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Atmospheric Chemistry and Physics
Discussions

Interactive comment on "Satellite observation of lowermost tropospheric ozone by multispectral synergism of IASI thermal infrared and GOME-2 ultraviolet measurements" *by* J. Cuesta et al.

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Dear Referee#1, Please find below the answers to each of your comments from page C1 to C11 of this Author comment (which includes the answers for the comments of the 3 referees).

(Answer 1) General comment: Dear referees, We would like to thank you very much for your remarks for improving the clarity of the paper. In the revised manuscript, called RM hereafter, we have addressed each of your comments by adding new analyses (including 4 new figures) and the corresponding explanations in the manuscript. Please,

find below the detailed answers and how they are introduced in the paper.

(Referee#1) Anonymous Referee #1 Received and published: 26 March 2013 General comment: The paper "Satellite observation of lowermost tropospheric ozone by multispectral synergism of IASI thermal infrared and GOME-2 ultraviolet measurements" by J. Cuesta et al. deals with improvements of Ozone retrievals from the Metop plateform using both infrared (IASI) and UV (GOME2) channels. The paper does not discuss geophysical processes related to tropospheric Ozone. It would therefore have been better suited for publication in AMT than in ACP. This work represents a real improvement to ozone observations from the Metop palteform. The paper is well written and the innovative retrieval method is correctly described. The main claim of the authors is that their multi spectral retrieval enables them to capture "lowermost tropospheric ozone" variations. This claim is not sufficiently supported by the evidences they give in their study and it is therefore an overstatement. Given the importance of the innovation presented, this study is suitable for publication. Nevertheless, the way the results will be presented will depend on the evidence the authors will provide to support their claim, which is required in the present review. If the evidence we require does not support the claim of the paper regarding the observation of lowermost tropospheric ozone, the authors will have to change the title and the conclusions of their paper.

(Answer 2) In order to better put in evidence the capability of IASI+GOME-2 to observe lowermost tropospheric (LMT) ozone, several additional analyses and figures have been added in the revised manuscript (RM). They include the following aspects: i) A quantitative validation against ozonesondes of the three satellite ozone retrievals: IASI+GOME-2, IASI and GOME-2. These comparisons show that IASI+GOME-2 is the only satellite retrieval, which shows LMT ozone variability close to the one measured by ozonesondes and very low mean biases (1%). For single-band retrievals, we remark strong underestimations of variability and significant negative biases in ozone concentrations, particularly for cases with higher concentrations (far from the a priori), likely induced by lower sensitivity to LMT ozone. This quantitative comparison against independent observations shows that the best retrieval (in terms of mean bias and variability) of LMT ozone is performed by IASI+GOME-2. See further details in answers (Answer 5) and (Answer 6). ii) In the RM, the qualitative comparison against CHIMERE chemistry-transport model smoothed by the retrieval averaging kernels (AVK) is done for both IASI+GOME-2 and IASI only. There is a very good qualitative agreement between the smoothed model and the observations for both cases. This shows clear consistency in the occurrence and location of the ozone plumes observed from space and the model (i.e. an independent source of information). Moreover, the differences between IASI+GOME-2 and IASI observations match very well those between CHIMERE smoothed by the AVKs of either retrieval. In consequence, the differences in vertical sensitivity between IASI+GOME-2 and IASI explain well the fact that only IASI+GOME-2 clearly shows the location of ozone plumes mainly located in the LMT. See further details in (Answer 9). iii) Additional analyses of the vertical distribution of ozone have been added in the comparison of satellite observations and CHIMERE. Model and observation vertical transects are used to support the statement that IASI+GOME-2 is capable of clearly observing ozone plumes mainly located below 3 km a.s.l., both over land and over ocean. Particularly, only IASI+GOME-2 is capable of describing a situation with high ozone concentration up to 3-4 km below a very low ozone concentration layer in the free troposphere, while IASI approach depicts low ozone concentration over the whole troposphere. See further details in answer (Answer 10).

(Referee#1) Theoretical characterisation: The claim of the authors to capture lowermost tropospheric Ozone is mostly based on theoretical characterisation of the retrievals with information content analysis: AVKs and DOFs and altitude of highest sensitivity for instance (The two latest products being directly derived from the AVKs). These parameters give interesting information about the retrievals but are based on tuning parameters that regularize the retrievals and cannot be taken as the “truth”. The only way to claim that the retrieved quantities are “good” or “better” is to compare them to independent observations.

(Answer 3) The theoretical characterisation of sensitivity of the satellite retrievals (based on AVKs and DOF calculations) is used as a first step to describe the expected performance of the multispectral and single band approaches. The capability of IASI+GOME-2 to capture LMT ozone is shown by a good agreement with ozonesondes (in intensity, variability and correlation) and a very good qualitative match of the LMT ozone plumes distribution over Europe with respect to CHIMERE model. See further comments above in answer (Answer 2).

(Referee#1) Validation with ozonesondes: This is the most important part of the paper to support the claim of the authors, but it is too weak to be convincing. -Validation sample: 119 ozonesondes, 3 months and Europe only is not much to support the strong claim of the authors considering the 6 years of operation of Metop and the availability of thousands of sondes all over the world. Furthermore if the authors keep the European focus, it should appear starting in the title: “Satellite observation of lower(most?) tropospheric ozone OVER EUROPE”. Indeed, the behaviour of the retrievals in other parts of the world is not discussed and is not straightforward at all.

(Answer 4) Done. The title of the RM is “Satellite observation of lowermost tropospheric ozone by multispectral synergism of IASI thermal infrared and GOME-2 ultraviolet measurements over Europe”. The scope of the analysis focused over Europe during the summer 2009 is also clearly remarked in the abstract as (line 15) “In this case study, when high ozone . . .” and (lines 23-24) “Validations with ozonesondes (over Europe during summer 2009)”, and similarly in the conclusions.

(Referee#1) -IASI versus IASI+GOME-2: one of the most important point of the paper is that the multi-spectral retrieval improves O3 retrievals in the LMT versus IASI only retrievals. But, the only real evidence that could support this claim is a joined comparison of IASI and IASI+GOME-2 versus ozonesondes. The authors only refer to previous IASI validation papers. This is not sufficient because the sonde sample is different and the comparison methodology is not the same. Furthermore, no LMT columns comparisons of IASI and O3 sondes are provided in the previous IASI validation papers.

As this is the central point of this study, the reader should be able to clearly see the improvement without searching elsewhere. Therefore, we ABSOLUTELY need to have the same statistics for IASI and IASI+GOME2 versus ozonesondes in this paper.

