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"Analysis of IASI tropospheric O_3 data over Arctic during POLARCAT campaigns in 2008" by M. Pommier et al.

Reply to Anonymous Referee #1

The authors would like to thank the Referee for his careful reading of the manuscript and for his constructive and detailed comments. We tried to improve the content as recommended. A detailed point by point reply (in blue) is provided hereafter.

This paper by Pommier et al. focuses on a comparison of the IASI ozone profiles at high latitudes with the POLARCAT aircraft measurement campaign and lidar measurements. It is a valuable analysis for users of the IASI O3 data, and a detailed evaluation of these observations over Arctic, which is a region with cold surfaces and low thermal contrasts. I found this manuscript appropriate for publication in ACP. However it needs some corrections before publication. I have some remarks that could help to improve the clarity of the manuscript. Indeed most of the results are not well highlighted or are tarnished by others conclusions. Also the text lacks of proper English writing and tend to make it difficult to understand the text. Here we suggest some corrections, but the text will need some polishing before publication.

The corrections and the manuscript were checked by a native English speaker.

General comments

- In the introduction, the author stated that the aim of this paper is "the analysis of IASI O3 data over the Artic (p33132, 14)". Is it an analysis or a validation (as presented later in the text)? It seems more to be an evaluation.

Agreed.
The new sentences are: "In this paper, we provide a detailed **evaluation** of IASI O_3 data over the Arctic. After a brief description of the IASI instrument, the retrieval algorithm and its performance in the Arctic (section 2), we describe the independent data used for the **evaluation** (section 3)."

- As the evaluation of the IASI tropospheric data is the major findings of this work, it deserves to be treated a bit more carefully. The authors wrote:
"p33140, 23-25: this shows the difficulty IASI has in capturing the variability of tropospheric O3 in Artic with sufficient precision as already noted in the discussion about the DOFS distribution". It is frustrating that the authors do not give more description and/or explanation of the reasons of such discrepancies."

An explanation of these discrepancies was given in the following sentence: "The poor agreement is probably also due to the low altitude of the tropopause (at around 8.1 km in spring and 9.2km in summer) as discussed further in the next section."

We changed the sentence and clarified our explanation:
“The poor agreement is possibly due to the low altitude of the tropopause (at around 8.1 km in spring and 9.2 km in summer) which, combined to the limited vertical sensitivity causes large overestimations of the retrievals in the UTLS as discussed further in the next section.”

We explain in more detail in section 5.2, that the tropopause height should influence the results in the UTLS and thus the tropospheric columns.

p33142, 16-17: consistent with the inability of IASI to capture the variability of the O3 close to the surface." If the authors find that IASI is not able to capture the ozone feature close to the surface, why do you keep considering it, as it degrades the agreement and the validation? At some point, the authors should state from which pressure level IASI give a reasonable agreement. And then keep this threshold level and discard the lower levels.

Surface retrievals are difficult for nadir-viewing instruments, in particular for cold regions. For other areas of the globe IASI shows some sensitivity even at surface levels. For the sake of completeness we think it is useful to include surface results over the Arctic.

We agree that the sentence “…consistent with the inability of IASI to capture the variability of the O_3 close to the surface” can be confusing. We changed it to:
“At altitudes below 8 km, IASI shows small biases in comparison to the smoothed lidar profile (10%) except at the surface (Fig. 8a). Note that in the part of the profile where the ACE-FTS climatology is used (above 8.8 km on average) there is a large positive bias of 64% at 10 km. The agreement is poorer between the average retrieved IASI profiles and the average smoothed lidar O_3 profiles, using lidar data above 4 km, with differences reaching 130% at 10 km (Fig. 8b).”

"p33142, 21-23: these differences are due to the lack of vertical resolution in the IASI retrievals and the correlation of vertical information with retrieved profile in the stratosphere".
Here a difference of 130% is effectively "not very good", please rephrase. You should not write "IASI profiles present good agreement between 0 and 8km!" but "IASI ozone profiles are usually biased (by less than XX%) between 0 and 8 km" etc... I think that the conclusions have to be clearer and more considered.

- We rephrased the sentence:
“The agreement is poorer between the average retrieved IASI profiles and the average smoothed lidar O_3 profiles, using lidar data above 4 km, with differences reaching 130% at 10 km (Fig. 8b).”

