Interactive comment on "Analysis of emission data from global commercial aviation: 2004 and 2006" by J. T. Wilkerson et al.

Responses to Anonymous Referee # 2

Referee's comments are included below with author responses following each comment.

Overall referee position:

In principle this is a valuable contribution to the science community, but the change in methodology between the two years without quantifying the impact of this change does not allow for a one-by-one comparison of these two years, and even less to derive regional growth rates from these data. This general approach is not convincing and even more other data (OAG, IEA) do not support the regional growth rates found within this study. The manuscript can be published after major revision and a second review, without these major changes I do not support the publication of this manuscript in the actual status.

**Major revision is complete. Please see responses to comments below which address the issues.**

Review Criteria

1. Does the paper address relevant scientific questions within the scope of ACP?

A new air traffic database for two recent years is a valuable contribution to the scientific community, particularly with a temporal resolution of only 1 hour and without extrapolating data of only a few days to a whole year.

**No Change recommended**

2. Does the paper present novel concepts, ideas, tools, or data?

The high temporal resolution of the data is unique in comparison with other air traffic inventories, furthermore, the employment of very detailed data, abandoning the need of extrapolation from a few days to one year.

For the 2006 air traffic inventory a new source of flight track data is included in addition to 2004 basic data, but it is not explained, whether these represent more data(flights) or only a different degree of detail. It is not very clear, why two years of data (2004 and 2006) are shown, as one should not compare the two years one-by-one anyway, as there have been plenty of changes in the methodology and in the data sources included.

**There was not a new source of flight track data in 2006 versus 2004, but an intelligent merging of existing information. AEDT better represents non-radar flight trajectories by learning where scheduled flights usually fly when travelling between a given origination and destination. Volpe calls these 'airways tracks'. Instead of assuming a great circle track, AEDT applies the airways track if available. This is now clarified in the paper near the end of section 2.1 as follows:**

***"For 2006, the same method was used to determine cruise altitude, but a more accurate flight corridor matching or "airways track" method was used which better represents non-radar flight trajectories by learning where scheduled flights usually fly when travelling between a given OD pair. This method determines the shortest distance for flights traveling between common OD pairs as the horizontal track, which better reflects where these aircraft typically fly. If a valid airways track did not exist between an OD pair (e.g. when track data between the two airports is non-existent), then a dispersed GC track was used as in the 2004 data. The airways track approach closely resembles radar data when comparing both within AEDT, neglecting reroutes due to adverse weather".***

Furthermore, the artificial over-count of flights in 2004, which is mentioned in section 3.4 and illustrated in Figure 7a makes the comparison of the two years even more questionable. The artificial over-count of flights in 2004 seems to reach about 10% more flights in all months between April and October (see Figure 7a). If the data were corrected from this "over-count", maybe the two years were better comparable. And if for example the same trajectory generation between origination and destination were used for both years (statistical distribution vs. known airways and great circles).

**We do agree these two data sets should not be directly compared. However, both datasets, as they are described here, are in use by current research projects, so we believe that both should remain in this publication. To better represent the over-count, the Section 3.4 (Temporal Results) was moved forward in the discussion. This section is the best place for the reader to visualize the error.**

**Inappropriate comparisons are removed and explicitly described in the middle of the Abstract:**

***"Furthermore, the original 2004 inventory contained a significant over-count due to an imperfect data merge and daylight savings error. As a result, the 2006 emissions inventory is considered more representative of actual flight activity. Here, we analyze both 2004 and 2006 emissions, focusing on the latter, and provide corrected totals for 2004".***

**And again at the end of the Introduction (section 1):**

***"Differences between the original 2004 inventory and the only 2006 inventory, due to changes in Volpe's methodology, availability of radar data, emissions Indices (EI), and other factors, are discussed herein. Because of these differences, comparisons between the original 2004 and 2006 data are limited to global methodology comparisons, and those data sets should not be compared directly with each other to show spatial trends between the two years. However, corrected 2004 global emission totals based on the 2006 methodology, are presented. These numbers do allow a comparison of global trends between 2004 and 2006. The 2006 dataset, though, is considered the benchmark inventory. Below, we address the 2006 data set and both the original and corrected 2004 inventories".***

I highly suspect the "decrease" of air traffic emissions and flown distances from 2004 to 2006 is only due to the many changes within the methodology of compiling the air traffic inventories. Therefore I would

either make the two datasets most comparable as possible or I would refrain from comparing the two datasets and interpreting possible artefacts. Other reliable data sources do not report a decrease of air traffic (or aviation fuel consumption) from 2004 to 2006, e.g. the IEA (2009) reports a global increase of CO2 emissions from international aviation bunkers from 368.07 (2004) to 400.16 (2006, the OAG (www.oagaviation.com) also reports an increase of the number of seats and the number of operations worldwide from 2004 to 2006. Such numbers must be revealed in this article and the findings of this paper can only then be discussed and set in context.

