Anonymous Referee #1:

Comments to the Author

Comment 1: The aircraft engine emissions have important impacts on air quality in and around airports and the potential exposure of nearby residential populations. The impact study of aircraft emission relies on the detailed and accurate emission information. This paper provides a detailed information about four-dimensional aircraft emission for landing and takeoff cycle from 2019 to 2023 based on the flight time and trajectory information. It could provide useful basis to further study of the environmental impacts. Overall, this MS is well-structured and is appropriate for the scope of the Earth System Science Data journal. There are several necessary revisions should be made before the manuscript could be considered for publication acceptance.

Response: We are very grateful to the referee for the insightful review. The comments have contributed much to improve the manuscript. According to the referee's suggestions, we have conducted a revision. Each comment has been addressed on a point-by-point basis, with the referee's comments are noted in black, the responses to the referees' comments are noted in blue, and the corresponding revisions in the main text are noted *in (black) italic fonts*. All the changes are also marked in Revised Manuscript. We hope that this revised version of the manuscript addresses all of the reviewer's concerns.

Comment 2: Introduction: It should be stated how much China aircraft emissions contributes to global aircraft emissions. This provides a general context for global implications in terms of pollution that emphasizes the importance of better estimates of the specific emissions mentioned in this study.

Response: We thank the referee for the advice. We have added the explanation of the contributes of aircraft emissions in China in line 77–81 in Section 1 of the revised manuscript:

"As the world's second-largest aviation market (CAAC), China contributes 13% of

global flight operations (Graver et al., 2020), and accounting for 7.8% to 23.5% of global aviation-related pollutant and carbon emissions (Ma et al., 2024; Teoh et al., 2024). Improving the accuracy of aviation emission estimates and enhancing temporal-spatial resolution in China can not only promote the green development of the Chinese aviation industry but also exert a far-reaching impact of global aircraft pollution mitigation."

Comment 3: What is the content of Section 2.1.2?

Response: We sincerely thank you for your careful check. The missing section may be caused by the typesetting and format conversion. We have added the corresponding content in lines 140–154 in P5–6:

"The daily maximum mixing layer height (MLH) serves as a key parameter for determining climb and approach modes of flight operations, and varies with region and time. Given data accessibility constraints, we substituted daily maximum MLH with the daily maximum planetary boundary layer height (PBLH), which shares analogous dynamic characteristics. The three steps for calculating climb and approach times are as follows.

1) *Different airport daily maximum PBLHs in 2019–2023 were obtained based on Weather Research and Forecasting (WRF) model. The model parameter settings are described in our previous study (Wen et al., 2023).*
2) *The relationship between flight time and height were established. In our previous study (Zhou et al., 2019), the relationship for different airports in different months under the approach and climb mode was built based on Aircraft Meteorological Data Relay (AMDAR) data. AMDAR includes the aircraft's position (longitude, latitude, and altitude), speed, and associated meteorological parameters which were collected by the aircraft navigation system. The recording intervals are set at 6 s for the first 60 s of the climb phase, followed by once every 35 s thereafter, and once every 60 s during the descent phase. The form of the relationship for climb and approach mode can be found in Text A1 of SI. The R^2 ($p < 0.001$) of the*

functional relationships of the climb and approach mode were above 0.93.

3) *Each flight's actual climb and approach times from 2019 to 2023 were calculated based on the relationship of climb and approach mode mentioned above, and the daily maximum PBLH at different airport."*

Comment 4: Section 2.1: The time-in-mode was described in detail in emissions calculation, however, other input data such as emission factors for different flight modes (taxi, takeoff, climb, and approach) were not sourced or calculated.