(Answer 5) Done. As introduced in (Answer 2), the RM also includes the validation analysis against ozonesondes for IASI only and GOME-2 only retrievals. The same statistics are given for the three satellite products, which confirm the performance enhancement of IASI+GOME-2 for capturing LMT ozone with respect to the single band observations. The same coincident pixels are used for the three products. After rejecting aberrant cases (see Answer 13 for more details) of the 3 retrievals, the number of ozonesondes used in the validation is 105. The main conclusions drawn from these statistics are that the only satellite observations that are capable of reproducing the variability and the concentration of ozone at the LMT without significant bias is IASI+GOME-2. Precision, expressed in RMS differences with respect to the ozonesondes, is very similar for the three satellite observations, as expected by the design of the constraint matrix of each approach (i.e. similar total retrieval error). Linear correlations with respect to raw ozonesondes measurements at the LMT are fairly similar for the three satellite products. However, only IASI+GOME-2 keeps both a good linear correlation (0.76) and similar variability as the raw ozonesonde measurements. This last one is significantly underestimated by 40% for IASI and 21% for GOME-2 only retrievals. Moreover, whereas IASI+GOME-2 shows very little mean bias, single-band ozone observations present a negative bias in the LMT and LT. This underestimation of the single-band retrievals is stronger (-20% for IASI and -12% for GOME-2 for LMT ozone >10 DU) when considering higher LMT concentrations. These statistics suggest that the lower sensitivity to LMT ozone of the single-band observations likely induces underestimations of both variability and ozone concentrations, particularly for polluted cases different from a priori concentrations. On the contrary, IASI+GOME-2 retrieves LMT ozone with little or almost no mean bias and variability fairly close to the one observed by ozonesondes. In the RM (page 16 line 26 to page 17 line 24), these conclusions are given as follows: "The results show very good agreement between

IASI+GOME-2 retrievals and ozonesondes (both smoothed by the retrieval AVKs and raw measurements), particularly in terms of mean biases and standard deviations (see Tables 2 and 3). In regard to the single-band retrievals (Tables 4 and 5, see also Figs. 7 and 8), only IASI+GOME-2 is capable of reproducing the mean ozone concentrations (mean biases <1 %) and the variability (within $\pm$10 %) observed by the ozonesondes (both smoothed and raw) at the LMT and the LT. The single-band retrievals show a negative bias for the LMT and LT concentrations (from -6 % to -11 %, see Figs. 7a-b) and they significantly underestimate the standard deviation (by -21 to -40 %, see Figs. 8a-d) with respect to ozonesondes (both smoothed and raw). For higher LMT ozone concentrations (> 10 DU, i.e. the average for raw ozonesondes), negative biases at the LMT are significantly greater for IASI (-20 %) and GOME-2 (-12 %), while it remains moderate for IASI+GOME-2 (-4 %). Too low standard deviations and greater negative biases for higher ozone concentrations are probably both linked to the lower sensitivity of the single-band retrievals to LMT ozone. The precision of the retrievals, expressed in RMS differences with respect to the ozonesondes, is very similar for the three satellite observations ($\sim$17 % and $\sim$22 % at the LMT respectively for smoothed and raw ozonesondes, Tables 2-5), as expected by the design of the regularization matrices of each approach (i.e. similar total retrieval errors). Linear correlations with respect to raw ozonesondes measurements at the LMT are fairly similar for the three satellite products (from 0.73 to 0.78, Tables 3 and 5), but only IASI+GOME-2 reproduces as well the variability measured by the ozonesondes (Fig. 8b). When comparing against LMT concentrations from smoothed ozonesondes (Fig. 8a), relatively high linear correlations are remarked for the three satellite observations (0.84 for IASI+GOME-2 and 0.89 for the single-band retrievals). Note that in this case the altitude at which the comparison against the smoothed ozonesondes is effectively made is H_LMTmax, thus it differs from one satellite retrieval to the other. Moreover, the validation results for IASI+GOME-2 are consistent for different cloud cover conditions. For cloud fraction below 0.1 (thus considering 67 ozonesondes), the multispectral LMT retrievals present a mean bias below 2 %, a standard deviation within 10 % of that for ozonesondes, RMS differences of 15 % (22 %) and linear correlations of 0.89 (0.79) with respect to smoothed (raw) ozonesondes."

(Referee#1) - Comparison methodology: the authors present basic validation statistics: biases, rms of the differences and correlation coefficients. Important information is lacking: is the variability captured by the retrieval close to the variability observed by the sondes? There is a much better and more synthetic way to present the ability of an observing system or of a model to capture the variability of a parameter: the Taylor diagram used among others for the evaluation of climate models. Based on their simple relationship, it allows seeing at one glance the 3 important statistical parameters (rms of the differences, correlation coefficients and variability) of many datasets relative to a reference dataset. It is therefore more convenient for the reader who does not have to search for this information in many tables. A single diagram would allow the reader to see immediately the improvements brought by the multi-spectral retrieval versus IASI for LT, LMT, TROPO and UPTO30 (that is 8 datasets on a single plot). For clarity two diagrams could be plotted, one for raw and one for smoothed sonde data. The biases would still have to be presented in tables.

(Answer 6) Done. In the RM, we have added a new Figure 8 that presents Taylor diagrams of the validation statistics of the 3 satellite observations. For clarity, we have chosen to plot in different diagrams the statistics for each of the 3 tropospheric partial columns for smoothed and raw sondes. Satellite retrieval standard deviations and the centred root-mean-squared differences are normalized by the standard deviation of the corresponding ozonesonde measurements. Each diagram compares the 3 satellite retrievals. In addition, a new Figure 7 of the RM shows mean biases of the 3 ozone satellite observations for the 3 tropospheric partial columns. Using Figs. 7 and 8, the inspection of the validation statistics and the comparison of the performance between the 3 satellite observations are indeed straightforward. See (Answer 5) for more details on the conclusions of this comparison.

(Referee#1) - Scatter plots: as they are, these plots do not bring much information

(RMS, biases and correlation coefficients are already in the tables and Taylor diagrams would be more efficient and informative). The only added value of a scatter plot would be to see the line representing the linear fit between the sonde and satellite data and the corresponding parameters (slope...). Furthermore, if the authors want to present scatter plots, they have to show IASI and IASI+GOME2.

(Answer 7) Agreed. We have supressed the scatterplot figure in the RM, for avoiding redundancy with the new Figures 7 and 8 (Taylor diagrams and biases) and for briefness.

(Referee#1) Comparison between IASI+GOME2 and CHIMERE: This part is interesting to qualitatively document a particular event of high O3 concentrations in the lower troposphere over Europe and the ability of the satellite observations to capture this event. But it has to be clearer in the text that the model is not used to validate the observations. I would like to draw the attention of the authors to some weaknesses of those comparisons: - they are based on colour maps visualisation and no quantitative statistics are presented.

(Answer 8) The comparison of IASI+GOME-2 and CHIMERE model is not used as a quantitative validation, as stated in the RM (page 19 lines 13-14) as "Rather than a validation, this comparison verifies the qualitative inter-consistency of IASI+GOME-2 and CHIMERE for describing the spatial distribution of ozone plumes..". For this reason, we describe the detection of ozone plumes, rather than showing global quantitative statistics.

(Referee#1) - in order to clearly characterise the difference or improvement of IASI+GOME2 versus IASI figure 8 should also present the LMT columns of IASI and of CHIMERE*AVK for IASI.

