Response to Referee #1 Comments on ESSD-2026-338

Dear Referee,

We sincerely thank referee for the positive evaluation of our manuscript and for the constructive comments. We have carefully considered all suggestions and revised the manuscript accordingly. Detailed responses are provided below.

Comment 1:

Introduction: The authors extensively introduced the definition, health impacts, climate effects, and global standard sampling methods of biogenic aerosols. However, it failed to clearly explain why a unified dataset urgently is needed in the East Asia region? I think this is the unique feature of this study.

Response:

Thank you for this valuable suggestion. We agree that the original Introduction did not sufficiently explain the scientific necessity of establishing a unified bioaerosol dataset for East Asia.

To address this comment, the Introduction has been substantially revised. The revised text now (1) discusses the limitations of existing bioaerosol observations, including methodological heterogeneity, limited spatial and temporal coverage; (2) highlights the specific characteristics of East Asia, such as frequent dust transport events, diverse climatic and ecological conditions, intensive human activities, and the large downstream population; and (3) clarifies that the increasing number of observations in East Asia remains fragmented in terms of sampling strategies, analytical methods, temporal coverage, and spatial distribution, which limits regional-scale comparisons and integrated assessments.

Based on these considerations, the revised Introduction explicitly emphasizes that a standardized dataset with unified sampling and analytical methods is required to support investigations of the spatial and temporal variability of bioaerosols across East Asia, as well as future studies related to climate, ecology, and public health.

Revision made:

Page 3, Line 67.

Revised:

In addition to methodological differences, the spatial and temporal coverage of bioaerosol sampling remains sparse (Zawadowicz et al., 2019). Many observations are restricted to isolated field campaigns or single-site stations, with particularly limited coverage in arid regions and developing countries (Shammi et al., 2021). In addition, long-term continuous records are scarce, and standardized time series spanning multiple years and sites are largely lacking. This limitation not only constrains the detection of long-term trends and interannual variability but also hampers the use of observations for model calibration and the assessment of climate-scale impacts (Huang et al., 2024a; Safatov et al., 2022). Furthermore, methodological heterogeneity across studies complicates data integration and limits large-scale analyses (Alfaro-Perez et al., 2025). Given the highly dynamic nature of the atmosphere, bioaerosol concentrations exhibit substantial spatial and temporal variability (Šantl-Temkiv et al., 2019), and conclusions derived from studies with limited spatial or temporal coverage may therefore be inconsistent (Jiang et al., 2022). Together, these factors further reduce the robustness of integrated assessments of bioaerosol impacts on climate, the environment, ecosystems, and human health (Gashi et al., 2025).

East Asia is one of the most densely populated and environmentally diverse regions worldwide (Su et al., 2015), characterized by frequent dust events driven by vast arid source regions in Central Asia and desert (Chen et al., 2026; Yu et al., 2023), rapid urbanization and industrialization (Tseng et al., 2024), intensive agricultural activities, and strong land – ocean interactions (Zhou et al., 2025; Lang et al., 2025). The abundance, dispersal, and community composition of atmospheric bioaerosols are influenced by meteorological conditions, including wind speed and direction, atmospheric stability, temperature, humidity, and precipitation (Uetake et al., 2019; Tignat-Perrier et al., 2019; Petersson Sjögren et al., 2023; Drautz-Moses et al., 2022). Under ongoing climate change, drought conditions are projected to intensify (Araujo et al., 2025; Xu et al., 2023), with East Asia expected to be particularly affected (Qi et al., 2024). Within this broad meteorological framework, dust events are of particular relevance in East Asia because the mobilization of mineral particles can simultaneously release soil-associated microorganisms and other biological materials into the atmosphere, while strong regional winds can transport these particles over long distances (Maki et al., 2019; Zhou et al., 2024; Tang et al., 2018). Thus, dust is an important mechanism linking terrestrial source areas with downwind environments. On this basis, the Dust – Bioaerosol (DuBi) field observation program adopted a source – transport – receptor perspective, incorporating observations in source regions, along transport pathways, and at downwind receptor sites. Given the extensive arid and semi-arid regions of East Asia and the large populations residing in downwind areas (Jin et al., 2022), the regional transport of dust-associated bioaerosols warrants particular attention because of its potential environmental and public health implications.

