Responses to Interactive Comments

Journal: Atmospheric Chemistry and Physics

Manuscript ID: ACP-2025-596

Title: Toxic Dust Emission from Drought-Exposed Lakebeds – A New Air Pollution Threat from Dried Lakes

The response for the reviewer's comments appears in blue, and manuscript changes are highlighted in red.

We thank Referee #2 for the insightful feedback. We have addressed all comments to the best of our ability, with detailed responses below.

Review of "Toxic Dust Emission from Drought-Exposed Lakebeds – A New Air Pollution Threat from Dried Lakes" by Qianqian Gao, Guochao Chen, Xiaohui Lu, Jianmin Chen, Hongliang Zhang, and Xiaofei Wang

The aim of this article is to study dust emissions and transport during droughts affecting lakes in China that have become erodible. Sediments can store pollutants (polycyclic aromatic hydrocarbons (PAHs), metals) that can then have an impact on human health. The methodology consists of taking sediment samples and then using a laboratory aerosol generator (GAMEL) to study the size distribution and composition of the emitted flux. The second part uses the regional CMAQ model. The third part calculates the population's exposure to these aerosols. The article is original and deals with a subject that has not yet been studied to any great extent. The methodology is based on measurements both in situ and in a wind tunnel to reproduce an emission due to wind erosion.

Response: We are grateful to Referee #2 for the detailed and constructive suggestions, which greatly help improve the clarity and quality of the manuscript. Our responses to each point are listed below.

Major comments:

Structure of the paper:

The supplement is very long and some parts could be included directly in the article: either in the text itself or as an appendix. The authors should sort out what is essential for understanding the work and what is extra (i.e. in the supplement). In this version, there are 4 figures in the article but 15 in the supplement. There could be 10 in the article, making it easier to understand the study as you read.

Response: Thank you for the thoughtful suggestion regarding the organization of figures between the main text and the supplementary information. Following your recommendation, we carefully evaluated all figures and identified those most essential to understanding the core findings of the study. As a result, we have moved additional figures from the supplementary information into the main manuscript, increasing the number of figures in the article from **4** to **7**.

Specifically:

we have moved the map (now revised as Fig. 1) to the beginning of the materials and methods section to aid readers in understanding the sampling design. A population density layer has also been added (bottom left panel) to highlight the spatial relationship between sampling sites and nearby human populations. This adjustment improves the spatial context and addresses the concern about figure timing and clarity. The individual PAH concentration figures (original supplementary Figure S6) from the supplementary information were merged with total PAH concentrations (original Figure 1) into a single, more informative Figure 2, now in the main text.

Two critical figures related to toxic equivalency and health risk assessment—Figure S15 (BaP_{eq} comparison) and Figure S14 (Cr_{eq} comparison)—have been moved to the main text as Figures 5 and 6, respectively.

These figures were chosen to best illustrate the central results and improve the coherence of the manuscript. We believe that including them in the main text provides a balanced and accessible presentation without overwhelming the reader.

Change in the manuscript:

2.1 Sampling location

In October 2022, during an extreme drought event, a total of nine lakebed soil samples were collected from the top 5 cm of the soil profile at Poyang Lake and Dongting Lake to examine the concentrations of PAHs and heavy metals in exposed lakebed dust. The sampling sites were distributed across three types of hydrological zones: (1) areas typically not submerged throughout the year (PY-D1, PY-D2, and DT-D1); (2) transitional zones that alternate between wet and dry conditions (PY-T1, PY-T2, and DT-T1); and (3) areas usually submerged but exposed due to drought (PY-S1, PY-S2, and DT-S1). The sampling sites around Poyang Lake were all located within one kilometer of the lake surface. Details of the sampling locations are provided in Table 1 and shown in Fig. 1. All collected soil samples were air-dried, sieved through a 2 mm nylon mesh to remove debris, thoroughly homogenized, and stored at 4 °C in the dark prior to analysis.

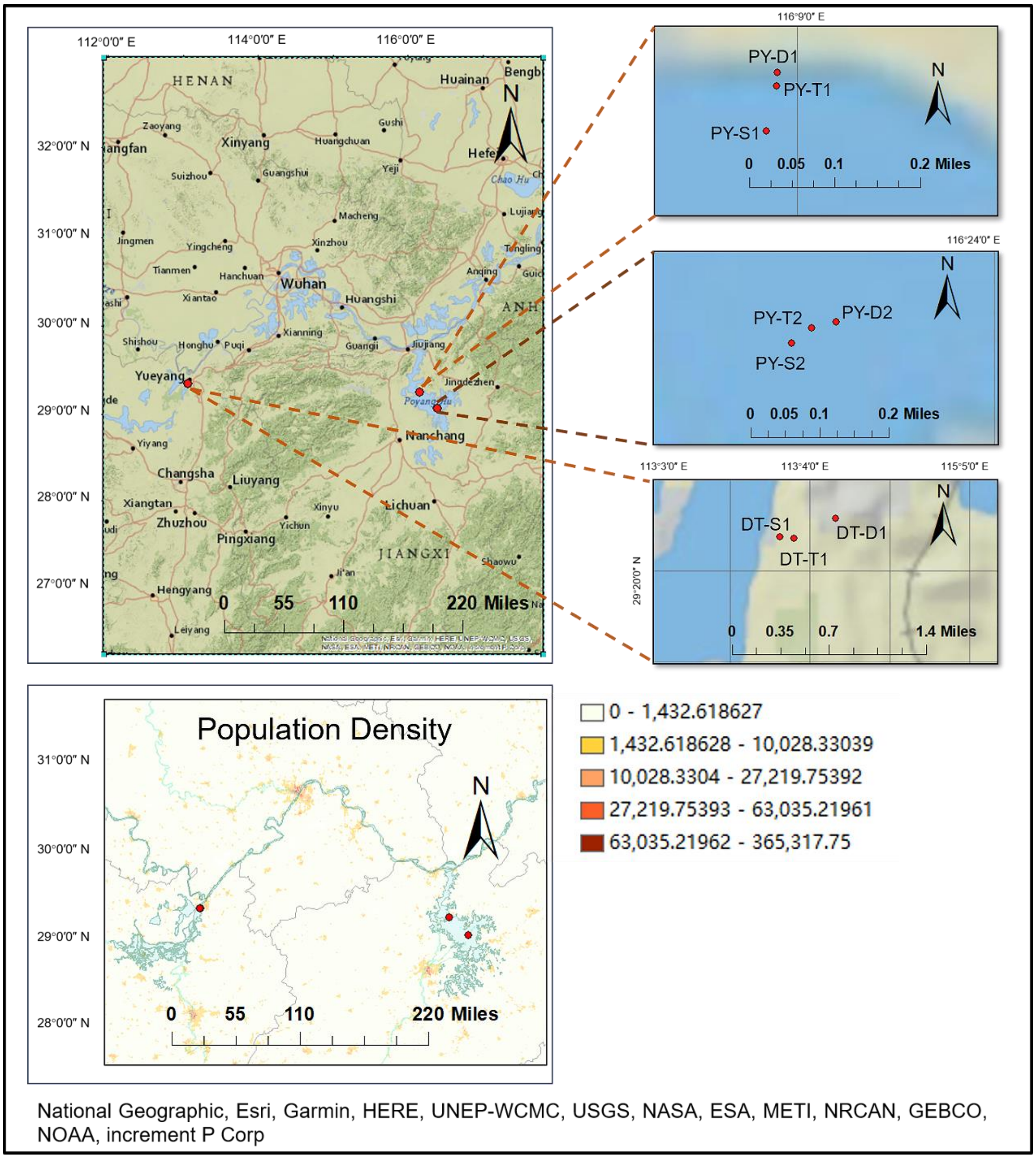


Figure 1. Sampling locations in Poyang Lake and Dongting Lake (marked as red dots). Sites PY-D1, PY-D2, and DT-D1 represent regions typically dry and exposed year-round. PY-T1, PY-T2, and DT-T1 are transitional zones that alternate between submerged and dry states. PY-S1, PY-S2, and DT-S1 are areas usually submerged but occasionally exposed due to extreme drought conditions. PY-D1, PY-T1, and PY-S1, along with PY-D2, PY-T2, and PY-S2, are located within Poyang Lake, while DT-D1, DT-T1, and DT-S1 correspond to Dongting Lake. A 2020 population density layer from WorldPop (1 km resolution) is overlaid, using a yellow-to-red color ramp to indicate increasing population density. The base map is sourced from National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI,

NRCAN, GEBCO, NOAA, and increment P Corp, as provided in the ArcGIS software.

