Roger Teoh et al.

Referee comment for the review of the article "A high-resolution Global Aviation emissions Inventory based on ADS-B (GAIA) for 2019–2021"

General comments

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

Aviation emission inventory datasets serve as input data for climate models to complete the background concentration of gaseous and particle emissions and atmospheric composition, are necessary to quantify the climate impact of air traffic or to assess the air quality, so the paper's content is relevant for climate research and environmental research community and fits to the scope of ACP.

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

Due to the application of real waypoint data from ADS-B on a global scale an emission inventory with a more realistic routing has been created that enhances spatial and temporal accuracy and thus also regard effects from Air Traffic Management. As there were analysed the three years 2019, 2020 and 2021, the impact of the COViD-19 pandemic on air traffic volume and emissions could be quantified on a global and regional scale and compared with the pre-pandemic situation in 2019. The calculation scheme and the input data to derive the nvPM emissions, that was applied in this study, is still novel, as the input data and the methodology have been published during last 2 years.

3. Are substantial conclusions reached?

Beyond the annual aviation emission totals for the global air traffic for 2019, 2020 and 2021, the effects of the COViD-19 restrictions in 2020 and the subsequent recovery on air traffic volume and emissions have been quantified for the whole world and the dominant regional domains Europe, East Asia and USA. A subsequent evaluation of the methodology and results with a related study support their reliability. The generated results of the worldwide emission quantities, their regional and vertical distribution, annual changes during COViD-19, and the analyses of lateral inefficiencies of the flight routes provide essential information for the scientific community with focus on climate research and air traffic environmental research, but also the aeronautic industry. The final case study gives an impression of the differences of inefficiencies and emissions depending on eastbound and westbound direction affected by Jetstream.

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

The applied methodology of simulating aircraft performance and fuel flow based on BADA models and Total-Energy-Model is state-of-the-art, the majority of defined region domains was already successfully applied in other studies and the made assumptions with respect to missing emission indices and the quality check of ADS-B data and extrapolation of waypoints due to data gaps seem plausible to the referee.

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

Annual air traffic routing data of three years with more than 100 million flights is a robust sample to assess the changes in traffic volume, emission quantities, lateral routing and vertical distribution from year to year on a global and regional scale and separated by short-, medium- and long-haul flights. The detailed investigation of the single route London ←→ Singapore consists of a sample of 8705 flights over 3 years (in average ~4 per day and direction) that should be sufficient for robust statistical analysis.

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

As the referee also works on simulation of global 4D aircraft emission inventory datasets he is familiar with all mentioned input datasets and so presented procedure e.g. how to define the regions and how to extrapolate emissions to cruise phase is well known to the referee. The detailed presented methodology in the SI document how to deal with data gaps in ADS-B data is comprehensible and should cover the majority of possible data errors.

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

The article starts with a long section where recently published studies with similar scope and comparable datasets were introduced with respect to their approach and the respective similarities and differences outlined. The novel aspects of this study have been emphasized. In the results section, there is subsection 3.3 dedicated to compare the results quantitively with a study with a similar scope, that has just recently been published and addresses the same time horizon and also used real routes data.

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

The title contains enough relevant keywords to allocate the content of the paper and contain aviation emissions, ADS-B data and the covered time horizon.

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

The abstract is a short and concise summary that lists most eye-catching results and conclusions in the same chronology as presented in the paper.

10. Is the overall presentation well structured and clear?

The paper is structured well and a clear storyline is noticeable.

11. Is the language fluent and precise?

The text is clearly verbalized and the key statements could be understood immediately.

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

All abbreviations in the article were introduced when mentioned first. The introduced formulae are presented in the SI document and all mentioned variables were introduced and named. Only the parameter air traffic density (Figure 2) is recommended to be introduced in the paper as for the referee the unit km-1 h-1 is not completely clear.

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

The presentation of the methodology, the results and the discussion are already well compressed to the essential methodology and results within the main article, a lot of detailed description is shifted to the SI.

14. Are the number and quality of references appropriate?

The number and the quality of the cited references is appropriate for the extent and scope of the study and the used input data. Most cited literature is peer-reviewed scientific journal articles; a few technical descriptions are documentations and manuals of datasets or applied models (e.g. Cirium, IEA, ICAO, EUROCONTROL, ECMWF) but are also essential and familiar in the scientific community with regard to aviation emission inventory modelling.

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

The attached material helps the referee a lot to understand the methodology in detail with regard to the quality check and processing of the ADS-B data, to get an overview of the quality of the available routing data and the allocation of the load factor and how nvPM emissions were derived. It also gives readers the opportunity to access the detailed numbers of all analysed traffic volume and emissions data also for the years 2020 and 2021, where in the main article mainly only changes relative to 2019 are presented.

Specific comments

1. ADS-B data provide information on the ground distance. To simulate the aircraft performance correctly information on Mach-Number or the True Air Speed (TAS) of the aircraft is necessary. Is the ERA-5 atmosphere data also used to convert ground speed to true air speed by modifying ground distance with heading information and 4D real wind speed data? Or was the assumption making that ground speed = air speed and wind effects on aircraft performance neglected? As differences of EIs and inefficiency distribution with regard to head and tail wind effects are presented in detail (Figure 7), the referee recommends to explain how the TAS/Mach number of the total energy model simulation will match the waypoint profile segments based on ground distance.
2. The air traffic density in this article is announced with the dimension [km^{-1} h^{-1}]. The referee recommends to introduce how the air traffic density is defined in this study, as it would be generally possible to define the air traffic density as e.g. the number of aircraft movements or passenger by area or volume unit and time unit.
3. The mass of NOx emissions is a mixture of several nitroxide gases and quantified as commonly nitrogen monoxide or nitrogen dioxide mass equivalent. The referee recommends to mention within the article in which way the mass of NOx emissions should be interpreted with regard to molar mass.
4. Figure 2 compares the annual mean air traffic density of the year 2019 with the monthly mean air traffic density of 2020, the global lockdown month including depicting the difference. The referee wonders if a comparison between April 2020 and April 2019 as the same period of the last year would be better in order to isolate the Lockdown effects and to improve comparability as other seasonal and interannual effects of air traffic volume would be excluded.
5. Does the dimensionless density, shown in the colorbar of Figure 5 results from a normalization with the annual total NOx emission from GAIA and Quadros et al. (2022), respectively, to enable comparability of the latitude-altitude pattern? Summing up density values of all shown grid cells would be 1?

6. Figure 7 e shows the distribution of fuel consumption per passenger-km. The referee wonders, where the information of passenger kilometre came from? The methodology of allocation of seat load factor was clearly described, but where does the number of seats for each aircraft come from? The absolute seat capacity would be required to derive the number of passengers for each mission, as described in SI document line 319. Or was alternatively an average seat number for the route London – Singapore assumed and obtained from Cirium database seat numbers? It would be helpful for understanding to mention this at least in the supporting information.
7. Supporting Information document, lines 203 – 205: Summing up the relative ratios of engine types, 75%, 9% and 15% will be 99% in total. Did there happen an inaccuracy due to rounding?

Final assessment: Minor revision