

Interactive comment on “Retrieval of MetOp-A/IASI CO profiles and validation with MOZAIC data” by E. De Wachter et al.

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We would like to thank the referees for their time and useful comments to help improve this paper. Hereby our replies to the different points which were addressed.

Anonymous referee #1

1) Referee #1 made a clear request to *remove all subjective language* ("excellent, reproduce, very good..").

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We have adjusted our wording as much as possible. The changes made are given below in combination with our replies to the specific comments which were addressed (highlighted in bold).

2) A second point referee #1 addressed was to clearly *state how well the data agrees within the calculated uncertainties*. The calculated uncertainty being the observation error, i.e. the error from noise, H₂O, temperature and emissivity.

The reviewer is right and we have used the measurement error instead of the smoothing error to compare with the RMS of the differences (Figs. 5 and 6). The measurement error takes into account the instrument noise but not the uncertainties due to fixed parameters (temperature, emissivity..). Nevertheless, previous studies that have made detailed error budgets for FTIR spaceborne sensors have shown that the smoothing error was the largest error and that the measurement error was comparable or larger than other errors resulting from fixed parameters uncertainties (see reply to reviewer #1 for details). Furthermore, in SOFRID we have used a conservative value for the radiometric noise for the retrieval in order to roughly take uncertainties in fixed parameters (such as temperature profile, spectroscopic parameters and surface emissivity...(note, water vapour is retrieved and does not enter the fixed parameter error)) into account as stated in Sect. 2.2. The resulting measurement error is therefore an approximation of the full observation error. The noise level used for the retrieval in FORLI is closer to the actual IASI noise resulting in a measurement error smaller than the observation error. The changes made are given below.

3) A third remark: *There also needs to be a discussion as to why the biases are changing in an inconsistent manner from site to site (Frankfurt to Windhoek) even though the variability of the MOZAIC data appears to be reasonably captured by the IASI data within the expected random uncertainties*.

C1926

The differences of agreement between IASI (FORLI and SOFRID) and MOZAIC at the two sites are already partly discussed in the paper. In particular we have shown that pollution stuck within the boundary layer together with a low thermal contrast in winter spring at Frankfurt are leading to large discrepancies between MOZAIC and IASI. On the other hand, we show that injection of fire plumes at high altitude during the fire season is leading to the capture of the fire peaks by IASI at Windhoek. Nevertheless, as mentioned by the referee, there is a difference in biases between Frankfurt and Windhoek and this needs to be discussed in more detail. A closer look at the plots shows that these differences are not indicating inconsistencies in the retrievals. Concerning SOFRID, it is stated in the text that it is overestimating background values (most pronounced for the nighttime retrievals). This results in a larger overestimation of lower tropospheric CO at Windhoek (13%) than at Frankfurt (4%) as Windhoek is characterized by low background concentrations with exception of the short vegetation burning season. The fact that the MOZAIC data are not covering the period after August 2009 accentuate the low concentration bias in the data because it implies a single vegetation burning season. Following the same logic, the comparisons show that FORLI rather overestimates high CO concentrations in the lower troposphere resulting in a large bias at Frankfurt (13%) and a lower bias at Windhoek (1.6%). In addition, it seems that FORLI overestimates the CO at the lowermost altitudes, as can be seen in Fig. 7, with relative differences for FORLI daytime retrievals between -10 and -20% between 800 and 900 hPa. Since Windhoek lies at an altitude of ~1700 m, we have a cut-off of these lowest altitudes, possibly leading to the lower bias at Windhoek. These explanations are now given in Sect. 4.4 and the conclusion.

Since different geographical conditions apply for the two sites (Windhoek is in a semi-arid region having a slightly smaller (~0.91) surface emissivity than the Frankfurt area (~0.94)), we looked at differences in surface emissivity between SOFRID and FORLI at these two sites, but differences are within 0.01 (see reply on errors (surface emissivity) to ref #2), excluding this as a possible cause for discrepancies between the

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two sites for the two retrieval algorithms.

For the upper tropospheric discrepancies from site to site we could not find a reasonable explanation. This is indicated in the text.

Page 3272, L9: The IASI retrieval errors were added and the wording was adjusted after sentence 2 in the abstract (Page 3272, L6):

"Lower (surface-480 hPa) and upper tropospheric partial column (480–225 hPa) comparisons as well as profile comparisons are made. The retrieval errors of the IASI products are less than 21 % in the lower troposphere and less than 10 % in the upper troposphere. A statistical analysis shows similar correlation coefficients for the two retrieval algorithms and smoothed MOZAIC of $r \sim 0.8$ and $r \sim 0.7$ in the lower and upper troposphere respectively. Comparison with smoothed MOZAIC data of the temporal variation of the CO profiles at the airports of Frankfurt and Windhoek demonstrates that the IASI products are able to capture the seasonal variability at these sites. "

Page 3272, L12: was changed to:

"At Frankfurt SOFRID (respectively (resp.) FORLI)."

