argue why we use the 3.9µm as a proxy; a wavelength common to MAJIS and IASI.
- Glint is itself an additional uncertainty Authors shall make it explicit.
  We agree, but this is the very reason why we have excluded glint-contaminated pixels from our analysis.
- 11 retained observations are all daylight (L141)....are not they?
  Yes they are all daylight.
- Fig. 7 / L146: can clouds be separated so the glint pattern is clearer?

  Unfortunately not, as glint is strong also above clouds (high reflectivity), like for instance in swath C13. Removing cloud-contaminated pixels would remove most of the data from this swath, and the glint pattern would then be even less clear.

- Explain the dark slit/line along the edge of some swaths (C11, C14, C15).

Indeed we forgot to mention it: the MAJIS array is 400 pixels-wide but during the Earth fly-by data was acquired in windowing mode, where only swath 64 (or 128) pixels-wide were recorded. For calibration and test purposes, data was acquired either for central, left or right edge pixels of the MAJIS detector array (we do explain this in the text; but will move it earlier, to section 3 in the description of IASI and MAJIS data). Furthermore, for left and right edge acquisition, observations were slightly off-centered on purpose to see the effect of straylight on the detector. The dark lines on the edge of some swath correspond to ~5 out-of-field pixels that did not receive any direct signal from the target: we will add this missing piece of information. Straylight was found significant only in the visible range and is documented in Langevin et al. companion paper.

Section 4 — Figure 2

- It can be confusing for reader to see data is over exposed and saturated, nevertheless still have lower radiance values, and he cloud signal in addition the glint. Plesea explain how a a swath can be glint-bright and saturation-dark at once , mechanism and how saturation is distinguished from clouds?

  Saturation is defined when raw Digital Numbers (uncalibrated radiances) are over a threshold of 11 000 in the infrared channel. It occurred for swath C12, C13 and C14 that had a twice longer acquisition time. Why in some cases this resulted in too low signal in specific spectral ranges is not well understood, but we feel it not necessary to dive into this issue in this paper. The main piece of information is that these saturated pixels are flagged and excluded from our analysis.

Section 4.4 Comparing IASI and MAJIS spectra

- Explain why the IASI footprint is an ellipse rather than a circle (in figure we see a circle, off-nadir projection foreshortening...
  The IASI footprint is an ellipse, as the circulat FOV will be elongated in the cross-track direction (it is a circle only for pure nadir). In the figure you do see that our co-locations encompass an ellipse (eg fig. 9, blue points) and for simplicity we did not represented graphically the full IASI footprint ellipse but just circled the central (longitude, latitude) of a given IASI data. We have revised our figure to now graphically display an ellipse for consistency in that figure (see new figures at the end).
- The 2–5% emission-angle correction (ratio of two 4A/OP spectra, L180) is another error source can be considered it in the error budget.
  We see it from a different perspective: as we account for differences in emission angles in our analysis (using synthetic spectra from 4A/OP), we make the assumption that this effect should be canceled out and do not consider it as a source of error.
- Clarify whether the “raw comparison” (L183) is before or after these corrections; the wording is confusing.
  Indeed this was confusing: the IASI-MAJIS comparisons discussed and shown in the submitted manuscript are done with a correction factor applied to IASI spectra based on 4A/OP calculations at different emission angles, so that this was not a “raw comparison”. Our updated analysis will make this point clearer: we will either show the raw comparison (and the effect of emission angle change as estimated from 4A/OP overplotted), or

comparisons with synthetic spectra computed with the actual emission angles (see text at the end).

Section 4 — Spectral shift & residuals

- L172: the 4 nm shift beyond 4 µm is asserted but not shown — provide a demonstrating figure, or state clearly it is documented in Langevin (2026) and confirm the spectra used here already include the correction.
  It is demonstrated and documented at length in Langevin paper through cross-correlation studies. We already stated that in our paper we only present results with MAJIS spectra corrected for this shift (see line 172-174). However it is true that we mention the shift in the abstract (we did so as it was the work reported here, eg MAJIS – IASI – 4A/OP comparisons, that revealed the shift and served as a basis for the analysis in Langevin paper), so that we understand the referee's confusion. We will thus add a figure highlighting the shift (see next page).

- L183: where does the 0.15 W/m²/sr/µm difference apply (below 4.57 µm?), and what are the peaks above 4.5 µm — water vapour? Explain.
  This difference applies beyond 4.55µm (see Fig. 10, middle panel). Water vapour lines dominate the spectra beyond ~4.9µm.
- L210: why 5.25 µm and not 5 or 4.75 µm? Why not anchor on specific water-vapour lines? The "<10% above 5–5.25 µm" claim is a bit arbitrary oplease revise these numbers carefully (and see Major 1 for the % plot).
  We will show plots both in absolute and relative units in the revised version (see text and figures at the end of the replies) to clarify this point.
- Can the water-vapour effect be modelled out with 4A/OP rather than invoked qualitatively?

  Yes this is what we did already in the submitted version (see lines 199-201 and reply to referee #1) and will be shown more clearly in the new figures (see at he end). Givent the results of the new analysis, we will not retain the water vapor variability as a main source of discrepancy anymore (small atmospheric temperature changes can produce rather similar changes).