"Among the compounds, NAP, FLU, and PHE dominated across most samples, while BaP, a carcinogenic PAH, was also consistently present. Compared to Poyang Lake sites (Fig. 2d and Fig. 2e), Dongting Lake samples (Fig. 2f) showed higher overall PAH levels and a greater proportion of high-molecular-weight species, particularly in fine particles."

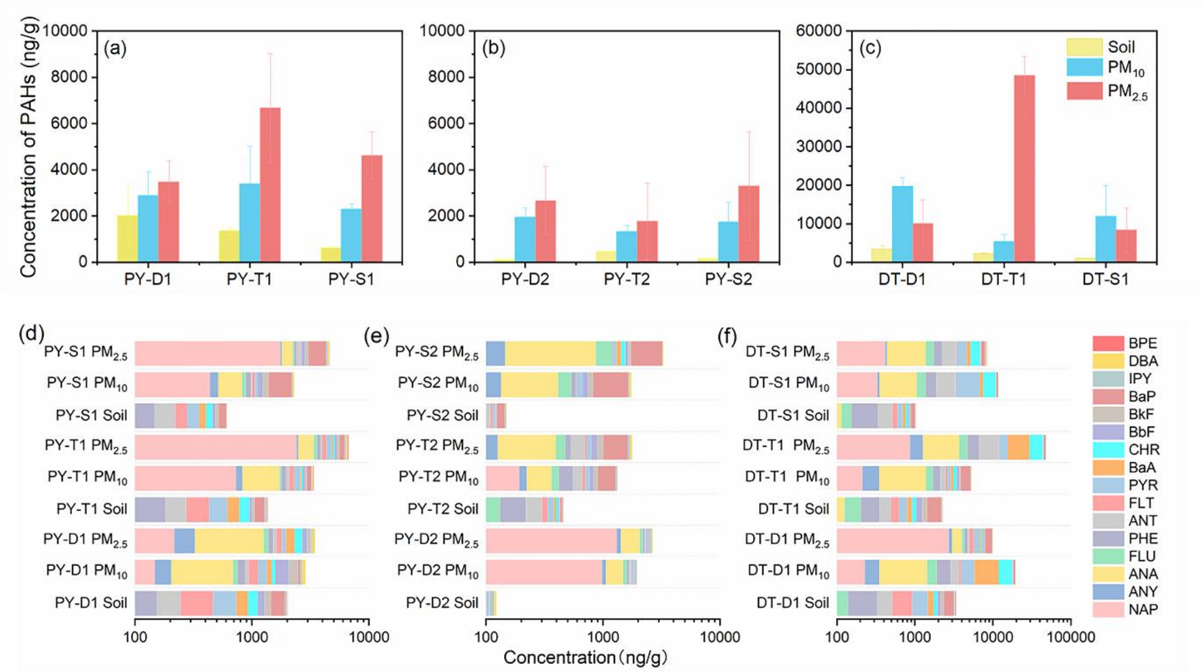


Figure 2. Concentrations and compositional profiles of PAHs in parent lakebed soils and associated dust aerosols from Poyang Lake (PY) and Dongting Lake (DT). (a)–(c) present total PAH concentrations (ng/g) in soils, dust-PM_{10}, and dust-$PM_{2.5}$ samples across different hydrological zones: dry (D), transitional (T), and submerged (S) for Poyang Lake (PY-D1, PY-T1, PY-S1; PY-D2, PY-T2, PY-S2) and Dongting Lake (DT-D1, DT-T1, DT-S1). (d)–(f) shows the compositional distribution of 16 priority PAHs in soil and dust aerosol samples from the same zones.

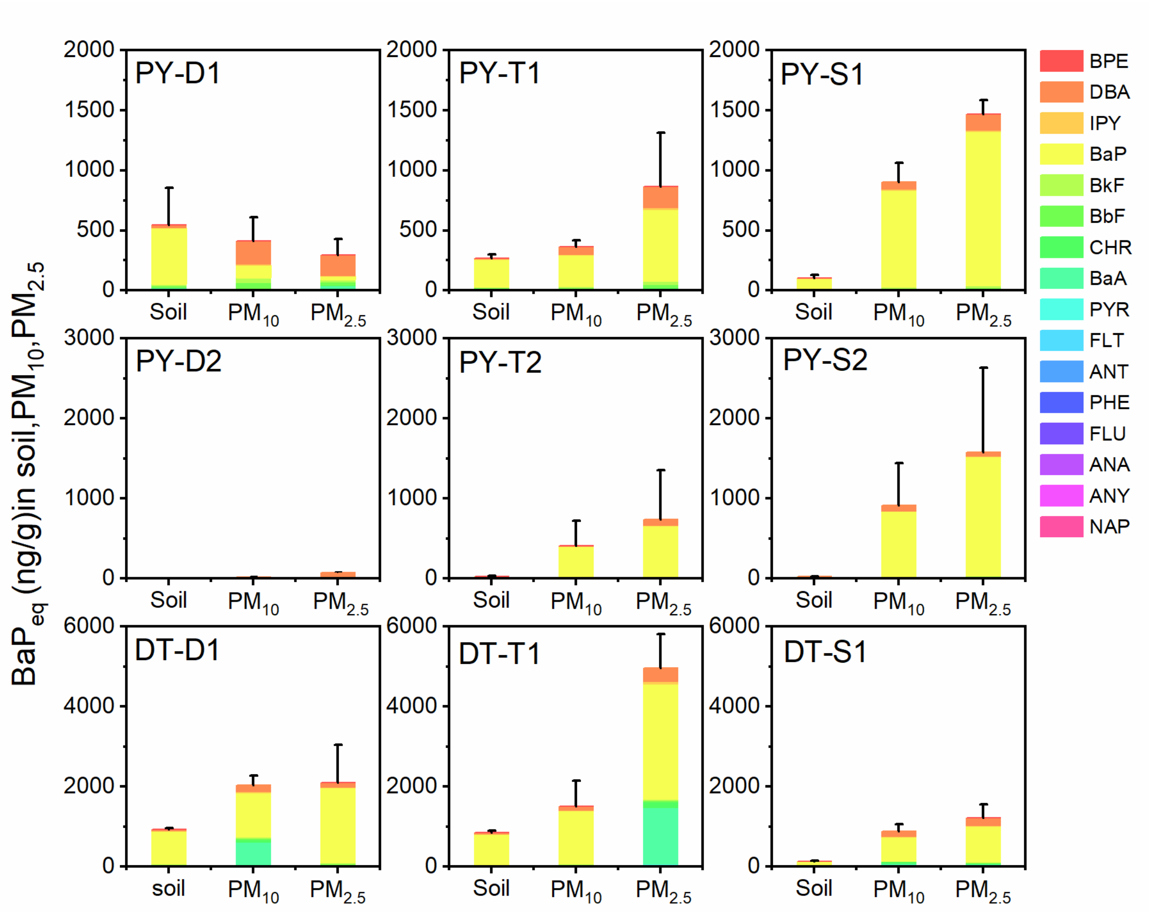


Figure 5. Comparison of BaP-equivalent concentrations of PAHs (BaPeq) in soil, dust-PM_{10} and dust-$PM_{2.5}$ samples at nine sampling sites in Poyang Lake (PY-D1, PY-T1, PY-S1, PY-D2, PY-T2, PY-S2) and Dongting Lake (DT-D1, DT-T1, DT-S1). The stacked bars show the contributions of individual PAH compounds to the total BaPeq at each site. BaPeq was calculated using toxic equivalency factors (TEFs) obtained from the U.S. EPA.

