

REVIEWER 1

This work describes an expansive analysis of the observations of the Earth from space by the Moon and Jupiter Imaging Spectrometer (MAJIS) on board the JUICE mission during a gravity assist passage by the Earth. The analysis spans the full wavelength range of the instrument, starting at reflected light from 500 to about 2800 nm, and including emitted light from the Earth surface and atmosphere from 3-5.5 μm . The work spans a wide range of different strategies over spectroscopic windows. The analysis are very detailed and where possible results are verified between them.

The paper is well written and the results are clearly presented. I have no doubt that the work presented here is an excellent preparation for the analysis of the observations in the Jupiter system. The results presented may also prove to be of direct relevance to the Earth science community.

I have no reservations about recommending this manuscript for publication, but I would strongly recommend addressing the following issues though. The other points are minor or textual things.

We thank the reviewer for the thorough read and review of the paper. We have addressed all the comments and reworked the manuscript accordingly, resulting in a much improved version of the work.

IMPORTANT NOTES

- Co-Author Sandrine Guerlet has now been added to the authors' list, as some cross-references to her work on the comparison with the IASI spectrometer have now been added in the manuscript.
- During the review process we noticed two software bugs affecting some of the results related to cloud altitudes' estimation. The first one was an incorrect association with altitude grids, yielding different amounts of overestimation of cloud heights. The second one was an uncorrected treatment of emissivity in retrieving cloud temperature from thermal brightness, also in this case yielding a differential overestimation of the cloud heights. Both errors have been corrected in the current manuscript version, somehow improving the consistency of the results. **See response to comment about F16A for more details.**

Authors responses to specific comments are given in red.

1. Units used on the figures. Figure 2E for instances are in values of radiance ($\text{W m}^{-2} \text{sr}^{-1} \mu\text{m}^{-1}$). Following SI definitions, these should be spectral radiance I think. I know can often be a point of discussion, so if in your experience radiance is correct, then that's fine by me, but please ensure consistency. For instance, in Figure 6B reflectance is used, which is incorrect for the range above 2800 nm. Same for 11E.

We thank the reviewer for noticing this. We have now updated "spectral radiance" in all figures in which "radiance" was displayed. Also, we now specify at the end of Section 2.3 that, for readability, in the manuscript the term "radiance" is used to refer to "spectral

radiance” instead. Moreover, I/F is now used instead of reflectance if the quantity is being discussed in the thermal range.

2. The color scheme used is somewhat unfortunate. Light blue and pink are not easy to see. If the figures are remade, it would be beneficial to make sure they are in a vector based format. Please ensure the titles of the figures are also better labeled.

All color/title/subtitle updates suggested by the reviewer have been applied. High-resolution figures are going to be uploaded upon the re-submission of the manuscript.

Please see the list of minor comments below.

title: 'perhaps reconsider the use of 'first-ever' in the title. Yes, this is the first fly-by of JUICE, but it's certainly not the 'first-ever' flyby by any other spacecraft.

'First-ever' is not appearing in our manuscript title. However, the special issue is named this way because this is indeed the first-ever flyby taking advantage of both the Earth and the Moon gravity to perform the maneuver.

Line 23 and 51. What is the time difference between the two observations?

No spatial/temporal coincidence could be achieved and the closest observations are acquired more than 500 km and 2 hours apart. This is expanded in Section 2.1, where Tables 1 and 2 provide details on the observing parameters related to the two datasets.

F2 F... not so helpful?

We also put panel F in the Figure to show more quantitatively how much different wavelengths are affected by the degradation, which is not readily evident from panel E, being in log scale.

Section 2.3 - 140 and on. Please briefly explain how the spectra in F3 are obtained from spectral radiance. In principle these can just be divided by the spectral radiance of the sun, but what is the spectrum of the Sun used here? MODTRAN is paid-for software, and SPIE is not a journal that is typically available.

As suggested by the reviewer, reflectances are obtained by dividing the observed spectral radiances by the solar spectrum by Kurucz. This is now specified in the text at the end of Section 2.3. The “newkur” spectrum is available from the website <https://earth.gsfc.nasa.gov/climate/projects/solar-irradiance/data> (website now cited in the text).

191 cox-munk <https://opg.optica.org/josa/abstract.cfm?uri=josa-44-11-838>

Reference added.

