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***Interactive comment on “CO<sub>2</sub> column-averaged volume mixing ratio derived over Tsukuba from measurements by commercial airlines” by M. Araki et al.***

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Interactive comment on “CO<sub>2</sub> column-averaged volume mixing ratio derived over Tsukuba from measurements by commercial airlines” by M. Araki et al.

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The authors thank Anonymous Referee #1 for his or her careful consideration of the manuscript and helpful comments. The authors have taken this opportunity to make several suggested improvements to the paper in response to these comments.

Reviewer: This paper presents an important dataset that could be extremely useful,

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particularly for validation of other measurements. In this respect, the dataset and potential application are valuable. There is no doubt that the CONTRAIL project enhances the collection of airborne measurements of CO<sub>2</sub> and being able to use the profiles obtained via these aircraft measurements to derive column-average dry-air mole fractions of CO<sub>2</sub> that can be used for satellite validation (and potentially for FTS calibration?) is a very worthwhile advance in the measurements obtained via that programme.

Reviewer: The comparison to FTS screams out for a figure including both datasets.

Response: The figure of XCO<sub>2</sub> by FTS was already published as Figure 11 in Ohyama et al. 2009. We are comparing the peak-to-peak seasonal amplitude for XCO<sub>2</sub> in 2007 and the growth rates of XCO<sub>2</sub> between FTS and the present analysis. Furthermore, we added a discussion of the comparison with XCO<sub>2</sub> by FTS as section 3.5 and Figure 2.

Some general thoughts:

Reviewer: Need to explain why you want the CO<sub>2</sub> over Tsukuba rather than Narita. At present, it seems like there is no need for the CO<sub>2</sub> columns to be over Tsukuba, and you could equally simply just use Narita as the location of choice.

Reviewer: L16-19: It is fair enough that you wish to use Tsukuba meteorological data in conjunction with the Narita CONTRAIL data, but if the idea is to validate over airports, why not 'shift' the meteorological data to Narita rather than the CO<sub>2</sub> data to Tsukuba? And why is the ancillary meteorological data necessary? This isn't clear without a description of the integration of the profiles to yield XCO<sub>2</sub>.

Response: Tsukuba is the most important validation site of data products observed by GOSAT. GOSAT makes observations in Tsukuba every three days, but not in Narita. Rawinsonde observations at the Tateno Aerological Observatory and the meteorological tower measurements at the Meteorological Research Institute are also performed in Tsukuba. We revised the introduction as follows: "To develop a method of XCO<sub>2</sub> calcu-

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lation using the CONTRAIL data, XCO<sub>2</sub> over Tsukuba, which is the dominant GOSAT observational point for validation, calculated. . .” In addition, we revised the final paragraph of the introduction to read “. . .for which Tsukuba observational data were used as ancillary meteorological data to make up for limitations in aircraft coverage.”

Reviewer: Type I/II analysis naming causes confusion consider replacing with xCO<sub>2</sub>\_obs and xCO<sub>2</sub>\_met. If you do insist on referring to them as Type I/II analyses, then make an explicit definition of each of the different xCO<sub>2</sub>s, possibly in a table, so that it is easy to see what the differences are.

Reviewer: Page 3405, L10-13: I find the nomenclature associated with the two types of analysis confusing (see general comment). I'd prefer something like XCO<sub>2</sub> was calculated based on two different sources of ancillary meteorological data: (i) Tsukuba observational data (hereafter denoted XCO<sub>2</sub>,obs) and (ii) global meteorological data (denoted XCO<sub>2</sub>,met).

Response: We would like to keep the present nomenclature for brevity. Definitions of the types are summarized in Table 1.

Reviewer: The manuscript keeps alluding to use for GOSAT validation without ever explicitly addressing this. I suggest reworking section 3.3 to be more explicit about addressing whether these data can be used for GOSAT validation - e.g. titling the section “3.3 Suitability for GOSAT validation”. May also want to mention the relative uncertainties c.f. the goal for GOSAT precision.