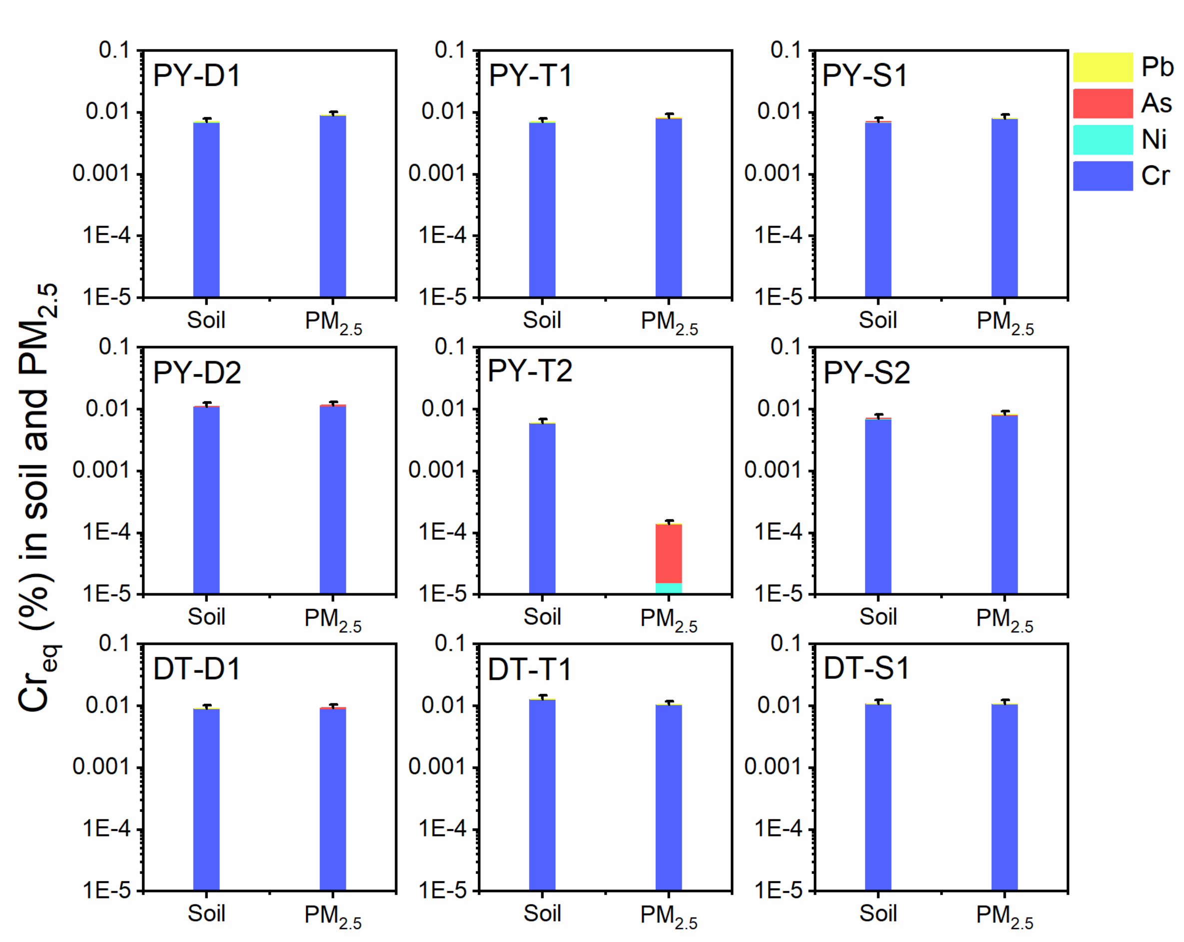
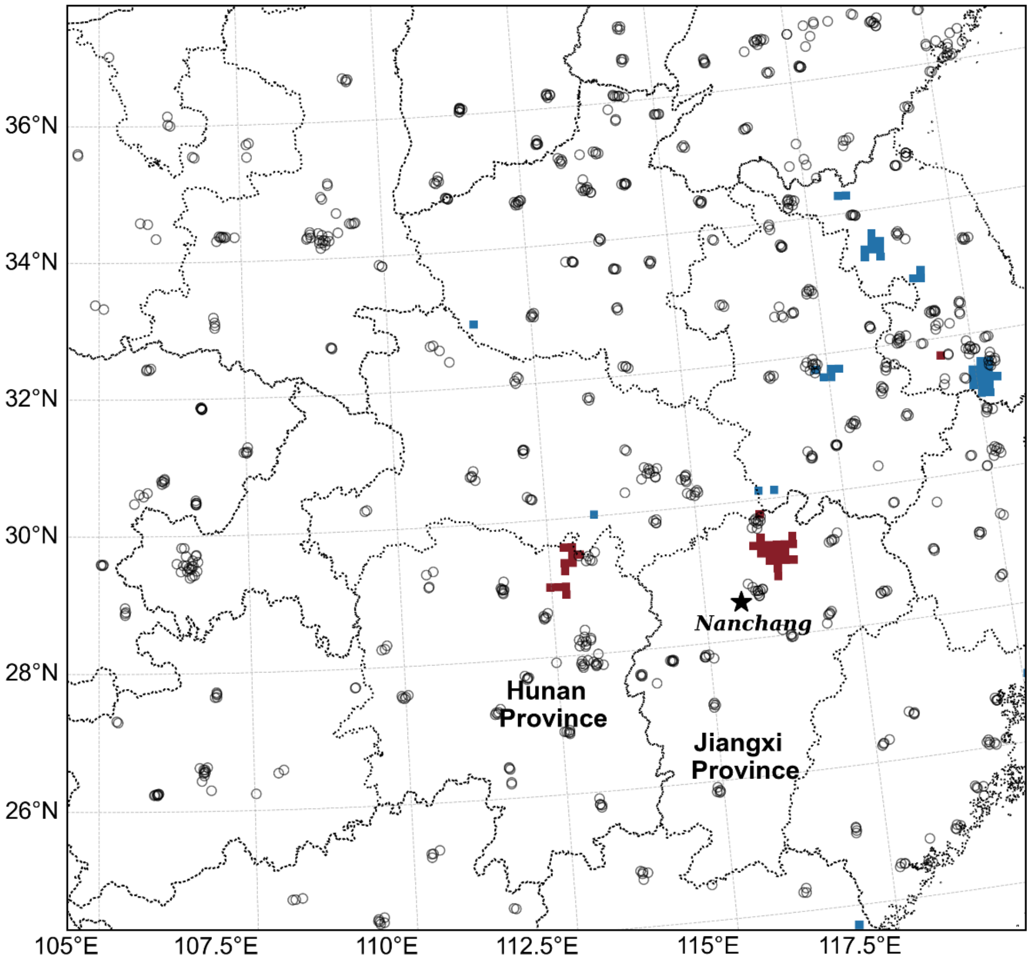


Figure 6. Comparison of Cr_{eq} (%) values of four toxic metals (Pb, As, Ni, and Cr) in natural soil and dust-PM_{10} samples at nine sampling sites in Poyang Lake (PY-D1, PY-T1, PY-S1, PY-D2, PY-T2, PY-S2) and Dongting Lake (DT-D1, DT-T1, DT-S1). Cr_{eq} values were calculated based on toxic equivalent factors (TEFs), and the stacked bars represent the relative contribution of each metal to the total Cr_{eq}.

