Reply to Anonymous Referee #1

We would like to thank the anonymous referee for his/her positive comments and the useful remarks, which helped to improve the manuscript. Our point-by-point responses to the comments are given below in blue.

First of all I have to admit that the topic of this paper if somewhere at the border of my personal research field. That means that I am not aware of all the existing literature in this field and I also may be unaware the current state of the art. Instead I concentrate in my review on the conclusiveness of the arguments, the consistency and the organization of the manuscript. Since ACP is not only read by retrieval experts, I paid particular attention to the understandability by atmospheric scientists from other research fields.

Summary: I find the paper useful and well organized and I haven't detected any major problems with the paper. Thus I recommend publication in ACP (subject to the caveat above). The authors may wish to consider the following comments listed below:

Title: The title adequately represents the content of the paper.

Abstract: the abstract adequately represents the main contents of the paper. All statements in the abstract are supported by the main part of the paper.

Introduction: The introduction puts the work presented in the manuscript in the context of existing work and justifies why the topic of the manuscript is important. I have only one very minor comment:

p21179 l24/25: The 'A' in 'AR5' seems to stand for 'assessment'. Wouldn't it thus be more intuitive to use the term 'IPCC assessment report' (instead of 'IPCC report' only) also in the text?

Following the suggestion of the referee we have revised the manuscript as follows: "According to the latest IPCC assessment report (IPCC AR5)…".

Section 2 IASI: This section reads well and seems to contain all required information.

Section 3: Calculations with FORLI: This section describes the retrieval algorithm used. Not many technical details are presented but this seems adequate because for these other papers are referenced and thus pure duplication of existing literature is avoided. Minor comments:

p21182 l20: I find it preferable to avoid acronyms and proper names in the section header. Couldn't a more generic wording be used, e.g. 'The retrieval algorithm' or something similar?

We understand the referee's concern; however, as there are more than one retrieval algorithms for the IASI mission, we want to explicitly point out that we use FORLI for the retrieval, as well that all changes and extra calculations done for the instantaneous radiative kernels and the longwave radiative effect are made on FORLI, using its characteristics and assumptions. We would like to keep the header as it is, if no major objection arises.

p21182 l22: The abbreviation 'ULB' seems not be defined.

The referee is correct indeed. The manuscript now reads "… software built at the Université Libre de Bruxelles (ULB) to serve …".

p21182 l24: The meaning of 'level 1C radiance observation' should be defined. It cannot be expected that every ACP reader knows the hierarchy of data products and the meaning of related abbreviations.

We agree with the referee. We have included the definition of the data levels and the related reference for more information. The manuscript now reads: "… for each Level 1C observation (observed spectrum after applying geolocation, calibration, resampling, apodization and quality control, as indicated in EUMETSAT (2014)).". We've also added the following reference in the revised manuscript: "EUMETSAT: IASI Level 1: Product Guide, EUM/OPS-EPS/MAN/04/0032 v4C, 2014.".

p21182 l25: Rodgers (2000) certainly is a correct reference for OEM. In his book, however, Rodgers does not use the term 'optimal estimation method'. This contradiction can be solved by either referencing some other work by Rodgers (e.g. Rev. Geophys. 1976) where he still uses the term 'optimal estimation method' or by mentioning that in his book the method is called 'maximum a posteriori'.

The referee is correct. We have fixed the issue as follows: "The retrieval algorithm is based on the maximum a posteriori solution as described in Rodgers (2000), also known as the optimal estimation method (OEM).".

p21182 l27: To a reader whose research field is not high-resolution radiative transfer calculation it may not be clear what the meaning of the LUTs is and why they are important. Please insert '… look-up tables (LUTs) of absorption cross-sections…' or whatever specification is appropriate.

The referee is correct. However, in the next paragraph there is a description of the main elements of FORLI for the ozone product, where the definition of the look-up tables is included. Therefore, we found it more appropriate to remove the text in the parenthesis in page 21182, lines 26-27 to avoid confusion and repetition. The manuscript now reads: "A detailed description of FORLI, methods, input parameters and approximations can be found …".

p21183 l12: For the retrieval it is adequate to discard cloud-covered pixels in order to avoid retrieval artifacts. However, if you have only clear-sky data available, will the estimated radiative impact of ozone be representative also on a global scale, or will there be a clear-sky sampling bias in your estimates?