(Answer 9) Done. In Figures 10 and 11 of the RM, we show LMT columns of IASI and CHIMERE smoothed by AVKs of IASI over Europe for the 19 and 20 August 2009, respectively. Indeed, the comparison between CHIMERE smoothed by IASI+GOME-

2 and IASI averaging kernels enables a straightforward explanation of the differences between IASI+GOME-2 and IASI observations. LMT ozone plumes clearly depicted or not by the observations are in very good agreement with those shown or not in the corresponding smoothed model. Ozone plumes located within the LMT are clearly depicted by CHIMERE smoothed by the AVKs of IASI+GOME-2, but they are only slightly suggested (mainly within the retrieval noise magnitude) when convolving by those of IASI. This gives further evidence that the enhancement of sensitivity described by the AVK calculations of IASI+GOME-2, with respect to IASI, allows a clearer detection of ozone plumes within the LMT. In the RM (page 21 lines 11-13), this is suggested as "The unique capacity of IASI+GOME-2 to detect these plumes over ocean is consistently remarked when smoothing CHIMERE by the AVKs of the two retrievals (Figs. 10c-d). "

(Referee#1) - the authors do not discuss an important feature of the LT and LMT O3 distributions which is rather unclear: enhanced columns from IASI+GOME2 over north eastern Europe (north of 45N and east of 20E) (fig. 7 a and b). These enhanced O3 columns are not observed with IASI (fig. 7c and d) but are clearly detected by GOME2 (fig. 7e and f). As GOME2 is more sensitive to the UTLS than to the LT this indicates that these enhanced LMT columns are POSSIBLY coming from a CONTAMINATION FROM UTLS O3. Furthermore CHIMERE do not simulate this feature (both from surface to 3km (fig. 9c) and from 3 to 6km (fig. 9d)) except partly just north of the Black Sea but high LMT columns appear when the IASI+GOME2 AVK are applied to the CHIMERE data (fig. 9b). This corroborates the hypothesis of an UTLS contamination of the LMT column by the AVKs. In order to confirm or to rule out an UTLS contamination, the authors have to look at UTLS properties over Europe during the studied period. Is there an intrusion of polar LS air over north eastern Europe? The answer will come from UTLS O3, PV/geopotential heights from CHIMERE and from other sources. In case such a contamination is confirmed, this has to be discussed in the paper as a weakness of the IASI+GOME2 L(M)T retrieval.

(Answer 10) We have addressed this issue in the new Figure 12 of the RM. The ozone layer shown by IASI+GOME-2 LMT columns in North-eastern Europe do not correspond to upper-troposphere/lower-stratosphere (UTLS) ozone, but it is a rather thin ozone layer that is located below 3-4 km a.s.l.. According to transects of both CHIMERE ozone distribution and ECMWF potential vorticity, the origin of this ozone layer is an intrusion of lower stratosphere air but that is located between 2 and 4 km a.s.l. and below a free troposphere with very low ozone concentration between 4 and 12 km a.s.l.. South of the descending filament (around 53°N in Fig. 12c), the CHIMERE transect and CHIMERE raw outputs maps in Figure 10 of the RM do depict this feature mainly below 3-4 km a.s.l.. Vertical transects of IASI+GOME-2 and IASI observations illustrate the difference on their performance for observing such complex tropospheric ozone distributions. On the one hand, IASI+GOME-2 does observe an ozone layer in the LMT located below a very clean upper troposphere. On the other hand, IASI only approach is not capable of vertically resolving this LMT ozone layer and it retrieves a rather clean troposphere with an intermediate ozone concentration (between the upper and lower troposphere). The ozone plume is also observed by GOME-2 as higher concentrations but extending over the whole troposphere. This example illustrates the capability of IASI+GOME-2 to observe LMT ozone layers even when its concentration largely differs from the upper troposphere (which is not the case for the single-band approaches). These findings are confirmed by transects of CHIMERE smoothed by IASI+GOME-2 and IASI only AVKs which are rather similar (in the structure and ozone concentrations) to the satellite observation transects. In the RM, these statements are given as (page 22 lines 1-26): "Otherwise, a different situation is remarked for the ozone plume over Poland (50-52°N 19-33°E in Fig.10a). This ozone layer is clearly shown by IASI+GOME-2 and CHIMERE at the LMT (raw and smoothed simulations, in Figs. 10e, 12c and 12e), but it is clearly absent from IASI observations and CHIMERE smoothed by IASI AVKs (Figs. 10f and 12f). According to transects of CHIMERE raw outputs and ECMWF potential vorticity (Figs. 12c-d), this plume (at 50-52°N) is a rather thin filament of ozone located between 2 to 4 km a.s.l., which originates from an intrusion of lower stratospheric air further North (at 53-56°N). As expected for stratospheric air, very low humidity is observed at the altitudes of this ozone filament (see radiosounding profiles at 2-3 km a.s.l. in Fig. 12d). Above this ozone-enriched layer, very low ozone concentrations extend up to 12 km a.s.l. (Fig. 12c). Figure 12g shows that IASI+GOME-2 is capable of resolving this complex vertical distribution of ozone (particularly at 50-52°N), showing higher concentrations at the LMT (i.e. the ozone filament) below a very clean upper troposphere, as also qualitatively depicted by raw CHIMERE outputs (Fig. 12c). The vertical structures and ozone concentrations depicted by IASI+GOME-2 observations match fairly well those shown by CHIMERE simulations smoothed by the multispectral AVKs (Fig. 12e). The descending part of the ozone filament is also apparent at 53-54°N both in IASI+GOME-2 observations (Fig. 12g) and CHIMERE outputs (Fig. 12c and 12e). On the contrary, IASI mainly detects low ozone concentrations in the free troposphere and is unable to resolve the ozone plume at the LMT (see Fig. 12h at 50-52°N). This is also shown by CHIMERE outputs smoothed by IASI AVKs (Fig. 12f), suggesting that it is mainly linked to the coarser vertical resolution and lower sensitivity of IASI with respect to IASI+GOME-2. On the other hand, GOME-2 retrievals do show enhanced ozone concentrations over Poland (at 50-52°N, see Fig. 9e), but extending over the whole troposphere (not shown) as expected by limited DOF_TROPO with respect to IASI+GOME-2."

(Referee#2) Anonymous Referee #2 Received and published: 25 March 2013 The paper describes a method for retrieving ozone vertical profile from a simultaneous use of collocated IR (IASI) and UV (GOME2) radiances. It analyses and discusses the results in terms of vertical sensitivity in the lowermost troposphere (and lower troposphere) and goes a step further by examining how the combination of instruments improves the retrieval of lower tropospheric ozone columns by comparing the retrievals during a summer pollution episode over Europe to model (CHIMERE) simulations. A comparison to ozone sondes at mid-latitudes is also provided. The paper is well written. It tackles an important but challenging methodological problem (until recently the advantage of the synergy was only demonstrated theoretically). Overall it provides good