Section 5 — Synthetic spectra & trace species

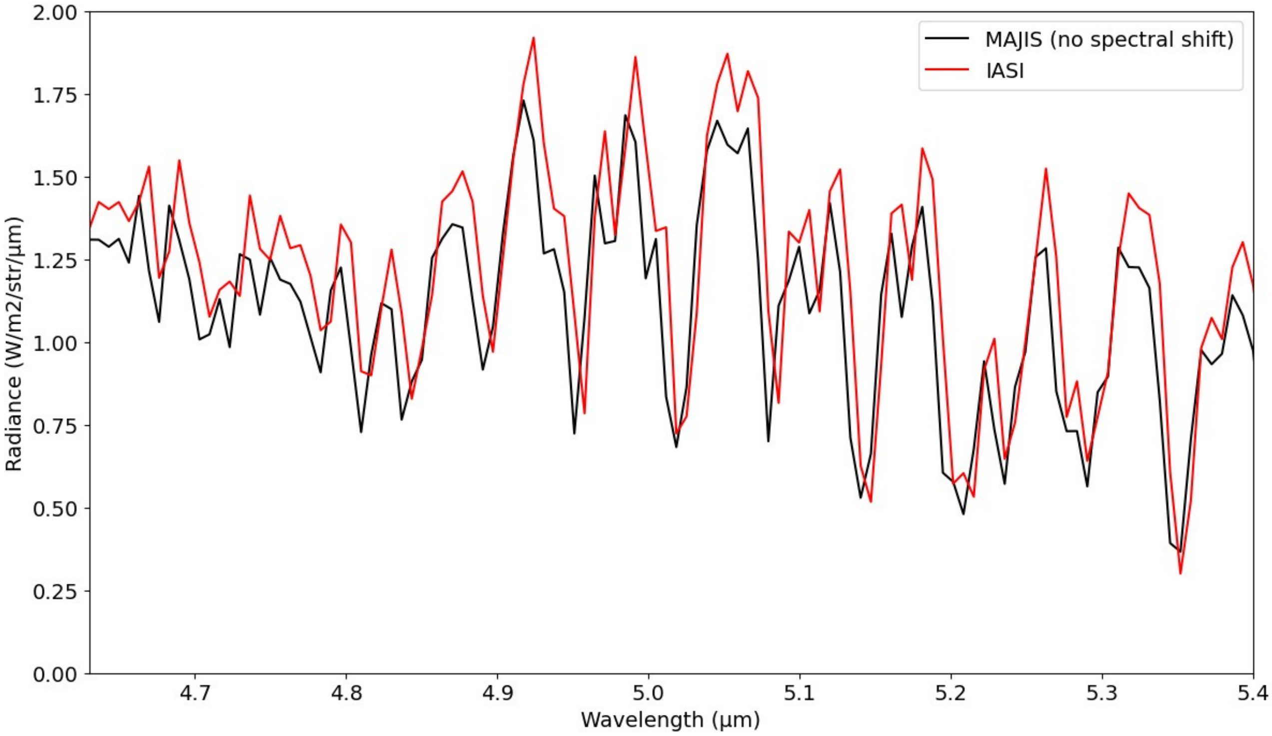
- The SNR (200–300) is derived from the variance of (MAJIS−4A/OP), which contains model and measurements error and it is not an instrument-noise metric. The authors can extend the discussion or estimate noise from a cleaner source (e.g. repeated-pixel variance).

  SNR values were estimated from an instrumental point of view from the read-out noise in Poulet et al. 2026 (same issue); as already quoted in the manuscript. The estimate we gave in our paper did not pretend to be an instrument-noise metric value, but has the merit of being an independent evaluation and shows good consistency with Poulet et al. study.

Conclusions

- The 4 nm shift is not demonstrated in the paper.
  Indeed but we never pretended to demonstrate it in our paper; it is done in a companion paper focused on spectral calibration (Langevin 2026); as said in the manuscript. However we are happy to add a figure below to illustrate this shift, through the comparison of a IASI

and a MAJIS spectrum without any correction. The shift actually varies depending on the pixel position on the array. For the quantitative analysis, based on cross-correlating MAJIS spectra with 4A/OP and IASI ones, the referee is invited to read Langevin et al., 2026.



- The water-vapour explanation is a hypothesis, not established (see Major 3)
  That was presented as an hypothesis, based on calculations done with 4A/OP for different amount of water vapor, as said in the submitted manuscript and will be illustrated in more details in this the revised version. The effect of other sources of variability such as atmospheric temperature or changes in emissivity will be added.

- The % error figures and band-by-band claims should be revised (see Major 1).
  We are not sure what the referee means by "band-by-band claims".
  We have revised our approach to quantify in more details the % error due to different factors (different emission angle, emissivity, meteorological conditions between IASI and MAJIS). We also show in the text and figures at the end, in addition to MAJIS-IASI (convolved at MAJIS resolution) comparisons, another type of comparison: (observed – 4AOP)$_{IASI}$ – (observed – 4AOP)$_{MAJIS}$, where the 4A/OP spectra were computed for the same emission angle as the corresponding observation, and using the native spectral resolution of each instruments. Indeed, this way the synthetic spectra with 4A/OP are computed with each instrument lineshape (ILS) function, and we avoid biases linked with convolving IASI (that has its own ILS, including an apodization) to MAJIS ILS. We believe the results are more convincing, and point to a bias of ~-7.5% for MAJIS data from C15. We added an estimate of radiometric biases between left and right edges of the detector array.

- Trace gases: retain the detection result but temper the retrieval-precision claims (

We can slightly change the conclusion but we feel like these precision values were already well tempered : they are not even mentioned in the abstract; they were already compared with natural variability of these gases (with a mention of non usefulness of CH4 for instance); and were clearly presented as minimal uncertainty values and not described as retrieval-precision values in the text.

Revised analysis of the IASI-MAJIS agreement, to be edited and included in a revised version of the manuscript depending on the referee’s opinion:

<u>Part 1:</u>

We detail below a more extended analysis of the comparison between IASI and MAJIS. The co-location criteria have not changed compared to the submitted version. The new figures below would replace the current figures 10 and 11.

Instead of showing a selection of co-located IASI data for swath C10, C11 and C15 (done for the sake of clarity of the figures in the submitted version), we now show all IASI data considered co-located to MAJIS ones for each swath separately, representing 30 out of the 39 IASI co-located data in total. The remaining 9 cases, located in swath C8 and C9, have been examined similarly and are discussed later.

In addition to direct MAJIS and IASI comparisons, we include plots of the difference between these two datasets both in absolute and relative (%) units. In these plots, we add the expected impact, based on synthetic spectra computed with 4A/OP, of small changes to surface temperature (+/-1K), atmospheric temperatures (+/-1K), emissivity (+/- 0.01 or 0.02 depending on cases), water vapor (+/- 10%) and emission angles (corresponding to the actual gap between IASI and MAJIS for each swath).

Location and footprints :