Model validation:

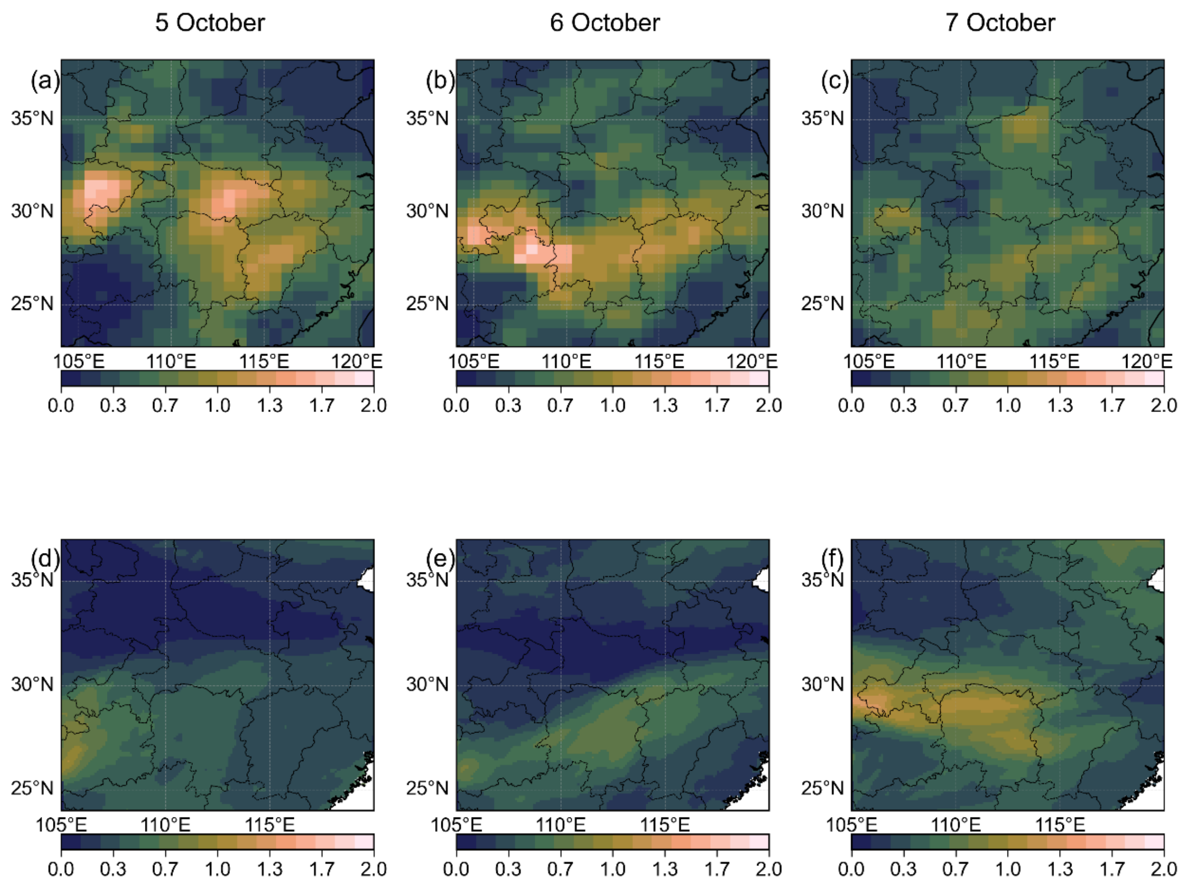
The CMAQ simulation appears to be not fully validated (only one site: Nanchang). Surface $PM_{2.5}$ and PM_{10} measurements exist, as well as AOD and Angstrom exponent with the AERONET network to quantify whether the simulation is realistic or not. It is important to validate the concentration before concluding on exposure and impacts. And the "alignment" (l.556) may be quantified with correlation (defined in the Supplement) for example. And the limitations of the simulation are not only due to the meteorology or land use but probably also to the source and sinks scheme i.e. the dust production model and the wet and dry deposition schemes used. Please information and data about these points.

Response: Thanks for your comments. The validation of $PM_{2.5}$ and PM_{10} in this study included not only the Nanchang sites but also 813 monitoring sites across the entire domain (as shown in the following figure (now added as Fig. S2)). A total of 486307 PM_{10} records and 464454 $PM_{2.5}$ records were used to ensure the model's accuracy for the entire domain (Table S8). For Nanchang specifically, we validated using the average of 9 monitoring sites located in the city (Fig. S9). The improvement of "alignment" was demonstrated both in the domain statistics (Table S8) and the Nanchang evaluation (Fig. S9).

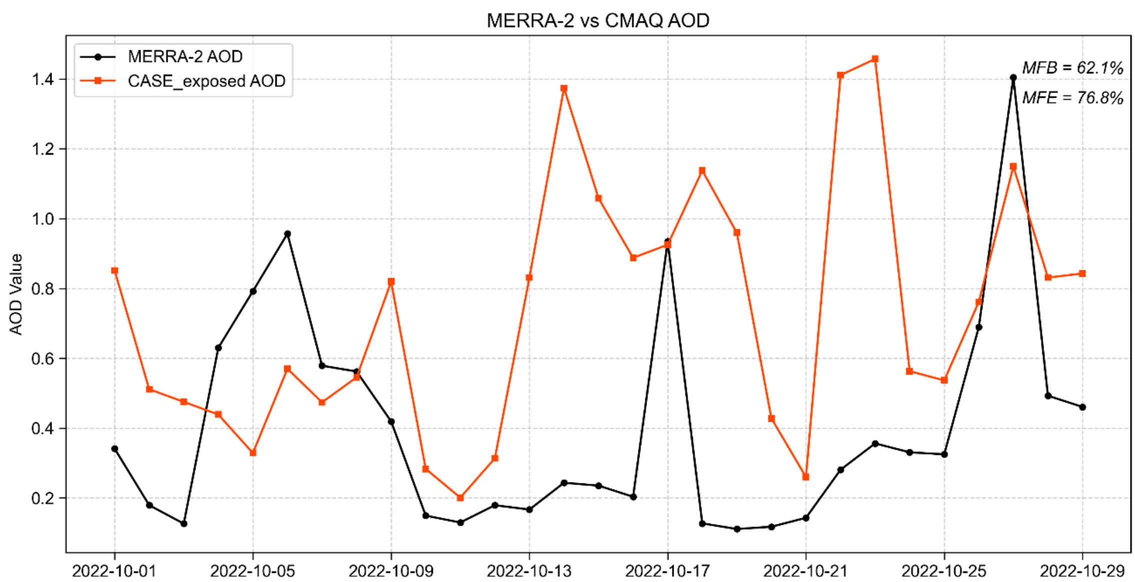


Supplementary Figure S2 Study area setting. Grid cells in the plot of blue are ordinary lakes, and those in red are the exposed lakebeds detected by sentinel-2. Nanchang near Poyang Lake is marked. Hollow circles indicate observation sites.