evidence of the improved performances of the combined ("multispectral" UV+TIR as called in the paper) versus individual (TIR or UV) ozone profile retrievals. However, I feel at the same time that there is insufficient critical analysis, here and there some overstatements and that the discussion is too much oriented towards the "positive" side. The paper is suited for ACP but before publication the following general comments should be addressed. GENERAL COMMENTS: 1. Section 3.2, especially page 2968. The discussion around the DOFS is done here on a relative (percent improvement) basis. In my opinion this is very misleading. For example, the authors explain that the DOF for the combined retrieval is 77 %, 40%, 21% higher than IASI for the column up to 1 km etc. . . But if I take it from Figure 3, the first number (77%) refers to a change of DOF from about 0.05 (IASI alone) to about 0.1 (IASI+GOME2). This is thus an increase of DOF of only 0.05. I wonder how significant that can be and more generally how representative a DOF of 0.1 is for a partial column. The same applies for all DOF numbers given in the paper (not for the altitude of maximum sensitivity, which is therefore probably also more convincing). I urge the authors to revise this part of the discussion of vertical sensitivity by providing absolute values for the DOF comparison and by building the discussion more critically and carefully around these. I would also suggest to add variabilities (plotted as shaded areas around the mean curve?) in Figure 3. Another example of overstatement (or lack of critical analysis) is provided with Table 1 and the related text page 2967: The text refers here to a significant gain of sensitivity of the combined retrieval as compared to IASI or GOME2 taken individually by comparing the total column DOF. The gain is indeed impressive, with a DOF increasing from 3.02 (IASI) or 3.68 (GOME2) to 5.2 for the combination. But the improvement in the troposphere (the focus of the paper) seems, from the other values listed in the table, far from being that impressive. So where is the improvement on the profile; in the UTLS or the stratosphere? The paper is too oriented towards what it wants to show and misses some other important aspects. According to this, the second sentence in the conclusion "The information content enhancement for IASI+GOME-2 enables an increase of sensitivity to the whole atmospheric column and especially below 3 km" is (unless I missed something) overstated and probably incorrect.

(Answer 11) We have addressed these comments as follows: In sections 3.2 and 5 of the RM, discussions on degrees of freedom are first expressed in absolute values and if relevant, relative differences are also given. Using new Fig. 3a and 3b of the RM, we have explained at which altitudes of the atmospheric column the gain of DOFs is most important. In the RM, it is explained as follows (page 12 line 25 to page 13 line 8) "Figures 3a-b show at which altitude levels the multispectral sensitivity gain is most significant, by comparing the AVKs diagonals averaged over land and over ocean (over Europe for 19-20 August 2009). With respect to IASI only, the sensitivity increase of IASI+GOME-2 is most important at the stratosphere (DOF_col above 20 km a.s.l. increases by $\sim$1.2). In regard to GOME-2 only, IASI+GOME-2 is much more sensitive at the whole troposphere (DOF_TROPO is higher by $\sim$1.0). When comparing at each altitude with respect to the most sensitive single-band retrieval, the multispectral gain of degrees of freedom is greater at both the lowest atmospheric layers (with +0.11 between 1 and 4 km a.s.l.) and the UTLS (upper-troposphere/lower-stratosphere, with +0.11 and +0.17 between 9 and 14 km a.s.l. over land and ocean, respectively). At the LMT, the mean DOF_LMT for IASI+GOME-2 is higher by at least 0.10 than for IASI only (and higher by 0.26 than for GOME-2 only see Table 1), both over land and over ocean. This multispectral enhancement of sensitivity is the greatest over the atmospheric column in relative terms: DOF_LMT of IASI+GOME-2 is 40 % higher than IASI and a factor 3 higher than GOME-2." Concerning Figure 3, if we add shaded areas or lines with pixel-to-pixel standard deviations around the mean values, the figure becomes unclear (areas are overlapped). The values of the pixel-to-pixel standard deviations of DOF and Hmax are already reported in Table 1 for the most important partial columns analysed in this figure, i.e. LMT and LT. The statement in the conclusions was mainly correct although incomplete (see above in this answer). It is rephrased in the RM as follows (page 23 lines 22-24) : "The information content enhancement for IASI+GOME-2 enables an increase of sensitivity to ozone in the whole atmospheric column, especially below 3 km a.s.l. (LMT, which is particularly valuable for ozone pollution studies) and

at the UTLS."

(Referee#2) 2. In section 3.3. the authors explain that (page 2970, lines 19-20) "both comparisons show good agreement between IASI+GOME2 retrievals and ozonesondes, with very similar results as for the IASI only retrieval . . .". This is important but surprisingly not discussed further in the paper. To fully support their findings and add critical information, the authors would need to include the IASI alone and GOME-2 alone retrievals vs ozonesondes comparison in the paper, especially in Figure 6 with similar diagnostics (R coefficient, bias, RMS). They should also add one Figure showing the comparison of profiles between the mean sondes, the mean IASI, the mean GOME2 and the mean IASI+GOME2 (with standard deviations), in order to discuss in what altitude range the improvement is and if it is significant.

(Answer 12) Done. A new quantitative validation against ozonesondes of the three satellite ozone retrievals is given: IASI+GOME-2, IASI and GOME-2. These comparisons show that IASI+GOME-2 is the only satellite retrieval, which shows LMT ozone variability close to the one measured by ozonesondes and very low mean biases (1%). For single-band retrievals, lower sensitivity to LMT ozone induces a strong underestimation of variability and significant negative biases in ozone concentration (thus closer to the a priori), particularly for cases with higher concentrations. This quantitative comparison against independent observations shows that the best retrieval (in terms of mean bias and variability) of LMT ozone is performed by IASI+GOME-2. See further details in (Answer 5) and (Answer 6). For sake of briefness, rather than showing new figures with the mean profiles, we prefer to show biases in Fig. 7 for the partial columns of main interest.

(Referee#2) 3. Few details are given here to the "failed" or "aberrant" retrievals. Considering the challenging aspects of the retrievals, if would be instructive to know more on, for instance, the fraction of failed retrievals but also (at least to some extent) the reasons for this. Beyond spectroscopy, which is discussed thoroughly, what is the impact of the fractional cloud cover, of aerosols, of TIR emissivity, of different air masses probed (viewing geometry of GOME2 vs IASI). . .. All seem critical, as they could lead to incoherencies between TIR and UV but this is not discussed. Furthermore, are the 200 "typical" residuals in Figure 1b examples of good fits? Are there other cases? I don't say here that bad results need to be shown but at least that the good ones be discussed in a balanced way. Related to this, on page 2970, the authors mention "quality checks". What are these? And on page 2971, what are "aberrant retrievals"; can the reasons for the failure be identified?

(Answer 13) Done. In the RM, we clearly explain the "quality checks" and the fraction of retrievals that are screened out in each case. It is explained in the RM (page 16 lines 6-16) "These tests verify the consistency of IASI spectra at the TIR atmospheric window with respect to Planck functions of possible surface temperatures and also discard pixels with too high fitting residuals (for the retrievals of surface temperatures and ozone profiles) or aberrant results (i.e. surface temperatures below 273 K or ozone mixing ratios below 0.1 ppb). For illustration, Figure 2c shows the results of these quality checks for the 19 August 2009 over Europe. In this case, 68 % of the pixels passed the tests, 18 % correspond to cloud fractions greater than 0.3, 9 % are screened out by the Plank function filter and the rest are removed by the filters of high fitting residuals (4%) or aberrant results (1%). For all cases of this validation study (during summer 2009 over Europe), these quality tests are passed by typically 7 to 12 satellite retrievals that are collocated with each ozonesonde." Moreover, we provide as well a new figure 2 showing the spatial distribution over Europe of IASI+GOME-2 residuals at the TIR and UV, clouds fractions, surface emissivity and aerosol distribution (from MODIS). By comparing coincident pattern, we do a first analysis of the major effects of cloud, surface and aerosols on the IASI+GOME-2 residuals. Further analyses are beyond the scope of the present paper and they will be addressed in a future publication. In the RM, this first analysis is presented as follows (page 11 line 26 to page 12 line 19) "Figures 2a-b show the spatial distribution of IASI+GOME-2 fitting residuals over Europe on 19 August 2009, at the TIR and the UV Huggins bands (for quality-checked pixels, see Section 3.3). Pixels from two satellite overpasses are shown (roughly east and west

