Carbon monoxide distributions from the IASI/METOP mission: evaluation with other space-borne remote sensors
By M. George et al.
Atmos. Chem. Phys. Discuss., 9, 9793-9822, 2009

Reply to Anonymous Referee #2

The paper "Carbon monoxide distributions from the IASI/METOP mission: evaluation with other space-borne remote sensors", by George et al. presents global distributions of CO retrieved from the IASI instrument and compares these with CO measurements from MOPITT, AIRS, and TES. Such a comparison is very valuable as it will allow to demonstrate the performance of IASI in comparison with the other satellite instruments and will provide important information when using these data for inverse modelling or data assimilation. Therefore, the topic of the paper is very interesting and suitable for publication in ACP. However, the presented comparisons are very limited and on a very basic level. Therefore I recommend to provide a more detailed statistical analysis taking into account the major comment given below and also taking into account the points raised by referee 1.

Dear Referee 2,

Thank you for the useful and constructive comments.
We wrote the initial paper with the goal to describe the IASI CO product (what is available in terms of vertical/horizontal information, accuracy) and we also provided some very preliminary early stage validation, with similar products obtained by other thermal infrared instruments (TES, MOPITT, AIRS). For these other missions, it is worth noting that the CO products were first described, see paper of Deeter (MOPITT), McMillan (AIRS), and Rinsland (TES) and then compared to each other, but only at a later stage.

Both you and the other reviewer suggested that we might improve the paper by taking into account the a priori/averaging kernel information when comparing CO products obtained by the different instruments. You also suggested to present the comparison of several months. The new manuscript now describes the validation for 3 months (different seasons), and the comparison is performed taking into account the different prior information, and to some extend the averaging kernels (when available). The agreement is now even better, so it was relevant suggestions. We apologize for the delay to provide an improved manuscript but it took us some time to set up the new calculations. A detailed point-by point reply is provided hereafter, and we explain the changes that were brought to the manuscript.

Major comment:

When comparing IASI CO with MOPITT, AIRS, and TES the averaging kernels and a priori need to be taken into account otherwise wrong conclusions could be drawn. See e.g. Luo et al. (2007), 'Comparison of carbon monoxide measurements by TES and MOPITT: Influence of a priori data and instrument characteristics on nadir atmospheric species retrievals'.

As mentioned in the introduction we were not planning on doing an extended validation at this stage. But we followed your recommendation, and all the CO integrated values compared in the new manuscript are now adjusted with the ad-hoc a priori following the methodology recommended by Luo et al. (2007). It improved the agreement between IASI and the other instruments. Table 2 has been modified accordingly, as well as the text.

We have modified/added the following sentences in the new manuscript:

In the introduction:
"In order to take into account the different a priori used for CO retrieval by each instrument, we have followed the method suggested by Rodgers and Connor (2003) and Luo et al. (2007a). The columns have been adjusted according to the a priori used by the different teams. A full treatment that takes into account the averaging kernels (Rodgers and Connor, 2003) is presented for TES and IASI, the two instruments with the higher differences in terms of vertical resolution."

In section 3:
"The CO measurements are retrieved using different a priori assumptions and vertical resolutions so we should due allowance for the differing characteristics of the observing systems, particularly their averaging kernels. In order to deal with the different a priori, we followed the method proposed by Rodgers and Connor (2003) and presented into more details for TES and MOPITT comparisons in Luo et al. (2007a). For each point of the grid, the Eq. (3) is applied to the IASI mean CO profile and then the total column is derived:

$$x_{adjusted}^{IASI} = x_{retrieved}^{IASI} + (\mathbf{A}^{IASI} - \mathbf{I})(x_a^{IASI} - x_a^{INSTR}) \qquad (3)$$

With $x_{adjusted}^{IASI}$ the IASI profile adjusted to the *INSTR* (ie MOPITT, AIRS or TES) a priori, $x_{retrieved}^{IASI}$ the IASI retrieved profile, $\mathbf{A}^{IASI}$ the IASI averaging kernel matrix, x_a^{IASI} and x_a^{INSTR} the a priori profile used for the IASI and the *INSTR* retrievals.