193. Please clarify whether this is instrumental stray light

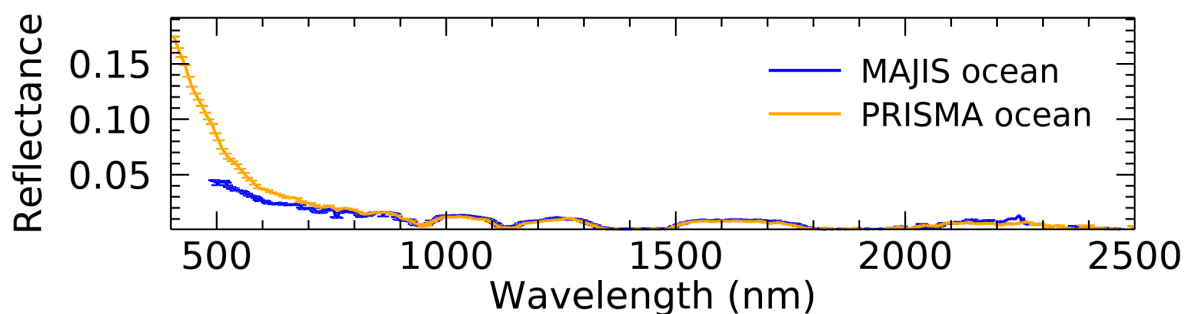
Yes, the effect is instrumental. Straylight assessment is fully described in the companion paper by Langevin et al., submitted to this same issue. We added a reference to this paper in the text.

F3 it looks like there's consistently less flux in the MAJIS spectra below 700 nm. Particularly the decrease in the reflectance is unexpected (F3B top two panels).

The decrease of flux in MAJIS clouds' spectra can be explained by different grain size and opacity of the sampled clouds (F3 in <https://doi.org/10.5194/amt-9-4615-2016>). This reference has now been added in the text to help understand how sensitive the spectral shape in this range is with respect to aerosols.

Panel F3B with the ocean spectra is slightly cut off. The reflectance of the Earth below 600 nm is pretty high, so it would be good to fully show this range. As this work is partly to assess the performance of the MAJIS instrument, it seems important to highlight the difference between the two instruments.

The panel is cut off to better show the agreement between the two spectra over the continuum. The information on the difference at lower wavelengths is fully covered in panel A at log scale. The full-range linear-scale figure would look like the image below, in which the comparison longwards of 1000 nm is unreadable.



233-234. Not entirely sure that the values below 700 nm are contaminated by scattering See for instance (<https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1002/2014RG000449> F13). These are disk integrated spectra, but particularly over relatively dark ocean the Rayleigh tail will be particularly strong.

We agree with the reviewer that Rayleigh scattering could be playing a role in this range, even if it is not possible to isolate the effects responsible for the differences in Figure 3 (as also different aerosols properties and the presence of straylight could produce similar discrepancies). This explanation has now been added to the text.

F4, the color light blue is hard to see. Is it possible to add the O3 trace in this one too? It's discussed in line 260, so would be relevant to show. I recognize that the figure may be more busy that way, but perhaps an offsets from 1 can be added.

O3 trace added, light blue color changed to grey.

273. English language detail... Exploit is almost exclusively used in a negative manner. I suggest using use, study or modeled.

Done.

F5 caption. These are not reflectances. Furthermore, I think the absolute values here would be super valuable for the community. Is it possible to obtain the spectral radiances here?

Caption updated and spectral radiances are now displayed.

6A/B. The light blue color is hard to see (I'm not color impaired).

Color changed.

6B. Similarly to F5, the photons here are not from reflectance, those are emission values.

Both panels have now been renamed as I/F, which is a radiance ratio without necessarily implying anything about the photon sources.

362. See comment on line 273 regarding the use of exploited. Also used on line 390, 527, 534

The term has now been changed at all lines.

390. I am not familiar with the K-means classification or the ENVI software package. Please briefly explain what is done here.

We have updated the description of what the algorithm is doing and referenced further technical details to Tou and Gonzalez, 1974. In brief, the algorithm is capable of grouping the observations into an ensemble of "K" non-overlapping clusters driven by spectral similarity, whose average spectra are representative of the main signatures in the dataset.

395. Not entirely clear what is meant with the term cluster

Changed to "average spectra". See also response to previous comment.

Section lines 389-417 would benefit from some restructuring. There a lot of information here, but it is hard to follow.

On the basis of the reviewer's suggestion, the paragraph has been reworked.

F8. Light green and light blue are both colors that are tricky to see on a white background. Please consider modifying.