We also added more information at the end of section 5.1.2 and it reads:
“In summary, the Arctic UTLS O_3 concentrations retrieved by FORLI do not compare well in summer with the reference data considered here but with a mix of positive bias

(high positive bias compared to the lidar and low bias with the Falcon-20) and negative bias (DC-8).
Overall, this analysis shows that the FORLI O_3 concentrations in the Arctic have the largest differences compared to the correlative aircraft measurements in the UTLS and to a lesser extent at the surface. While the latter differences probably relate to the generally weak sensitivity of IASI to the Arctic boundary layer (low thermal contrasts), the former is not yet fully explained. It could be due in part to the limited vertical resolution and/or to the use of a global covariance matrix, which causes undesired mixing between tropospheric and stratospheric concentrations, but may also be linked spectroscopic problems."

- We also changed the sentence in the conclusion from: "IASI profiles present good agreement between 0 and 8 km with smoothed in situ profiles where RD are generally lower than 40% (lower than 25% over the sea whatever the season), with IASI underestimating the smoothed in situ profiles in both seasons. For most of the cases, the bias is lower, below 20 %, comparable to TES validation results between 2 and 7 km (Boxe et al., 2010)."
Now reads: "IASI O_3 profiles are usually biased low between 0 and 8 km (by less than 40% and less than 25% over sea whatever the season), with IASI underestimating the smoothed *in situ* profiles in both seasons. Often the bias is reduced below 20% between 2 and 7 km."

In the same way, we changed the sentence:
"However, the [0–8 km] partial columns show better agreement with RD of less than 15% over the sea during both seasons and the land during summer."
To:
"However, the [0-8 km] partial columns show low biases (by less than 15%) over sea during both seasons and land during summer."

- A longer discussion about DOFs is needed to a better understanding of the text:
Please note that you should rather write DOFs instead of DOFS (here and everywhere in the text) p33135, 15-16: There is a contradiction between this sentence "during both seasons... , the DOFS varied between more than 1.0 to 4.0..." and the next paragraph. Maybe could you add a map of DOFs for total profile in addition of Fig4 and Fig5 for [0-8km] O3 columns? Could you clarify whether the DOFs varied between more than 1.0 to 4.0 or range from 0.04 in spring to 0.7 in summer? Are you sure of what you show? What information can you have with a DOF lower than 1? Or equal to 0.04? What sort of issue could bring DOFs lower than 1?

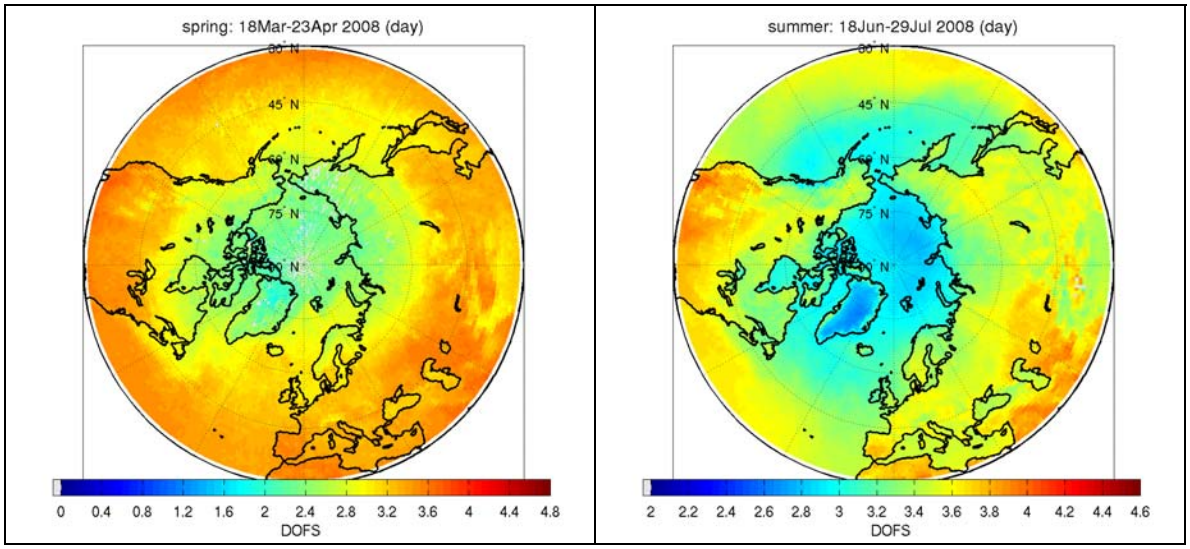
- DOFS is for Degrees Of Freedom for the Signal.

- DOFS can be calculated per total column or per partial columns and we did both. We clarified by adding the term "for the total column" to the following sentence:
"During both seasons that were studied in 2008, the DOFS **for the total column** varied between more than 1.0 (always above 65°N) to 4.0 in the Northern Hemisphere."