The two above-mentioned papers also recommend to smooth the CO profile of the higher resolution instrument with the averaging kernel functions of the lower resolution instrument. The equation to obtain the smoothed column is:

$$\mathrm{x}_{\mathrm{smoothed}}^{\mathrm{INSTR}} = a^{IASI}\, x_{retrieved}^{INSTR} + (i - a^{IASI})\, x_a^{IASI} \qquad (4)$$

With $\mathrm{x}_{\mathrm{smoothed}}^{\mathrm{INSTR}}$ the *INSTR* column smoothed by the IASI averaging kernels, a^{IASI} the IASI averaging kernel vector corresponding to the total column, $x_{retrieved}^{INSTR}$ the *INSTR* retrieved profile and x_a^{IASI} the IASI a priori profile."

In section 3.3:
"All CO columns are corrected for the a priori assumptions according to Eq. (3). Some extended tests were performed to compare IASI and TES CO total columns using Eq. (4), in order to take the averaging kernel information into account. As the smoothed TES column is compared to the IASI column adjusted with the TES a priori, we use the Eq. (4) with the TES a priori profile. For these two instruments, it is obviously the TES CO profiles that need to be smoothed by the IASI averaging kernel information, because of the higher spectral resolution of the TES instrument. As we lacked some of the averaging kernel information for other instruments, as the spectral resolutions are more similar, and as the impact on the coefficient correlations for TES-IASI was

found to be limited (see Table 2, italic values), we restricted this study to TES. It is worth noting that this impact is limited because we compare integrated columns, and that it is much more visible when profiles are directly compared."

Specific comments:

1. The authors present results only for August 2008, but write that other months have also been investigated (p.9803,l.21) and give similar conclusions. Is this still true when the a priori and averaging kernels are taken into account in the comparisons? It would be illustrative to add a table with correlation coefficients also for a few other months for the global comparison. See also the next comment.
As recommended, we added in Table 2 the correlation coefficients for two other months: November 2008 and February 2009 (chosen such as to have some seasonal variability).

2. Fortems-Cheiney et al. (Atmos. Chem. Phys. Discuss., 9, 7505-7529, 2009) report higher emissions derived from IASI CO compared to MOPITT. This seems to be in contradiction with the findings in this paper: In section 3.3 the authors write that 'MOPITT is consistently higher than IASI for all latitudes'. Can you explain the differences between your results for August 2008 and those of Fortems-Cheiney et al. for the period July-November 2008? Is August 2008 different from the other months?
Thanks for your careful reading of the two papers and having noticed this issue. Just after submitting the 2 papers (a bit in a rush due to the deadline of the special issue...) we noticed it and started detailed investigation. In the George et al. paper the IASI-MOPITT comparison is performed on columns (molecules/cm^2) and for August 2008, November 2008 and February 2009. In the Fortems et al. paper, the IASI-MOPITT comparison presented in Fig.7 is done at around 700 hPa, in kg/kg, for June, on a different grid.

In order to investigate further on this issue, a detailed comparison was performed for August and June, on total columns and on mxr at about 700hPa. Our findings are that the data at 700 hPa are consistent with the columns, ie MOPITT CO is higher than IASI. For August: see Fig. A in Annex hereafter that you can directly compare to Fig 6 of the George et al. paper, and for June: see Fig B and C (also hereafter).

After this checks, the Fortems et al. paper authors improved their satellite data treatment (comparison of the levels of their model and the levels of the satellite data). They are currently working on correcting their paper.

Note that after adjusting the IASI total columns with the MOPITT a priori, the bias for global has dropped from 12 to 9.7 % for August 2008. In the text, the sentence is now: "MOPITT is higher than IASI with an average bias of 9.6% for data averaged over all latitudes" (average for August 2008, November 2008 and February 2009). The MOPITT validation paper by Emmons et al. also report that MOPITT V3 products have some positive bias.