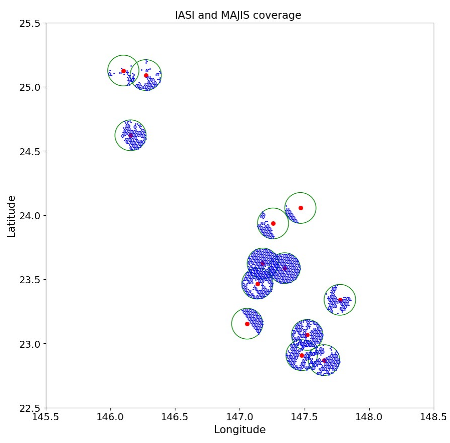


Figure 2: Case C10

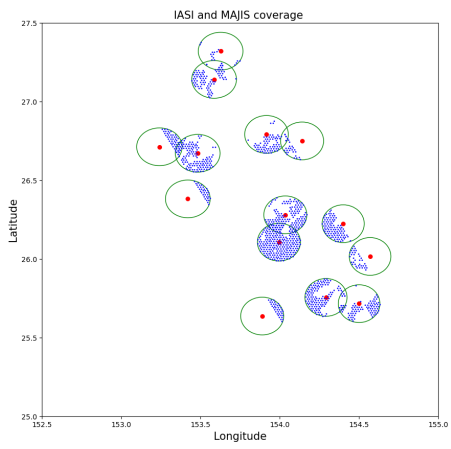


Figure 1: Case C11

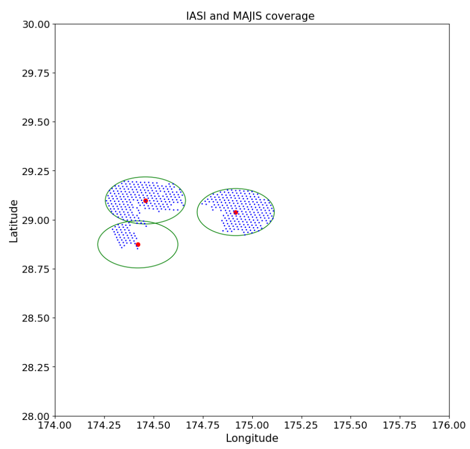


Figure 3: Case C15

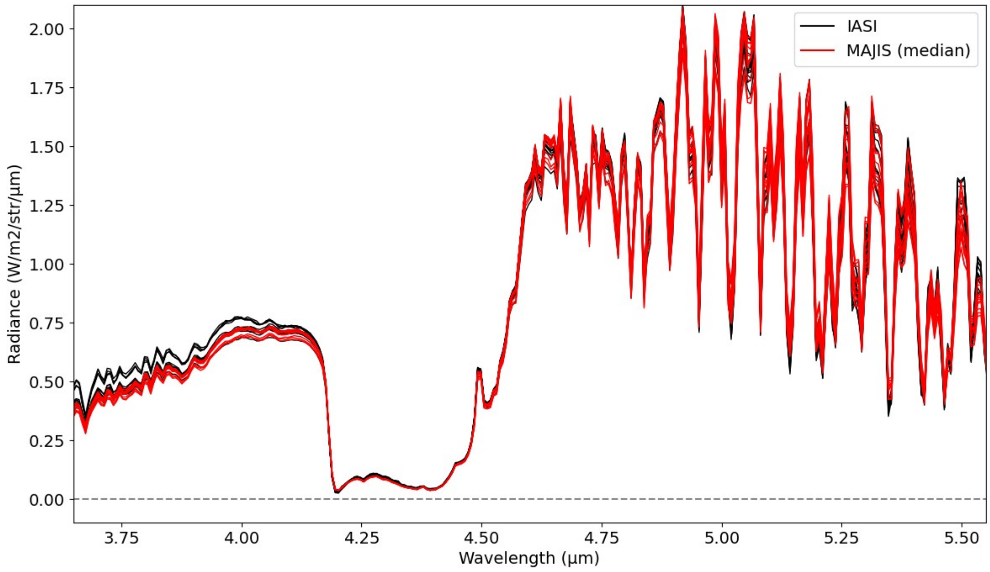


Figure 4: Case C10

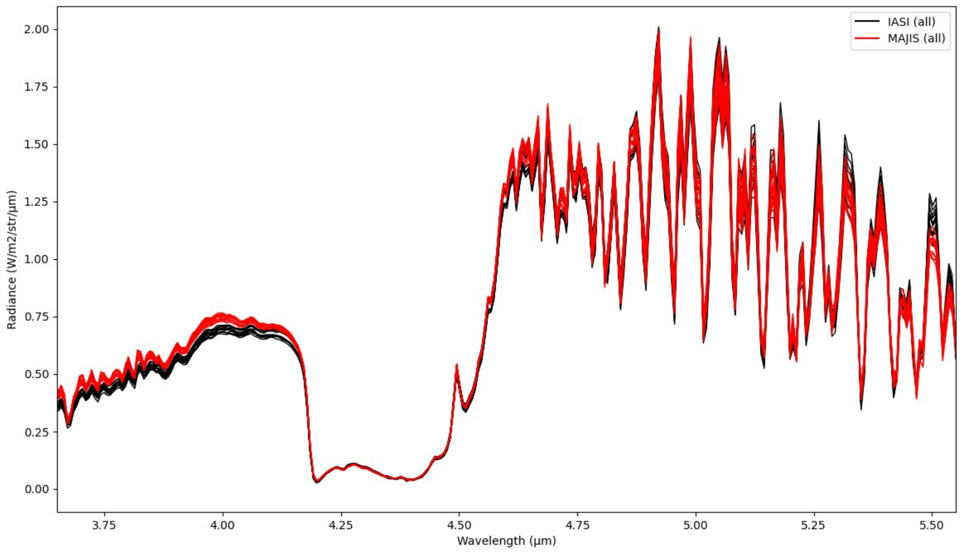


Figure 5: Case C11

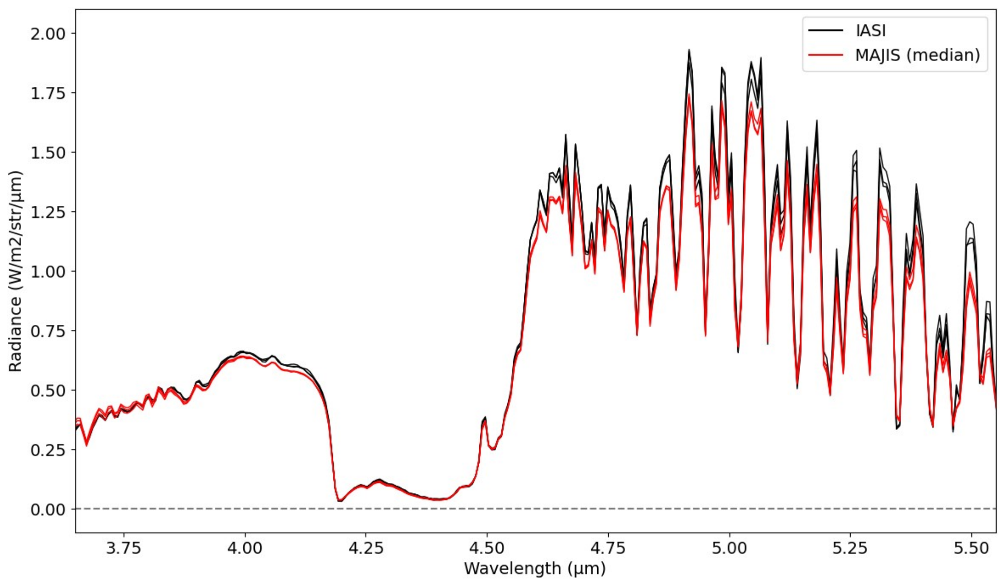


Figure 6: Case C15

IASI – MAJIS difference, in % (grey lines + the median as black bold line)