Colors changed to green and grey respectively.

Not clear what the different traces are. Are these identified by the K-means classification? The statement 'colors are ordered with increasing reflectance of the 1700 nm from (cyan to green)' is confusing. Please clarify the use of colors, and label the sub figures with titles that

are slightly more helpful.

Color legend added to each panel and Figure caption updated accordingly.

Consider relabeling the radiance to spectral radiance here.

Done.

479 'Only the last three can be appreciated in the MAJIS spectra'. Consider replacing appreciated with 'are visible' or 'can be distinguished'. The mean is the same, the statement 'can be appreciated' suggest a value of beauty, which is inappropriate here. (Although I do recognize that the observations are of exquisite quality and definitely appreciate the work and analysis performed here!)

Replaced with "detected".

F11. Change the title to the ones corresponding to Tables 1 and 2 and add a clear time stamp (i.e. add spaces to the number string), 20240920024630_20240820024634_0001 is not a helpful title for a sub-figure.

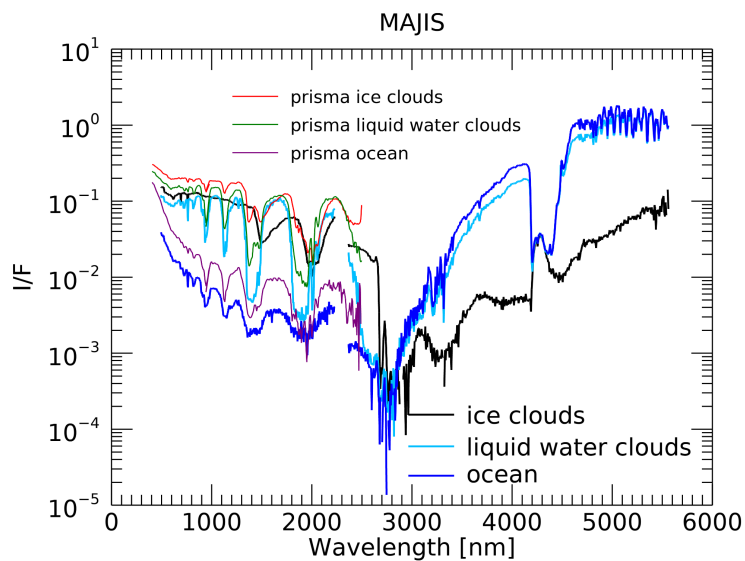
Done

F11 E&F. Please consider relabeling, the photons about 2700nm are not from reflected light. Refrain from using light blue as a color.

Y axis relabeled to I/F for both panels, color updated.

F11 E&F These figure panels could probably be combined, this may help visualizing the slopes of the spectral radiance between the two different instruments.

Instead of making a radiometric/spectral comparison here (already discussed in Figure 3), the purpose of panels E and F is to show that spectra related to the pixel masks in panels C and D do indeed show the spectral signatures typical of ocean, liquid water clouds and ice clouds, as discussed at the beginning of Section 4.1. Moreover, a combined image would look a bit too crowded, as shown below.



637. Probably helpful here to remind the reader of the time difference between these two observations.

We are not sure if the reviewer is referring to the observations in Figure 11. If this is the case, now the UTC times of both observations are displayed in panels from A to D.

F12 consider subfigure titles

Done.

F13 consider using 'spectral radiance'. Please relabel the sub-figures.

Done.

F16A It is hard to see what the cloud top height is here for the untrained eye. The text mentioned 10KM, consider making this clearer in the figure by making the 10 KM bold for instance.

We updated Figures 14, 15 and 16 since during the review process we noticed two software bugs affecting some of the results about cloud top altitudes. The first one was an incorrect association with altitude grids, yielding different amounts of overestimation of cloud heights. The second one was an uncorrected treatment of emissivity in retrieving cloud temperature from thermal brightness, also in this case yielding a differential overestimation of the cloud heights. Both errors have been corrected in the current manuscript version, somehow improving the consistency of the results. These changes affected Fig.14, Fig.15, and Fig.16, and of course forced adapting the associated interpretations in sections 4.2.1, 4.2.2. In particular:

- In Fig.14: color scales have been adjusted to the new ranges of altitudes;
- In Fig.15: All distributions are somehow shifted towards lower heights. The distribution associated with thermal brightness underwent greatest changes, being affected by both errors, and is also now split in two parts, referring to pixels dominated by water ice (in

blue) and liquid water (in red). In both cases, the unity emissivity already stated in the text is now confirmed.