- In the next paragraph, the sentence as "In spring, the DOFS over [0-8 km] range from 0.04 to as much as 0.6 during daytime…" corresponds to the description of the Figs. 4b and 5b. These figures represent the distribution of the DOFS over [0-8 km] range, gridded on 1° ×1°.
We changed the sentence:
"In spring, the DOFS for the [0-8 km] column reach 0.6 during daytime and 0.8 during night-time (Fig. 4b). During the summer, DOFS reach 0.7, both in daytime and for the few pixels during night (Fig. 5b)."

Over the Arctic, the minimum value reached is very low (e.g. 0.04 in the spring daytime) showing there is very limited information. Nevertheless, these DOFS are not representative of the observations used in our study. This is a mean value in a specific grid of the map.
The IASI pixels used for the validation between 0 and 8 km, are characterized by DOFS over [0-8 km] ranging from 0.06 (almost no information added) to 0.81 (mean ~ 0.5).

- We did not show the distribution of the DOFS for the full profiles (see below), because it does not seem necessary to show these maps since we focus on the tropospheric ozone products.



DOFS for the total column on a 1°×1° grid during the day, for the spring campaign (left) and summer campaign (right).

After these comments are taken into account, the author would probably need to correct their abstract and conclusion (especially 33147, lines 8 to 15)

In the abstract we changed:
"The correlation between IASI O_3 retrieved partial columns and the smoothed aircraft partial columns is good with DC-8 *in situ* data in spring over North American forest fire regions (r = 0.68), and over Greenland with ATR-42 lidar measurements in summer (r = 0.67). Correlations with other data are less significant highlighting the difficulty with which IASI is able to capture O_3 variability in the Arctic upper troposphere and lower

stratosphere (UTLS) with sufficient precision as noted in comparison with the [0-12 km] partial columns. However the [0-8 km] partial columns show good results with IASI which displays a negative bias (by less than 26% over snow) compared to columns derived from *in situ* measurements. Despite these difficulties in the Arctic UTLS, this work also shows that IASI can be used to study particular cases where stratospheric intrusions are present using a O_3/CO ratio diagnostic."
By:
"The correlation between IASI O_3 retrieved partial columns and the smoothed aircraft partial columns is good with DC-8 *in situ* data in spring over North America (r = 0.68), and over Greenland with ATR-42 lidar measurements in summer (r = 0.67). Correlations with other data are less significant highlighting the difficulty of IASI to capture precisely the O_3 variability in the Arctic upper troposphere and lower stratosphere (UTLS). This is particularly noted in comparison with the [0-12 km] partial columns. The IASI [0-8 km] partial columns display a low negative bias (by less than 26% over snow) compared to columns derived from in situ measurements. Despite the relatively high biases of the IASI retrievals in the Arctic UTLS, our analysis shows that IASI can be used to identify, using O_3/CO ratios, stratospheric intrusions."

In the conclusions we added/changed (in bold):
"On average, the vertical sensitivity in the retrieval of the IASI **total columns** is similar over land and sea surfaces in spring and summer, and is only slightly higher in summer (DOFS ~ 3.3) compared to spring (DOFS ~ 2.8). **The DOFS for the column between the surface and 8 km range from 0.4 in spring to 0.75 over land in summer**."

Moreover, many sentences in the conclusion were changed.

Specifics comments and typos
The details of these changes are provided point by point in the following.

p33130,5: replace "each" by EVERY.

It has been replaced.

p33131,5: Please rephrase: (e.g. "The satellite measurements of tropospheric ozone include..."

We changed:
"Sources of tropospheric O_3 information from satellites include tropospheric partial columns derived from the Global Ozone Monitoring Experiment (GOME) (Liu et al., 2005), or more recently from the Ozone Monitoring Instrument (OMI) (Ziemke et al., 2009) and the Tropospheric Emission Spectrometer (TES) (Boxe et al., 2010)."
By:
"Sources of satellite data providing information on tropospheric O_3 include tropospheric partial columns derived from the Global Ozone Monitoring Experiment (GOME) (Liu et al., 2005), or more recently from the Ozone Monitoring Instrument (OMI) (Ziemke et al., 2009) and the Tropospheric Emission Spectrometer (TES) (Boxe et al., 2010)."

p33131,25: Please rephrase (e.g. "This project aims to assess the quantification...")