**Thanks for the references. These and others are referred to in Section 3.1. Also, the corrected 2004 total result allows for supporting comparison**

3. Are substantial conclusions reached?

The points given in the summary section which are related to regional increase or decrease, or changes in the vertical distribution of flights or average flight length, are questionable findings and may only be caused by the changes in the methodology used. If one aims to compare regional air traffic density of different years to derive regional growth rates, the methodology used for the compilation of the data must be as similar as possible.

**Agreed, See response to comment 2 above**

**There are so many differences, that quantifying the effects of one or even all is not possible within the time frame of the project. Furthermore, the data, as it exists, are used in ongoing research and this serves as a data reference/summary for such studies.**

As explained above, I highly suspect the “decrease” between 2004 and 2006 to be an artefact caused by too many changes within the methodology, and I highly recommend these issues to be clarified, before the manuscript is published. Because of the changes of data additionally incorporated and differences in the compilation of routes between 2004 and 2006, I do not trust the comparisons of regional changes between the two years, what the authors interpret maybe caused by regional growth rates but may also well be caused by different data sources, different generation of trajectories.

**See response to comment 2 above**

The findings with respect to regional growth rates are not in agreement with data from OAG between 2004 and 2006, where an increase of the number of seats and the number of flights is found between 2004 and 2006 for all regions except for flights within North America, but even for flights from and to North America an increase is found from 2004 to 2006.

**See response to comment 2 above and comment 4 below**

4. Are the scientific methods and assumptions valid and clearly outlined?

Why are so many changes in the methodology employed between the two years, without quantifying the differences?

**The intention of this paper is not to interrogate different methodologies, but to report and analyze the content of existing and disseminated data already in use by several researchers. The description in this paper of the data and methods used to obtain them is a very brief summary of the system to help orient the reader. Volpe and FAA and are constantly improving AEDT, and have accumulated a long list of papers describing in-detail the methods and improvements. Several more of these references have been added to the text in section 2.1**

Why are different EI given in Table 1 for 2004 and 2006, without discussing the change? And even more, NOx, SOx, etc. is not shown for 2004 anyway It is not clear, why the EI of PM is changed in such an extreme way between 2004 and 2006. Please give reasons for this change, I don't believe the emissions or the fuels have changed so much without any reliable statement. Please do not only give "personal communication", but discuss the chosen values in context of values given in the literature. . .

**EI of organic PM was an erroneous value. Corrected**

**More details have been included to describe different EI values in Section 2.2**

**AEDT methods are continually improved. As more appropriate numbers and methods are determined, they are added into the data processing routines. This paper discusses the resulting emissions footprints while providing insight into the origination of the data. Many references are provided at the end of Section 2.1 and throughout that guide the reader to highly resolved details on the models used to generate the data.**

5. Are the results sufficient to support the interpretations and conclusions?

No. See above.

**Corrected; See above**

6. Is the description of experiments and calculations sufficiently complete and precise to allow their reproduction by fellow scientists (traceability of results)?

The description of the changes of the methodology between 2004 and 2006 should be more detailed. Furthermore a quantification of the changes of methodology would be helpful. Is it possible to calculate the 2006 data set twice, once with the old and once with the new methodology? Or maybe a correction of the 2004 data ("artificial overcount") could then enable the authors to make a more reliable comparison between the two years?

**See response to comment 4**

**Corrected 2004 total fuel burn is now available and has been included. Spatial/temporal reanalysis of the corrected 2004 dataset is not possible due to time, project, and budget constraints. However, the corrected total enables several realistic comparisons.**

7. Do the authors give proper credit to related work and clearly indicate their own new/original contribution?

Other air traffic inventories in addition to the SAGE inventory should be mentioned, too, e.g. TRADEOFF, AERO2K, QUANTIFY.

**Comparisons to these and older SAGE reports has been expanded in Section 3.1, including a new figure comparing annual emissions.**

It is not very clear, what the difference in fuel burn between 2004 (SAGE) and 2004 (Wilkerson) causes. The authors only very vaguely state, that they included an improved estimation of unscheduled flights. Maybe this could be explained a bit more detailed.