Page 3272, L16: was changed to:

"At Windhoek, the impact of the vegetation fires in Southern Africa from July to November is captured by both SOFRID and FORLI, with an overestimation of the CO.."

Page 3272, L20: was changed to:

"Profile comparisons at Frankfurt and Windhoek showed that the largest discrepancies are found between the two IASI products and MOZAIC for the nighttime retrievals."

Page 3273, L12: MOPITT, AIRS and TES are mentioned at Page 3274 L8:

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"George et al. (2009) evaluated global distributions of FORLI CO total columns with the nadir-looking TIR instruments MOPITT, AIRS and TES."

Regarding the discussion on the error analysis, page 3276, L14 was changed to:

"This value is almost a factor 10 higher than the estimated radiometric noise in this spectral region (Clerbaux et al., 2009), to roughly take uncertainties in fixed parameters (such as temperature profile, spectroscopic parameters and surface emissivity) into account."

Section 4.3: The following text was added at the end of this section:

"The errors on the lower and upper tropospheric partial column have been estimated for SOFRID and FORLI. Here the retrieval error is presented, which is the sum of the smoothing error and the measurement error. The smoothing error is the dominant source of error for CO retrievals in the TIR (Barret et al. 2005, Worden et al. 2004) and accounts for the low vertical resolution of the retrievals. For SOFRID, the 1- σ retrieval errors range between 10.7 and 20.5% for the lower troposphere and between 6.5 and 9.5 for the upper troposphere. FORLI retrieval errors are slightly lower and range between 7.7 and 19.1% and 5.3 and 8.3% for the lower and upper troposphere."

Page 3282 L11-14: was changed to:

"The slope and intercept is 1 and near 0 for daytime lower tropospheric FORLI and smoothed MOZAIC, and 0.76 and 0.32 for SOFRID."

Section 4.4:

The values for the standard deviation were replaced by the values for the root-mean-square of the differences (rmsd) in Figs. 5 and 6. Contours of the measurement error in ochre are now displayed in the lower panels of both figures instead of the total

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retrieval error (previously given in pink). Therefore, the last 3 sentences in the caption were changed to:

"The relative difference between smoothed MOZAIC and IASI ($(\text{MOZAIC} - \text{IASI})/((\text{MOZAIC} + \text{IASI})/2)$), in percentage) is given below each figure in blue, with its mean (μ) and root-mean-square (rmsd). The ochre contours represent the IASI measurement error. The data is smoothed by a 5-point moving average."

Page 3282, L22 - Page 3283, L4 was changed to:

"The IASI data (red) are compared to the raw (gray) and smoothed MOZAIC (black) data at these two sites. The mean (μ) of the relative difference between smoothed MOZAIC and IASI partial columns (blue lines in Figs. 5 and 6) and the root-mean-square of the difference (rmsd) are summarized in Table 2. The IASI 1- measurement (S_{meas}) and retrieval error (S_{retr}) are listed as well. The rmsd gives an estimate of the error of the (aircraft and retrieved) partial columns and should be compared to the calculated IASI error budget. Since the smoothed MOZAIC partial columns are compared, the smoothing error has not to be considered (Haefele, 2009), but only the measurement error and errors introduced by uncertainties in the fixed parameters of the radiative transfer model. Note that for SOFRID a conservative value for the radiometric noise for the retrieval was used, to include uncertainties in temperature, spectroscopy and emissivity (see Sect.2.2). For FORLI, the radiometric noise used for the retrievals is close to the actual IASI radiometric noise leading to slightly lower measurement errors."

Page 3283, L10: was changed to: "We find that SOFRID lower tropospheric CO is biased high compared to smoothed MOZAIC by 3.6 %."

Page 3283 L13: was changed to:

"Note how SOFRID captures the same variability as MOZAIC on short timescales from

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January to September 2009. "

At Page 3283 after L26, the following part was added:

"The rmsd between smoothed MOZAIC and IASI is larger for the FORLI product (22.4 %) compared to SOFRID (14.2 %) in the lower troposphere and is comparable in the upper troposphere (~16 %). These values are higher than the IASI measurement error estimated from the theoretical analyses, especially in the upper troposphere. This is not completely surprising as several error sources are not taken into account in the present study. First, one has to consider that the rmsd includes both the error on the MOZAIC and IASI partial columns. Second, even if the coincidence criteria are chosen optimally, the difference of sampling between the satellite and the aircraft is a source of random difference between both. Third, as previously explained, a rough estimate of the uncertainties introduced by the model parameters was made (or not considered for FORLI), which probably leads to an underestimation of these uncertainties. Finally, the use of a too low (resp. too high) radiometric noise (a priori variability) may result in an artificially high variability in the retrievals and therefore an excessive rmsd. Nevertheless, the cause of the discrepancies between error estimates and rmsd need to be further investigated. Note, the measurement errors are roughly half of the retrieval errors (Table 2) showing that the smoothing error is by far the largest source of random error."

Page 3283, L28: was changed to: "In the lower troposphere, very close agreement is found between SOFRID and smoothed MOZAIC for the fire emission peaks, but we see an .."