- In Fig.16: we updated panel A with larger fonts and adapted the color scale in panel B to the new range of altitudes.

763 The use of 'of course' here seems what colloquial

Removed.

765 'quick and robust way for estimating'. I don't want to change the meaning of the sentence, but 'quick and robust way of estimating' seems a bit of a contradiction in terms, and actually quite labor intensive. Perhaps 'independent method of estimating the ... ' describes it better?

Rephrased to "quick and independent".

F19 caption. I don't think I understand the 'samples and number of lines' description. Is the point here that these are maps where the pixels aren't directly assigned to a location? In principle this is not an issue, but the meaning of 'lines' and 'samples' isn't clear. I'd suggest to just remove the number on the axis as the message seems more descriptive than absolute here?

As the reviewer says, these maps do not directly refer to specific longitude-latitude coordinates. The 'samples' indicate the spatial pixels in the spectrometer's slit, while 'lines' refer to adjacent acquisitions of the slit in the cube. This explanation was already given in F16 caption and we now also added it in F19 for consistency.

917-918 and 920. I would avoid the use of 'of course' here. It doesn't help clarify what is described and could be perceived as condescending.

Removed.

932: summary of atmospheric wave parameters ... add the 'atmospheric wave'. Unspecified use of 'parameters' can be confusing. We're at figure 20 and table 5 now, good to help readers keep track of material! The table might also move around in the editorial process, being not directly under the subheading.

'Atmospheric wave' is now added in the caption, along with the list of the provided parameters.

F23. Suggest to make the spectra larger, text is hard to read unless reader can zoom in on the figures. I would also think the paper would benefit from vector-based images, this makes them much more clear, particularly if one wants to zoom in on the details. What is going on at 2300 nm btw? Is this an artifact from switching detector types perhaps? If so, mention this in the caption perhaps.

Figure panels have been rearranged to be larger. Regarding the 2300 nm noisy region, it is due to the boundary between MAJIS VISNIR and IR channels and it has been now removed from the plot since not useful for the discussion

REVIEWER 2

This paper presents a first analysis of new data acquired during MAJIS/JUICE Lunar-Earth gravity assist manoeuvre together with coordinated observations by PRISMA, a satellite by Italian Space Agency covering a spectral range compatible with MAJIS-VISNIR channel. MAJIS reflectance spectra (500-2500 nm) allow to identify the absorption features of the main Earth's atmospheric gases: H₂O, O₂, CO₂ and CH₄. Although it was not possible to achieve spatial/temporal coincidence (because of PRISMA Sun-Synchronous Low Earth orbit), the authors exploit PRISMA spectrometer data as proxy to compare with MAJIS Earth observations and provide the first scientific benchmark to check MAJIS' capabilities to detect and analyse features of scientific interest, like clouds, atmospheric waves, etc.

The work focuses on MAJIS response over ocean and clouds, which are the main targets observed during the flyby and describes several methods to: 1) identify surface/cloud features, 2) to characterize ice and 3) estimate cloud's altitude using the data from the two spectrographs.

The paper is well structure and the results are valuable and it will be very useful for the scientific community to plan future JUICE observations. I recommend the publication of the manuscript after minor corrections. The general comments aim to make the paper more readable for a non specialist (e.g. scientist outside JUICE community, outside planetary atmosphere science).

We thank the reviewer for all the comments and suggestions, as they allowed us to further refine the paper structure and flow.

- Co-Author Sandrine Guerlet has now been added to the authors' list, as some cross-references to her work on the comparison with the IASI spectrometer have now been added in the manuscript.
- IMPORTANT NOTE
 - During the review process we noticed two software bugs affecting some of the results about cloud top altitudes. The first one was an incorrect association with altitude grids, yielding different amounts of overestimation of cloud heights. The second one was an uncorrected treatment of emissivity in retrieving cloud temperature from thermal brightness, also in this case yielding a differential overestimation of the cloud heights. Both errors have been corrected in the current manuscript version, somehow improving the consistency of the results. These changes affected Fig.14, Fig.15, and Fig.16, and of course forced adapting the associated interpretations in sections 4.2.1, 4.2.2. In particular:
 - In Fig.14: color scales have been adjusted to the new ranges of altitudes;
 - In Fig.15: All distributions are somehow shifted towards lower heights. The distribution associated with thermal brightness underwent greatest changes, being affected by both errors, and is also now split in two parts, referring to pixels dominated by water ice (in blue) and liquid water (in red). In both cases, the unity emissivity already stated in the text is now confirmed.