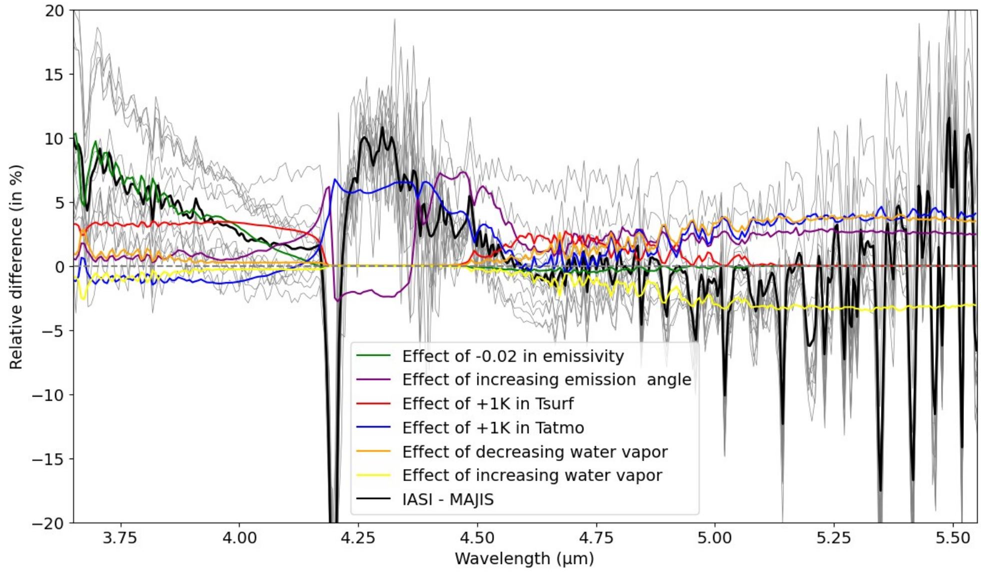


Figure 7: Case C10

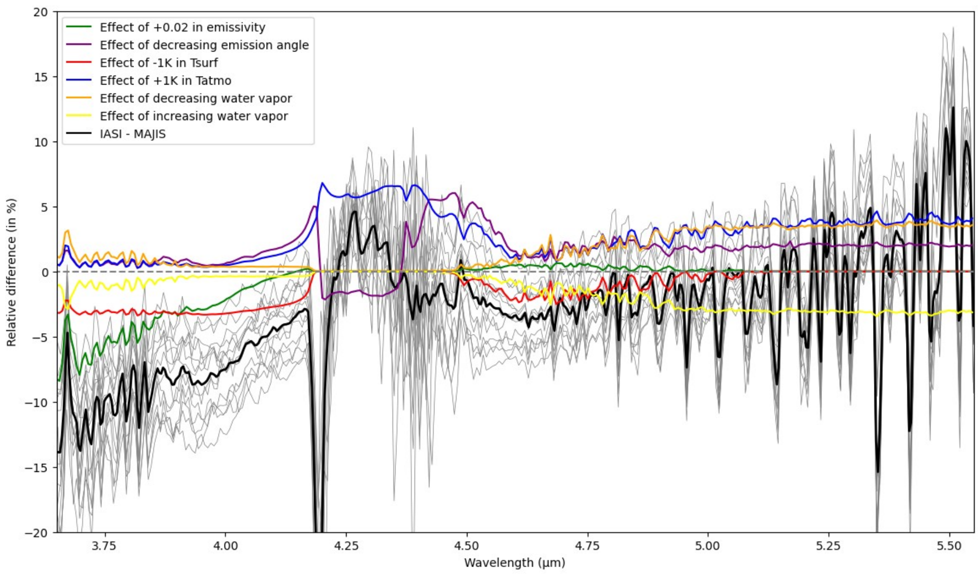


Figure 8: Case C11

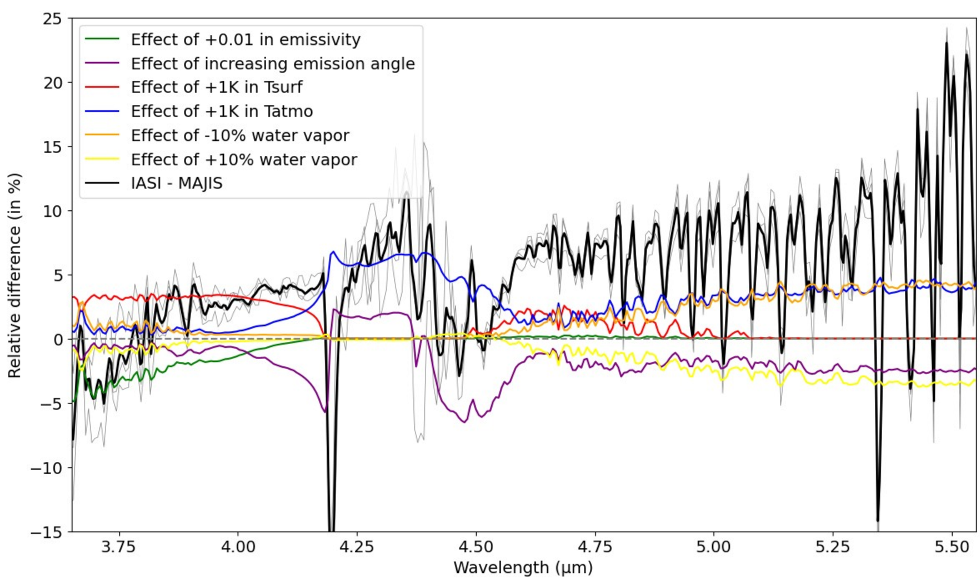


Figure 9: Case C15

IASI – MAJIS difference, in radiance units (grey lines + the median as black bold line)