Despite increasing bioaerosol observations in East Asia, existing studies are often fragmented in terms of sampling protocols, temporal coverage, and analytical methodologies (Safatov et al., 2022). This methodological and observational heterogeneity limits regional comparisons and large-scale assessments and makes it difficult to distinguish genuine environmental variability from differences introduced by sampling and analytical procedures (Pogner et al., 2024a). Accurate assessment of bioaerosol-related effects therefore requires broader observational networks, longer and more continuous monitoring records, and greater methodological standardization to facilitate regional and transregional data integration and sharing (Huang et al., 2024a). Accordingly, the establishment of a bioaerosol dataset with broad geographical coverage and consistent sampling and analytical methodologies is essential for advancing regional-scale research and applications (Sajjad et al., 2023; Gashi et al., 2025; Boifot et al., 2024; Jiang et al., 2022). Such a dataset would enable a more comprehensive characterization of the geographic distribution, spatiotemporal variability, and environmental and health impacts of bioaerosols, while supporting the assessment of public health risks under climate change and providing a scientific basis for mitigation strategies and policy development.

Comment 2:

Line 106-110: A custom-designed bioaerosol sampler was employed here. I'm wondering whether the collection efficiency of this sampler has been verified before? What are the comparison results with commonly used international standard samplers (such as the Andersen sampler)?

Response:

Thank you for this valuable comment. We appreciate the referee's concern regarding the sampling performance of the custom-designed bioaerosol sampler. We would like to address it from three aspects:

1. The polycarbonate membrane filter-based sampling approach employed in this study has been widely adopted by the bioaerosol research community over the past two decades and is well established as a mainstream methodology. Notably, it has been used extensively by research groups conducting long-term atmospheric bioaerosol monitoring in East Asia, including the work of Teruya Maki (Kindai University, Japan) and Daizhou Zhang (Prefectural University of Kumamoto, Japan), among others. The broad application of this sampler type across independent research teams provides substantial evidence of its reliability and scientific acceptance.
2. The collection efficiency of polycarbonate membrane filters has been rigorously evaluated in the literature. Guo et al. comprehensively evaluated the performance of six bioaerosol samplers in an aerosol wind tunnel. Polycarbonate membrane filters were assessed and compared with several commonly used bioaerosol samplers, including gelatin filters, the AGI-30 impinger, and the BioSampler. Their study demonstrated that polycarbonate membrane filters exhibited excellent performance during long-term sampling, although they were less effective at maintaining microbial viability. Since our study did not involve the assessment of microbial viability, this limitation did not affect our analyses. As shown in Fig. 1,

during the 60 min long-term sampling performance test, the total biological sampling efficiency of the polycarbonate membrane filter was consistently and significantly higher than that of the AGI-30 and other samplers.

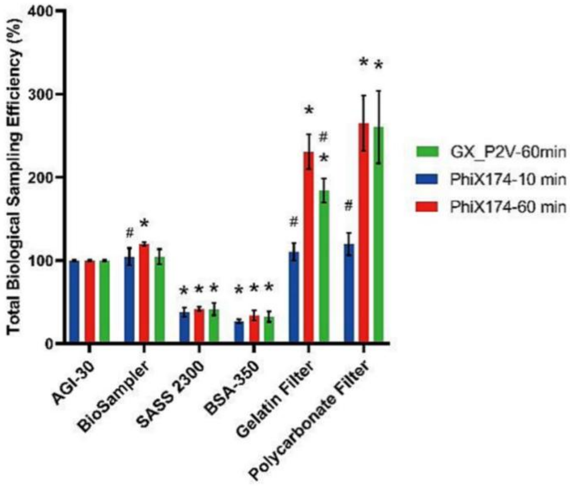

Figure 1: Total biological sampling efficiency of the tested bioaerosol samplers compared to that of AGI-30(Guo et al., 2024).