We changed:
"This allows quantification of the impact of pollution on atmospheric composition and climate change in the Arctic"
By:
"This project aims to assess the impact of pollution on atmospheric composition and climate change in the Arctic."

p33133,7: Here indicate the key atmospheric species (O3,CO, etc...) that are measured by IASI.

The sentence is now:
"…daily global measurements of key atmospheric species (e.g. CO, O_3, NH_3, CH_3OH, HNO_3) enabling the analysis of local pollution events, global distributions and transport (Clerbaux et al., 2009)."

p33134, 19-22: Is there any reason, reference or previous study that suggests such data selection? Or is it arbitrarily chosen ?

Quality checks have been performed and it has been noticed that the operational cloud filter provided by Eumetsat was not flagging all cloudy scenes perfectly (e.g. the contamination due to low altitude cirrus clouds proved to be difficult).
A detailed description paper [Hurtmans et al., 2012] for the FORLI-O_3 code used in this paper is now available and provides more details on the data screening. The reference has been added to the manuscript.

p33135, 1-4: I don't understand the link between the two sentences.

In these sentences, there was no link between the filter and the description of the figures 2a and 2b. We changed the sentence as below:
"Figure 2 shows the corresponding number of IASI observations on a 1° ×1° grid. Note in Figure 2b the high density of observations at high latitudes in the summer period compared to Figure 2a, showing that most of IASI data used for the validation were provided during the day."

p33135, 10: Here and everywhere else change DOFs instead DOFS.

As explained previously, we have kept the definition with the acronym DOFS.

p33136: Here we suggest different titles for the section, which are in better agreement with the text: "Aircraft O3 measurements used for evaluation" for Sect.3, "Evaluation in Artic free troposphere..." for Section 5.1.1, and "Evaluation using ozone lidar measurements..." for Section 5.1.2

We followed your recommendation and changed the titles.

p33136, 15: Why the ATR-42 data have not been corrected? Please correct the sentence and explain.

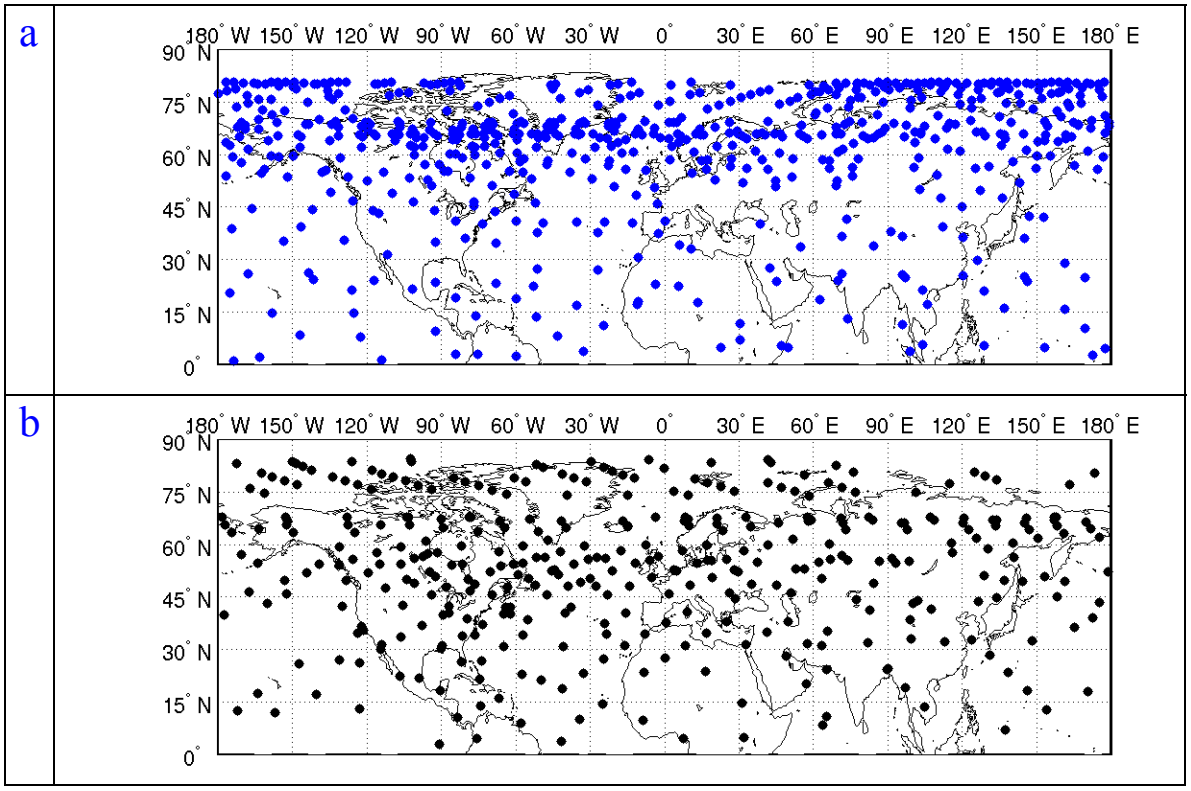
It is a mistake. The data were corrected and thus the sentence was changed: “The ATR-42 data has been corrected in this study.”

p33137, 18: Remove "less than".