- In Fig.16: the color scale in the right panel has been adapted to the new range of altitudes.

- Authors' responses are given in red after each specific comment.

General comments:

-Introduction

1. I suggest to improve the introduction to include a little bit more the context of JUICE, e.g short description of the missions, main instruments on board, and main goals of MAJIS.

As suggested by the reviewer, we now briefly introduce the JUICE mission (a cross reference to Hueso et al. in the same special issue on JANUS data investigation is now also provided), the payload and MAJIS main objectives and capabilities. The detailed description of the instrument is still referenced to Poulet et al., 2024a paper, and to Section 2.1 for the main instrumental characteristics useful for understanding the analysis.

2. Same for PRISMA. Briefly describe what it is? It's the first time the reader acquaints about this instrument. Although you describe it later in more details, it would be useful to include a short presentation in the introduction.

Similarly to the previous comment, we now added a very brief description of the PRISMA mission, leaving a reference to Section 2.2 for the specific instrumental details.

3. It's not very clear how the cubes for the comparison between PRISMA and MAJIS are selected. In Section 2.3.1 and Figure 2 you explain they are the "two closest PRISMA and MAJIS cubes". This refers to "closest in time" right? please clarify .

The full quoted line reads "Figure 2 shows the two closest PRISMA and MAJIS cubes (~550 km and ~2 h apart)" so we are referring to both time and space. We now rephrased to "Figure 2 shows the two PRISMA and MAJIS cubes that are closest from both a spatial and temporal point of view (~550 km and ~2 h apart)" to make it more clear.

Figure 1 shows regions in which PRISMA cubes and MAJIS are "close" in space too, for example 06 (for PRISMA) and C08-09 (for MAJIS) or 03 with C10. Have they been considered to be studied also? If not why?

While several cubes have footprints that are close to each other, their acquisition times are very different, as reported in the last column of Table 2. Indeed, PRISMA sessions 06 and 03 have been registered about 1 day and 2 days before MAJIS and so they show completely different scenes in terms of cloud coverage. In Figure 2 we are comparing the two cubes which are closest both in space and time in order to make considerations about the overall signal and the differences induced by the spatial resolution of the two instruments. Nevertheless, other cubes from tables 1 and 2 are compared throughout the analysis, see for example Figure 3, 8, 11, 12, 14.

-Methods:

While the method is well described for "Surface and clouds identification" (Section 3.1) , "Ice characterisation" (Section 3.2), for other topics, like "Cloud shadow analysis" (Sec. 3.3.2) and section 3.4.1 the method is very vague. For example, how do you measure the parameters in table 5? Is a "manual" or "by eye" detection? Do you use a pipeline or automatic detection? Please, provide more details (e.g. lines 599-602 please, explain it better, how do you estimate the expansion speed?)

We have reworked both sections 3.3.2 and 3.4.1 to provide more details about the methods and how they will be applied to the data. While the analyses presented in the manuscript are mostly intended to give an overview of several topics of scientific interest which will be investigated with MAJIS data, each of these topics may be subject of dedicated future works.

Particularly for the circular waves, we have added some equations, to better explain the method. Regarding the wave expansion speed, the calculated values for the two images we analysed had not been reported in the paper, although it was calculated. They are equal to about 45 km/h and 100 km/h for C7 and C4 images respectively. The values have now been added in the text. We thank the reviewer for catching this point.

Minor comments:

Abstract, Line 19: It 's a bit wierd to start the sentence with "At the Earth", do yo mean "During the Earth flyby"

Rephrased.

Also, I suggest to add "on board JUICE", in line 19 " xxxxx (MAJIS) on board JUICE, acquired xxx".

Done.

Fig1. It would be useful to indicate in the figure where terminator is, and where daytime observations start.

The terminator was not shown since MAJIS and PRISMA footprints refer to different absolute times. Now we have added a nightside/terminator line, specifying in the caption that it refers to the time when MAJIS crossed it, while PRISMA data are always at daylight, at nearly constant local time.

Fig7: Please, Indicate in the figure caption which cubes are you using from MAGIS

Done.

Fig8: Please, replace the title of the panels to add the name of the instrument as well, similar to what you do in Figure 12, panels A and B. Same for the other Figures (11, 13, etc). The codes 20240820214720, 20240820214813 etc do not mean anything for the readers. Alternatively, it could be more useful to indicate the name of the cubes (e.g. C16, C17 etc) than the code numbers.