**The differences are addressed more explicitly in Sections 3.1 and 3.2.**

8. Does the title clearly reflect the contents of the paper?

Ok. But the title depends on the final version of the paper. If focus is on regions, this could be mentioned in the title, if focus is on e.g. improved methodology, also.

**We think title should remain as is. '…Global Commercial Aviation.'.**

**If the title was '…Global emissions…', then could indicate global and regional emissions. However, we think current title captures it.**

9. Does the abstract provide a concise and complete summary?

Ok for the moment, but the abstract says nothing about regional differences, although this subject fills 3 pages of the article, 5 tables and 1 figure.

**More explicit regional information is now included in the abstract**

***"This activity led to 162.25 Tg of carbon from $CO_2$ emitted globally in 2006, more than half over three regions: the United States (25.5 percent), Europe (14.6), and East Asia (11.1). Despite receiving less than one percent of global emissions, the Arctic receives a uniformly dispersed concentration of emissions with 95.2 percent released at altitude where they have longer residence time than surface emissions".***

10. Is the overall presentation well structured and clear?

Yes ok, if other points are resolved.

**Done**

11. Is the language fluent and precise?

Generally ok. Only some points (see below).

**No Change recommended**

12. Are mathematical formulae, symbols, abbreviations, and units correctly defined and used?

Yes.

**No Change recommended**

13. Should any parts of the paper (text, formulae, figures, tables) be clarified, reduced, combined, or eliminated?

Clarification: Please quantify the differences between 2004 and 2006 and what part is due to "fewer flights" and what due to methodology used.

**See response to comment 2**

Clarification: Figure 2, regional differences between 2004 and 2006 should be discussed in more detail (maybe a difference plot would be helpful) and other information should be consulted to support the statements (e.g. OAG, IEA, to prove why here or there more or less flights in 2006 compared with 2004).

**The over-counts occurred primarily where we have good radar coverage (primarily North America and Western Europe), and this is stated in the paper. As such, the over-counts do not allow strict comparisons of regions except maybe over Eastern Europe, which is less affected (but not immune) to the over-count. Since removing these comparisons between the uncorrected 2004 and 2006 results, a difference plot would no longer be appropriate.**

Reduction/Elimination:

Table 1: Emission indices for 2004 not necessary, if the changes are not discussed.

**Discussed in more detail throughout paper now.**

**See comments below**

Figure 6 not really necessary. Figure 3 and Figure 9 may also be not necessary.

**We believe all three of these figures are relevant and informative:**

**Figure 6 highlights the uniform distribution of emissions over a small geographic area and is relevant to climate studies revered to in section 1 of this paper.**

**Figure 3 provides useful visual information regarding length-duration distribution of flights.**

**Figure 9 provides visual footprint of several highly studied emissions species and these images provide a very useful reference for related studies.**

Table 9 not necessary.

**We think table 9 is relevant since it describes how FAA recommends speciating the emissions reported in this document.**

14. Are the number and quality of references appropriate?

See Point 7.

**Included more references and comparisons. See response to comment 7 above**

15. Is the amount and quality of supplementary material appropriate?

Ok.

Further points:

For the whole document: If rounded numbers are presented in the table, please use the same numbers in the text or use the numbers discussed in the text also in the tables. And please refer more often and more detailed to numbers in the tables (e.g. column. . .)

**Done**

Page 2946

Line 16: Give percentage for dominant regions.

**Done**

Line 17: Quantify the impact of the methodology change between 2004 and 2006.

**See response to comment 2 above**

Line 25: Be more specific: CO2 emissions

**Done**

Page 2947

Line 9: Per what? Per year? Related to what?

**Per year; clarified as follows:** ***"For example, India reported an increase in its domestic aviation activity by 41 percent from 2005 to 2006."***

Page 2948

Line 22: . . . as much measured data as possible: Too vague, and what is meant by "measured"?

**Corrected to 'real data' (see Page 2948 cumulated response below)**

Line 24: . . . data from several sources. . . : What sources?

**Identified (see Page 2948 cumulated response below)**

Line 25: . . . radar coverage. . .: Only US?

**North America and Western Europe as described (and clarified) a few sentences later. (see Page 2948 cumulated response below)**

Line 25: Military later excluded?