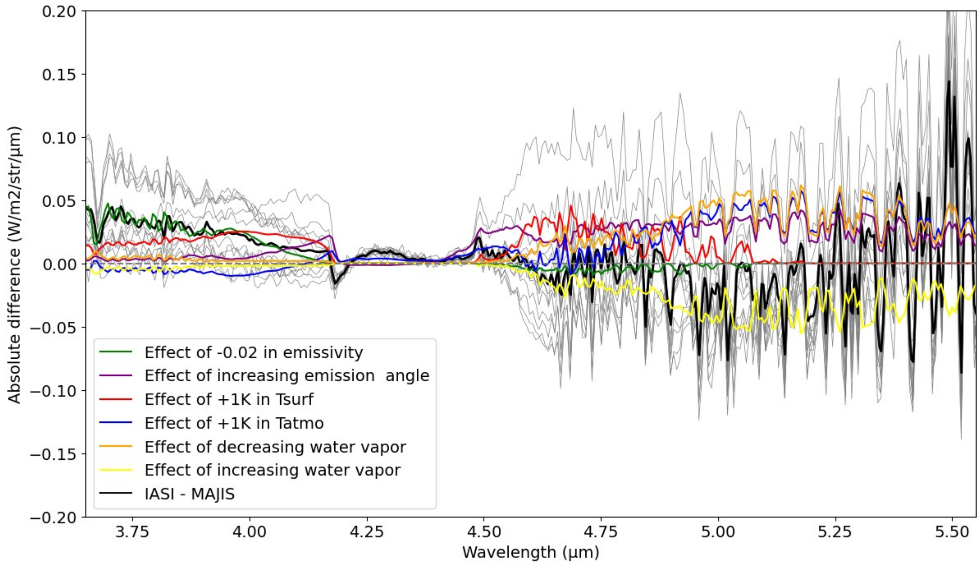


Figure 10: Case C10

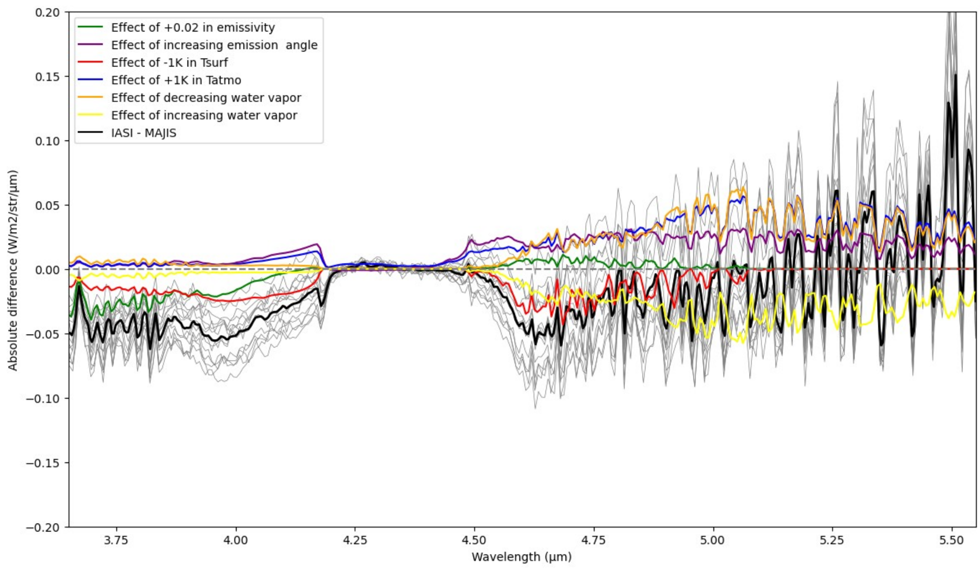


Figure 11: Case C11

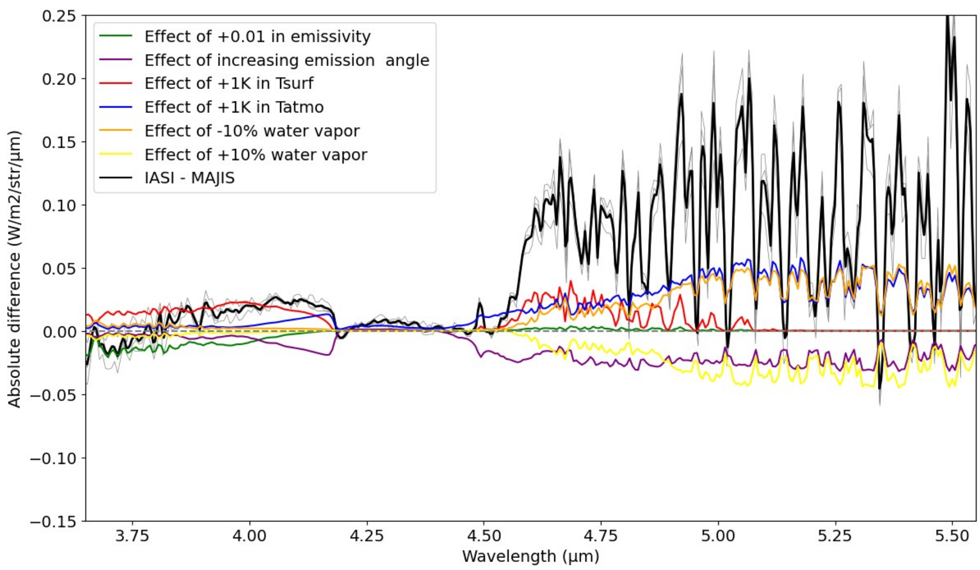


Figure 12: Case C15

Several observations can be made:

- The “raw” comparison of IASI (convolved) spectra – MAJIS ones, from 3.65 to 5.55µm [excluding the 4.2 region where the signal is close to zero], roughly lies in the range -10 to 10% (swath C10 and C11) and -5 to 20% (swath C15).

- The difference between the two datasets displays spikes beyond 4.5µm. Part of these peaks may reflect actual differences but part of these are also artefacts. This highlights the shortcoming of convolving IASI spectra to MAJIS coarser spectral resolution : this method gives satisfactory results to first order, but cannot – by construction – exactly reproduce a spectrum as if it was made with the MAJIS Instrument Lineshape (ILS) function. Indeed, the degraded IASI spectra are the product of the IASI ILS operation, followed by our convolution.

- Small changes on geometric, surface and meteorological conditions produce changes in synthetic spectra of the order of ~+/-5%. These are wavelength dependent; for instance, changing the emissivity has no noticeable effect beyond 4.1 µm. We do not conclude here that the IASI-MAJIS differences are due to changes in meteorological conditions; we simply raise this point at this stage to highlight the challenge of inter-instrument comparison when the data is not strictly co-located.