Additionally, due to the lack of AERONET data in central China, we utilized MERRA-2 reanalysis AOD data (550 nm) for comparison with our simulation results, as shown in the following figures (the figures have been added to the supplementary information as Fig. S10 and Fig. S11 with corresponding text adjustments in **materials and methods** and **results and discussion**). Figure S10 presents spatial distribution of AOD from MERRA-2 reanalysis (0.5° × 0.625°) and CASE_exposed simulation results (12 km × 12 km) during October 5–7. Figure S11 displays the time series of AOD at a grid point near Nanchang (29.3°N, 115.8°E). Although discrepancies exist between the simulation and reanalysis results, the overall spatiotemporal distributions are generally consistent. The model captured the relatively high AOD in Hunan and Jiangxi provinces, though the absolute values exhibited certain biases, likely due to unadjusted parameterizations. However, comparisons with other CMAQ-based dust modeling indicate that AOD discrepancy is a common issue, and our model's performance was consistent with these previous studies (Kong et al., 2022; Liu et al., 2021). Given the resolution differences between the CMAQ and MERRA-2, the uncertainties in both satellite retrievals and model simulations, the similar performance between our results and previous studies, and satisfactory performance in mass concentration validation, we consider that the CMAQ results are robust for this analysis.



Supplementary Figure S10. Spatial distribution of AOD from MERRA-2 reanalysis (a-c) and CMAQ (CASE_exposed scenario) (d-f), during 5–7 October 2022.



Supplementary Figure S11. Time series of AOD at a grid point near Nanchang (29.3°N, 115.8°E) from MERRA-2 reanalysis and CMAQ (CASE_exposed scenario).

We have added the description of uncertainties. The source and sink schemes employed in this study were based on previous studies (Gao et al., 2023b; Hu et al., 2017; Zhang et al., 2012; Choi and Fernando, 2008; Binkowski and Shankar, 1995).

Change in the manuscript:

Materials and methods section

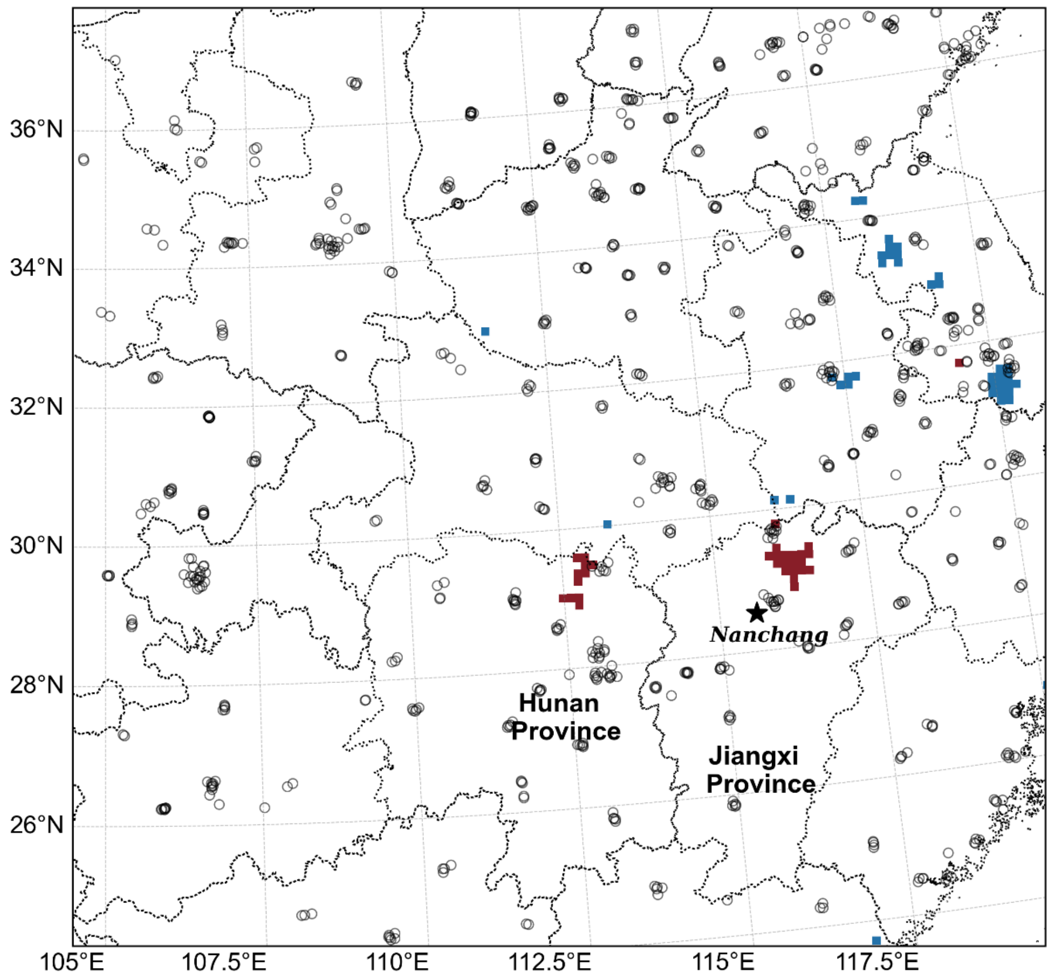
"Additionally, aerosol optical depth (AOD) at 550 nm, derived from the Modern Era Retrospective-analysis for Research and Application version 2 (MERRA-2) reanalysis dataset, was employed to further assess the simulations (Gelaro et al., 2017)."

Results and discussion

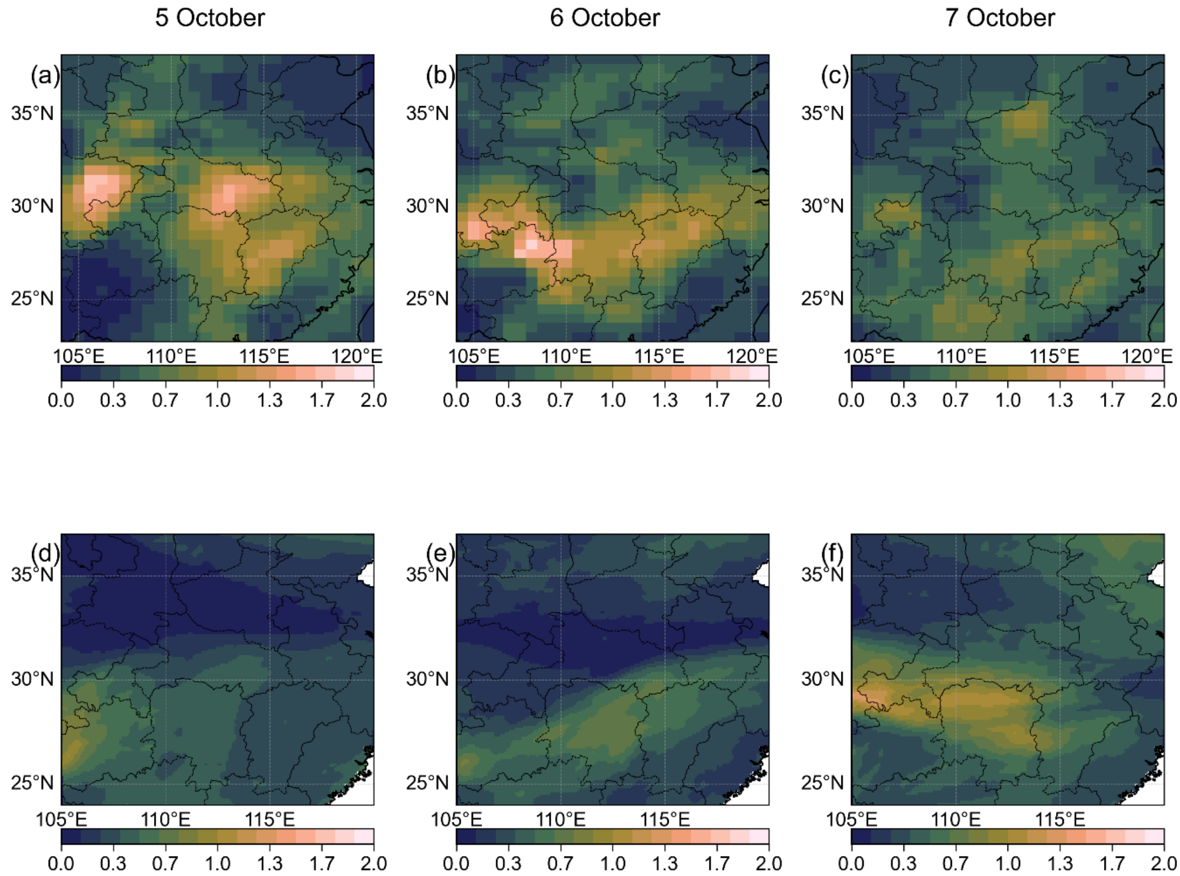
"Additionally, we also compared the modeled AOD with MERRA-2 dataset. The comparison indicated that although discrepancies exist between the simulation and reanalysis results, the overall spatiotemporal distributions were consistent, capturing the relatively high values over the two lake regions (Fig. S10 and Fig. S11). Given the uncertainties in both satellite retrievals and model simulations, satisfactory performance in mass concentration validation, and the similar performance between our results and previous studies (Kong et al., 2022; Liu et al., 2021), we consider that the simulation results remain acceptable for this analysis."