**Yes, military later excluded (see Page 2948 cumulated response below)**

Line 26: . . .captures every scheduled flight. . .

**…captures information about every scheduled flight… (see Page 2948 cumulated response below)**

**Page 2948 cumulated response:**

***"The AEDT inventory provides four-dimensional (latitude, longitude, altitude, and time) flight trajectories using as much real data as possible, described below. The data are collected by the Enhanced Traffic Management System (ETMS) at the Volpe Center, which serves as the hub of information. ETMS receives a continuous flow of data from numerous sources, including Terminal Radar Approach Control Facilities (TRACON), individual airlines, Automated Radar Tracking Systems (ARTS), and Air Route Traffic Control Centers (ARTCC). ETMS is the FAA's electronic recording of flight position and flight plan information used for air traffic management. It captures every flight within coverage of FAA radars, including scheduled, cargo, military (later excluded), charter, and unscheduled flights. Volpe estimates that unscheduled flights account for an estimated 9 percent of all flights. Unscheduled flights primarily affect non-radar portions of the globe and are included by***

***scaling known flights. ETMS also captures information about every flight that files a flight plan, whether or not the aircraft enters radar-controlled airspace. Radar coverage encompasses all of North America and parts of Western Europe, and records an estimated 50-60 percent of global commercial flights (Volpe, 2003)".***

Page 2949

Line 2: . . . records and estimated 50-60 percent. . .: How is this estimated?

**Defined in [Volpe 2003] reference. Moved reference to appropriate location in paragraph. (see Page 2948 cumulated response above)**

Line 3: Please clarify: Does this mean additional flights in 2006 or just more detailed data with additional information?

**More detailed information on non-North American flights; clarified as follows:**

***"Additionally, in the 2006 inventory, data collected by EUROCONTROL's Enhanced Tactical Flow Management System (ETFMS) were included. This expanded AEDT's total radar-provided schedule and flight data to include most of Europe. For the 2004 inventory data, European operations were represented primarily by the Official Airline Guide (OAG), where ETMS coverage did not exist (e.g., Europe)."***

Line 11: How do you know ETMS is incomplete?

**If part of radar trajectory is missing then ETMS is incomplete; clarified as follows:**

***"When radar tracking is unavailable or information is incomplete for a particular flight, the tool refers to the OAG, which lists scheduled passenger flights by participating airlines".***

Line 12: . . . statistical distribution. . .: Please be more precise: according to ac-type, according to flight distance?

**Clarified as follows:**

***"For incomplete ETMS flights and all of ETFMS and OAG flights, trajectories are generated. In 2004, trajectories were generated from statistical distributions of cruise altitudes and horizontal tracks between origination and destination (OD) airport pairs. The distributions for a given flight-distance category (e.g. 200-250 nm) were generated by statistically analyzing a large set of ETMS flights for jet or turboprop engines, the percentage of each flight that occurred along the OD Great Circle (GC), the distance from the GC, and the probability distribution of the offset distance from the GC. The resulting distributions of horizontal tracks provide a "dispersion" effect around the OD GC estimate. An analogous method was applied to determine cruise altitudes."***

Line 20: . . . then a GC track was used. . .: How often does this happen? Please quantify. Why don't you apply the same statistical distribution in 2006 as in 2004? Or why has GC method not been used in 2004?

**See response to Comments 2 and 4 above**

Line 26 ff: Meaningless and dispensable sentence.

**Improved:**

***"The agencies that control these databases, FAA and EUROCONTROL, have increased the amount of exchange of flight-movement information; so, both databases are expected to improve in accuracy and completeness as collaboration continues."***

Page 2950:

Line1: Say a few words about temporal resolution of base data also in this section.

***"The horizontal and vertical resolution of the segment end points are 10e-6 degrees and 10e-4 meters respectively; and the time is resolved to integer seconds. "***

Line 11: Why are cancelled flights taken into account?

**Erroneous, removed.**

Line 11: 9 Percent: How is this number estimated?

**2004 Species emissions values shown in table 5 (old study) compared with 2004 results in table 4 (current study). Current study values range from 8% to 10% higher than the old study (roughly speaking) so simply an approximation of the whole. Since the corrected 2004 result is a global total for fuel burn, the statement is rewritten to compare just fuel burn difference of 8.6%:**

**"The 2004 fuel burn results reported here are also 8.6 percent higher than fuel burn reported for the same year in a previous SAGE inventory report (Kim et al., 2005c), which are shown in Table 5 in units consistent with this study."**

Line 11: Unscheduled flights are regionally very different, how is the scaling done, are regional differences included?