- Looking at the IASI-MAJIS difference in absolute terms (radiance units), and taking swath C11 as an example, we notice that this difference is correlated to the spectroscopic signatures relative to a change in surface temperature in the range 4.5 to 4.75µm (compare the black and red lines); and to spectroscopic signatures relative to changes in atmospheric temperatures and water vapor in the range 4.9 to 5.55µm (compare the black and blue and orange lines). We also notice that the individual IASI-MAJIS differences (grey lines) seem to all follow similar trends, slightly shifted with respect to one another: for instance, in the range 4.9 to 5.55µm, whether these differences are positive or negative, they all spectroscopically correlate to a decrease in water vapor or an increase in temperature (the grey lines are positively correlated to the orange and blue lines; not to the yellow one even when the grey lines have negative values). All these elements point to a systematic radiometric calibration bias as the main origin of the IASI-MAJIS difference in the spectral range 4.5-5.55 µm.

- The observed inter-instrument bias cannot be explained by the difference in emission angle, as radiative transfer simulations with 4A/OP predict a correction of opposite sign.

- Looking at the IASI-MAJIS difference in relative terms (% units), swath C15 appears to be the clearest case to highlight a systematic, wavelength independent calibration bias. Indeed, invoking a constant -7.5% bias in radiance in MAJIS observation would bring the averaged IASI-MAJIS difference roughly centred around the purple line, representing the theoretical effect of the slight emission angle difference between these scenes. **Another demonstration of this ~7.5% bias is done in the “Part 2” paragraph further down.**

- For swath C11, the IASI-MAJIS difference is overall negative and below the purple line that mimics the effect of difference in emission angle, pointing towards a small positive calibration bias of MAJIS, contrary to C15, except near 4.3 µm and beyond 5.3µm. Swath C10 is less clear, showing even more wavelength-dependent IASI-MAJIS mismatch. We thus cannot quantify potential calibration biases as we did for swath C15.

For swaths C10 and C11:

→ Between 3.65 and 4.1µm, the IASI-MAJIS difference presents a spectral slope that could be hypothetically represented by a change in emissivity of +0.02 combined to constant radiometric bias of - 5% in MAJIS data (swath C11), or an average change in emissivity of -0.02 (for swath C10), although for this swath there is a large dispersion of slopes among individual co-locations. Such emissivity changes could reflect different windspeeds and/or wind directions between the acquisitions by the two instruments, about 2 hours apart.

→ Between 4.2 and 4.6µm, the IASI-MAJIS difference is spectrally anti-correlated to the change in emission angle (compare the black and purple lines): here, a change in atmospheric temperature seems indispensable to reconcile the two observations. For both C10 and C11, a slightly warmer temperature in the upper atmosphere (probed by the 4.2 µm CO2 band) at the IASI time (9h30 on average) compared the the MAJIS time (7h40 on average) would help reconcile the two datasets. However, we only simulated here a constant +1K temperature change on the entire vertical profile, and the magnitude of the needed temperature change to match MAJIS observations is impossible to assess without performing a retrieval on the MAJIS data.

→ Complementary information could be gained from retrievals of the vertical profiles of temperature and water vapor, along with a constant radiometric bias but 1) would probably give several combinations of solutions (underconstrained and ill-posed inverse problem) and 2) is outside the scope of this paper. In addition, even if we did have these ensembles of best fitted atmospheric profiles, we would still be unable to conclude on the exact magnitude of a radiometric calibration bias given the lack of independent temperature and water vapor measurements at the same local time.

To conclude, C15 provides the best co-located pairs, taken only 20 minutes apart from IASI, and points to a constant negative radiometric bias of -7.5% of MAJIS data (see also next paragraph); while C11 tentatively point to a small positive bias. This discrepancy is not necessarily in contradiction: a radiometric calibration bias could depend on the pixel position on the array (C15 corresponding to the left edge of the detector). We expand on this aspect in Part 3 further below.

Part 2: complementary demonstration of the 7.5% radiometric bias in MAJIS data for swath C15.

In order to lower the effects of the potential artefacts linked to convolving IASI to MAJIS resolution, and to also directly take into account the effects of slight different emission angles, we performed another comparison experiment: We simulated synthetic spectra with 4A/OP at the native resolution of IASI and MAJIS separately, and for their respective viewing geometry (see fig. 13). We did that only for swath C15 as the difference in local time is small and we assume now that different meteorological conditions play a minor role.

The difference between synthetic and observed spectra is shown in fig. 14: the goal here is not to discuss the observation – model residuals specifically for each instrument, but to focus on the inter-instrument differences. The difference between $(4A/OP – obs)_{IASI}$ - $(4A/OP – obs)_{MAJIS}$, shown in fig. 15, clearly demonstrates a wavelength-independent calibration bias between instruments, with

MAJIS having on average 7.5% less flux than IASI observations, raising to 10% beyond 5.3µm. This method has also the advantage of cancelling out some potential errors in the forward model.