Response: The title of this section was revised to “Variability of XCO<sub>2</sub> within 6 h around 13h00 local time (LT): Suitability for GOSAT validation”. The goal for GOSAT uncertainty, which may be 1% for XCO<sub>2</sub>, is discussed elsewhere (Yokota et al. 2004). One of the aims of the present work is an estimation of GOSAT uncertainty.

Reviewer: The manuscript would benefit from an explanation of: (i) the integration of in situ/aircraft to column-averaged, or reference somewhere that does. (ii) the derivation

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of uncertainties & assumptions leading to them.

Response: We mentioned uncertainties in the meteorological tower observations and aircraft observations. Uncertainties of XCO<sub>2</sub>(I) based on the real XCO<sub>2</sub> are produced mainly by the difference between the real profiles and the assumed high- and low-altitude profiles of CO<sub>2</sub>. Since the uncertainties ( $=\{(\text{Bias})^2 + (\text{Standard deviation})^2\}^{1/2}$ ) are difficult to estimate, we discussed uncertainties of XCO<sub>2</sub>(II and I) based on XCO<sub>2</sub>(I). The variability of XCO<sub>2</sub> within 6 h as discussed in section 3.3 is one of the most effective uncertainties of XCO<sub>2</sub>(I).

Specific comments:

Reviewer: L18 in abstract: to me a figure of 0.922 ppm does not seem like a small uncertainty. Relative to the desired GOSAT precisions it is, but in absolute terms it is not.

Response: We revised the abstract as “This small uncertainty relative to GOSAT precision suggests...”

Reviewer: L2-3: What makes the ground-based FTS a powerful tool for satellite validation?

Response: Ground-based FTS can provide XCO<sub>2</sub>, and TCCON reported that the accuracy and precision of the FTS product were 1 ppm, which is sufficiently smaller than the uncertainty of the satellite product.

Page 3408:

Reviewer: L20: The X'CO<sub>2</sub> concept comes out of nowhere. Also, Figure 2 does not show a calculation, it shows the result of a calculation - reword to “... were calculated and are shown in Fig. 2”

Response: Corrected.

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Reviewer: L4-10: I don't entirely follow this paragraph, especially when XCO<sub>2</sub>(I') based on XCO<sub>2</sub>(I) is referred to. If XCO<sub>2</sub>(I) is being used as 'truth', then the reference to bias is fine, but it is not clear how the uncertainties are derived.

Response: We added an explanation that "The uncertainty ( $=\{(\text{Bias})^2 + (\text{Standard deviation})^2\}^{1/2}$ ) of ..."

Reviewer: L19- : It is not clear how the uncertainties are derived. Also, in Table 2, listing uncertainties of 0.0 is unrealistic. Again, the calculation of biases and uncertainties for one type of analysis 'based' on another is confusing. It is not clear what is actually being done here, or why? This would benefit from an explanation of how and why this is done.

Response: No one knows the real CO<sub>2</sub> concentration profile. However, we need the uncertainty of the derived XCO<sub>2</sub>. It was assumed that the type I analysis may determine the proximal value of the real XCO<sub>2</sub>. We calculated relative uncertainties based on the type I analysis. We added an equation and an explanation to section 3.1 and Table 2, respectively. The title of Table 2 was revised as "Relative uncertainties of. . .".

Page 3410

Reviewer: L10/Section 3.3: It seems like this is approached with reverse logic. It would be better to state up front that you wish to assess the integrated profiles for their suitability for GOSAT validation. In fact, I think this section would be better titled Suitability of CONTRAIL-derived XCO<sub>2</sub> data for GOSAT validation, and look at the time window, and also refer to the profile-derived XCO<sub>2</sub> uncertainties relative to what is necessary to adequately validate GOSAT.