**Unscheduled flights only account for a small fraction of emissions. This was misrepresented previously, so we have restated this section to draw more attention to the over-count:**

***"The difference between the two 2004 reports is in small part due to better representation of unscheduled flights in the current report. However, it is largely due to an over-count which is best explained in Section 3.2 below."***

Line 22 ff: Discuss with other PM EI from peer-reviewed literature. Give reasons for the "radical" change of PM EI.

**Clarified with the following in Section 2.2:**

***"The EI for black carbon (BC) particulate matter (PM) used in the AEDT's 2004 inventory was 0.2 g/kg-fuel which represents the EI for PM during a portion of the aircraft operation, including takeoff and climb out; however this represented a small portion of the activity and effectively over-predicts BC emissions. For the 2006 inventory, AEDT chose to use 0.035 g/kg for BC EI which is more consistent with cruise emissions. Both 2004 and 2006 EI values fall between the low and high range of other inventories as summarized by Lee et al. (Lee et al., 2009). Recent work by Volpe and the FAA (Wayson et al., 2009) has advanced the methodology to estimate PM emissions by disaggregating non-volatile PM, from fuel organics and sulfur-related compounds; however, this is intended for airport operations at ground level conditions rather than cruise-related operations."***

Page 2951

Line 2: "If" instead of "While"

**Corrected**

Line 13: "emissions species" instead of "chemical"

**Corrected**

Page 2953

Line 4: In view of other reliable data sources (OAG, IEA) I question whether the decrease between 2004 and 2006 is possibly only due to the change of the methodology and not by less flights.

**Comparison removed (see response to comment 2 above)**

Page 2954

Line 9 ff: How is the usage of another EI (e.g. BC) justified? Please clarify.

**Clarified with the following in Section 2.2:**

***"The EI for black carbon (BC) particulate matter (PM) used in the AEDT's 2004 inventory was 0.2 g/kg-fuel which represents the EI for PM during a portion of the aircraft operation, including takeoff and climb out; however this represented a small portion of the activity and effectively over-predicts BC***

***emissions. For the 2006 inventory, AEDT chose to use 0.035 g/kg for BC EI which is more consistent with cruise emissions. Both 2004 and 2006 EI values fall between the low and high range of other inventories as summarized by Lee et al. (Lee et al., 2009). Recent work by Volpe and the FAA (Wayson et al., 2009) has advanced the methodology to estimate PM emissions by disaggregating non-volatile PM, from fuel organics and sulfur-related compounds; however, this is intended for airport operations at ground level conditions rather than cruise-related operations."***

Line 20: "enhancements": Please be more precise.

**See response to comment 4 above**

**Sentence not necessary and removed; earlier sentences clarified as follows:**

***"Changes in CO are due to improvements made in AEDT for terminal-area fuel burn calculations and changes in EIs. The highest EI of CO is at low thrust setting, such as during the idle (taxiing operations) or descent portions of flight. While the terminal area represents a proportionately small amount of the overall fuel burn, it represents a substantial portion of the overall CO produced. "***

Line 26: "improved estimation of unscheduled flights": very vague, please be more precise.

**VOLPE estimates that unscheduled flights account for about 9% of all commercial aviation. However, any unscheduled aircraft in radar range will still be recorded. Since radar coverage encompasses a larger portion of aviation, a large portion of unscheduled flights are also account for directly. It is unknown what fraction and geographic**

***"The difference between the two 2004 reports is in small part due to the inclusion of unscheduled flights in the current report. However, the difference is largely due to an over-count which is best explained in Section 3.2 below."***

Page 2957

Line 1: . . . decreased . . . (please refer to Table 7)

**Corrected**

Line 2ff: . . . increase in short-haul or local flights. . .: Not convincing, maybe much more caused by changes in methodology.

**Direct comparison removed (see response to comment 2 above). Removed 2004 flight distance-duration portion of table. Since the fuel burn number is inaccurate due to over-count, then the distances and durations are also inaccurate.**

Line 28: . . . the total US region on average falls second. . . to Europe, whereas over the Eastern US the highest emissions per unit area are found.

**Corrected**

Page 2958

Line 6: . . . third of emissions compared with the US box region. . .

**Corrected**

Line 26: Sentence makes not really sense. CO2 emissions are always spreaded uniformly because of their long lifetime. Maybe this could be clarified by comparing the air traffic density or the fuel consumption. But Figure 6 is not really necessary anyway.