Response: We thank the referee for the advice. We have added the description of EI and FF calculation method in lines 126–134 in Section 2.1.1 of the revised manuscript:

"The EI of an aircraft type in different modes were calculated as (2):

$$EI_{i,m,j} = n_i \times \sum_k EI_{k,m,j} \times P_{i,k}, \qquad (2)$$

where $EI_{i,m,j}$ *is the emission index of aircraft type* i *in mode* m *(g/kg) of pollutant* j *(NOx, HC, and CO);* n_i *is the number of engines fitted to aircraft type* i*;* $EI_{k,m,j}$ *is the emission index of engine* k *in mode* m *of pollutant* j *(g/kg); and* $P_{i,k}$ *is the proportion of aircraft type* i *equipped with engine* k*.*

The FF of an aircraft type in different modes were estimated as (3).

$$FF_{i,m} = n_i \times \sum_k FF_{k,m} \times P_{i,k}, \qquad (3)$$

where $FF_{i,m}$ *is the fuel flow of aircraft type* i *in mode* m *(kg/s);* $FF_{k,m}$ *is the fuel flow of engine* k *in mode* m *(kg/s); and the definitions of other parameters are similar to those used in (3)."*

Comment 5: Provide a table summarizing the emission factors used for key pollutants or cite the references.

Response: We thank the referee for the advice. We have added the Table SX to present the calculation method of emission index for different pollutants. In addition, we have added the description in line 135–138 in Section 2.1.1 of the revised manuscript:

"In addition, the first-order approximation 3.0 (FOA3.0) (Wayson et al., 2009) method was used to recalculate the EI of PM, which is not included in EEDB. The emission factor of SO_2 is related to the sulphur content of jet fuel, so we used 3.868 g/kg as the emission factor of SO_2 (GB6537). In summary, the reference of the EI for different pollutants were shown in Table S1."

Table S1: The reference of the emission index (EI) for different pollutants.

Pollutant	Reference
HC	EEDB
CO	EEDB
NOx	EEDB
PM	EEDB; Wayson et al., 2009
SO_2	GB6537

Comment 6: Section 2.2: It is recommended to cite more classical literature on the application of the DBSCAN algorithm in this field.

Response: We thank the referee for the advice. We have added more classical literature on the application of the DBSCAN algorithm, including the application in the identification of road traffic, ship, and aircraft trajectories.

We have added the description in line 212–216 in Section 2.2.2 of the revised manuscript:

"DBSCAN is a density-based clustering algorithm widely used in machine learning and data mining (Chen et al., 2021; Tekin et al., 2024). For the transportation industry, it is used for the identification research of road traffic, ship, and aircraft trajectories (Gui et al., 2021; Deng et al., 2023; Li et al., 2023). The DBSCAN algorithm belongs to unsupervised learning, and the initial value setting does not significantly affect the clustering results (Ventorim et al., 2021)."

Comment 7: While the DBSCAN algorithm is referenced for flight trajectory recognition, the paper does not provide a detailed explanation of its parameters (e.g., minimum points, radius).

Response: We thank the referee for the advice. The DBSCAN algorithm relies on two input parameters, the minimum number of samples (MinPts) and distance threshold (ε). MinPts determines the minimum number of points required to form a dense region, while ε specifies the maximum distance between two points to be considered as within the same neighbourhood.

We have added the description in line 224–227 in Section 2.2.2 of the revised manuscript:

"The DBSCAN algorithm relies on two input parameters, the minimum number of samples (MinPts) and distance threshold (ε), to cluster the data space based on three basic concepts: directly density-reachable, density-reachable, and density-connected (Sander et al., 1998). MinPts determines the minimum number of points required to form a dense region, while ε specifies the maximum distance between two points to be considered as within the same neighbourhood…"

Comment 8: Section 3: What is the basis for determining the high-resolution spatial grid (0.03° × 0.03° × 34 vertical layers)?

Response: We thank the referee for the advice. This high-resolution grid was chosen to accurately capture the horizontal and altitude distribution characteristics of aircraft emissions during the LTO cycle, while also enabling the integration of the emission inventory into numerical models for subsequent research.

We have added the description in line 286–302 in Section 2.3.2 of the revised manuscript:

"For the horizontal resolution, most airport runways are approximately 3–4 kilometers (CAAC) in length and certain pollutants (such as CO) are predominantly emitted during taxiing, i.e., on the runway. 0.03°×0.03° is capable of reflecting the horizontal

distribution characteristics of aircraft emission. In addition, 0.03° × 0.03° is also a common resolution for air quality models. Therefore, the horizontal resolution of the 4D-LTO emission inventory is 0.03° × 0.03° with the latitude and longitude range of 3.40°N–53.56°N and 73.44°E–135.09°E, respectively.