Response: The title was revised to "Variability of XCO<sub>2</sub> within 6 h around 13h00 local time (LT): Suitability for GOSAT validation". We added a discussion of the uncertainty of the present XCO<sub>2</sub> at the end of Section 3.3 as follows: The majority of the uncertainties of XCO<sub>2</sub>(I and II) based on the real XCO<sub>2</sub> can be derived from the difference

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between the real profiles and the assumed high- and low-altitude profiles and are difficult to estimate. We discuss the uncertainties of XCO<sub>2</sub>(l and l<sup>âŠš</sup>) based on XCO<sub>2</sub>(l) in sections 3.1 and 3.2. The variability of XCO<sub>2</sub>(l) within 6 h discussed in section 3.3 may be one of the most effective uncertainties of XCO<sub>2</sub>(l) based on the real XCO<sub>2</sub>.

Page 3411

Reviewer: First paragraph: I'm not sure that it is necessary to define northern and southern as case N and case S.

Response: Corrected.

Reviewer: How are high concentrations of CO<sub>2</sub> defined?

Response: If the concentration of CO<sub>2</sub> observed in the low altitudinal region by an aircraft in case S is higher than that in the MRI tower and is >400 ppm, it is high.

Reviewer: As you only exclude data falling in to the southern airspace and high aircraft CO<sub>2</sub> only category, is it really necessary to complicate matters by introducing the cases S and N, and 1, 2 and 3? I think it would be clearer to simply explain why the data from case S1 should be excluded, and then highlight that only one point was removed. In fact, I think that the entire section (Screening criteria) is unnecessary, and the explanation of the removal of that point could be placed in the following section (at line 23).

Response: Corrected.

### 3.5 Amplitude of seasonal variation

Reviewer: I don't like the use of the term "fitting curve" -it does not seem right. "Fitted curve" is better, but I think you should consider replacing it by "least-squares fit" when discussing the difference between the measured and fitted values.

Response: Corrected.

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Reviewer: Were all individual points used in the fit, or were monthly/weekly averages and standard deviations used?

Response: All individual points were used in the fit. We revised section 3.4 as “In order to determine the seasonal variation parameters, the XCO<sub>2</sub>(I) data obtained by each flight were ...”

Reviewer: Were any errors in the fitted co-efficients generated? Do the growth rates, maxima, minima of XCO<sub>2</sub> and X'CO<sub>2</sub> agree within these uncertainties?

Response: Errors in the fitted coefficients were generated. The maxima and minima of XCO<sub>2</sub> and X'CO<sub>2</sub> agree within these uncertainties. We added the errors of the tentative growth rates of XCO<sub>2</sub> and X'CO<sub>2</sub> as “The values determined for  $a_2$  (2.27  $\pm$  0.14 and 2.45  $\pm$  0.12 ppm/yr, where the errors are 1 standard deviation of  $a_2$  in the fit) show tentative growth rates for XCO<sub>2</sub> and X'CO<sub>2</sub>...”

Reviewer: It would be nice to see a more detailed comparison to the FTS measurements of Ohyama et al.

Response: We added a discussion of the comparison with XCO<sub>2</sub> of FTS as section 3.5 and Fig. 2.

Reviewer: Also, what is the value/usefulness of your measurements for validating the FTS measurements, or vice versa?

Response: The number of FTS sites is limited. JAL aircrafts measure CO<sub>2</sub> over 43 airports throughout the world. After evaluation of the present method of analysis in Tsukuba, the method will be useful over airports worldwide. In this paper we discuss the comparison with XCO<sub>2</sub> by FTS. The validation of FTS will be discussed in a future paper.

Reviewer: At this point, it would also be nice to have some brief geophysical explanation of what causes the seasonal cycle that is measured.

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Response: In general, plant activity produces the lowest value of XCO<sub>2</sub> around September and the highest around March and April in the northern hemisphere. The lowest value arises from CO<sub>2</sub> absorption by plant photosynthesis, which is sufficiently larger than CO<sub>2</sub> production by plant respiration. Absorption is less in winter, which leads to the highest value.