At Page 3284 after L1: we added:

"The larger overestimation of lower tropospheric CO at Windhoek than at Frankfurt can be explained by the low background concentrations at Windhoek throughout the year except during the short vegetation burning seasons. The fact that the MOZAIC

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data at Windhoek are not covering the period after august 2009 accentuate the low concentration bias in the data because it implies a single vegetation burning season."

Page 3284 L2: was changed to:

"Lower tropospheric FORLI has a small bias of -1.6% relative to smoothed MOZAIC, although higher relative differences are observed for the fire maxima of $\sim 10\%$. The analysis of the CO profiles presented later in this section will help to understand the lower tropospheric bias difference between Frankfurt and Windhoek for FORLI. "

Page 3284 L7: was changed to:

"Upper tropospheric SOFRID is biased high compared to smoothed MOZAIC by 3.7% ."

At Page 3284 after L19: the following part was added:

"The rmsd is below 20% and 16% in the lower and upper troposphere respectively. The rmsd is greatly reduced for FORLI in the lower troposphere compared to the rmsd value at Frankfurt. Again, rmsd values are higher than the measurement errors with larger discrepancies in the upper than in the lower troposphere."

Page 3286 after L1: the following text was added:

"For FORLI, the bias profiles are similar at Windhoek and Frankfurt except that the large overestimation (up to 20%) of FORLI in the lowermost layers at Frankfurt is not observed at Windhoek (Figs. 7 and 8). This may result from the fact that Windhoek is located at ~ 1700 m a.s.l., above the altitude where the overestimation is the highest. Furthermore, most of the time (except during the vegetation burning season) the BL above Windhoek is less polluted than the BL above Frankfurt and FORLI has the tendency to overestimate the high rather than the low CO concentrations. These points highlighted by the profiles analysis partly explain the difference in biases for FORLI lower tropospheric CO between Frankfurt and Windhoek."

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Section 5 Conclusions:

Page 3286 L12: was changed to :

"MOZAIC and the two IASI products of lower (surface-480 hPa) and upper (480–225 hPa) tropospheric partial columns showed correlation coefficients of $r \sim 0.8$ and $r \sim 0.7$ respectively."

The following sentence was added after L19 (Page 3286):

"The retrieval error of the IASI products was estimated to be less than 21% and less than 10% for lower and upper tropospheric columns respectively, with slightly lower values for the FORLI retrieval."

Page 3286 L22: was changed to :

"Overall, both retrieval products showed close agreement with.."

At Page 3287, first paragraph:

" SOFRID lower tropospheric columns were positively biased by 3.8 % at Frankfurt and 12.8 % at Windhoek. Profile comparisons demonstrated an overestimation of the low CO background values and an underestimation of the high CO values by the nighttime SOFRID retrievals. This leads to a larger overestimation of lower tropospheric CO at Windhoek than at Frankfurt as Windhoek is characterized by low background concentrations with exception of the short vegetation burning season. In the upper troposphere, SOFRID was biased high by 10.5 % at Frankfurt but showed a better agreement with smoothed MOZAIC at Windhoek (biased high by 3.7 %). "

Page 3287 L7-15: was changed to:

FORLI lower tropospheric columns were positively biased (13.0 %) at Frankfurt. At Windhoek, a small positive bias of 1.6 % relative to smoothed MOZAIC was found with increased relative difference values for the fire maxima ($\sim 10\%$). A closer investigation of the profiles revealed that at Frankfurt, the polluted BL CO concentrations are

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smoothed to higher altitudes, most pronounced for the FORLI nighttime retrievals. In addition, an overestimation of the high CO concentrations at the lowermost altitudes by the daytime retrievals was observed. Windhoek is located at $\sim 1700\text{m a.s.l.}$, above the altitude where FORLI overestimates CO, and has a clean BL most of the time. This partly explains the lower bias observed in the lower troposphere at Windhoek than at Frankfurt. In the upper troposphere, FORLI was biased low by 0.9 % and 10.0 % at Frankfurt and Windhoek respectively.

At Page 3287, after L15:

"However, we found no explanation for the differences in biases by the IASI data between Frankfurt and Windhoek in the upper troposphere."

Page 3287, before the last paragraph: "The rmsd values between IASI retrievals and MOZAIC are larger than could be expected from the estimated errors, especially in the upper troposphere. Possible causes for this discrepancy include underestimation of errors from uncertainties in fixed parameters, sampling errors, and a too strong constraint applied on the measurement during the retrievals. This problem will be addressed in future developments of the retrieval algorithms."

Page 3287 last paragraph: was changed to:

"In conclusion, SOFRID and FORLI showed biases no higher than 13% compared to the MOZAIC reference set and showed their ability to correctly reproduce the CO variability in the lower and upper troposphere. Discrepancies found between the two IASI products and MOZAIC could in a large part be explained by the lower thermal contrast during nighttime, which leads to less vertically resolved nighttime measurements."

Please also note the supplement to this comment:

<http://www.atmos-meas-tech-discuss.net/5/C1925/2012/amtd-5-C1925-2012-supplement.pdf>

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