For the altitude resolution, while ICAO defines the LTO cycle with a fixed mixing layer height (915 m), in reality, the mixing layer height varies significantly with region and time, leading to variations in the altitude range of the LTO cycle. Therefore, to better reflect the vertical distribution of aircraft emissions above 915 m during the LTO cycle, this study set the altitude range from 0 m to 15668 m. In addition, to ensure that the emission inventory can be effectively used in air quality models, this study used the air quality model commonly used 35-layer sigma stratification strategy (Wolfe et al., 2016). Therefore, the altitude resolution was divided into 34 layers from 0 m to 15668 m (0.0 m–38.3 m, 38.3 m–76.7 m, 76.7 m–115.3 m, 115.3 m–154 m, 154 m–231.8 m, 231.8 m–310.3 m, 310.3 m–389.3 m, 389.3 m–469 m, 469 m–549.3 m, 549.3 m–630.3 m, 630.3 m–711.9 m, 711.9 m–794.2 m, 794.2 m–960.7 m, 960.7 m–1130.1 m, 1130.1 m–1302.3 m, 1302.3 m–1477.6 m, 1477.6 m–1656.0 m, 1656.0 m–1929.7 m, 1929.7 m–2211.1 m, 2211.1 m–2599.3 m, 2599.3 m–3107.2 m, 3107.2 m–3643.1 m, 3643.1 m–4210.5 m, 4210.5 m–4813.9 m, 4813.9 m–5458.5 m, 5458.5 m–6151.2 m, 6151.2 m–6900.4 m, 6900.4 m–7717.4 m, 7717.4 m–8617.3 m, 8617.3 m–9621.2 m, 9621.2 m–10759.7 m, 10759.7 m–12080.6 m, 12080.6 m–13664.8 m, 13664.8 m–15668 m.).”

Comment 9: Does this resolution significantly improve the representation of emissions compared to conventional models with fewer layers?

Response: We thank the referee for the advice. While ICAO defines the LTO cycle with a fixed mixing layer height (915 m), in reality, the mixing layer height varies significantly with region and time, leading to variations in the altitude range of the LTO cycle. However, conventional models with fewer layers cannot reflect the vertical emission distribution characteristics above 915 m during the LTO cycle. Therefore, our resolution improves the representation of emissions above 915 m during the LTO cycle

We have added the description in line 291–294 in Section 2.3.2 of the revised manuscript:

"For the altitude resolution, while ICAO defines the LTO cycle with a fixed mixing layer height (915 m), in reality, the mixing layer height varies significantly with region and time, leading to variations in the altitude range of the LTO cycle. Therefore, to better reflect the vertical distribution of aircraft emissions above 915 m during the LTO cycle, this study set the altitude range from 0 m to 15668 m."

Comment 10: Section 3.2: The data in this paragraph is messy to show as a list, can it be shown as a table or some other form?

Response: We thank the referee for the advice. To present the data more clearly, we have added the Table S6 of the SI to present the change of the LTO number during and after the COVID-19 pandemic. In addition, we have added the description in line 376–378 in Section 3.2 of the revised manuscript:

"As can be seen from Figure 5(a) and Table S5, from January 20 to February 13, 2020, aircraft activity rapidly dropped to the lowest point owing to the impact of COVID-19, showing that the number of LTO on February 13, 2020, was 84.8% lower than the same period in 2019."

Table S5: The difference of LTO numbers before, during and after the epidemic compared with the same period in 2019

Date	LTO number (10^4)	LTO number for the same period in 2019 (10^4)	LTO number change rate compared the same period in 2019
2020.1.20	1.71	1.56	9.2%
2020.2.13	0.24	1.61	-84.8%
2021.2.12	0.28	1.65	-83.1%
2021.8.12	0.67	1.70	-60.3%
2021.11.9	0.63	1.55	-59.5%

2022.4.4	0.19	1.57	-87.7%
2022.11.29	0.30	1.53	-80.4%
2023.4.6	1.45	1.45	-0.1%

Comment 11: Section 4: The study area is China, and the literature of the comparative study is better supplemented with more studies of Chinese airports.