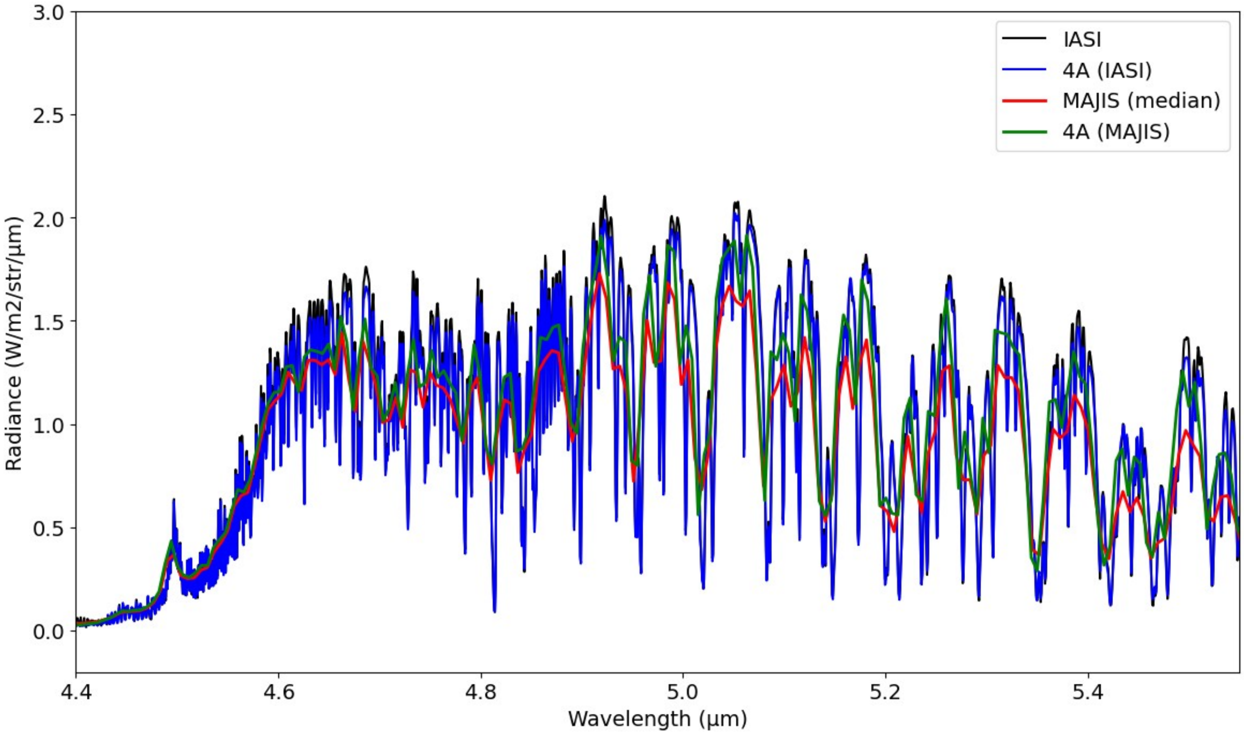


Figure 13: Illustration of 4A/OP synthetic spectra computed with the IASI ILS and viewing geometries (in blue), compared to IASI spectrum (in black) and a 4A/OP spectrum computed with MAJIS ILS and viewing geometries (in green) compared to a MAJIS spectrum (in red).

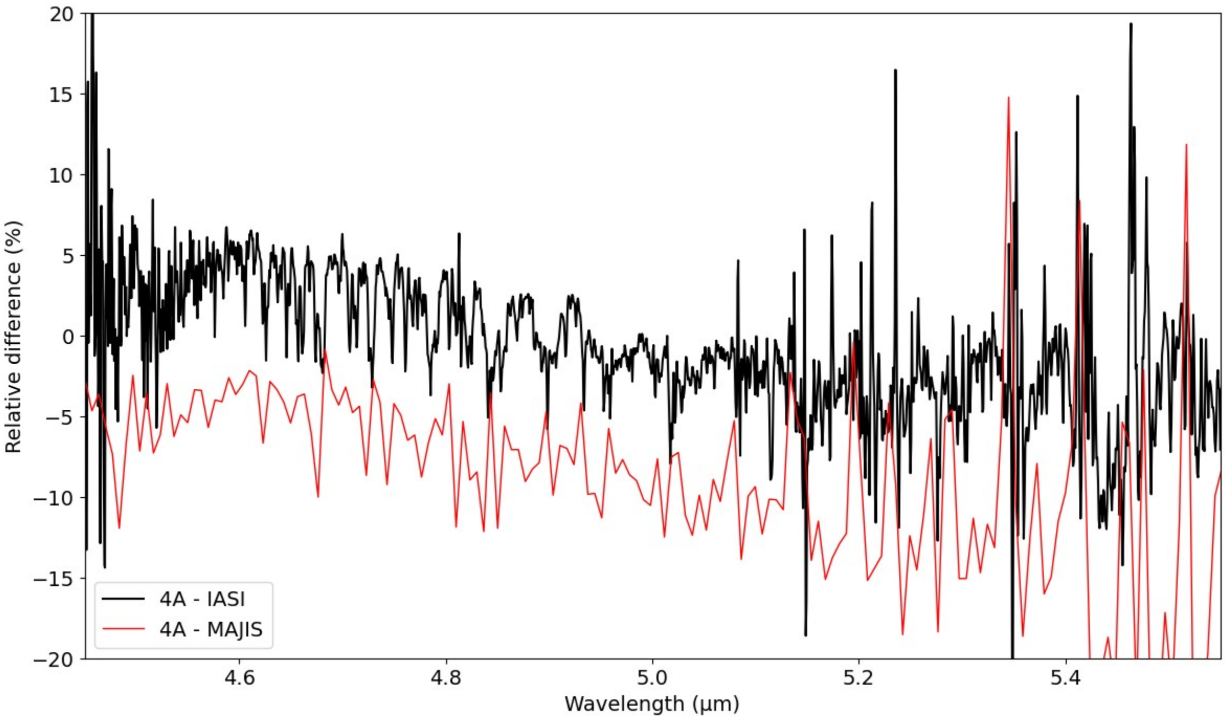


Figure 14: Differences of synthetic spectra minus observed ones, separately for IASI (black) and MAJIS (red), at their native spectral resolution and viewing geometries.