of 15° E). For both spectral bands, residuals are rather homogeneously distributed at the regional scale and they mainly vary with the cross-track or swath position. Higher residuals are expected for significantly weaker signal intensities (measured by either IASI or GOME-2), for which signal-to-noise ratios are lower. This is the case of TIR radiances for viewing angles far from nadir (between 10° E and 20° E and east of 5° W) and also for lower surface temperatures (i.e. the Atlantic). Reflectances at the UV are about a factor ∼2 lower for positions east of the satellite track (between 5° and 15° E and east of 30° E). Higher UV residuals on the western part of the swath (over Spain and southeast of Italy) are likely linked to less effective "soft" corrections of the calibration errors for these cross-track positions. These distributions (Figs. 2a-b) are equally observed for the fitting residuals of the single-band retrievals (not shown). Moreover, similar residuals are obtained for y_{UV+TIR} constructed with different y_{TIR} and the same y_{UV}, for all the analysed cases with low cloud fractions (< 30 %). Figures 2d-f show co-located cloud fractions, surface emissivities and aerosol optical depth (the last two derived from MODIS satellite observations). No coincident patterns are clearly apparent between IASI+GOME-2 fitting residuals and the horizontal distribution of cloud fractions below 30 % or high aerosol optical depths. Only some sparse pixels near thicker clouds (e.g. over the Atlantic or west of the Black sea) show higher residuals (either TIR or UV), which might have been missed by the cloud-screening checks (see Fig. 2c). Moreover, surface emissivity might not have a significant impact on the fitting residuals at the TIR, except over the Alps (see Figs. 2a and 2e). "

(Referee#2) 4. Table 1 Looking at the altitude of maximum sensitivity we see a rather large variability, especially for IASI (3.02 +- 0.67 for the LMT). In the case of IASI, is this due to thermal contrast? And what is the reason for GOME2; surface reflectivity? The paper should make clear if in the favorable cases for the TIR or the UV the combination remains as advantageous (or reversely highlight the cases in which the combination is the most advantageous). For instance, it seems that in the best cases the IASI alone retrievals provide a sensitivity down to 2.3 km, pretty close to the combined retrievals. This is briefly discussed page 2969, line 7 but again, a more detailed discussion as function of the principal parameters influencing the sensitivity to the surface concentrations would be helpful.

(Answer 14) Done. We have added new comments on the RM on the main factors affecting the altitude of maximum sensitivity at the LMT and when the multispectral combination is more or less favourable. In the RM, this analysis is detailed as follows (page 14 line 28 to page 15 line 15): "For different regions, H_LMTmax for IASI+GOME-2 varies significantly, reaching for example $\sim$1.6 km a.g.l. in Spain and $\sim$2.6 km a.g.l. in France, thus depending on the main conditions driving the sensitivity of the single-band retrievals. For all pixels of Fig. 6 with simultaneously higher thermal contrasts (from 10 to 15°C) and higher cloud fractions (from 0.2 to 0.3), H_LMTmax for IASI+GOME-2 is on average 1.8 km a.g.l., thus respectively 0.9 and 2.0 km below that for IASI and GOME-2, respectiverly. For both negative thermal contrasts (from -10 to -5°C) and lower cloud fraction (below 0.1), the multispectral sensitivity maximum at the LMT peaks at 3.6 km a.gl., which is 1.5 and 0.7 km below that for IASI and GOME-2 only. Moreover, the multispectral gain of sensitivity at the LMT is particularly advantageous for compensating the lack of sensitivity of one of the single-band retrievals. For all pixels with negative thermal contrasts (from -10°C to -5°C), H_LMTmax for IASI+GOME-2 is on average 1.7 km below that for IASI. For all cases over land with low cloud fractions (below 0.1), the multispectral H_LMTmax is located 1.8 km below that for GOME-2. On the contrary, the sensitivity enhancement of IASI+GOME-2 may be relatively less significant with respect to IASI or GOME-2 in conditions of high sensitivity. The multispectral H_LMTmax is located 0.7 km below that for IASI for high thermal contrasts (from 10 to 15°C) and also 0.7 km below that for GOME-2 over land for high cloud fractions (from 0.2 to 0.3)."

(Referee#2) MINOR COMMENTS Page 2961, line 17: The retrieval is not sequential (as TIR and UV are combined in a single vector) but this would be an alternative option for combining the information. This just to say that the word "sequential" is here ambiguous and, I think, could be avoided ("independently" says it all).

(Answer 15) Corrected. In the RM, it is indicated as "For each IASI pixel, multispectral retrievals are processed independently."

(Referee#2) Page 2968; third paragraph: the discussion of the altitude sensitivity is given here in comparison of the LMT, which is not defined on a "geophysical" basis but arbitrary as the ground-3 km layer. The authors should accordingly be careful in the way the results are presented as it sounds that if the altitude of maximum sensitivity is higher than this arbitrary 3km limit, the retrievals misses something important.

(Answer 16) Corrected. In the RM, we rephrased it as (page 14 lines 4-5) ". . . averaging kernels for all levels within the LMT peak above the LMT partial column."

(Referee#2) Page 2969, line 12: 400 below H_LTmax. Not sure that a value of 2.6 km for HLTmax is mentioned before.

(Answer 17) Corrected. For IASI+GOME-2 over land on 19 August over Europe, H_LMTmax is in average 300 m below H_LTmax. We have changed it accordingly.

(Referee#2) Page 2969: Last paragraph of section 3.2. This discussion is unclear to me. Please clarify.

(Answer 18) This comment on the previous manuscript indicated how AVK were calculated and the error that would be done if the uncertainty of the instrumental parameters was neglected. It was suppressed in the RM, as it is not relevant for showing the capacity of IASI+GOME-2 and also for sake of briefness.

(Referee#2) Page 2973, throughout section 4.1. : What is the altitude of the pollution plumes? Is it boundary layer pollution? Or higher up? CHIMERE should be able to tell and it would be instructive to know if the instruments (alone or with the combination) are able to probe this surface layer.

(Answer 19) Done. In the Fig. 12 of the RM, we show the altitude of the atmospheric mixing boundary layer estimated by the model as well as transects of the vertical distribution of the ozone plumes simulated CHIMERE. The ozone plumes extend vertically up to 3-4 km and sometimes up to 2.5 km or 3 km a.s.l.. As satellite overpasses are in the early morning (around 9h local time), most ozone plumes are located above the atmospheric mixing layer and sometimes partly within. In the RM, this is expressed as follows (page 21 lines 1-4) "According to CHIMERE outputs without smoothing (Fig. 10e and the vertical transect of Fig. 12a at 44-50° N), high ozone concentrations (15 mol μm-3) of the Western plume extend vertically from the top of the atmospheric mixing layer (at 1 to 1.5 km a.g.l. over land) up to 3.5 to 4 km a.s.l.." and (page 21 lines 24-27) "According to CHIMERE transects (Figs. 12b-c), the plumes over Hungary (46°N 20°E) and Romania (44°N 27°E) are mainly located at the LMT (up to $\sim$3 km a.s.l.), respectively above and within the atmospheric mixing layer."