Now removed.

p33138, 11: Why did you use data in February to make a spring climatology?

We agree that the usual definition of spring does not include Feb as the definition of summer does not include Sep. Nevertheless, in order to get enough data and to get a significant climatology, we decided to use four month averages.
The ACE-FTS data are unevenly distributed and with this 4-month average we can obtain good global coverage from the northern mid-latitudes to the North Pole as shown in this figure.



a: Distribution of ACE-FTS occultation from Feb to May 2006. b: Distribution of ACE-FTS occultation from Jun to Sep 2006.

p33138, 14: Please change to "the maximum altitudes for IASI profiles ..."

We changed by: “the maximum retrieval altitude for IASI profiles”.

p33139, 13: Please change to "All IASI and smoothed profiles are averaged BOTH by altitude and by aircraft: ... "

It has been changed.

p33140, 1: Please, change than to THAT.

We changed “than” by “that”.

p33140, 20: Could you explain or give insight on the reason of this discrepancy?

This bias between both partial columns is probably due to limited vertical sensitivity in IASI in the troposphere. IASI slightly underestimates the values for [0-8 km] columns while it largely overestimates the O_3 gradient in the UTLS.

Thus we added this sentence:
“This bias is probably due to limited vertical sensitivity in IASI data at these altitudes.”

We also added this sentence in the conclusion:
“The biases in the Arctic boundary layer is related to a low thermal contrast whilst the inconsistencies in the UTLS, require further investigation. These are probably due to limited vertical resolution or to the use of a global covariance matrix, which causes undesired mixing between tropospheric and stratospheric concentrations, but may also be linked spectroscopic problems.”

p33141, 4-6: Please refer to a figure to help the reader.

We modified the sentence (in bold) and the number of the figure is added at the end:
“This difference between both American aircraft is also observed in the bias with [0-8 km] columns and **in the *in situ* part of the average smoothed *in situ* profiles** (0-7.6 km with the DC-8 and 0-4.9 km with the WP-3D) **(Figs 6a & b)**.”

p33141, 27-29: Please rephrase.

We changed:
“A strong anti-correlation with IASI is found for the [0-8 km] partial columns. Similar results are found for the ATR-42 which flew through a mixture of aged pollution plumes and clean background air masses, with the profiles (between 1 and 6 km) and with the partial columns (RD ~15.6% and ~13.5% respectively) (Figs. 7b and 7c).”
By:
“A strong anti-correlation with IASI is found for the [0-8 km] partial columns over Siberia. These columns are also biased by 15.6% (Fig. 7b). Similar results are found for the ATR-42 profiles (between 1 and 6 km) and with the partial columns (RD ~13.5%)

(Fig. 7c). The ATR-42 flew through a mixture of aged pollution plumes and clean background air masses."

P33141, 30: The author stated that the two aircraft carried the same instruments. But what is your point? How does it contribute to the agreement/disagreement between aircraft and IASI. Please clarify.

We meant to say that both aircraft used the same instrument and gave similar results. Nevertheless, we agree that this sentence is confusing, we so decided to delete it.

p33142, 14: Please change to "these data can be used to validate higher altitude measurements..."

It has been changed. The new sentence is: "These data can be used to validate higher altitude measurements in the IASI profiles as well as the [0-12 km] partial columns."

p33142, 19: Please change to "The agreement is RATHER POOR... "

Now the sentence is: "The agreement is poorer between the average retrieved IASI profiles and the average smoothed lidar O_3 profiles, using lidar data above 4 km, with differences reaching 130% at 10 km (Fig. 8b)."

p33143: Please change "... according surface" to "according to surface". Also could you give more information on the lidar capability in the UTLS?

- We changed it, now there is "according to surface".

- The accuracy of the ozone lidar is better in the UTLS than in the lower troposphere because the ozone concentrations are well above the detection limit and because the systematic errors (interference with aerosol, bias due to the signal processing) are smaller. The main limit in the UTLS is the random noise which increases with altitude and is accounted for in this work. The lidar data are discarded when this random noise is larger than 50% for a 5 min profile. The uncertainty on the average becomes less than 10% in the altitude range 10-12 km.