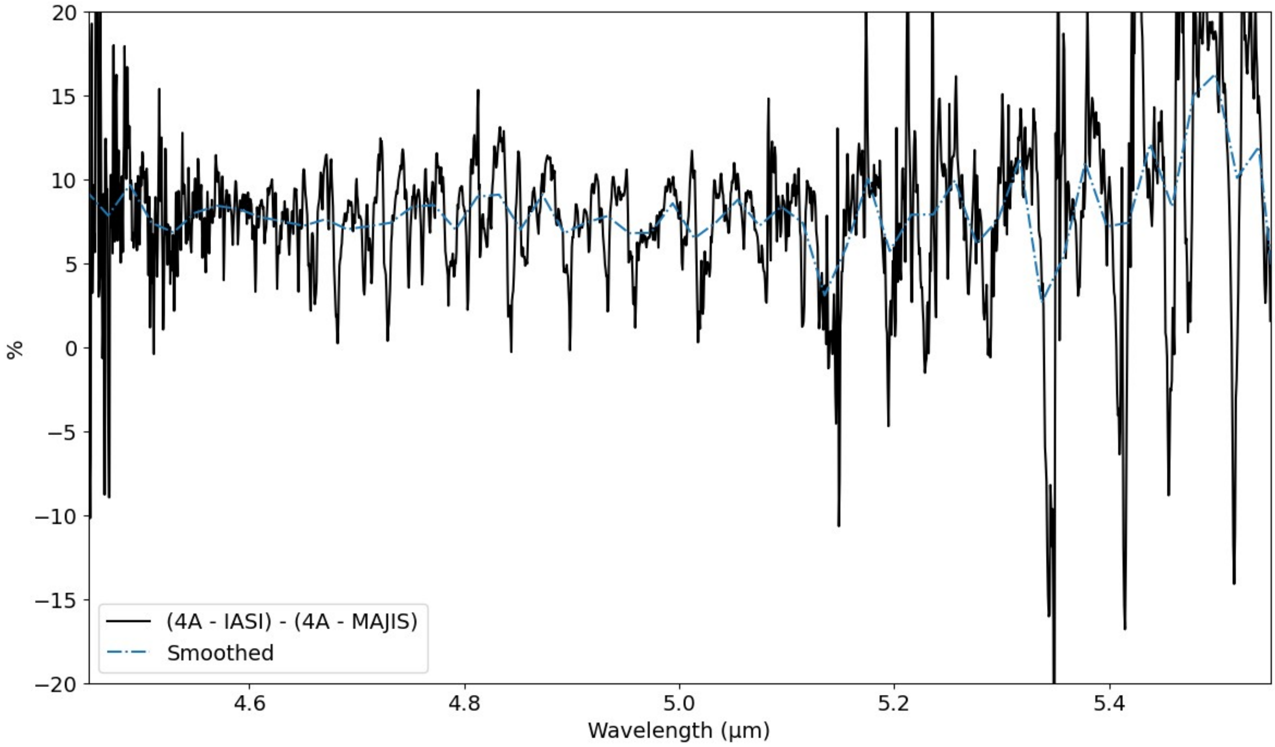


Figure 15: The black line illustrates the bias between IASI and MAJIS (MAJIS having a negative bias with respect to IASI); it is the difference between the black and red lines from figure 14, and a smoothed one is shown as a dashed blue line.

Part 3: tentative characterisation of a radiometric bias that depends on pixel position.

Finally, we explored the sign of the IASI-MAJIS bias for different swath (C08, C09, C11, C15), reported in the table below. These different swath correspond to the first or last 64 pixels (left or right edge) of the 400-pixel wide MAJIS array. We omitted C10, corresponding to the middle of the detector's array, for which there were no clear trend.

C08 and C09 are acquired further away (in local time) to IASI observations, and the nominal criteria of 2h30 of difference in local time retains only a few number of co-locations. Loosening the criterion to 3 hours allows to gather much more co-located data, but at the cost of an even greater bias between instruments, reaching 25% in the core of the 4.2 CO_2 band (not shown). However, interestingly, we note that the sign of the inter-instrument bias (apart in the 4.2 µm region) is different between C08 and C09, despite their very close spatial locations.

Even if we cannot quantify the IASI-MAJIS bias from swath C08 and C09, due to a too great local time difference and sensitivity to different meteorological conditions, we took advantage of that very close location of C08 and C09 (see fig. 16) to investigate a potential calibration bias between the left edge pixels of swath C09 and the right ones of swath C08.

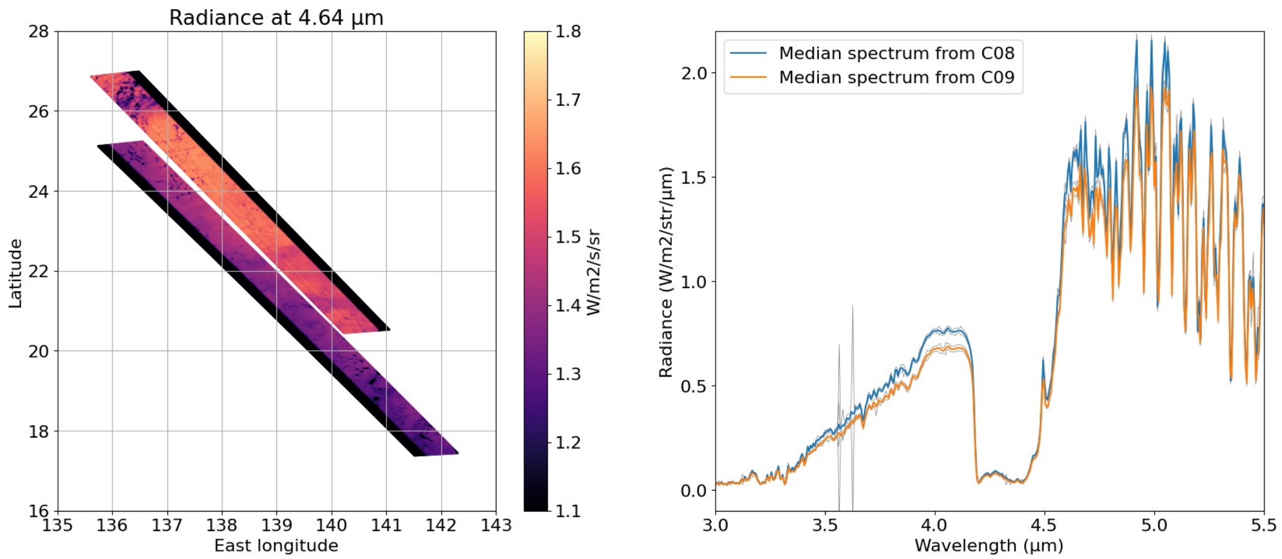


Figure 16: Comparing radiances from swath C09 (lower left swath) and C08 (upper right swath). The right panel shows a comparison between the median of spectra acquired from swath C08 or C09 between 22 and 23° latitude, after cloud filters have been applied. Difference in emission angles is only 3° between the two spectra and cannot account for their mismatch.

Figure 16 above demonstrates a clear higher radiance from swath C08, corresponding to the right edge of the detector, compared to C09 (left edge of the detector). The local time was approximately the same (only 3 minutes away), as well as their emission angles (3° difference). This difference is almost constant between 3.5 and 4.9 µm, amounting to 13%, and is lower (falling to a minimum of 5%) at other parts of the infrared spectrum.

This is consistent with our previous finding of a positive bias of C08 compared to IASI and a negative bias of MAJIS compared to IASI in swath C09 and C15 (left edge of the detector).

We summarize these findings in the table below. Combining the estimate of a -7.5% bias for MAJIS left edge (based on IASI-MAJIS comparison in C15) and the ~ 13% maximum bias between right and left edges (based on C08/C09 ratio), we estimate that the right edge has a positive bias in the range ~0 – 5% depending on wavelength.

More data are clearly needed to further characterize these biases, but this first JUICE fly-by has already allowed a nice preliminary characterization. Despite the challenges of inter-instrument comparisons, we can conclude that calibration biases of MAJIS are smaller than 10% on most of the spectral range, but caution that a pixel-dependent bias might exist. The next JUICE Earth fly-by, planned for September 2026 will hopefully bring complementary constraints.

Left edge	Bias sign of MAJIS compared to IASI* and estimated value	Right edge	Bias sign of MAJIS compared to IASI* and estimated value
C15	negative	C08	positive
C09	negative	C11	positive
	-7.5% (from C15)		+5 % maximum; wavelength-dependent ? (from C08/C09 ratio and C15 bias)

*(here interpreted as “MAJIS - IASI”)