Minor comments:

1. Abstract, l.9: 'especially when thermal contrast is important'. Do you mean 'when thermal contrast is significant'?

Yes we mean 'when thermal contrast is significant'. We corrected it in the abstract.

2. Abstract, l.17: 'and can explain' . This is not shown in the paper.

We removed the sentence "The choice of the a priori assumptions influences the retrievals and can explain some of the observed differences" and added "The IASI CO columns are compared with MOPITT, AIRS and TES CO columns, adjusted with the a priori".

3. p.9796, l.17: the proper references for SCIAMACHY are as follows: Buchwitz et al. 2004, 2007; de Laat et al. 2006, 2007; Frankenberg et al. 2005

-Buchwitz, M., de Beek, R., Bramstedt, K., et al.: Global carbon monoxide as retrieved from SCIAMACHY by WFM-DOAS, Atmos. Chem. Phys., Vol. 4, pp 1945-1960, 2004

-De Laat, A. T. J., Gloudemans, A. M. S., Schrijver, H., van den Broek, M. M. P., Meirink, J. F., Aben, I., and Krol, M.: Quantitative analysis of SCIAMACHY carbon monoxide total column measurements, Geophys. Res. Lett., 33, L07807, doi:10.1029/2005GL025530, 2006.

-De Laat, A. T. J., Gloudemans, A. M. S., Aben, I., Krol, M., Meirink, J. F., van der Werf, G. R., and Schrijver, H.: SCIAMACHY carbon monoxide total columns: statistical evaluation and comparison with CTM results, J. Geophys. Res., 112, D12310, doi:10.1029/2006JD008256, 2007.

We added these references in the introduction and in the References list.

4. p.9799, l.4: 'typical observation': since this is an observation with high thermal contrast I wouldn't call this a 'typical' observation.

We removed the adjective 'typical'.

What do the residuals look like for an observation with low thermal contrast? Are they comparable or larger?

For an observation with low thermal contrast, the residuals are comparable or smaller. See Fig. 6 in Turquety et al. (2009, same special issue). When the thermal contrast is low, there is less signal in the spectrum so the smoothing error is larger but the observed spectrum generally fits better with the calculated spectrum, leading to a smaller RMS.

5. p.9800, l.12: 'latitudes above and below 60 degrees': do you mean above 60 N and below 60 S or do you mean something else?

Yes we mean 'latitudes above 60°N and below 60°S'. We corrected it.

6. p.9803, l.11: 'partially clouded scenes' whereas p.9802, l.3 mentions: 'retrieved from AIRS cloud-cleared radiances'. Can you explain?

Cloud cleared radiances are produced for all the retrievals (using the 9 IR scenes to extrapolate to the true clear column radiance). Then the AIRS retrieval code will yield a retrieval for cases with a cloud fraction up to 100%. But scenes with a cloud fraction higher than 80% are not reliable so we are filtering these cases in the comparison. We specified the filters in section 3.1.3.: 'For this study, AIRS V5 data were accessed through the NASA Goddard DAAC and filtered with Qual_CO=0, CloudFrcStd<=0.8, TSurfStd=>250K and (PSurfStd – Pbest)<200mb)."

In the scene presented in the initial version of the paper (Fig. 4), the cloud fraction for AIRS was 46%, so it's a partially clouded scene. But because the Referee 1 has asked to choose another scene with higher information content, this sentence has been removed.

7. p.9804, l.4: ..different intensity.. : 'magnitude' may be a better word.
We replaced 'intensity' by 'magnitude'
How large are the differences between the different instruments? Also, what is the range of background values among the different instruments? The value of 4e17 for IASI sounds rather low.
Further validation for background CO values is need, but we think that when mixing ratios are at ~50 ppbv the CO signature is less intense and hence any instrument is less sensitive.

8. p.9804, l.22-29 and p.9805,l.1-3: since the comparisons are done without taking the averaging kernels and a priori into account, these conclusions need to be checked after a proper comparison has been performed. The same holds for the conclusion section.
All the numbers in the paper and in the conclusion have been corrected after adjusting the IASI columns with the MOPITT, AIRS and TES a priori. The agreement is generally better.