This is a good point. As it can be seen in Table 3 in Worden et al. (2011), there's an almost 40% difference between clear-sky and all-sky (incl. cloudy scenes) averages of tropospheric LWRE (that, computed with the anisotropy approximation though). So yes, we expect that there will be a clear-sky bias in our calculations. However, we can only process clear-sky data and therefore we provide only clear-sky IRKs and LWRE. If we want to compare with some other reference and/or model, only clear-sky scenes should be considered for all datasets. In order to address the referee's comment we have added the following text in page 21195, line 5: "… around 45000 data points are included. Moreover we recall that only cloud-free measurements are processed, which will cause biases in the distributions and time series in comparison to what would correspond to (real) all-sky conditions, as discussed in Worden et al. (2011).".

The all-sky calculation should be motivation for further investigation, but this is beyond the scope of the present paper. Here, we focus on the description of a new method for the IRK calculations, on first results from IASI, and on how these can be exploited.

p21183 l18/19: What you do here is certainly adequate, but a reader from outside the retrieval community might miss the point here. Perhaps add some further information of the kind: 'Since the retrieval does not use the whole ozone band which is relevant in the context longwave radiative forcing but only those parts which contain most information on the ozone vertical distribution,…'

We have addressed this comment by changing the manuscript as suggested (page 21183, line 20 and after) to: "… after the last iteration. As noted above, for the retrieval FORLI uses a limited band, which nevertheless contains most of the information on the ozone vertical distribution. However, as we show in Sect. 4, the calculation of the IRKs, and consequently of the LWRE, is based on the integral over the wavenumber, among others. Thus, it is most appropriate to use the full ozone band to avoid underestimations. Furthermore, since the IRKs and LWRE are strongly…".

p21183 l26: Here a reference to the concept of averaging kernels and degrees of freedom by Rodgers may be adequate.

We agree that an explanation was missing. The manuscript now reads "… pieces of information can be retrieved. These independent pieces of information, also known as degrees of freedom for signal (DOFs), are the trace of the averaging kernels matrix (AVKs) (see Rodgers (2000) for details). The maximum sensitivity, which can be obtained by the peak of the AVKs, is found from the mid-troposphere …".

p21184 l8-23: The reader may ask to which degree the remaining biases affect the estimate of the radiative forcing contribution. My first idea would be that spectroscopic error might indeed cancel out here: wrong spectroscopic data cause wrong ozone amounts, but I would expect first order cancellation of both these errors when these quantities are then used to estimate the radiative forcing impact. This would then be a further advantage of your method. The adequate place for the discussion of this issue would be the end of Section 5.1. If my argument is valid or not, however, depends on how the LWRE errors are actually estimated, and the suggested cancellation may not actually happen.

At this point of the article we discuss the errors and biases on the retrieved ozone product of IASI-FORLI as presented in other studies, after a short presentation of the product itself (page 21183, line 25 – end of Sect. 3). The error estimation for the LWRE is indeed presented at the end of Sect. 5.1. We address the referee's concerns about the error budget along with his last comment, which points to the end of Sect. 5.1.

Section 4: IASI instantaneous radiative kernels This technical section seems to include all relevant information. I admit that I have not double-checked the entire formalism. Just a few minor comments:

p. 21186 l13: Why adverb 'arbitrarily'. 'Precision' is a noun. Thus wouldn't the adjective 'arbitrary' be correct?

The issue is fixed. The manuscript now reads "… be approximated to arbitrary precision using …".

p. 21189 l1/2 While the acronym FORLI has already been defined, the acronym FORLI-O3 has not been defined, and the reader can only guess that this might mean FORLI along with the O3 LUTs. Please specify.

As FORLI is used to retrieve other species than O_3, namely CO and HNO_3, in order to distinguish which species we refer to, we usually write "FORLI-O_3, FORLI-CO etc.". However, since in this paper we only refer to O_3, this is not as useful and we have removed the "-O_3". The manuscript now reads: "… with the forward model of FORLI the spectra and …".