3. In addition, some of our sampling campaigns required continuous operation for 12h or even longer. Under such conditions, filter-based sampling offers several practical advantages over impingers or impactors, including the absence of liquid evaporation and sampler overloading during extended sampling periods. Moreover, it provides a stable sampling mechanism, convenient transportation and sample preservation, portable power-bank operation, and easy disassembly and component replacement. Considering both the methodological evaluations and the practical requirements of the DuBi observation network, we concluded that this sampler represented the appropriate choice for our study.

Comment 3:

In Table 1, the Land Surface labels for several sites are marked as "-" (such as Dunhuang, Kanazawa). Is it a case of missing data or unclassified data? Please fill in the land use types for all sites (such as desert, farmland, forest, etc.).

Response:

We thank the referee concern for this helpful suggestion. The symbol "-" in the original version of Table 1 does not indicate missing sampling data. Following the referee's suggestion, we carefully re-examined the original field records and photographs for each sampling site and supplemented the corresponding land surface information. As a result, land surface categories have now been provided for all sampling sites in Table 1. This revision improves the completeness of the site metadata and provides a clearer description of the environmental characteristics of each sampling location.

Revision made:

Page 4, Line 103.

Revised:

Sampling Site	**Land Surface**	**number of samples**	**Latitude & Longitude**	**Sampling Period**	**Sampling Duration**
Dunhuang	Desert	13	（94.5° E, 40.1° N）	2011/9/9-2011/9/10 2021/7/11-2021/7/19	1-12h
Kanazawa	Urban	47	（136.7° E, 36.5° N）	2011/3/22-2011/5/1 2017/4/21-2017/5/15 2017/9/5-2017/9/28	6-15h
Hakui	Urban	2	（136.8° E, 36.9° N）	2013/4/28 2014/3/28	1h
Tsogt-Ovoo	Desert	14	（105.2° E, 44.2° N）	2014/3/16-2014/3/18 2017/4/29-2017/5/4	2-18h
Namie	Forest & Ground	59	（140.8° E, 37.6° N）	2015/8/19-2018/3/22	2-7h
Erlianhot	Sandy land	111	（111.9° E, 43.7° N）	2016/3/30-2016/5/25 2017/8/17-2017/8/19	2-24h
Zhangbei	Sparse grassland	140	（114.7° E, 41.2° N）	2016/3/29-2016/5/31	2-15h
Jinan	Urban	121	（117.1° E, 36.7° N）	2016/3/23-2016/6/4	7-34h
Dalanzadgad	Road	5	（104.4° E, 43.6° N）	2017/5/1-2017/5/3	7-11h
Bayannur	Urban	2	（107.4° E, 40.8° N）	2017/8/4	3-6h
Ulanqab	Sparse grassland	2	（113.1° E,41.1° N）	2017/8/4-2017/8/5	3-8h
Xilinhot	Urban	1	（116.1° E,44.0° N）	2017/8/5-2017/8/6	8h
Arxan	Urban	4	（119.9° E,47.2° N）	2017/8/6-2017/8/7 2017/8/14	3-9h