9. p.9805, l.15-16: This is not mentioned earlier in the paper. Please also add this to section 3.3. See also specific comment 1.
We added in section 3.3:
"In fact, radiative transfer issues occur when processing the IASI data over very cold/icy and very hot/sandy surfaces. The local emissivity influences the sensitivity at the surface level and for the moment, local emissivity data are not yet available from EUMETCAST."

10. p.9805, l.18-20: this is very similar to what is written in l.5-7 (p.9805). There is no need to say this twice.
We replaced "This paper provides a preliminary assessment of the IASI CO global distributions by comparing" by "This paper compares".

11. Fig. 3: An interesting figure, but due to the large spectral range shown, the CO retrieval windows are difficult to compare. Adding a blow-up of the region defined by the start wave number of the TES retrieval window (_2100 cm-1) up to the end wave number of the AIRS retrieval window (_2210 cm-1) for each instrument would help. In addition, please add the exact ranges of the CO retrieval windows (in cm-1) of each instrument to the caption of fig. 3.
We added 3 subplots as recommended, with the CO retrieval window (one for each instrument) in this figure. The new number of this figure is 4 (because we added a figure with the different a priori, as asked by the other referee). We added in the section 3.2: "On the right part of the plot, an enlargement is shown with the spectral window used for the CO retrieval (different for each mission)." See below the new figure and caption.

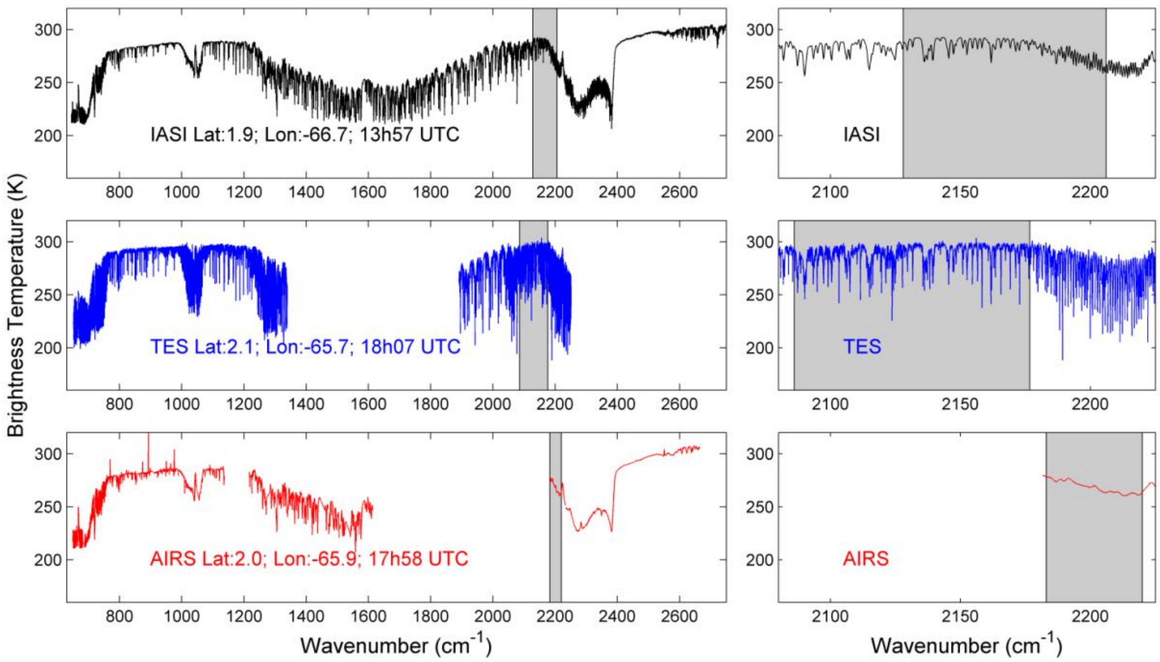

Figure 4. IASI, TES and AIRS radiance spectra (in brightness temperature) around Northern Brazil, on August 1st, 2008. The spectral range used for the CO retrieval are highlighted in grey. For the full spectral range covered by each on the left and zoomed for the CO window on the right (IASI [2143 2181.25]; TES [2086.06 2176.66] and AIRS [2181.49 2221.12].