Based on this comment we have also removed the "-O_3" in page 21192, line 11 and page 21194, line 16.

Section 5: Longwave radiative effect Also this section reads convincing.

p21192 l12: THE top row (?)

The issue is fixed. The manuscript now reads "The top row represents …".

p21194 l5: not sure if the term 'artifact' is adequate here. It is somewhat counterintuitive to call something an 'artifact' if it is closer to truth. Perhaps '…but this is a cancellation of errors owed to…'

We agree. The manuscript now reads "… but this is due to the compensation of positive and negative biases for …".

p21194 end of Sect. 5.1: c.f. my comment to p21184 l8-23. The line intensity error, however, is not (fully) included in the error obtained from the RMS. Thus my suggested error compensation does not happen. I have, however, another question w.r.t. the error estimation: The retrieval error us inferred from the RMS, i.e., it uses the information from the residual between the modeled and the measured spectrum. Thus it seems not possible in any straight forward manner to attribute a different retrieval error to different altitudes of the retrieved ozone profile. Instead only one retrieval error per observation can be inferred. The long wave radiative effect, however, depends also in the distribution of ozone over altitude; attribution to the ozone amount to the incorrect altitude may also cause an error of the longwave radiative effect. Beyond this, as stated above in the paper, the smoothing error makes a considerable contribution. As far as I can see, these error sources are not considered in the error estimate of the LWRE.

The referee has a good point. For the error of the LWRE we consider the following two contributions: that originating from errors on the forward model and that coming from the retrieval. A good estimation of the forward model error is the RMS of the residual between the observed and the modeled spectrum. For the error on the ozone profile we consider the total retrieval error from the optimal estimation method. Now, we have to keep in mind that the LWRE refers to a column of ozone: even if the retrieval errors on the ozone profile can at some altitudes reach 20%, those on the columns, and in particular the total column, are much smaller. For instance, the IASI-FORLI ozone tropospheric column is found to have an error of ±15%, while the total column has an error of ±7% in some cases, but usually is around ±3% (see end of Sect. 3 and Hurtmans et al. (2012)). This error makes overall small contribution to the total LWRE error, which is therefore mostly driven by the forward model error. It is true, that this error estimation may not be totally appropriate for the tropospheric column, but it is not straightforward to attribute part of the forward model error to different altitudes and our discussion therefore refers to the total column.

Note that Worden et al. (2011) presented their error budget as well only for the total LWRE and they too use the RMS residual to account for most errors. In detail, they assumed that the IRKs, coming from the Jacobians and retrieved with respect to the lnVMR, are without error. The IRKs with respect to the VMR include the retrieval error (see Table 1 in Worden et al. (2011)). Likewise, for the LWRE they use the lnVMR (with corresponding IRKs in lnVMR) instead of the VMR, to avoid retrieval errors. In Worden et al. (2011) however they use the anisotropy approximation, which gives additional errors, as shown in Table 2 of their study.

In order to clarify the manuscript with regard to the error budget, we have rewritten the end of Sect. 5.1 regarding the LWRE error budget as follows:

“To produce an error budget for the LWRE, we account for the following two contributions: that of the forward model, for the part of the IRK formulation and that of the retrieval, for the profile of O_3, based on Eq. (9). A good estimation of the forward model errors is the root-mean-square (RMS) value of the spectral residual between the observed and the modeled spectrum. The LWRE, as the product of Eq. (9), refers to a column of ozone. For the integrated total LWRE, the contribution of the retrieval is very small, and therefore we consider only the RMS to account for all errors. A typical RMS for good quality ozone retrievals with FORLI is around 2.24×10^{-8} $Wcm^{-2}sr^{-1}cm$, which translates for the total LWRE global average to a ±3.2% error. In some cases the RMS can be larger, but the data are not kept when its value is above 3.5×10^{-8} $Wcm^{-2}sr^{-1}cm$, which places an upper bound of ±4.6% on the LWRE error.”

Section 6: Conclusions The Conclusions adequately summarize the main finding of the paper, and useful recommendations are provided.