Response to Referee #1

We thank the referee for helpful comments to improve this paper. Our responses are detailed below. Please note that ***referee's comments*** and our responses are in different styles.

General comments: This paper reports 10 years of CO2 measurements from the upper troposphere and from vertical profiles above 16 airports across Asia, obtained from commercial airline flights by the CONTRAIL program. This data set is extensive, high quality, unique and especially valuable for the reason that it defines the CO2 field above the surface in a sparsely observed part of the atmosphere.

In this study the authors investigate the upper tropospheric CO2 distribution over the Asia-Pacific region. They focus on some notable features, for example zones of low summertime CO2 above East Asia and boreal Asia, and interpret them in terms of surface exchange and transport processes using the NICAM-TM model.

Specific comments: This is a good paper that makes a solid contribution to its field. My only issue with the science presented relates to the discussion of vertical profiles above Asian cities in section 3.2 (3rd paragraph). The claim is made that these profiles differ from others outside of Asia with "absence of a dramatic decrease of CO2 near the ground in the summer. . .. .implying that the observed vertical profiles in the summer are not strongly influenced by uptake underneath". My concern is that by nature of this program where the vertical profiles are above large population centres (and CO2 source regions), there may be a bias towards higher CO2 in the boundary layer than what was observed in vertical profile data elsewhere. The authors should address this possibility.

We thank the referee for recognizing the value of our data and for the important suggestion. It is true that our observations have collected vertical profiles from/to airports adjacent to big cities, and that the measurements, especially in the BL, are subject to influence from nearby urban emissions. We are aware of this feature and indeed have found notable increases of CO_2 in the BL over some airports. For instance, histograms of ΔCO_2 in the BL over the Asian airports show a distribution with an extended tail toward positive values than a compact Gaussian distribution. We could therefore have redrawn Figure 4 with median values, instead of averages, to reduce the effect of "polluted" profiles. However, the difference between average and median below 2 km falls mostly within < 1 ppm throughout the year over all the airports in Figure 4, except SHA and HKG where the value is ~1.5 ppm on yearly average. In fact, visual difference between average- and median-based Figure 4 is small. We note that the occurrence of "polluted" profiles is dependent on several factors, such as airport location relative to a nearby city, magnitude of nearby emissions and local meteorology. These features will be addressed in our future publication. In summary, although an "airport bias" likely has significant contribution in the BL over some of the CONTRAIL airports, we consider that the effect is small within the scope of this study. The following new paragraph has been added in the section for clarification on the issue:

"It is likely that some features shown in Fig. 4, especially in the BL, are due to the influence of nearby CO_2 emissions. Indeed, at some airports, large elevation of CO_2 values have been observed frequently in the BL. In order to reduce possible bias due to such pollution events, we did redraw Figure 4 with median ΔCO_2 values, instead of averaged values. We found no clear visual difference in the overall features discussed below. In fact, differences between average and median are mostly < 1 ppm even below 2 km at all airports, except SHA and HKG where the value is ~1.5 ppm on yearly average. Although pollution events are observed frequently over these two airports (as described below), we consider such "airport bias" in the climatological vertical profiles to be small within the scope of this study. Influence of nearby city emissions on the CONTRAIL observations will be addressed in our future publication."

In addition, considering that vertical profile of CO_2 is determined by balance between uptake and emission in footprint areas, the original sentence has been modified to:

"…, implying that the observed vertical profiles in the summer are not dictated by overwhelming uptake underneath."

There is one section where some clarification and more detail is required. The 1st paragraph of section 2.1 (line 16-19 on page 3) describes standard gas measurement intervals. Where it is stated "intervals were initially 10 min. . ...20 min..." it is not clear if the 10 and 20 minute intervals etc. refer to the duration of,

or the time between standard analyses. It would be helpful to specify exactly what the analysis time cycles are. For example, during the 14 minute cycle, sample air is measured for x minutes, then standard 1 for y minutes and standard 2 for z minutes. It would also be useful to record what time or fraction of these data are rejected after switching gas streams.

We have now added the following sentences (underlined):

"The standard gases are currently introduced into the NDIR cell every 14 min during the ascent/descent portion of the flight and every 62 min during the constant altitude portion of the flight (cruise) typically at 8–12 km i.e. during the ascent/descent (cruise) measurement cycle, sample air is measured for 12 (60) minutes, then standards 1 and 2 are measured for 1 minute each. These standard gas intervals were initially 10 min during ascent/descent and 20 min during cruise until December 2005; the 20-min interval was then changed to 40 min until October–November 2011. The CME data are recorded as 10-s averaged measurements during ascent/descent (~100-m intervals in altitude) and at 1-min intervals during cruise (~15 km intervals horizontally). The data are rejected for 40 s after switching the gas stream and also when a standard deviation for the average period exceeds 3 ppm and when any failure in pressure/flow control is observed in the CME data record."