"However, uncertainties still exist in the simulated concentrations due to limitations in model inputs (e.g., satellite-derived land use data, meteorological fields from WRF simulations, and emission inventories), model parameterizations, and observational biases."

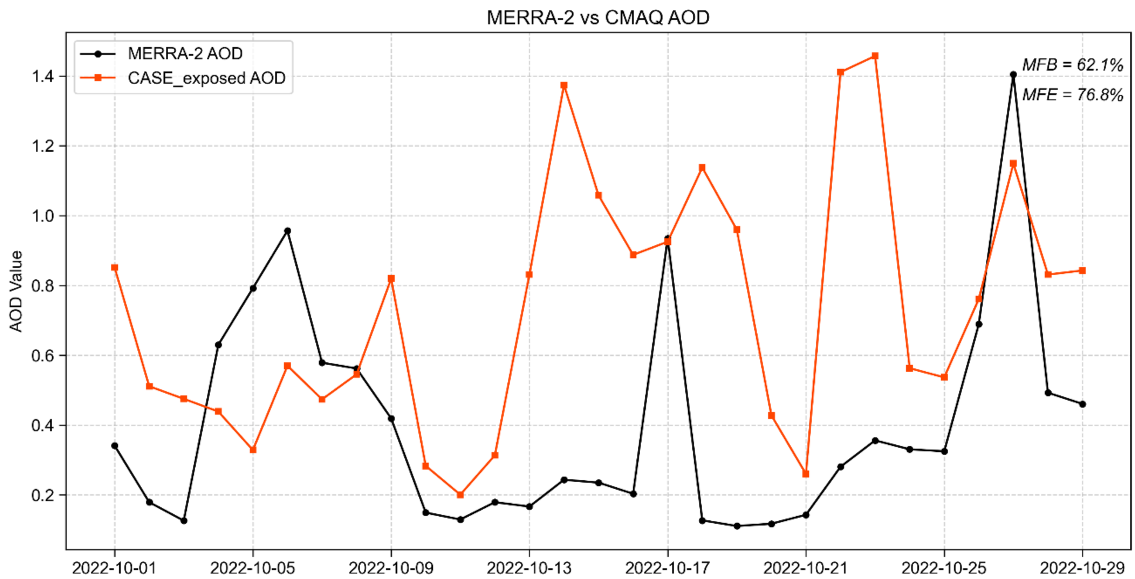
Supplementary information



Supplementary Figure S2. Study area setting. Grid cells in the plot of blue are ordinary lakes, and those in red are the exposed lakebeds detected by sentinel-2. Nanchang near Poyang Lake is marked. Hollow circles indicate observation sites.



Supplementary Figure S10. Spatial distribution of AOD from MERRA-2 reanalysis (a-c) and CMAQ (CASE_exposed scenario) (d-f), during 5–7 October 2022.



Supplementary Figure S11. Time series of AOD at a grid point near Nanchang (29.3°N, 115.8°E) from MERRA-2 reanalysis and CMAQ (CASE_exposed scenario).

Minor comments:

Some sentences are difficult to understand, as in the abstract:

l.36 "Critically, for the first time, we show that..."

Response: Thank you for your insightful comment. We agree that the phrase "Critically, for the first time, we show that..." may overstate the novelty of our finding. To avoid overclaiming and to adopt a more objective tone, we have revised the sentence.

Changes in manuscript:

“This study provides new evidence that…”

l.135 What are A1 and A2? It is unclear where it is cited. The Figure is here necessary and a list of the sampling sites should be more understandable. And the already existing Table S1 could be in the main text in section 2.1.

Response: We followed the reviewer’s suggestion to improve the clarity and presentation of the sampling site information. Here are our revisions:

1. The original labels such as A1 and A2 have now been replaced with more descriptive code that indicate the lake name (Poyang or Dongting) and the hydrological zone (Dry, Transitional, or Submerged). This change has been applied consistently throughout the manuscript, including all figures, figure captions, and main text references. The new naming format follows the structure:

Original Label	New Label	Description
A1	PY-D1	Poyang Lake – Dry Zone site 1
A2	PY-D2	Poyang Lake – Dry Zone site 2
A3	DT-D1	Dongting Lake – Dry Zone site 1
B1	PY-T1	Poyang Lake – Transitional Zone site 1

Original Label	New Label	Description
B2	PY-T2	Poyang Lake – Transitional Zone site 2
B3	DT-T1	Dongting Lake – Transitional Zone site 1
C1	PY-S1	Poyang Lake – Submerged Zone site 1
C2	PY-S2	Poyang Lake – Submerged Zone site 2
C3	DT-S1	Dongting Lake – Submerged Zone site 1

2. To ensure the spatial layout of the sampling design is clear to readers, Figure 1 (map of the sampling sites) has been retained and referenced earlier in the **materials and methods** section to aid understanding.
3. We agree that Table S1, which includes detailed information about each sampling site (e.g., coordinates, classification, zone description), is important for the reader. Therefore, we have moved Table S1 to the main text as Table 1 in Section 2.1, as suggested.

Changes in manuscript:

Table 1. The properties of different soils.

ID	Type	Color	Density (g/cm^3)	Location	Longitude	Latitude
PY-D1	Sandy Loam	Brown	1.18826	Duchang County, Poyang Lake	116.157996 E	29.243726 N
PY-T1	Sandy Loam	Brown	1.007	Duchang County, Poyang Lake	116.157990 E	29.243528 N
PY-S1	Loamy Sand	Brown	1.08158	Duchang County, Poyang Lake	116.157810 E	29.242878 N
PY-D2	Sandy Clay Loam	Yellow	0.9787	Yugan County, Poyang Lake	116.396692 E	29.053927 N
PY-T2	Silt Clay	Black	0.92936	Yugan County, Poyang Lake	116.396182 E	29.053813 N
PY-S2	Silt Clay Loam	Brownish Yellow	1.17544	Yugan County, Poyang Lake	116.395759 E	29.053549 N
DT-D1	Silt Clay Loam	Brownish	1.30354	Yueyang County, Yueyang City	113.069367 E	29.338117 N

DT-T1	Sandy Clay Loam	Yellow Brown	1.08312	Yueyang County, Yueyang City	113.064997 E	29.336263 N
DT-S1	Silt Clay	Black	1.01874	Yueyang County, Yueyang City	113.063560 E	29.336425 N

l.157: The Table is in the supplement but could be where it is cited. The caption could be enriched and provide much more details about the Table's content.