Annex plots

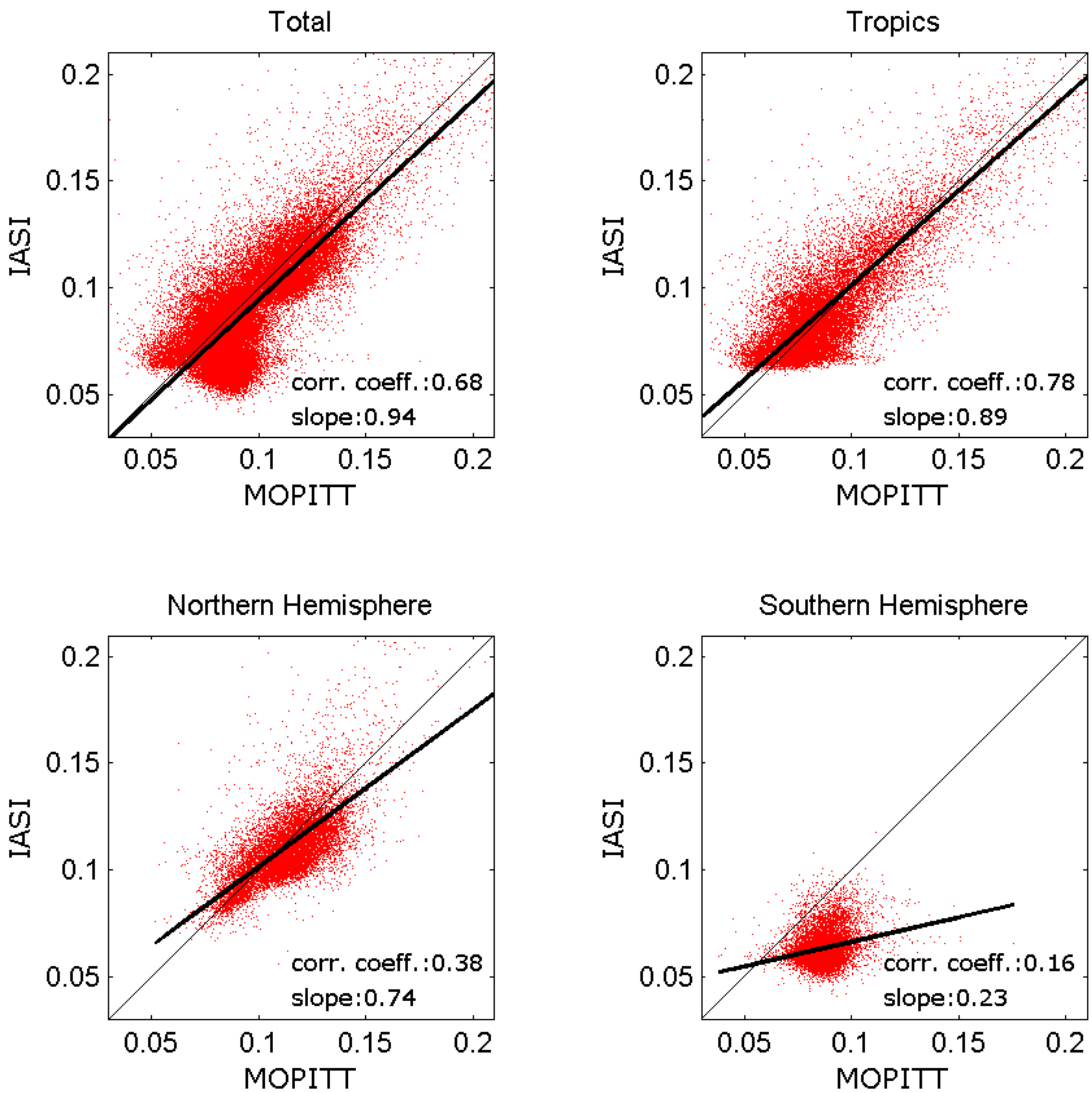

Fig. A: Scatter plots between IASI and MOPITT for August 2008 (day only), at the level closest to 700 hPa, in ppmv, for the latitudes bands used in Fortems et al: Total: [-65°,65°], Tropics: [-30°,30°], Northern Hemisphere: [30°,65°] and Southern Hemisphere [-65°,-30°]. Data are averaged over a 1°x1° grid.