Several papers discuss the accuracy of the airborne lidar in the UTLS:

G. Ancellet and F. Ravetta. On the usefulness of an airborne lidar for O_3 layer analysis in the free troposphere and the planetary boundary layer.J. Environ. Monit., 5:47--56, 2003.

J. Kowol-Santen and G. Ancellet. Mesoscale analysis of transport across the subtropical tropopause. Geophys. Res. Lett., 27:3345--3348, 2000.

F. Ravetta and G. Ancellet. Identification of dynamical processes at the tropopause during the decay of a cut-off low using high resolution airborne lidar ozone measurements. Mon. Weather Rev., 128:3252--3267, 2000.

G. Ancellet and F. Ravetta. A compact airborne lidar for tropospheric ozone (ALTO): description and field measurements. Appl. Opt., 37:5509--5521, 1998.

P33143, 15: We suggest for the section title: "Influence of the surface properties".

It is a good suggestion. Now we use this new section title.

p33144,1-2 : "this difference is less than 25% over sea nut reaches 40% over land close to the surface..." Why still considering surface as the author stated previously IASI is not good enough near the surface (as explained in section5.12)? This lowers your agreement and the reader might think at the end that IASI has a too large bias...

As explained previously, it still seems important to talk about the surface as we are doing a tropospheric validation even if we know that it is difficult at polar latitudes.
That is why we modified the sentence as follow:
"This difference is less than 25% over sea (Figs. 9a and c). Over land, except at the surface level where the difference reaches ~ 40%, RDs are less than 33% in spring (Fig. 9b) and less than 20% in summer (Fig. 9d)."

p33144, 4-5: Why the seasonal difference over land is in better agreement in summer than in spring? Please explain.

This seasonal difference could be explained by a better vertical sensitivity (see DOFS) between the surface and 8 km.
We added (in bold) these explanations in the following sentences:

"This slight difference in DOFS for total columns in summer is due to higher sensitivity from 0 to 6 km over land, explained by a better thermal contrast (Clerbaux et al., 2009). This was already observed with the CO retrievals (Pommier et al., 2010). Over sea, higher vertical sensitivity between 6 and 12 km is also observed. **The thermal contrast has a large impact on the sensitivity in the first layers over land, with a DOFS for the [0-8 km] range around 0.75 in summer, whilst it is lower (~ 0.4) for the spring and over sea in summer.**"

And:
"A seasonal difference is also observed for the [0-8 km] IASI columns over land which are less biased in summer (by less than 15%) than in spring (by less than 26%) **which could be due to the difference in vertical sensitivity. Over sea, where the [0-8 km] DOFS does not vary seasonally,** the RDs are similar in both seasons (≤ 14%)."

P33144, 21: Change Table 3 to Table 2.
p33144, 23: Change Table 4 to Table 3.
p33144, 27: Change Table 3 to Table 2.

The numbers were changed

p33145, 2: Change "the lower tropopause" to "a lower tropopause".

I changed “the” by “a”.

p33145, 16: Why FLEXPART is used to determine the tropopause altitude?

We did not use FLEXPART to determine the tropopause altitude. But as you can see in the following figure (from the paper by Roiger et al. 2011), the 2 PVU dynamical tropopause calculated from ECMWF analysis in the FLEXPART model, present the same feature than the O_3 gradient observed by IASI along this flight (cf. Fig. 11a).