Technical comments: A list of technical corrections follows. Many of these address overuse of "the" or "a". While the English used in the paper is generally very good, the readability could be easily improved by attention to these instances.

We thank the referee for many technical corrections. Our responses follow below.

Page 1, line 17 – delete "the" to leave "Pacific Rim of continental East Asia"

Corrected.

P2, line 5 – "an increasing number"

Corrected.

P2, line 16 – reword to ". . .less-well studied features of the CO2 distribution that are associated with the Asian monsoon."

Corrected.

P2, line 31 – "another zone of low CO2"

Corrected.

P3, line 27 – "flights to continental East Asia"

Corrected.

P3, line 29 – "over continental Asia"

Corrected.

P4, line 5 – reword to "Although measurements at other airports are less regular, data from sites where a substantial number of vertical profiles have been taken and cover much of the year, are included in this study."

Corrected as follows:

"Although measurements over other airports are less regular, data from sites where a substantial number of vertical profiles have been taken and cover much of the year are included in this study."

P4, section 2.2, 1st paragraph – It would be appropriate to define here what is meant by upper troposphere.

The following sentence has been added at the end of the paragraph:

"In this study, the UT is defined as the region at altitudes of > 8 km and with PV of < 2 PVU."

Figure 3 suggests altitudes > 8 km. It might also be worth briefly commenting on the upper boundary, presumably the tropopause, and how its height varies with latitude.

This issue has been addressed in our previous papers (Sawa et al. 2008, 2012, 2015). We have however added the following sentence:

"Note that most commercial airliners cruise at altitudes of 9–12 km, and that this cruising altitude region is deemed in large part stratospheric at higher latitudes (e.g. 86% and 64% of the data taken at > 40° N was stratospheric in January and July, respectively), whereas it mostly resides in the UT at lower latitudes (< 10% of the data at < 30° N was stratospheric throughout the year).”

P4, line 11 – “in atmospheric composition”

Corrected.

P6, line 3 – “low CO2 values” and “of UT”

Corrected.

P6, line 4 – “by moderately”

Corrected.

P6, line 5 – “over boreal”

Corrected.

P6, line 7 – “with distinctly”

Corrected.

P6, line 22 – “by CONTRAIL observations”

Corrected.

P6, line 23 – “500-m altitude”

Corrected.

P6, line 24 – “due to boundary layer (BL) processes”

Corrected. We apologize for this being missed in the previous manuscript.

P6, line 25 – “”is beyond the scope of this study”

Corrected.

P7, line 1 – “CONTRAIL observations provide greater”

Corrected.

P7, line 28 – “east coast of continental”

Corrected.

P7, line 30 – “lagging the lower troposphere (LT) minimum”

Corrected. We apologize for this being missed in the previous manuscript.

P8, line 7 – “uptake by crops”

Corrected.

P8, line 11 – “measurable”

Corrected.

P8, line 14 – “in tropical Asia”

Corrected.

P8, line 20,28,31 – “observations”

Corrected.

P8, line 33 – “depletion of CO2 over boreal”

Corrected.

P10, line 9 – Fig. 4g instead of 5g

Corrected. We apologize for this mistake.

P11, line 14 – “in boreal”

Corrected.

P11, line 20 – “in the UT is consistent”

Corrected.

P11, line 29 – “over boreal”, also replace “inferring” with “implying”

Corrected.

P12, line 1 – "in boreal"

Corrected.

P12, line 2 – delete "relatively"

Corrected.

P13, line 14 – "sweep continental"

Corrected.

P13, line 18 – "from continental"

Corrected.

P13, line 21 – replace "flights" with "profiles"

Corrected.

P16, line 4 – Matsueda and Inoue (1999) appears in the reference list but is not referred to in the text

We thank the referee for noting this omission in the paper. Since this reference is important in the history of the CONTRAIL observations and of interpretation of the data taken in the UT over the western Pacific, it is now refereed to in section 4.1.2.

Figure 6 – 1) add y-axis (latitude) labels, 2) the black lines showing geopotential height in the last column are meaningless without some numerical labeling

Both x- and y-axes labels have been added. We have also labeled the black contours of geopotential height.

Figure 6 caption, lines 1-2 – columns 1 – 4 show ΔCO2, ΔFF CO2 and ΔBB CO_2

Figure 6 caption, line 6 – CO2 isolines

The caption has been changed as follows:

"Figure 6: Comparison of the observed and simulated distributions of CO_2 in the UT. Column 1 shows ΔCO_2 observed by CONTRAIL CME. Columns 2–4 show ΔCO_2, ΔFF CO_2, and ΔBIO CO_2 simulated by NICAM-TM. The CONTRAIL data are simply averaged for each grid, and the NICAM-TM data are sampled at locations and times corresponding to the observation data and analyzed in the same manner. Also shown are the simulated monthly distributions of CO_2 at 250 hPa pressure surface in 2011 (column 5). Solid lines in white and black in the column 5 indicate CO_2 isolines and geopotential height at 250 hPa pressure surface, respectively.”