We sincerely thank the reviewers for their careful evaluation of our revised manuscript and for their constructive comments. We have carefully considered each suggestion and further revised the manuscript to improve its clarity, transparency, and methodological justification. In particular, we have clarified the sources and linkage of the underlying databases, provided additional explanations for the uncertainty settings, and refined the terminology describing the engine-level fuel-flow calculations. We believe these revisions have improved the manuscript, and we hope that our responses adequately address the reviewers' remaining concerns.

Reviewer 1

I appreciate the authors' revisions and efforts to address my comments, but the following two points still require clarification.

Comment 1:

1.Please identify the sources and versions of the flight schedule and aircraft static databases. Clarify whether FLIGHT_INFO_ID is shared by the original QAR and schedule datasets or assigned during preprocessing; if assigned, briefly describe how the records were linked.

Response 1:

We thank the reviewer for requesting this clarification regarding database provenance and record linkage. Both the flight schedule dataset and the aircraft static database were obtained from the 2023 annual operational archive maintained by the Civil Aviation Flight Quality Monitoring Base Station of China (operated by the China Academy of Civil Aviation Science and Technology, CAST, and synchronized with the official 2023 Civil Aviation Administration of China fleet registration records). Because both the QAR dataset and the flight schedule dataset are exported directly from this same centralized monitoring platform, the unique flight sequence identifier (FLIGHT_INFO_ID) is natively present and shared across both original datasets as the system's built-in primary key. Consequently, the QAR records and flight schedule records were linked directly via this native FLIGHT_INFO_ID. We have updated Sections 2.2.3 and 2.3.1 to explicitly state the sources and 2023 archive versions of both databases and to clarify that

FLIGHT_INFO_ID is natively shared.

In Section 2.2.3, the text was revised to specify the database version and clarify the native sharing of FLIGHT_INFO_ID, reading as follows:

"The flight schedule data were also obtained from the 2023 annual operational archive of the Civil Aviation Flight Quality Monitoring Base Station of China (maintained by the China Academy of Civil Aviation Science and Technology, CAST) and cover scheduled civil aviation flights operated within mainland China, excluding Hong Kong, Macao, and Taiwan, throughout 2023. The dataset provides basic flight information, including airport identifiers, aircraft type, engine type, and departure and arrival times (Table 2).

The original time fields were recorded in Coordinated Universal Time (UTC) and were converted to China Standard Time (UTC+8). Because both the QAR data and the flight schedule dataset are exported from the same centralized monitoring platform, the unique flight sequence identifier (FLIGHT_INFO_ID) is natively shared across both original datasets. The processed schedule data were therefore directly linked to the QAR records using FLIGHT_INFO_ID, providing basic flight attributes for the QAR records. The matching of engine types in the schedule data with the International Civil Aviation Organization (ICAO) Engine Emissions Databank (EEDB) is described in Section 2.3.1."

In Section 2.3.1, the first paragraph was revised to identify the source and version of the aircraft static database, reading as follows:

"Building upon the basic flight attributes linked via the shared FLIGHT_INFO_ID in Section 2.2.3, the aircraft registration number (AC_TAIL) and aircraft type (AC_TYPE) were extracted for each flight record and linked to the 2023 Civil Aircraft Static Database maintained by CAST and the Civil Aviation Flight Quality Monitoring Base Station of China (synchronized with official CAAC fleet registration records) to identify the installed engine types... "

Comment 2:

2.The revised framing of the Monte Carlo analysis as uncertainty propagation is helpful. However,

Shapley decomposition explains how the assumed input uncertainties contribute to the simulated output variance; it does not establish whether those assumptions accurately represent real-world errors. Please provide clearer empirical or literature support for the key uncertainty parameters in Table 3, particularly the different fuel-flow uncertainties assigned to QAR, ADS-B, and SFD.

Response 2:

We sincerely thank the reviewer for this helpful suggestion. We agree that Shapley decomposition quantifies the contributions of prescribed input uncertainties to the simulated output variance but does not independently validate their magnitudes. We have therefore revised the discussion following Table 3 in Section 2.4 to clarify the literature basis for the uncertainty parameters, particularly the different fuel-flow uncertainties assigned to QAR, ADS-B, and SFD. We have also distinguished literature-reported error ranges from additional modelling allowances adopted where directly transferable empirical estimates are unavailable. The revised relevant part of Section 2.4 is provided below:

"The fuel-flow uncertainties were parameterized according to the measurement or reconstruction procedures used in each framework. For the QAR-based approach, a 1.5% systematic bias was assigned, slightly exceeding the typical fuel-flow sensor accuracy of ±1% (Baumann et al., 2021). The temporally correlated component was set to 0.5%, consistent with the 0.2% – 0.5% average dynamic errors reported in the same study. An additional 0.2% additive residual was prescribed to account for unresolved measurement variability. For the ADS-B-based approach, fuel flow is reconstructed from trajectory-derived aircraft states and performance models. Krajček Nikolić et al. (2024) reported phase-dependent errors reaching 17.2% during initial climb and -53.5% during approach, although the mean whole-flight error was 1.2% (standard deviation: 1.3%) based on five flights. Considering these phase-dependent discrepancies, a 10% systematic bias was adopted as a conservative modelling allowance. The 6% temporal component and 1.0% additive residual were prescribed to represent time-varying reconstruction errors and unresolved local discrepancies. For the SFD-based approach, a 20% systematic bias was adopted, informed by the approximately 17.7% standard deviation of flight-level fuel-burn errors reported for schedule-derived trajectories by Lee (2005). The 10% temporal component and 1.5% additive residual were prescribed to represent additional uncertainties in the generalized fuel-flow profile.