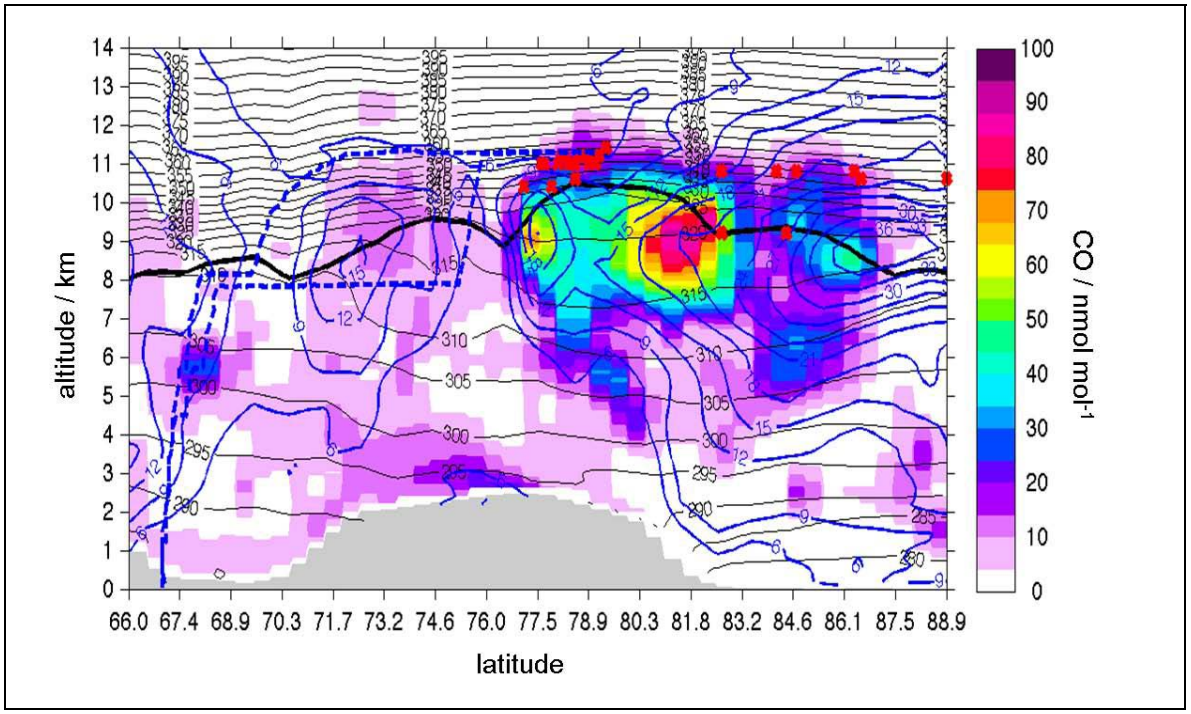


Fig. 8. Cross section of the FLEXPART Asian anthropogenic excess-CO tracer (see black line in Fig. 6h). Colours represent the modeled Asian excess-CO above atmospheric background values (see colour-scale on the right). The dashed blue line shows the Falcon flight path on 10 July. Also given are the 2 PVU dynamical tropopause (thick black line), isentropes (thin black lines), and isotaches (thin blue lines), as calculated from ECMWF analysis.

We also changed the sentence (in bold) to clarify this point: “This is shown by the IASI O_3 gradient (Fig. 11a) and predicted by the FLEXPART model **used in the study by Roiger et al. (2011)**.”

p33145, 19 Change "the IASI O3 concentrations retrieved by FORLI at the tropopause..." to "the IASI O3 concentrations retrieved by FORLI in the UTLS..."

We changed it

p33145, 22-23: Change to "the variability OF this ratio provideS information..."

It was done

p33145, 28: Change "in THE northern part..."

“the” was added.

p33146, 20: Change "shows HOW IASI can provide..."

“how” was added.

p33146, 26-27: Replace "in air masses" by "FOR air masses"... "As well as air masses in the upper troposphere".

It was corrected.

p33147, 1: Replace "For the comparison" with "For comparison purposes..."

It was replaced.

p33148, 5: Replace "by stratospheric air masses" with "UTLS air masses".

We guessed that you wanted to say the opposite. Thus we changed “UTLS” to “stratospheric”.

p33155: Update of the reference Wespes et al, 2011.

The reference was updated.

p33160, Fig 1a: Please improve the resolution. The legend is hardly readable. The zoom on ATR-42 flight area is too small to give enough information of the flight tracks.

We re-plotted Figs 1a and also 1b (below) in order to be consistent with the colours for the ATR-42 flight track (black instead of magenta):