**Corrected: 'distributed uniformly', not 'spread uniformly'**

Page 2959:

Line 1ff: Misleading, as transport of emissions is not investigated within this study.

**(see Page 2959 cumulated response below)**

Line 5ff: Please refer to Table 8.

**Done**

Line 6: . . . similar to 2004 at 318 kg/km2. . . : no, not similar, almost 10% difference to 2004 values of 347.

**Page 2959 cumulated response. Arctic section re-organized to highlight important details:**

***"Another region of interest is the Arctic. The total emissions over this region were about 0.64 percent of the 2006 global total, resulting in a mean emission rate about 1/6 per unit area as the global mean. Yet, in 2004, the fractional emissions and the emissions per unit area over the Arctic were twice those of 2006 (Table 8). This difference between the two years is likely due primarily to the difference between horizontal track generation methods. Flights between Europe and North America through the NAFC pass close to the Arctic Circle. If a horizontal airways track does not cross into the polar region, then none of the emissions from any flight along that trajectory can contribute to the geographical region totals. However, the dispersion method used in the 2004 data allows some of the flights between a given OD pair to pass further north and contribute to the region totals. There are several near-Arctic corridors that can contribute directly to polar emissions depending on the GC method.***

***In both years, emissions over the Arctic were distributed uniformly horizontally throughout the polar region (Figure 9), and over 95 percent were emitted at altitude (above 7 km) where they have a longer residence time (due to greater stability in the upper troposphere and lower stratosphere, where Polar***

***emissions occur) than those emitted near the surface at other latitudes. For comparison, in 2006 only 67.2 percent of emissions over the U.S. and 64.4percent of emissions over Europe occurred above 7 km. Circulation patterns in the upper mid-latitudes trap polar emissions and push mid-latitude emissions further north (such as those from NAFC) into the polar region (Forster et al., 2003). Any emissions deposited within or near the Arctic Circle are likely to accumulate over the polar region, which further increases the polar emission concentrations and potential climate impacts on this very sensitive region. So despite different track generation methods, climate effects are likely to be similar when comparing impacts to the Arctic region."***

Line 25: Please refer to Figure 7a. How much does the over-count make up? In Figure 7a it looks like about 10% off-set. What is the reason for this over-count? Why does it not happen in 2006? Is it possible to correct the 2004 data? Have you looked at regional differences of this over-count? Maybe interesting / important if a correction is envisaged!

**We did not properly address over-count, so re-written below. Also, it is not possible to quantify the 12-month over-count; however, it is possible to estimate the daylight savings over-count error. Please refer to the rewritten Section 3.2:**

***"Figure 5a shows the daily annual carbon from CO2 emissions (CO2-C) for 2004 and 2006. Since most emissions occurred in the Northern Hemisphere, the annual temporal distribution was dominated by the Northern Hemisphere seasons. Air travel increased in early April and continued through October and dropped off during the winter. The increase in air traffic in summer led to a peak in daily emissions from July through August. Mid-winter activity dropped to a low in January and February. However, the 2004 data set contains an artificial over-count of operations all year and a daylight savings coding error is evident from April through October.***

***For flight schedule information, radar-based (ETMS) and schedule based (OAG) were pulled together globally. The attempt to merge these data sources was not perfect and resulted in some double-counts throughout the year, primarily over North America where radar coverage occurred. This over-count was also present in the previous SAGE emissions report referred to above. While most of the difference between the current corrected 2004 study and the older 2004 SAGE study represents the difference in track methodologies, a smaller undetermined amount lies with this underlying double-count and other continual improvements to the database.***

***During daylight savings period, a bug in the merging resulted in a much more significant double-count during these months. We can estimate the daylight savings error by estimating the effect of the jump in emissions in each of the seven months. From Figure 5a, the uncorrected 2004 CO2-C daily mean emissions are about 0.01 Tg per day higher than computed for 2006 during non-daylight savings months. Taking this into account when comparing the two curves, uncorrected 2004 data are about 14 percent higher than expected in April and May, 13 percent higher in June, 8 percent higher in July and August, and 11 percent higher in September and October. Combined, the daylight savings portion of the over-count is estimated at about 6.2 percent or 11 Tg of CO2-C for the year. Subtracting this***