Reviewer: The use of “global” to describe NCEP/CIRA data is confusing. Could “re-analysis” or “climatological” or some other term be used?

Response: Observational data by rawinsonde and a meteorological tower are available in a specific area. We need global data to obtain XCO<sub>2</sub>. NCEP and CIRA were selected since they are global data. We revised “global meteorological data” to “global climatological data.”

Reviewer: What fraction of the difference between XCO<sub>2</sub>\_obs and XCO<sub>2</sub>\_met is due to the interpolation from lowest aircraft altitude to the ground in XCO<sub>2</sub>\_met?

Response: The observed CO<sub>2</sub> concentration data on the ground were not used to obtain XCO<sub>2</sub>(II). In many cases, the observed CO<sub>2</sub> ground concentration was higher than that at the lowest aircraft altitude, which can be the reason for the bias of XCO<sub>2</sub>(II) based on XCO<sub>2</sub>(I) as shown in Table 2. We inserted the above comment in section 3.2.

Technical comments:

All technical comments were applied to the revised manuscript.

Reviewer: Why the lowest tropopause, and not the average, for example?

Response: The lowest tropopause is in general the boundary between the troposphere and the stratosphere.

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Interactive comment on Atmos. Chem. Phys. Discuss., 10, 3401, 2010.

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Table 2. Relative uncertainties of  $X_{\text{CO}_2}$  based on type I analysis (ppm)<sup>a</sup>. To show small relative values, the uncertainties are given to 3 decimal places.

Altitudinal range			Analysis Type			
			$X_{\text{CO}_2}(\text{I})$	$X_{\text{CO}_2}(\text{I})$	$X_{\text{CO}_2}(\text{II})$	$X_{\text{CO}_2}(\text{II} - \text{I})$
$X_{\text{CO}_2}$	Entire	Bias	0.0	-0.043	-0.621	-0.578
		Standard deviation	0.0	0.067	0.682	0.691
		Uncertainty <sup>b</sup>	0.0	0.080	0.922	0.901
$X'_{\text{CO}_2}$	2–10 km	Bias	0.0	-0.018	-0.019	-0.001
		Standard deviation	0.0	0.029	0.037	0.022
		Uncertainty <sup>b</sup>	0.0	0.034	0.041	0.022

<sup>a</sup> We assumed that the type I analysis determines the proximal value of the real  $X_{\text{CO}_2}$  in the present analysis.

<sup>b</sup> (Uncertainty) =  $\{(\text{Bias})^2 + (\text{Standard deviation})^2\}^{1/2}$

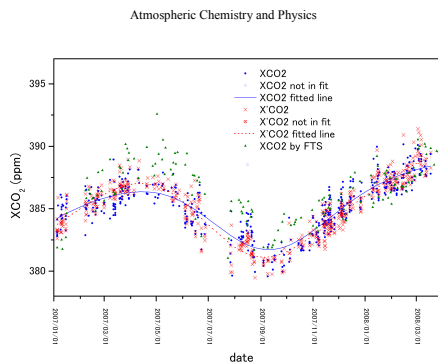


Figure 2. Time series of  $X_{\text{CO}_2}$  and  $X'_{\text{CO}_2}$  from type I analysis over Narita using CONTRAIL data from January 2007 to May 2008. Data from 493 flights by five airliners were analyzed.  $X_{\text{CO}_2}$  (blue marks and solid blue line) were numerically integrated to cover the entire altitudinal range, i.e., from the ground level to the lower thermosphere (85 km), and for  $X'_{\text{CO}_2}$  (red marks and dotted red line) over the altitudinal range of 2–10 km. Data on 16 August 2007 were not included in the fit. Daily averaged  $X_{\text{CO}_2}$  using the scaling retrieval algorithm by FTS are plotted by green marks.