Annex plots

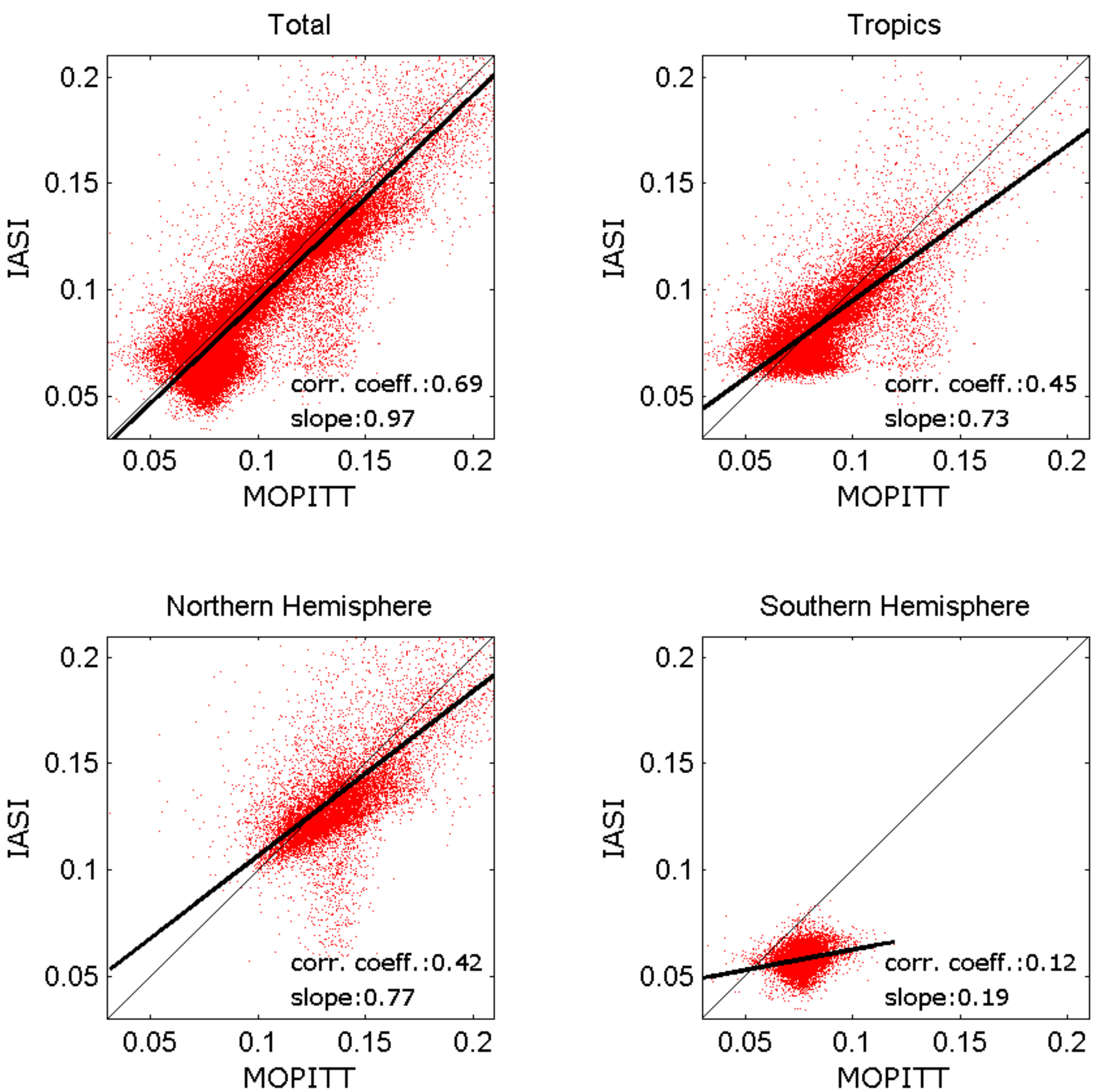

Fig. B: Same as Fig. A (at the level closest to 700 hPa) but for June 2008.