***daylight savings error reduces the reported 2004 CO2-C emissions to about 166 Tg globally. After subtracting the daylight saving error, there still remains a smaller over-count of undetermined amount. The remaining difference between the two reports is a combination of the inclusion of unscheduled flights and other regular improvements in the process.***

***The known over-counts were resolved before the 2006 data were computed, by using ETMS exclusively in regions where radar coverage occurred (primarily North America). Thus, the 2006 data set more accurately captures seasonal trends, with peak operation count in the Northern Hemisphere summer months and lowest during the winter months. Again, the data here should not be used to indicate emissions trends between 2004 and 2006, but the results here are useful to researchers already using either dataset for global or regional climate studies.***

***The daily emission curves in Figure 5a show an oscillation illustrating the weekly periodicity. Integrating all emissions by day of the week shows aviation activity peaked on Thursday and Friday and dropped off for the weekend (Figure 5b). The daily and weekly profiles were tallied relative to Universal Time Coordinate (UTC), which led to an investigation of emission contributions by the hour. A compilation of the hourly global data resulted in the 24-hour profile in Figure 5c, which shows annual average emissions per hour. The over-counts affected primarily North America were radar coverage existed, which is evident by the behavior of the 2004 hourly emissions curve in Figure 5c. As shown earlier, less fuel was, in fact, burned in 2004 than in 2006. It follows that comparisons between the two years should also show less per day or per hour than in 2006. That said, as activity rapidly increases in North America, beginning around 12 UTC, the 2004 curve increases faster than the 2006 curve; thus, indicating the over count is embodied primarily in North American activity. This evidence does not show up in Figure 5b, since the data were aggregated by day.***

***The composite image in Figure 6 shows the integrated annual emissions incrementally through the day, again relative to UTC. Hour 0 UTC is midnight in London, and afternoon in Asia where the industry is still very active. Over the next several hours, planes from Asia begin making their way toward Europe and arrive in time for the local morning rush hour. By hour 8 UTC, rush hour in Great Britain has ensued and aviation activity over Europe is increasing quickly. 12 UTC is 7AM Eastern Standard Time along the U.S. Eastern Seaboard; and aircraft racing across the North Atlantic join an increasing amount of aircraft originating in Eastern U.S. Over the next three hours, the rest of North America begins to add to aircraft activity as Europe begins to slow down at the end of the work day. Toward the end of the day in the U.S., aircraft along the east coast begin red-eye flights toward Europe, and aircraft along the pacific coast head out over the pacific toward Asia where the activity starts all over again the next day. "***

Page 2960

Line 20 ff: very meaningless section. If you don't write more about this and set this in context to the rest of the text and other air traffic inventories, this section can be discarded.

**Agreed. Included description of the data and some resources. Beginning of section is as follows:**

***"In general, other emitted species have the same over-all footprint as CO2-C; however, for convenience, NOx-as-NO2, SOx-S, and BC emissions are shown in Figure 10. Within AEDT and SAGE, NOx emissions are based on the ICAO Engine Emissions Databank, which reports on an NO2 mass basis. So emissions of NO, NO2, and HONO are reported as emissions of NO2 mass-equivalence (Kim et al., 2005b). Similarly, SOx is reported as SO2 in the database, and sulfur from SO2 is obtained by the molecular weight ratio of S to SO2 (0.50). Both NO2 and SOx-S are proportional to fuel burn. However, BC emissions are also a function of engine dynamics. As described in Section 2.2, The BC EI used for the 2006 inventory is significantly less than that used in 2004. Older inventories have used an EI equivalent to take-off and climb-out (0.20 g-BC/kg-fuel). Since 74.6 percent of fuel is burned above 7 km, this BC EI most likely significantly over predicts total BC. The 2006 inventory used an EI more appropriate for cruise performance (0.035 g-BC/kg-fuel) which better represents BC emissions; however, it probably under-predicts total BC emissions."***

Page 2961

Line 6: . . . may be in large part due to the difference in horizontal track generation . . . : Please quantify to what extent caused by difference in methodology.

Line 12: . . . in most regions. . . a small decline or very small increase.

Line 20f: Quantify differences in height distribution caused by methodology.