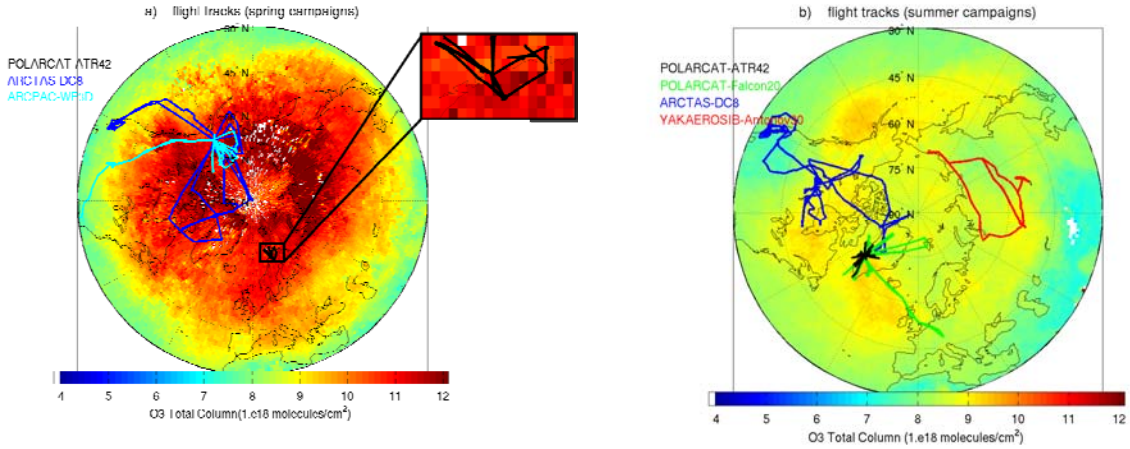


Fig. 1 Global distributions of daytime IASI total O_3 columns averaged from 18 March to 23 April 2008 (period of POLARCAT spring campaigns) with a zoom on ATR-42 flight area (a) and for 18 June to 29 July 2008 (period of POLARCAT summer campaigns) (b). IASI data are averaged over a 1° ×1° grid. White areas indicate no data. Flight-tracks for all flights of the DC-8 (blue), ATR-42 (black), WP-3D (cyan), Falcon-20 (green) and Antonov-30 (red) aircraft are superimposed on the maps.

p33161, Fig2: Having the same scale on both graphs would be helpful to the reader.

We changed the scale for both maps and we use the same one (from 0 to 150).

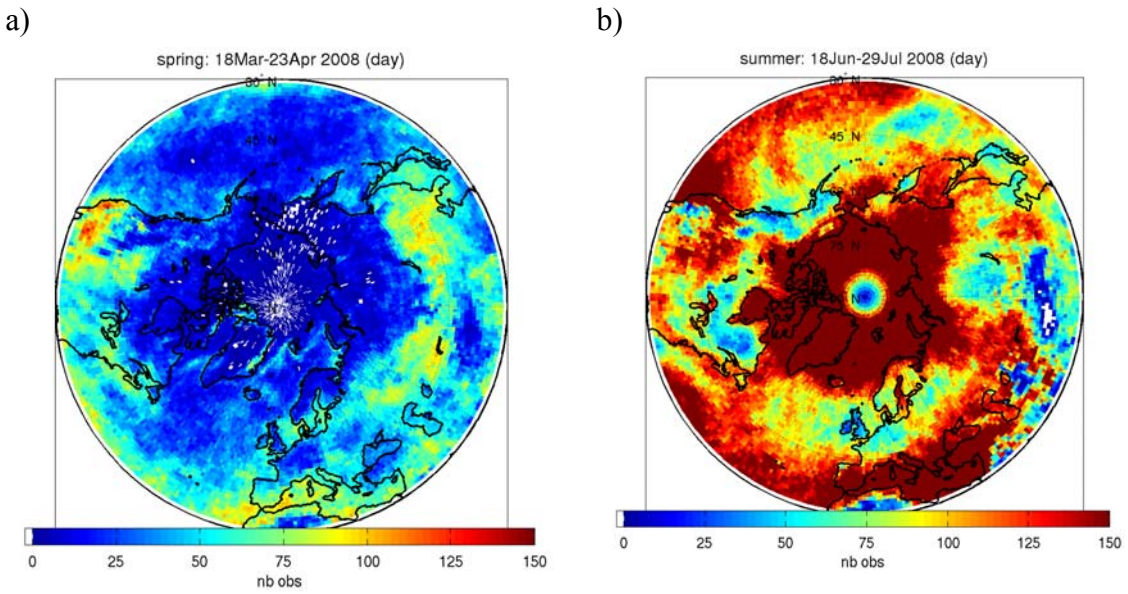


Fig. 2 Distribution of the number of daytime IASI data gridded on 1° ×1° using the RMS and bias filter for the spring (a) and summer (b) POLARCAT campaigns. White areas indicate no data.

p33162, Fig3/Fig4: DOFs instead of DOFS

See before: we decided to keep the definition of DOFS, Degrees Of Freedom for the Signal.

p33165, Fig6: "errors bars represent the variability of measurements". Is it 1σ, 2σ, 3 σ?

The variability corresponds to the standard deviation, 1 σ.
We added this information in the legend for Figs. 6, 8, 9 and 10. We also changed the word “measurements” by “averaged smoothed data”:
“Error bars represent the variability of **averaged smoothed data (standard deviation ±1σ)**.”