Environmental uncertainties were specified according to the data sources used in each framework. For QAR, pressure and temperature perturbations were set to 0.5% and 0.5 K, respectively, representing small allowances for onboard measurement uncertainty. For ADS-B, which uses ERA5 meteorological fields, these values were increased to 1.5% and 2 K. The 2 K temperature perturbation provides a conservative allowance relative to the approximately 0.57 – 1.66 K upper-air temperature observation errors reported for ERA5 (Hersbach et al., 2020), while the pressure perturbation was prescribed to account for residual meteorological uncertainty. For SFD, pressure and temperature perturbations were further increased to 3% and 5 K, respectively, to reflect the absence of flight-specific meteorological information (ICAO, 1993). Distance and airborne time were assigned 8% perturbations to represent differences between scheduled and actual operations, while taxi time was assigned a larger 30% perturbation to account for operational variability (Simaiakis & Balakrishnan, 2016; Teoh et al., 2024).

Uncertainties in the emission indices of NOx, CO, HC, and nvPM were set to 8%, 12%, 12%, and 18%, respectively, and applied consistently across the three frameworks. These values represent prescribed residual uncertainties in engine-specific emission parameters and their application to in-service conditions (Kim et al., 2007; Wasiuk et al., 2015). Koopmann et al. (2014) reported approximately ±10% uncertainty for BFFM2 calculations under non-reference conditions, as well as engine-to-engine variability of ±16%, ±23%, and ±54% for NOx, CO, and HC, respectively. The adopted values therefore represent residual perturbations after engine-type matching, rather than the full range of engine-to-engine variability. The 18% nvPM perturbation was prescribed to account for uncertainties in particulate emission parameters. Fuel sulfur content was sampled from a truncated Gaussian distribution to represent its variability and influence on SO2 and sulfate emissions (Kapadia et al., 2016). The resulting input uncertainties were propagated through 10,000 Monte Carlo simulations, and output uncertainty was quantified using the coefficient of variation (CV), defined as the ratio of the standard deviation to the mean of the simulated emissions."

Reviewer 2

Comment 1:

I have only one minor suggestion regarding terminology. Could the authors clarify the use of "single-engine" throughout the manuscript since the QAR system records fuel flow for each engine. This clarification would improve clarity for readers using the underlying data.

Response 1:

We thank the reviewer for pointing out this potential terminology ambiguity. We agree that the term "single-engine fuel flow" could be misinterpreted as referring to aircraft equipped with only one engine. Our intended meaning was that fuel flow and emissions are calculated on a per-engine basis, consistent with the engine-level formulation of the ICAO EEDB reference curves and the BFFM2 normalization procedure.

Specifically, the QAR system independently records the 1-Hz fuel flow of each operating engine (e.g., FF1 and FF2 for two-engine aircraft). In our calculation framework, the measured fuel flow of each engine is independently converted to reference conditions and matched to the corresponding EEDB emission-index curves. Emissions are then calculated for each engine separately and summed across all operating engines to obtain aircraft-level emissions.

To avoid confusion, we have replaced "single-engine fuel flow" with "per-engine fuel flow" or "individual-engine fuel flow" throughout the manuscript, including the Abstract, Section 1, Section 2.3.1, Section 2.3.2, and Section 5. The specific modifications across the manuscript read as follows:

In the Abstract, the sentence was revised as follows: "Integrating 1-Hz per-engine fuel-flow measurements with observed flight trajectories, ambient temperature and pressure, and specific humidity profiles via the Boeing Fuel Flow Method 2 and atmospheric corrections, this dataset yields temporally and spatially explicit emission estimates for CO_2, NO_x, SO_2, PM, CO, and HC."

In Section 1 (Introduction, Paragraph 6), the sentence was revised as follows: "Synthesizing measured per-engine fuel flow with airborne thermodynamic parameters and reanalysis humidity profiles, we derive a four-dimensional inventory of CO_2, NO_x, SO_2, PM, CO, and HC emissions,

and examine how input uncertainties propagate across QAR, ADS-B, and schedule-based frameworks."

In Section 2.3.1 (Paragraph 2), the text was revised to clarify the per-engine definition: "Following engine identification, the corresponding reference emission indices (EIs) were extracted from the EEDB and parameterized as continuous functions of per-engine fuel flow. The QAR system records fuel flow independently for each engine at 1-Hz resolution, providing the engine-specific fuel-flow input required for the emission-index parameterization described below.."

In Section 2.3.1 (Paragraph 4), the sentence was revised as follows: "The resulting engine-specific reference EI relationships were subsequently combined with the instantaneous per-engine fuel-flow measurements from QAR to determine the reference EIs corresponding to actual flight operating conditions."

In Section 2.3.2 (Paragraph 3), the sentence introducing Eq. (2) was revised to state: "The measured fuel flow for each engine (W_f) was then independently converted to its corresponding reference-condition fuel flow according to the BFFM2 formulation:"

In Section 5 (Conclusion, Paragraph 1), the sentence was revised as follows: "Incorporating 1-Hz per-engine fuel flow with observed flight trajectories, onboard ambient temperature and pressure measurements, and ERA5 specific humidity profiles, the inventory characterizes aviation emissions under actual operating conditions rather than relying solely on schedule-based or performance-model proxies."