**The three comments on *Page 2961* all refer to a summary section which has been rewritten. Comments have been addressed; please refer to the new conclusion below:**

***"We have analyzed global commercial aviation emissions from 2004 and 2006 in total and disaggregated by regions. In 2006, the global commercial aircraft fleet flew 31.26 million flights, burned 188.20 million metric tons of fuel and covered 38.68 billion kilometers. We have also shown corrected 2004 total fuel burn, 174.06 million metric tons, and estimated the effect of an over-count error due to a daylight savings bug. Differences between the uncorrected 2004 and 2006 results are due to the difference in horizontal track generation, other methodologies and database improvements, and some double counting. Over-count errors occurred where there was radar coverage, primarily North America and Western Europe. We have shown that different horizontal track methods can impact the quantification of regional emissions and trends. When radar data is not available AEDYT employed a dispersed Great Circle method in 2004 and an airways track method in 2006, with the latter being more representative of actual flight activity.***

***The commercial aviation fleet emitted a total of 162.25 Tg of CO2-C throughout 2006. The U.S., Europe, and Asia were subjected to 51.1 percent of these emissions despite covering only 7.5 percent of the global surface area. The global average for CO2-C emissions per unit area was 318.1 kg/km2 in 2006. The Arctic received only 0.6 percent of the total emissions, but the per unit area emissions was about one sixth of the 2006 global average. Typical wind patterns in the upper mid-latitudes tend to***

***trap these emissions over the arctic and push mid-latitude emissions into the arctic risking significant consequences to this area of high sensitivity to climate change.***

***In 2006, an average flight covered 1237.2 km in 2.06 hours and produced 4.2 kg/km of CO2-C, which indicates a dominance of short-haul flights in the annual datasets. Short-haul flights represented 85.2 percent of all commercial flights and accounted for 53.9 percent of the total distance travelled in 2006. These flights indicate a potential for transportation platform switching onto trains or buses. With improved pricing, policies, or incentives, existing transit systems or future high-speed rails may offer a means for offsetting a subset of these flights and the associated emissions.***

***We have also shown the temporal distribution of emissions on a weekly, daily and hourly basis. The seasonal peak occurred in July and August, with a decrease from November through March. During an average week, peak activity occurred on Thursday and Friday and was slowest on Monday and Tuesday. The hourly distribution of emissions was lowest at about hour 7 UTC and quickly ramped up through about 15 UTC accounting for Western European and North American rush hours. The hourly emissions remained high until the end of the Asian evening rush around 2-4 UTC.***

***Climate impacts from CO2-C and other greenhouse gas emissions including from aviation are relatively well understood. However, the potential impacts of aviation on climate are unique since most of the emissions occur at altitudes where other anthropogenic sources are absent. The effects of aviation on stratospheric ozone and global climate from persistent contrails and contrail-induced cirrus clouds are potentially significant, but there are large uncertainties in relating aviation emissions to changes in radiative forcing or surface temperature from contrail-associated pathways. Knowing where these emissions occur is the first step in computing the potential impacts. Data presented here support a continuing effort to quantify the effects of aircraft exhaust on climate and global tropospheric air pollution."***

Table 1: Why EI changed between 2004 and 2006? NOx, SOx, etc is not shown for 2004 anyway.

**Changes described in more detail in Section 2.2. Corrected a few typos in 2004 values.**

Table 4: Please discuss absolute numbers also in comparison with other emission inventories (e.g. AERO2K, TRADEOFF, QUANTIFY). Potentially this table could be reduced to distance, fuel and number of flights, as the other species are not discussed and are only dependent on EI and fuel consumption.

**Reduced table to fuel burn and CO2-C since those are the two values discussed in the majority of the paper. A comparison with other database inventories has been addressed in section 3.1.2 which includes new plot showing various inventory totals.**

Table 6: If shorter trajectories are calculated for 2006 due to differences in the methodology, it is no wonder, the average flight length is shorter. Please quantify the differences in methodology. I don't think this is a statistically significant difference in flight length. For short-haul flights and total flights the difference is of the order of 1% only. . . In Table 6 write "Average" instead of Avearge"

**Inappropriate comparisons removed (see response to comment 2 and comment 4 above)**

**Also, we removed 2004 flight distance-duration portion of table. The fuel burn number is inaccurate due to over-count, so the distances and durations are also inaccurate.**

Table 7: Headings of last two columns are not in right position.

**Corrected**

Figure 2: Please discuss the differences between 2004 and 2006 more detailed in the text. Maybe difference plot would be helpful. What happened at southern hemisphere, Australia, Asian Continent, northwards of Russia: Why such a large reduction there? Please discuss and present reasons for decrease. . .

**Done. Difference plot may confuse the issue further since the spatial results are not really comparable. Additional discussion has been included throughout text.**