Response: Thank you for the helpful suggestion. We agree that more detailed captioning improves the clarity and utility of the table. We have expanded the caption of Table in the supplementary information to provide full information on sampling sites, environmental conditions (dry, transitional, submerged), and particle types ($PM_{2.5}$ and PM_{10}), as suggested. Regarding the table's placement, since the data serve as supplementary information rather than the core results, we believe supplementary information is the appropriate location.

Changes in manuscript:

"Table S1 presents $PM_{2.5}$ and PM_{10} dust aerosol mass (g) collected from nine sites across Poyang and Dongting Lakes under dry, transitional, and submerged conditions, based on three replicate measurements."

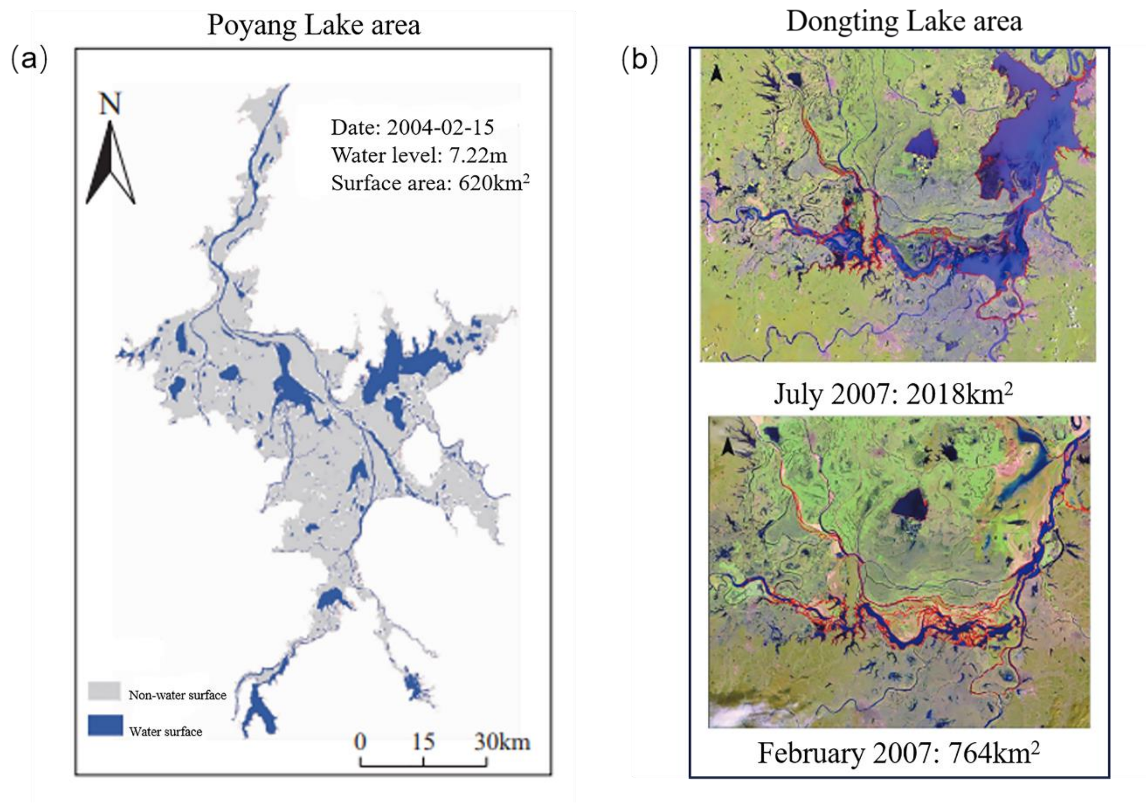
Table S1. Mass (g) of particles collected in dust aerosols for $PM_{2.5}$ and PM_{10} across three replicates ($PM_{2.5}$-1 to $PM_{2.5}$-3 and PM_{10}-1 to PM_{10}-3). Sampling sites include dry (D), transitional (T), and submerged (S) regions of Poyang Lake (PY) and Dongting Lake (DT).

EXP	PY-D1	PY-T1	PY-S1	PY-D2	PY-T2	PY-S2	DT-D1	DT-T1	DT-S1
$PM_{2.5}$-1	0.0131	0.011	0.0134	0.0143	0.0118	0.0111	0.0137	0.0112	0.0123
$PM_{2.5}$-2	0.0155	0.0129	0.0151	0.0127	0.0118	0.0139	0.0131	0.0112	0.0149
$PM_{2.5}$-3	0.0163	0.0124	0.0134	0.0164	0.0145	0.0161	0.0137	0.0123	0.0129
PM_{10}-1	0.0226	0.0222	0.0214	0.0213	0.0246	0.0253	0.0229	0.0223	0.0226
PM_{10}-2	0.0288	0.0212	0.023	0.0223	0.0241	0.022	0.0225	0.0298	0.0215
PM_{10}-3	0.0227	0.0217	0.0223	0.022	0.0232	0.0276	0.0236	0.0232	0.0243

Figure S3: what are 2007.2 and 2007.7: month and year? please use a correct notation.

Response: We appreciate the reviewer's comment. The values "2007.2" and "2007.7" refer to fractional years, corresponding approximately to February 2007 and July 2007, respectively.

Changes in manuscript:



Supplementary Figure S3. Lake area of Poyang and Dongting lakes. Water surface area of Poyang Lake (a) and Dongting Lake (b) during drought periods. Data were obtained from these studies (Liu et al., 2022; Li et al., 2013).

l.208: the domain is large and it is not sure that only three days of spin-up are enough. Can you explain this choice?

Response: We acknowledge the reviewer's concern regarding the relatively short spin-up period. The initial and boundary conditions in our model incorporated general atmospheric background conditions for initialization, rather than starting from zero concentrations.

Consequently, the required spin-up period can be relatively short. The configuration has been implemented in previous studies (Ma et al., 2025; Baek et al., 2023; Qiao et al., 2021). Furthermore, the initial and boundary conditions for d02 (12km resolution covering central China) were derived from prior simulations of larger domain (d01, 36km resolution covering the whole of China), ensuring greater accuracy in the input conditions. Therefore, a three-day spin-up period was adequate for this study.

l.265: The choice to estimate 'inhalation exposure' may be correct. But why calculate it using PM_{10} when you have $PM_{2.5}$ more able to deeply penetrate the lungs?

Response: Thank you for your valuable comment. While it is true that $PM_{2.5}$ can penetrate more deeply into the human respiratory system, our health risk assessment was based on PM_{10} for the following reasons.

First, we aimed to assess the contribution of exposed lakebed dust to atmospheric particulate matter and the associated health risks during the sampling period. During this period, atmospheric PM_{10} concentrations were notably higher than $PM_{2.5}$, making PM_{10} the dominant inhalable fraction.

Second, we quantified the concentrations of PAHs and heavy metals in both $PM_{2.5}$ and PM_{10} fractions derived from lakebed dust (Figure S13 and Figure S14). The concentrations found in $PM_{2.5}$ were significantly lower than those in PM_{10}, resulting in calculated health risks that were below threshold levels. Therefore, PM_{10} was used for the inhalation exposure assessment, as it better reflects the inhalable particulate burden and provides a more conservative estimate of the health risks associated with lakebed dust emissions.

Therefore, we choose PM_{10} to estimate 'inhalation exposure'.

l.271: why daily maximum and not daily mean?