Response: We thank the referee for the valuable advice. We have added more literatures of Chinese airports in line 466–468 in Section 3.4 of the revised manuscript:

"Figure 8 uses the NOx emissions in January 2023 to show the differences between the 4D-LTO emission inventory and the LTO emission divided in previous study (Mokalled et al., 2018; Bo et al., 2019; Lawal et al., 2022; Wang et al., 2023; Zhang et al., 2023) in terms of height distribution (Fig. 8(a)–(b)) and horizontal distribution (Fig. 8(c)–(e))…"

Comment 12: For the result of emission during 2020-2023, while the authors compare results with previous ICAO-based methods, the statistical measures of validation (e.g., R^2, RMSE) are not clearly presented.

Response: We thank the referee for the advice. We have utilized the Mean Absolute Error (MAE) and Mean Absolute Percentage Error (MAPE) as statistical indicators to evaluate the discrepancies between our 4D-LTO emissions inventory dataset and the previous ICAO-based methods. We have added the description in line 469–470 in Section 3.4 of the revised manuscript:

"Two statistical measures, Mean Absolute Error (MAE) and Mean Absolute Percentage Error (MAPE), were employed to quantify these differences…"

Comment 13: It should be further clarified the datasets used for validation, including observational data from airports and other inventory results.

Response: We thank the referee for the valuable advice. In Section 2.1, this study used the actual data to verify the running time data (taxi in, taxi out, climb, approach) used in the calculation of emissions. In Section 2.2, this study used the actual flight trajectory data to verify the performance of the DBSCAN model. In addition, we also to compared our dataset with previous study's spatial allocation methods. The description of the comparison in line 307–313 in Section 2.4 of the revised manuscript:

"Our dataset was compared with the spatial allocation methods commonly used in previous studies. (1) Other studies typically assign aircraft emissions in the LTO cycle according to the standard altitude for each mode as defined by ICAO (Mokalled et al., 2018; Bo et al., 2019; Wang et al., 2023; Zhang et al., 2023). (2) The conventional horizontal distribution method for aircraft emissions in the LTO cycle assumes that aircraft emissions are radially distributed (Lawal et al., 2022). The Federal Aviation Administration (FAA)-recommended the standard climb rate of 200 ft per nautical mile. Therefore, the standard climb rate and ICAO standard altitude determine the horizontal distribution of aircraft emissions around the airport. The running time, altitude, and horizontal range of each mode defined by ICAO are shown in Table 1…"

Comment 14: Line 444: The results mention a rebound in emissions by 2023 to 95.3% of 2019 levels, but this observation is not broken down by pollutant or flight mode.

Response: We thank the referee for the advice. We have added the description of the rebound in emissions for different pollutants in line 544–545 in Section 5 of the revised manuscript:

"However, in 2023, the emissions of different pollutants quickly bounced back to 82.9%–94.1% of the 2019 levels, resulting in HC, CO, NOx, PM, and SO_2 emissions of 3.2 Gg, 46.1 Gg, 62.3 Gg, 1.1 Gg, and 18.4 Gg, respectively."

Comment 15: Apart from NOx, other pollutants such as HC and PM are not discussed in detail, why? and what are their specific temporal and spatial patterns?

Response: We thank the referee for the advice. In this study, the temporal variations of different pollutants were introduced in Section 3.2. Regarding the spatial patterns, NOx makes a significant contribution to overall aircraft emissions and has a substantial impact on air quality. Furthermore, the spatial distribution of PM and SO_2 emissions from aircraft is similar to that of NOx. Notably, HC and CO are predominantly emitted during the taxi mode (Yang et al., 2018), which occurs on the runway. During the LTO cycle, emissions of HC and CO at other altitudes are negligible. Consequently, HC and CO emissions are concentrated in the first layer of the grid where the runway is located. In summary, this study primarily focused on the spatial distribution of NOx emissions. We have added the description in line 399–403 in Section 3.3 of the revised manuscript: *"During the LTO cycle, HC and CO emissions, predominantly emitted during taxi mode (Yang et al., 2018). Consequently, HC and CO emissions are distributed in the first layer of the grid where the runway is located. NOx is an important contributor to overall aircraft emissions and has a significant impact on air quality (Zhang et al., 2024). Furthermore, the spatial distribution of PM and* SO_2 *emissions from aircraft is similar to that of NOx. In summary, this study mainly analyzed the spatial distribution of NOx emissions."*