(Referee#2) TECHNICAL CORRECTIONS: Page 2962, line 6: Cai et al. (2012) Page 2970: Uccle is in Belgium. Page 2974, line 13 HungAry.

(Answer 20) Corrected.

(Referee#3) Anonymous Referee #3 Received and published: 25 March 2013 General Comments The paper by Cuesta et al. presents a demonstration of the improvement of sensitivity to lower tropospheric ozone upon combining information from IASI and GOME-2 observations. The authors use an altitude dependent regularization approach to constrain the inversion and can show in the form of the averaging kernels enhanced sensitivity to ozone in parts of the troposphere above the single instrument cases. A lower tropospheric ozone pollution event in north Western Europe in August 2009 is further used to demonstrate how well the joint and single instrument approaches perform. The profiles are evaluated against 3 months of ozonesonde profiles at this time of year and in the same geographical region and compared with two days of output from a chemistry transport model. In general this paper is well presented and researched, although relies heavily on the reader to seek specific explanations or descriptions of methodology elsewhere in the literature, including for some aspects or derivations that are essential to the methodology presented. Some aspects of the method should be presented more clearly as at times it is confusing. The authors are able to clearly

demonstrate the advantage of combining the measurements from both sensors, which is a significant step. However, I do not think it is sufficiently made clear in the title or the paper that the information presented (including numbers quoted and conclusions drawn) relates to just a small region or a short period of time. This is a short case study paper rather than a full validation of the technique. This is important to emphasise because a case study in Northern Hemisphere summer over Europe provides arguably optimal conditions for retrieving tropospheric ozone with both instruments, and the technique might not yield such significant improvements under different conditions globally, seasonally or over the life of the instruments. The paper is very suitable for publication in ACP, but subject to addressing some of the following points.

(Answer 21) Done. The title of the RM is "Satellite observation of lowermost tropospheric ozone by multispectral synergism of IASI thermal infrared and GOME-2 ultraviolet measurements over Europe". The scope of the analysis focused over Europe during the summer 2009 is also clearly remarked in the abstract as (line 15) "In this case study, when high ozone . . ." and (lines 23-24) "Validations with ozonesondes (over Europe during summer 2009)", and similarly in the conclusions.

(Referee#3) Specific Comments 1) Introduction: In addition to the often referenced EAA (2011) there are a number of other direct references that at relevant which the authors may wish to consider for variety (eg http://www.biogeosciences.net/9/271/2012/bg-9-271-2012.pdf)

(Answer 22) Done. We have added new references in the introduction as follows (page 3 lines 3-4) "human health (e.g. Gryparis et al., 2004; Ito et al., 2005) and ecosystems (e.g. Fuhrer and Achermann, 1994; USEPA, 1996; EEA, 2011)", also (page 3 lines 8-9) "agricultural crops and forests (e.g. Fuhrer, 2009; Van Dingenen et al., 2009; Hollaway et al., 2012)" and finally (page 3 line 13) "(nitrogen oxides, carbon monoxide and volatile organic compounds, e.g. Crutzen et al., 1999)"

(Referee#3) 2) Introduction page 2960 line 3: It would be contentious to say that this is a completely validated method due to the very limited temporal and spatial application of the method presented in this paper, without such a caveat or ability for the reader to compare it to prior knowledge.

(Answer 23) Done. In the RM, we have replaced the sentence by (page 4 lines 29-30) "To the authors' knowledge, this is the first method combining real IASI and GOME-2 observations that shows good results against ozonesondes.".

(Referee#3) 3) Section 2, page 2960 line 18: What is the reason for using the smaller GOME-2 pixels when the method of Cai et al., 2012 did not? Is it to reduce the inhomogeneity of the scene for the combination with the smaller IASI pixels? The combining of GOME-2 pixels is specifically to increase the signal to noise because not doing so results in very noisy tropospheric ozone retrievals, so it would be very relevant to comment on this.

(Answer 24) The use of 40x80 km2 GOME-2 pixels in the IASI+GOME-2 method is mainly for spatial consistency between GOME-2 and IASI measurements. This is remarked in the RM as (page 5 line 13) "... but here with a 1/8 finer pixel resolution for spatial consistency with IASI pixels...". Cai et al. (2012) co-added spectra of GOME-2 channel 2 for matching the GOME-2 channel 1 spatial resolution, besides the improvement of signal-to-noise ratio of the spectra. Using small GOME-2 pixels is not likely to lead to much noisier tropospheric ozone retrievals, as a significant portion of the residuals are systematic and they would not be reduced by co-adding spectra.

(Referee#3) 4) Section 2.1 page 2061 line 13: The presence of cloud would be expected to impact spectra from both instruments differently in different pixel domains. This may introduce some homogeneity issues, how are they addressed? I would suggest that the description of the treatment of cloud could be generally improved. It affects both IASI and GOME-2 radiances differently and there are a number of ways of handling this. The ozonesonde comparison later in the paper eliminates IASI and GOME-2 pixels with a high cloud fraction but not necessarily those with cloud at a

high altitude which even with a low cloud fraction can impact the retrievals depending upon how clouds are dealt with in the forward model, for which there is only a passing reference to other papers.

(Answer 25) Additional information on cloud treatment is given in the RM. However, it is important to remark that performing accurate and consistent treatments of clouds in both UV and IR domains may be very complex and it is beyond the scope of the current paper. We use the approaches of the two validated and state-of-the-art methods by Cai et al (2012) for the UV and Eremenko et al. (2008) for the IR. Clouds are treated for all altitudes with the same approximations (see below). Besides, validations of IASI+GOME-2 retrievals against ozonesondes show very similar results for near-clear sky conditions as for all pixels with cloud fractions up to 0.3. In the RM, the following comments on cloud considerations are included (page 7 lines 11-13) "Partial cloud cover and aerosols are not explicitly modelled in KOPRA, but their effects in the IASI spectra are partially compensated by offsets for each TIR micro-window (Eremenko et al., 2008; Dufour et al., 2010)." And (page 7 lines 14-20) "In the UV spectra calculations, we treat pixels with partial cloud cover as a mixture of clear sky and cloudy scenes according to the Independent Pixel Approximation (e.g. Cai et al., 2012). Cloud fractions are derived by comparison between the reflectivity measured by GOME-2 at 347 nm (where ozone absorption is weak) for each pixel and those calculated for clear sky and fully cloudy conditions. Clouds are modelled as Lambertian surfaces with a reflectivity of 80 % (Bhartia and Wellemeyer, 2002), located at the effective altitudes estimated by the FRESCO algorithm (Koelemeijer et al., 2001) using GOME-2 measurements of the O2 A band at 762 nm."

(Referee#3) 5) Section 2.1 page 2961 line 23: Have the authors considered that one way of increasing the degrees of freedom for signal for the GOME-2 only retrieval would be to use more of the spectrum below 290nm?

(Answer 26) In IASI+GOME-2, we do not use GOME-2 measurements below 290 nm because they do not contain information on tropospheric ozone and they have low signal-to-noise ratio. We comment on this in the RM as (page 6 lines 12-14) “GOME-2 measurements below 290 nm are not used due to lack of information on tropospheric ozone and low signal-to-noise ratios.”