Ewenki Autonomous Banner	Urban	7	（119.8° E,49.1° N）	2017/8/7-2017/8/8	4-11h
Ergun	Urban	3	（119.9° E,51.3° N）	2017/8/9-2017/8/10	3-9h
Labudalin	Wetland	2	（120.1° E,50.2° N）	2017/8/10-2017/8/11	4-10h
New Barag Left Banner	Sparse grassland	3	（118.3° E,48.2° N）	2017/8/13-2017/8/14	4-9h
East Ujimqin Banner	Sparse grassland	2	（117.0° E,45.5° N）	2017/8/15-2017/8/16	4-9h
Abag Banner	Sparse grassland	2	（115.0° E,44.0° N）	2017/8/16-2017/8/17	4-9h
Baotou	Sparse grassland	2	（110.1° E,42.5° N）	2017/8/19-20174/8/20	4-11h
Urad Middle Banner	Sparse grassland	2	（108.5° E,41.6° N）	2017/8/20-2017/8/21	4-9h
Urad Rear Banner	River dam	2	（107.0° E,41.1° N）	2017/8/21-2017/8/22	4-11h
Alxa Left Banner	Grassland	2	（105.5° E,38.9° N）	2017/8/22-2017/8/23	4-10h
Yonago	Urban	96	（133.3° E,35.4° N）	2015/3/4-2015/6/19	19-30h
Yongin	Urban	68	（127.16° E,37.2° N）	2015/3/9-2015/7/4	17-120h
Lhasa	Urban	11	（91.0° E,29.6° N）	2018/5/7-2018/5/8 2018/5/27-2018/5/31	9-13h
Everest Base Camp, Xigaze	Alpine gravel bare ground	28	（86.9° E,28.1° N）	2018/5/11-2018/5/24	7-14h
Tazhong	Desert	40	（83.7° E,39.0° N）	2019/7/7-2019/7/30	9-22h
Minfeng	Grassland	31	（82.7° E,37.1° N）	2019/7/11-2019/7/31	11-12h

Tazhong–Minfeng route	Desert	8	（82.9° E,37.5° N）	2019/7/23-2019/8/1	2-3h
	Cropland		（80.1° E,37.1° N）		
	Desert		（80.1° E,37.4° N）		
	Desert		（81° E,38.6° N）		
	Grassland		（75.2° E,37.8° N）		
	Grassland		（76° E,39.5° N）		
	Grassland		（82.8° E,37.1° N）		
Ngari	Urban	50	（79.7° E,33.4° N）	2019/7/7-2019/7/31	11-12h
Namtso	Alpine meadow	80	（91.0° E,30.8° N）	2020/8/3-2020/8/24	9-13h
Qinghai	Urban	8	（101.8° E,36.6° N）	2020/7/16-2020/7/20	2-12h
	Alpine meadow		（99.8° E,36.7° N）		
	Sparse grassland		（99.1° E,36.8° N）		
	Urban		（100.1° E,37.3° N）		
	Cropland and urban		（100.3° E,38.2° N）		
	Cropland		（101.5° E,37.5° N）		
Yuzhong	Grassland	62	（104.1° E,36.0° N）	2020/10/31-2020/11/19	2-6h
Yadong	Forest	141	（88.9° E,27.4° N）	2021/6/22-2021/8/30	11-13h

Comment 4:

Also, in the Sampling Duration column of Table 1, the stations of Namie and Yongin are marked as "-". What is the exact duration of the sampling?

Response:

We thank the referee for this helpful comment. The sampling duration information for the Namie, Yongin and other sites has been carefully re-checked against the original field records in consultation with the co-author responsible for these sampling campaigns. Following this verification, the exact sampling durations for these sites were confirmed and have now been included in Table 1. This revision improves the completeness and accuracy of the sampling metadata and ensures that consistent information is provided for all sampling locations included in the dataset.

Revision made:

Page 4, Line 103.

Revised:

Sampling Site	Land Surface	number of samples	Latitude & Longitude	Sampling Period	Sampling Duration
Dunhuang	Desert	13	（94.5° E, 40.1° N）	2011/9/9-2011/9/10 2021/7/11-2021/7/19	1-12h
Kanazawa	Urban	47	（136.7° E, 36.5° N）	2011/3/22-2011/5/1 2017/4/21-2017/5/15 2017/9/5-2017/9/28	6-15h
Hakui	Urban	2	（136.8° E, 36.9° N）	2013/4/28 2014/3/28	1h
Tsogt-Ovoo	Desert	14	（105.2° E, 44.2° N）	2014/3/16-2014/3/18 2017/4/29-2017/5/4	2-18h
Namie	Forest & Ground	59	（140.8° E, 37.6° N）	2015/8/19-2018/3/22	2-7h
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Zhangbei	Sparse grassland	140	（114.7° E, 41.2° N）	2016/3/29-2016/5/31	2-15h
Jinan	Urban	121	（117.1° E, 36.7° N）	2016/3/23-2016/6/4	7-34h
Dalanzadgad	Road	5	（104.4° E, 43.6° N）	2017/5/1-2017/5/3	7-11h
Bayannur	Urban	2	（107.4° E, 40.8° N）	2017/8/4	3-6h
Ulanqab	Sparse grassland	2	（113.1° E,41.1° N）	2017/8/4-2017/8/5	3-8h
Xilinhot	Urban	1	（116.1° E,44.0° N）	2017/8/5-2017/8/6	8h
Arxan	Urban	4	（119.9° E,47.2° N）	2017/8/6-2017/8/7	3-9h

				2017/8/14	
Ewenki Autonomous Banner	Urban	7	（119.8° E,49.1° N）	2017/8/7-2017/8/8	4-11h
Ergun	Urban	3	（119.9° E,51.3° N）	2017/8/9-2017/8/10	3-9h
Labudalin	Wetland	2	（120.1° E,50.2° N）	2017/8/10-2017/8/11	4-10h
New Barag Left Banner	Sparse grassland	3	（118.3° E,48.2° N）	2017/8/13-2017/8/14	4-9h
East Ujimqin Banner	Sparse grassland	2	（117.0° E,45.5° N）	2017/8/15-2017/8/16	4-9h
Abag Banner	Sparse grassland	2	（115.0° E,44.0° N）	2017/8/16-2017/8/17	4-9h
Baotou	Sparse grassland	2	（110.1° E,42.5° N）	2017/8/19-20174/8/20	4-11h
Urad Middle Banner	Sparse grassland	2	（108.5° E,41.6° N）	2017/8/20-2017/8/21	4-9h
Urad Rear Banner	River dam	2	（107.0° E,41.1° N）	2017/8/21-2017/8/22	4-11h
Alxa Left Banner	Grassland	2	（105.5° E,38.9° N）	2017/8/22-2017/8/23	4-10h
Yonago	Urban	96	（133.3° E,35.4° N）	2015/3/4-2015/6/19	19-30h
Yongin	Urban	68	（127.16° E,37.2° N）	2015/3/9-2015/7/4	17-120h
Lhasa	Urban	11	（91.0° E,29.6° N）	2018/5/7-2018/5/8 2018/5/27-2018/5/31	9-13h
Everest Base Camp, Xigaze	Alpine gravel bare ground	28	（86.9° E,28.1° N）	2018/5/11-2018/5/24	7-14h
Tazhong	Desert	40	（83.7° E,39.0° N）	2019/7/7-2019/7/30	9-22h

Minfeng	Grassland	31	（82.7° E,37.1° N）	2019/7/11-2019/7/31	11-12h
Tazhong–Minfeng route	Desert	8	（82.9° E,37.5° N）	2019/7/23-2019/8/1	2-3h
	Cropland		（80.1° E,37.1° N）		
	Desert		（80.1° E,37.4° N）		
	Desert		（81° E,38.6° N）		
	Grassland		（75.2° E,37.8° N）		
	Grassland		（76° E,39.5° N）		
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	Sparse grassland		（99.1° E,36.8° N）		
	Urban		（100.1° E,37.3° N）		
	Cropland and urban		（100.3° E,38.2° N）		
	Cropland		（101.5° E,37.5° N）		
Yuzhong	Grassland	62	（104.1° E,36.0° N）	2020/10/31-2020/11/19	2-6h
Yadong	Forest	141	（88.9° E,27.4° N）	2021/6/22-2021/8/30	11-13h

Comment 5:

On Line 235-239, I wonder if the "mid-April concentration peak" might correspond to a specific biological event (such as pollen outbreak, agricultural activities)? Has the author provided any other relevant data (such as pollen counts) for support or made an appropriate speculation about the possible causes?