Response: Thank you for your comment. In this study, the "maximum daily concentration" in refers to the highest 1-hour average concentration within one day. When assessing acute health risks, the acute value (AV) adopted here is based on reference values provided by CalEPA OEHHA (https://oehha.ca.gov/air/general-info/oehha-acute-8-hour-and-chronic-reference-exposure-level-rel-summary), which mentioned “exposure averaging time for acute RELs is 1 hour”. Since acute exposure means the effects of short-term concentrations rather ran long-term averages (e.g., 24-hour means), the use of maximum hourly concentrations ensures a more accurate representation of the actual health risks under acute exposure scenarios.

l.332: this part is partly a repeat of the 'methodology' section

Response: Thank you for your helpful comment. We agree that this part partially repeated content from the methodology section. We revised the manuscript and made it more concise.

Changes in manuscript:

“As described in the Materials and methods, dust aerosols were generated using the GAMEL system, which simulates natural sandblasting and yields realistic particle size and composition.”

l.348: Perhaps it should be interesting to have the population map superimposed to the locations of the sampling sites.

Response: Thank you for the suggestion. We have added a population density layer (bottom left panel in revised Fig. 1) to visualize the spatial relationship between the sampling locations and surrounding human populations. The population data were obtained from the WorldPop dataset (2020) with a spatial resolution of 1 km. A yellow-to-red color ramp was applied to represent different population density ranges, where darker colors indicate higher densities.

Changes in manuscript:

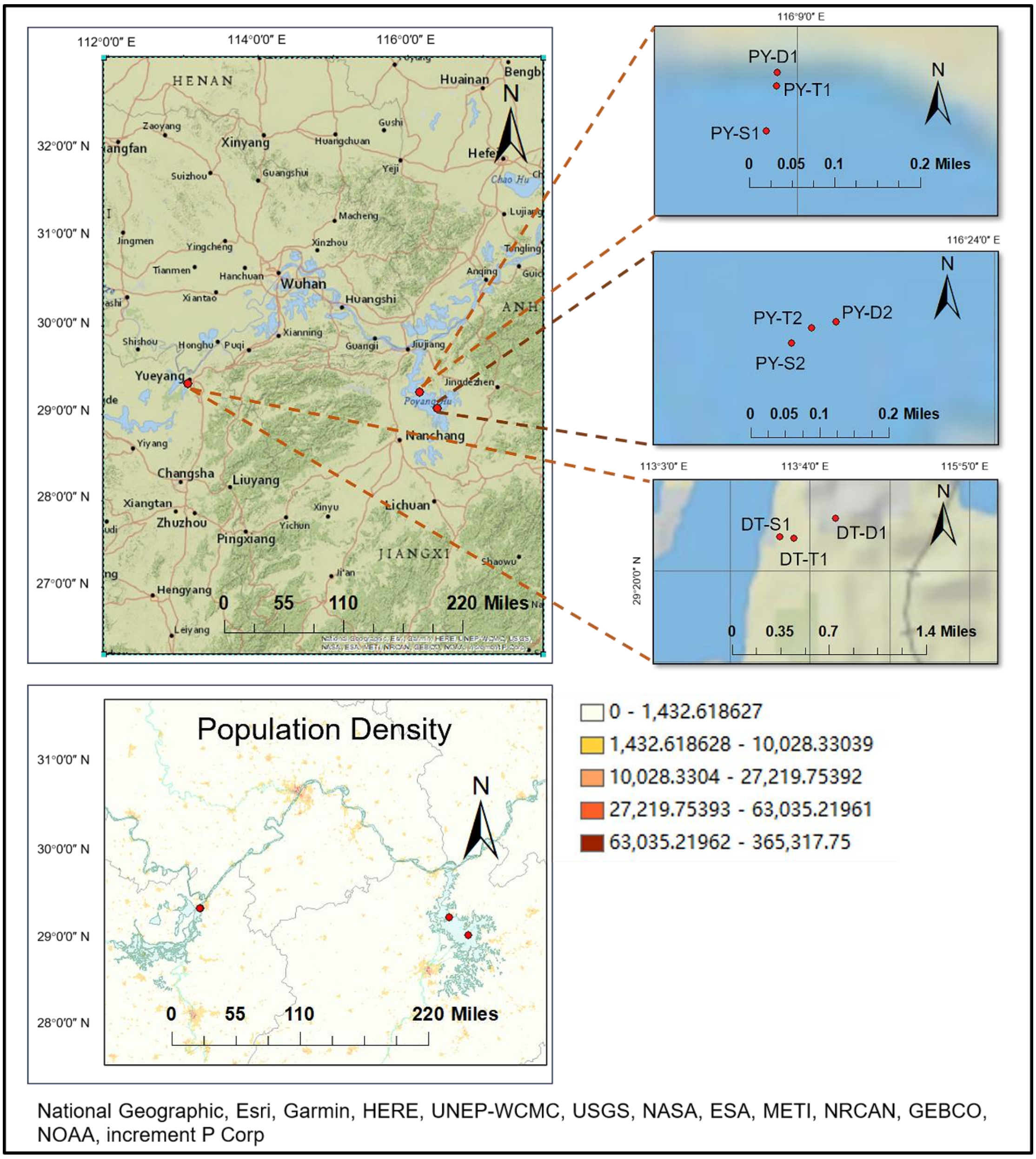


Figure 1. Sampling locations in Poyang Lake and Dongting Lake (marked as red dots). Sites PY-D1, PY-D2, and DT-D1 represent regions typically dry and exposed year-round. PY-T1, PY-T2, and DT-T1 are transitional zones that alternate between submerged and dry states. PY-S1, PY-S2, and DT-S1 are areas usually submerged but occasionally exposed due to extreme drought conditions. PY-D1, PY-T1, and PY-S1, along with PY-D2, PY-T2, and PY-S2, are located within Poyang Lake, while DT-D1, DT-T1, and DT-S1 correspond to Dongting Lake. A 2020 population density layer from WorldPop (1 km resolution) is overlaid, using a yellow-to-red color ramp to indicate increasing population density. The base map is sourced from National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI,

NRCAN, GEBCO, NOAA, and increment P Corp, as provided in the ArcGIS software.

l.372: I don't understand how it is possible to have PM2.5 > PM10 > soil in concentrations ng/g?? The fact to have PM2.5>PM10 is not possible. Please check and explain.

Response: The concentrations presented in Figure. 2 are absolute concentrations expressed as ng of contaminant per gram of collected particulate mass (ng/g). These values reflect the mass-normalized contaminant levels within each size fraction rather than their total abundance. This explains why it is physically possible for $PM_{2.5}$ to exhibit higher ng/g concentrations than PM_{10}—finer particles often have larger surface area-to-volume ratios, enabling greater adsorption of surface-active contaminants such as PAHs and certain trace metals.

This enrichment effect in finer fractions has also been observed in our previous study (Gao et al., 2023a). The observed $PM_{2.5} > PM_{10}$ > soil pattern highlights that specific contaminants are selectively associated with finer aerosol.

l.456 Figure 3: maximum daily concentrations are huge. It is the first vertical model level? Some concentrations are n ug/m3 others in ng/m3, could you explain?

Response: Thank you for your careful observation. The figure displayed surface concentrations, which represented the first vertical model level. Notably, the huge values were localized to a very limited number of grid cells—specifically, exposed lake surfaces—where concentrations were exceptionally high. However, these concentrations decreased sharply to typical background levels in the surrounding areas, which we consider to be reasonable and consistent with spatial distribution patterns expected under such conditions.

Regarding the units, PAHs are typically present in the atmosphere at much lower concentrations compared to PM and heavy metals such as Cr. As reported in previous studies, PAH concentrations in ambient air are commonly in the range of a few ng/m^3 (e.g.(Jung et al., 2011; Evagelopoulos et al., 2010)). In contrast, PM and Cr concentrations are usually expressed in μg/m^3 due to their relatively higher abundance. Therefore, different units were used in the figure to clearly visualize and distinguish the concentration levels of each component.

We thank Referee 2 again for the comments and suggestions!

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