(Referee#3) 6) The approach presented uses a vertical grid of 1km interval which given the number of independent pieces of information for each altitude makes them very highly correlated. This is not made sufficiently clear to the reader. The 0-3 km and 3-6 km sub-columns are not independent. This last point is touched on at the end of section 4 but the vertical correlation should be indicated, especially in reference to the averaging kernels.

(Answer 27) Done. This is commented in section 3.2, while describing the IASI+GOME-2 averaging kernels (page 13 lines 18-21) “Figures 4a and 4d suggest as well that LMT ozone partial columns derived from IASI+GOME-2 are expected to also depend on ozone concentrations a few kilometres above the LMT (up to 5 or 6 km a.s.l. over land). ”

(Referee#3) 7) Section 2.1 page 2963 line 9: It would be good to state why a “soft” recalibration is applied to the GOME-2 data if it is important, as it is not clear from the sentence.

(Answer 28) The “soft” recalibration improves the calibration consistency between channels 1 and 2 of GOME-2, while decreasing the fitting residuals of channel 2 by 30%. It also reduces significant systematic biases on retrieved ozone profiles (up to 15% for GOME-2 only retrievals), which depend on cross-track position and instrument degradation with time (see Cai et al., 2012). In the RM, it is written as (page 7 line 31 to page 8 line 2) “This recalibration improves the calibration consistency between channels 1 and 2 of GOME-2; and it decreases the fitting residuals of channel 2 by 30 %. It is also meant to reduce systematic biases on retrieved ozone profiles (up to 15% for GOME-2 only retrievals, see Cai et al., 2012), which depend on cross-track position and instrument degradation with time.”

(Referee#3) 8) Section 2.3: I am confused by the terminology and explanation of the altitude dependent regularisation matrix. Eremenko et al., (2008) states that the method yields an information content not dependent upon the prior knowledge. In that paper, the prior covariance matrix is replaced by the regularization matrix in defining the averaging kernel A (c.f. Rogers 2000, page 56). In this paper however, the a priori total error is introduced but not fully explained. The description of s_colËĘtot seems inconsistent with its use in Eremenko et al., (2008) if they are termed a priori errors. Are they rather a posteriori errors? In equation 2 it isn’t clear to me how s_LMTËĘtot and the other sub-column values are calculated. It is not clear from this to what extent the altitude-dependent regularization also acts as a smoothing function to the profile, which would be pertinent to the interpretation of the results. I don’t feel that the altitude regularization matrix is sufficiently explained to make the work reproducible, or for the reader to understand the relative impacts of the covariance matrices on the results.

(Answer 29) The same kind of retrieval errors and general approach is used in both the present paper and in Eremenko et al. (2008). This is stated in the RM as (page 9, lines 8-11) “As done by Kulawik et al. (2006) and Eremenko et al. (2008), the regularization matrix is not determined by prior knowledge on ozone vertical distributions (i.e. climatology), but it relies on the minimization of the retrieval errors and the maximization of the degrees of freedom.” As in Eremenko et al. (2008), we replace the prior covariance matrix of Rodgers (2000) formalism by the regularization matrix. This is indicated by (page 9 lines 26-28) “We estimate the total retrieval error matrix R_UV+TIR following Rodgers’ (2000) formalism but replacing the prior covariance matrix by the regularization matrix (as in e.g. Steck and von Clarmann, 2000, Steck, 2002).” Concerning terminology, both the present paper and Eremenko et al. (2008) are not in a Bayesian framework since Tikhonov-Phillips regularizations are used. Thus the terminology “a posteriori” or “a priori” errors are not appropriate terms. In the RM, we have replaced these terms by “retrieval errors”, corresponding to s_totcol and Stot the matrices. Moreover, the regularization matrix R is used to calculate the averaging kernel matrix using equation 3 of the paper. The AVK matrix determines the smoothing characteristics of the retrieval and it can be used to interpret the results. For clarifying this aspect, we write in the RM (page 10 lines 10-14) “The AVK matrix represents the sensitivity of the retrieval to the true atmospheric state and it determines the smoothing of the retrieval. It is calculated by a classical expression using the Tikhonov-Phillips regularization matrix (e.g. Steck and von Clarmann, 2000; Steck, 2002, Eremenko et al., 2008)”

(Referee#3) 9) Section 2.3, page 2965, line 4 and section 3.3 page 2971 line 13: By matching the coefficients in this way, isn't the contribution from GOME-2 measurements then always going to be limited?

(Answer 30) The contribution of GOME-2 will not be limited by matching the retrieval errors between IASI and IASI+GOME-2. Indeed, if additional information is added by GOME-2 measurements to the retrieval, it can either reduce the retrieval errors or improve the vertical resolution (or degrees of freedom). In the optimal estimation approach, it depends on the prior covariance matrix. In Tikhonov-Phillips regularization, it is influenced by the choice of user-defined regularization matrix. With our selection of N and k coefficients, the additional information provided by GOME-2 will not reduce the retrieval errors, but the vertical resolution or equivalently the degrees of freedom with respect to the IASI only approach. It is clarified in the RM as (page 9 lines 22-25) “In this way, the additional information provided by GOME-2 measurements will improve the vertical resolution or the degrees of freedom (without reducing the retrieval errors) of IASI+GOME-2 retrievals with respect to IASI only.”

(Referee#3) In terms of spectral consistency between the UV and TIR, does the fit of YUV degrade when YTIR is also fit? It would be very relevant to comment on these points because they pertain to the relative improvement of the joint approach.

(Answer 31) The simultaneous fit of y_UV and y_TIR in IASI+GOME-2 does not increase the residuals of either spectrum with respect to the single-band approaches. Both the magnitude and the spatial distribution of the residuals (over Europe on 19

August 2009) at each band are practically the same for IASI+GOME-2 as for the single-band retrievals. It is indicated in the RM by (page 11 lines 18-19) “Practically the same magnitudes of residuals are obtained when fitting independently y_UV and y_TIR for the single-band retrievals” and (page 12 lines 8-9) “These distributions (Figs. 2a and 2b) are equally observed for the fitting residuals of the single-band retrievals (not shown).”

(Referee#3) 10) Section 3: It would add context to the size of the fit residuals to indicate how their specified values compare with the measurement noise. I would disagree that systematic features in the fit residuals for GOME-2 in channel 2 are only “slightly apparent”. Whilst the axis scale of Figure 1b is not optimised to show this, close inspection does indeed show that there is a robust systematic shape particularly compared to the other wavelength regions – and in the region where tropospheric ozone information is derived from GOME-2.

(Answer 32) Corrected. In the RM, we clearly indicate the existence of these systematic residuals (also for GOME-2 only) and a possible explanation of their origin (page 11 lines 19-25) : “For the TIR and shorter UV bands, residuals as a function of wavelength are mostly random (see examples in Fig. 1b) and near the magnitude of measurement noise ($\sim$6 % and $\sim$0.3 % for the shorter UV and TIR bands). Some systematic features are apparent for longer UV wavelengths, which are in the order of magnitude of radiometric noise ($\sim$0.3 % or reflectance values of $\sim$3 10-4) and equally apparent for GOME-2 only. Probably, they are linked to remaining errors in wavelength shifts and radiometric calibration (not fully corrected by the “soft” recalibration).”

(Referee#3) 11) Section 3.1 page 2967 line 8: This is quite a difficult sentence to follow, I would suggest rewording it. Do the authors mean that using multiple IASI pixels for each GOME-2 pixel yields similar fit residuals in clear-sky pixels? Is this the case globally or in the case study presented in this paper?