Comment 16: Line 460: The emissions above 915 m account for 24.6%, what is the significance of this finding? Does this altitude range impact local air quality differently than ground-level emissions?

Response: We thank the referee for the advice. The ICAO defines the LTO cycle with a fixed mixing layer height of approximately 915 m. However, in reality, the mixing layer height varies significantly with region and time, resulting in variations in the altitude range of the LTO cycle. Previous studies (Köhler et al., 2008; Lee et al., 2013; Yim et al., 2015; Zhang et al,.2023) that presents the high-altitude (above 915 m) emissions can significantly impact ground-level air quality through atmospheric transport and chemical reactions. This study found that some of these high-altitude emissions were belong to the LTO cycle, and this part of emissions accounted for 24.6% of the total emissions during the LTO cycle. Therefore, ignoring these emissions would bring uncertainty in subsequent assessments of the impact of the LTO cycle on air quality and health.

We have added the description of the significance of our finding in line 459–462 in P19 of the revised manuscript:

"Based on previous study (Köhler et al., 2008; Lee et al., 2013; Yim et al., 2015; Zhang et al., 2023), high-altitude emissions can significantly impact ground-level air quality through atmospheric transport and chemical reactions. When assessing emissions during the LTO cycle and their impact on air quality and health, we must fully consider the contribution of above 915 m emissions."

Comment 17: Health impacts are mentioned in the introduction, but there is no specific health-related discussion in the discussion, specific pollutants such as NOx and $PM_{2.5}$ are known to cause respiratory and cardiovascular issues, please add or cite references.

Response: We thank the referee for the valuable advice. We have added the health-related descriptions and references in line 346–349 in Section 3.1 of the revised manuscript:

"Emissions of pollutants from aircraft, such as NOx and $PM_{2.5}$, are known to cause respiratory and cardiovascular issues (Boningari et al., 2016; Hu et al., 2022; Hou et al., 2024). Therefore, it is essential to pay attention to the growing trend of aircraft activities in order to anticipate and address its potential health impacts."

Comment 18: The dataset is established for China, how can the methodology be applied to other regions with different aviation?

Response: We thank the referee for the advice. While our 4D-LTO emission inventory dataset was initially established for China, the methodology possesses broad applicability. When applying our methodology to other regions with different aviation profiles, researchers can directly construct airport-specific models by adhering to the 4D emission inventory method detailed in Section 3.2, and inputting localized parameters e.g., operational activity data, airport-specific emission factors, and airport-specific flight trajectory datasets.

We have added the description in line 566–568 in Section 5 of the revised manuscript:

"Furthermore, by adjustments to accommodate regional differences, e.g., operational activity data, airport-specific emission factors, and airport-specific flight trajectory datasets, our methodology possesses broad applicability and flexibility."

Comment 19: Linking the conclusion to wider global challenges such as climate change or international emissions reduction targets for aviation will be better.

Response: We thank the referee for the valuable advice. We have added the description of the related to climate change and international emissions reduction targets for aviation in line 564–569 in Section 5 of the revised manuscript:

"By conducting in-depth analysis of our refined dataset, we can quantify the aviation industry's contribution to climate change and explore potential emission reduction pathways. Furthermore, by adjustments to accommodate regional differences, e.g., operational activity data, airport-specific emission factors, and airport-specific flight trajectory datasets, our methodology possesses broad applicability and flexibility. The application of our methodology to other regions, is a fundamental in formulating effective strategies and policies to achieve global aviation emission reduction targets."

Reference

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