Done.

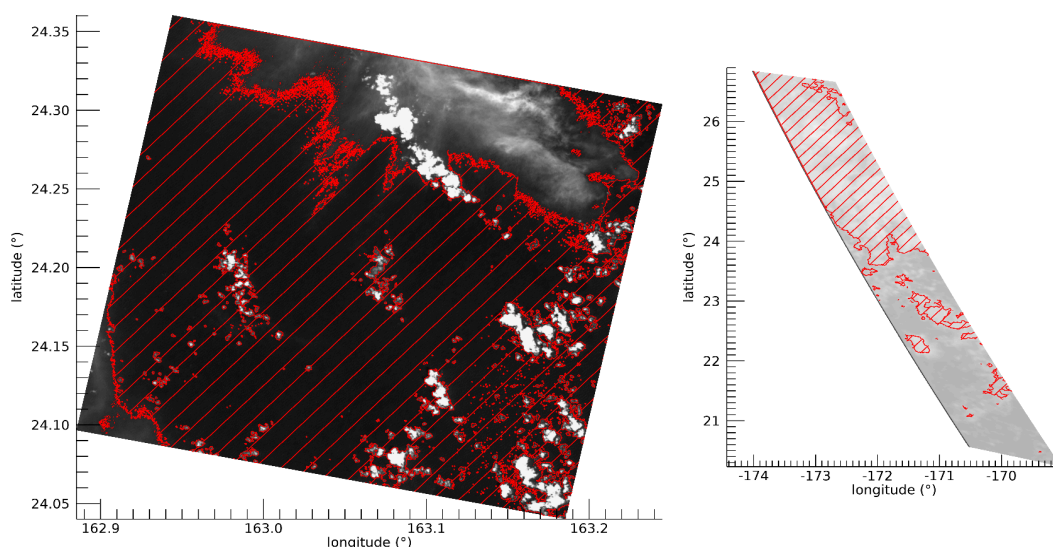
Figure 11, line 632: put a comma before respectively

Done.

Fig.14: It would be useful to add the real image/cube of each instrument to check the correlation with the clouds detected

The main purpose of this figure is to compare the capability of MAJIS-VISNIR wrt PRISMA in the detection of different cloud populations at different altitudes through the coverage of O₂ bands.

As explained in the text, these retrievals have to exclude observations for which the O₂ band is too shallow, as can be due to either a) signal saturation (the main issue in MAJIS C17 cube, where saturation is widespread over the brightest ice clouds), b) cloud free or thin aerosol condition, c) very high clouds. We find these conditions often occurring in the data, so the cloud tops are retrieved with this method for small areas only. E.g., the rejected areas in the cubes of fig.14 are indicated by red patterns in this figure:



These are the areas already filled in grey in fig.14. We do not deem that showing such images will add more value to the content of fig.14, which is visually already quite crowded. Nevertheless, the requested information is already available for MAJIS cube C17 in the lower panels of Figure 17.

Fig16: line 769: "refer to cloud altitudes" ---> " refer to estimated altitude relative to surrounding decks"?

Rephrased to *"The yellow lines show how long the expected shadow would be in the actual geometry by changing the cloud top altitude."*

Table 3: In the "Ice clouds "row: Check the size of the character in the column "spectral signature". The text outside the parenthesis seems to be smaller.

Thank you for spotting this. This is now corrected.

Table 4: For clarity, I would suggest to replace the entries in italic with colors, or to apply a color to the cells which refers to MAJIS dataset only.

The color of the cells of MAJIS-only parameters has been changed to light blue.

Line 589: "wavelength" --> "horizontal wavelength"

Done.

Line 615: Figure 11B---> 11A ?

We thank the reviewer for spotting this, it is now corrected.

Line 944 Missing point after parenthesis.

Corrected.

Lines 951-953: This sentence is not clear, please review it to indicate clearly the values for the radii and for the horizontal wavelengths for the selected cubes C7 and C4.

Rephrased to "The minimum and maximum radii, along with the expansion speed and wavelength derived from the images, are as follows: for cube C7, these parameters are respectively 35 km, 50 km, about 45 km/h and 15 km; for cube C4 they are 20 km, 110 km, about 100 km/h and 20 km. In both cases, the thunderstorm-triggering events appear to occur approximately one hour before the corresponding observations."