(Answer 33) Done. Indeed, we mean that (page 12 lines 10-11 of the RM) “. . . similar residuals are obtained for y_UV+TIR constructed with different y_TIR and the same y_UV, for all the analysed cases with low cloud fractions”

(Referee#3) 12) Section 3.2, first paragraph: It is not sufficiently clear in this section over what domain the statements made about the approach apply. There is an indication in the table caption but it should be mentioned in this paragraph so that the statements can be taken in context.

(Answer 34) Done. We clearly indicate in the paragraph (page 13 lines 23-24 of the RM) “ ..on average for land pixels over Europe on 19-20 August 2009”.

(Referee#3) 13) Section 3.3: The end of the first paragraph states that “The comparison is made for each ozonesonde with the average of collocated satellite retrievals.” Are all pixels within the collocation criteria for a given sonde averaged, resulting in one mean profile representing that region/timeframe? Smoothing over this large area effectively removes noise from the retrieved profile. Is an average AK applied to the sonde or are individual AKs applied to the sonde and a mean value taken? Perhaps it would be positive to give a more detailed description of the method used to validate the case study. It would be useful to state how well the sonde performs against the prior in addition to the convolved and direct comparisons.

(Answer 35) Done. Indeed, typically 7 to 12 retrievals are averaged and then compared to the ozonesonde. Smoothing is done with each of the AVK and then the average is taken. These aspects are explained in the RM as follows (page 15 line 31 to page 16 line 4) “The comparison is made for each ozonesonde with the average of collocated satellite retrievals (thus partly reducing random errors). For comparisons accounting for the retrieval sensitivity, we calculate “smoothed” ozonesonde profiles by convoluting with each of the AVKs of the collocated satellite retrievals and then taking the average.” And (page 16 lines 14-16) “For all cases of this validation study (during summer 2009 over Europe), these quality tests are passed by typically 7 to 12 satellite retrievals that are collocated with each ozonesonde.” Moreover, we include a comment on the

likelihood between the mean partial columns measured by the ozonesondes and the prior (page 16 lines 21-22): “The average profile of the ozonesondes is similar to the average profile used as a priori for the retrievals (differences are below 2 % for the LMT and the LT).”

(Referee#3) 14) Unphysical or aberrant retrievals are mentioned. How do the authors know if it is a good retrieval or not? It is not sufficient to just discuss those that worked well without at least an indication of the frequency of aberrant retrievals or their origin, and the figures do not indicate where a pixel was removed because of cloud or because it was aberrant. Are all (non-cloudy) IASI pixels used or are there any other quality control criteria applied? Is there any scan position dependence on the product or its uncertainty?

(Answer 36) Done. These aspects are explained in detail in the RM, in the text and using a new figure. Please see answer (Answer 13) for a complete description of these issues.

(Referee#3) 15) Section 4 page 2972 line 13: Conditions precipitous to these events are discussed in the literature and a personal communication seems inadequate as a reference. For example, see references within Richards et al., (2013) [ACP 13] which though focussed on high ozone events in Southern Europe also discusses mechanisms.

(Answer 37) The reference (Foret et al., personal communication) describes to a complete analysis of the particular study case of 19-20 August 2009 over Europe. We have added the reference concerning meteorological conditions leading to ozone pollution over Southern Europe in the following way (page 19 line 9): “. . . as similarly analysed over Southern Europe by Millan et al., 2002”.

(Referee#3) 16) In the comparison with the chemistry transport model in section 4, it would be useful to see how the prior sub-column amounts compare. The sub-column ozone (as measured in Dobson Units) is strongly influenced by orography and it is not immediately obvious from figures 7-9 where enhancements are due to a deeper physical column (which occur over sea) or an actual ozone plume. If the prior does indeed consist of a constant (latitude-dependent) volume mixing ratio a plot of the prior in DU would make the skill of the retrieval immediately clear in the places where it departs from the prior.

(Answer 38) In order to clarify this aspect we have added the following statement (page 20 lines 31-32) "Note that lower concentrations at the edges of the plumes may also result from thinner partial columns over mountains (e.g. east of Spain, the Alps or the Pyrenees; also apparent in the DOF_LMT distribution in Fig. 6a)." We prefer not to include a new figure for sake of briefness, since numerous figures where already added in the RM (4 figures) and particularly in this paragraph (12 new panels in these figures).

(Referee#3) Technical Corrections Introduction page 2958 line 5: The sentence starting "Air pollution's most important. . ." is a cumbersome sentence and "damages on" would need to be "damages to" to make sense. I would suggest rewording as "The most important damage to ecosystems by air pollution is caused by ozone through. . ."

(Answer 39) Corrected as recommended.

(Referee#3) Introduction page 2958 line 17: I would suggest "capable" or "suitable" in place of "adapted" in this context, since it is not a transitive case.

(Answer 40) Corrected. It is replaced by "capable of".

(Referee#3) Introduction page 2958 line 18: Since the paper concerns IASI, I would suggest replacing the text in brackets "(e.g. . . .)" with "such as the Infrared. . . (IASI) onboard the MetOp satellites (Clerbaux et al 2009)"

(Answer 41) Corrected.

(Referee#3) Introduction page 2958 line 24: I would suggest somehow breaking apart the sentence beginning "They are based on. . ." which is 7 lines long. The part "space-

borne instruments as the Global. . ." should probably be "spaceborne instruments such as the Global. . ."

(Answer 42) Corrected. The TIR examples are announced in the difference sentences starting by "In the TIR, spaceborne ozone observations are derived from IASI. . ." and "such" was added.

(Referee#3) Introduction page 2957 line 5: It should be specified for future clarity that the IASI and GOME-2 data considered here are from the instruments aboard MetOp-A, particularly as the sentence goes on to mention the future platforms.

(Answer 43) Done. We indicate it as follows (page 4 lines 27-28 of the RM) "This paper presents the capabilities of our new multispectral approach, so-called "IASI+GOME-2", to probe lowermost tropospheric ozone (here implemented with MetOp-A measurements of IASI and GOME-2)"

(Referee#3) Introduction page 2959 line 27: The use of the word "provided" here isn't quite correct in this context. "resulting from" or "afforded by" would be suitable alternatives. Introduction page 2960 line 1: The footprint size of a GOME-2 pixels at the edge of the swath is the same as at nadir, unlike IASI.

(Answer 44) Corrected. We replaced by "resulting from" and "at nadir" is only indicated for IASI.

(Referee#3) Section 2.1 page 2961 line 5 & 7: Was the data used in the study specifically from these sites? If so using 'from example given' is redundant.

(Answer 45) Corrected. "e.g." were suppressed.

(Referee#3) Section 2.3: "a priori" should be italicised.

(Answer 46) Done.

(Referee#3) Section 2.3 page 2966 line 12: Should ". . .and it provides with a greater number. . ." read ". . .and provides a greater number. . ."

(Answer 47) Corrected.

(Referee#3) Section 3.2 page 2967 line 16: Should “in average” actually read “on average”? Section 3.3 page 2971 line 15: “. . .keep as low as the ones for IASI. . .” would be better as “keep as low as those for IASI. . .”

(Answer48) Corrected.

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