Annex plots

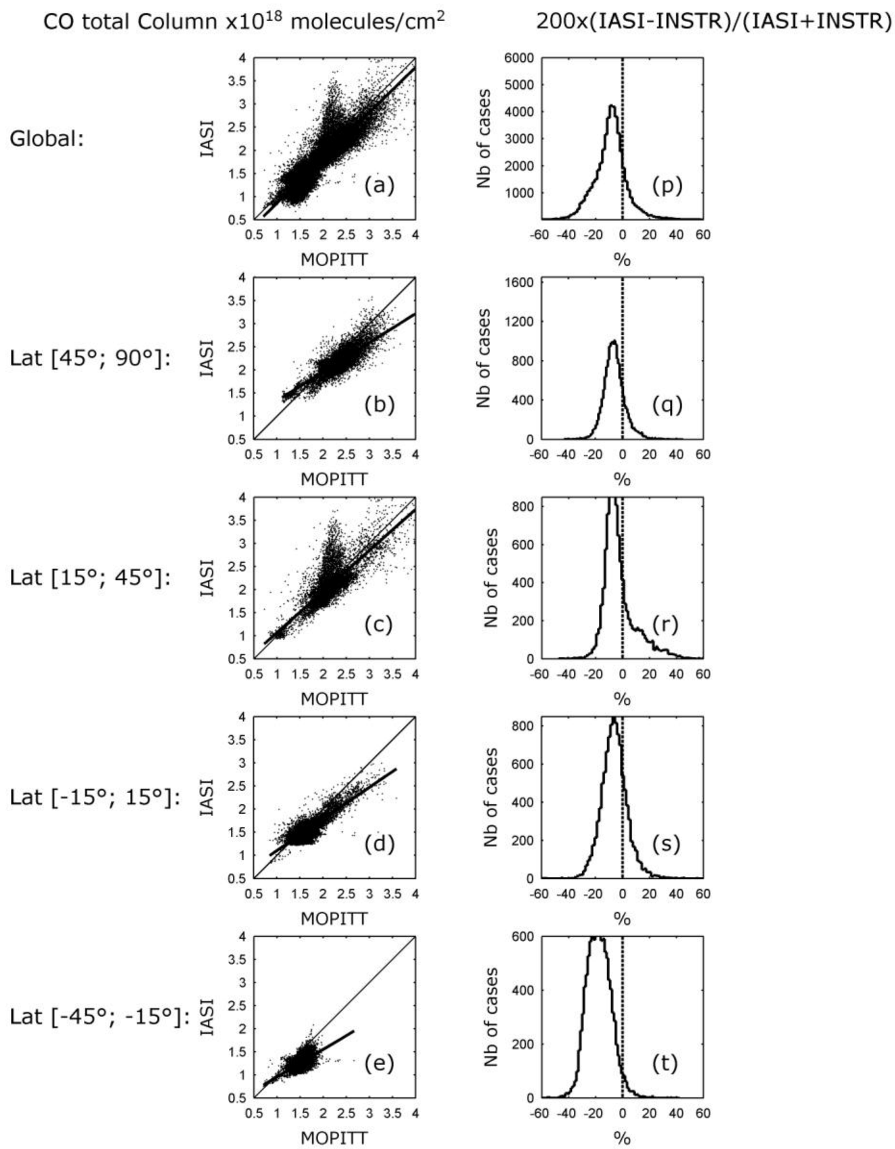

Fig. C: Same as Fig. 6 in George et al. (total columns) but for June 2008.