Response:

We thank the referee for this insightful comment. Following the referee's suggestion, we further investigated whether the concentration peak observed in mid-April could be associated with a biological event. To this end, we obtained historical pollen observations for the Chugoku–Shikoku region from the Ministry of the Environment Government of Japan(https://www.env.go.jp/page_00209.html).

Pollen observations were unavailable at the Yonago sampling site or surrounding stations on 17–18 April, preventing a direct comparison between the observed bioaerosol concentration peak and local pollen concentrations. To further investigate the possible cause of this event, we combined pollen monitoring data with Hybrid Single-Particle Lagrangian Integrated Trajectory model (HYSPLIT) (Fig. 2). Backward trajectories were calculated at arrival heights of 10, 50, and 100 m above ground level for the sample collected from 23:00 LST on 17 April to 19:00 LST on 18 April. The results showed that the low-level air masses reaching Yonago during the sampling period predominantly originated from the southwest. Based on these transport pathways, we further examined pollen observations from four monitoring stations located southwest of Yonago. All four stations exhibited unusually high pollen concentrations around 17 April. Taken together, the pollen observations and backward trajectory analysis suggest that the observed bioaerosol concentration peak was likely associated with a regional pollen outbreak and its subsequent atmospheric transport. Nevertheless, because pollen observations were unavailable at Yonago and its surrounding stations during the sampling period, this interpretation should be regarded as a plausible explanation rather than direct evidence, and further observations are needed to confirm the underlying mechanism.

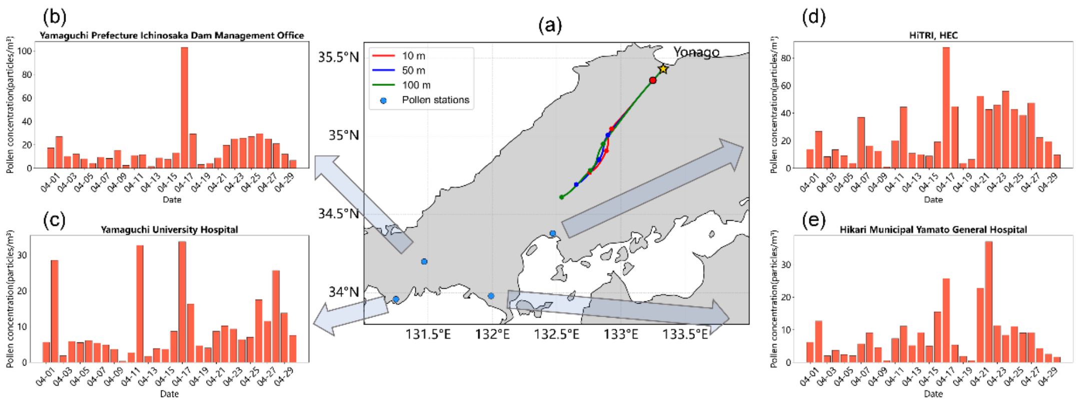

Figure 2: (a) Cases of 18 h backward air mass transport trajectories for the Yonago sampling site at starting heights of 10, 50, and 100 m above ground level, simulated by the HYSPLIT model at 0500 UTC 18 April 2015. Each trajectory node represents a 6 h interval. Temporal variations in pollen concentrations at four sampling sites during April 2015: (b) Yamaguchi Prefecture Ichinosaka Dam Management Office, (c) Yamaguchi University Hospital, (d) Hiroshima Prefectural Technology Research Institute, Health and Environment Center, and (e) Hikari Municipal Yamato General Hospital.

Comment 6:

This study mainly showed the diurnal variation characteristics. However, the sampling period is from 2011 to 2021, covering different seasons. So if you have those data, It's better that the authors analyze the variation patterns of concentration and community structure on a seasonal scale. This will be of great value for understanding the annual cycle characteristics of biogenic aerosols.

Response:

We sincerely thank the referee for this valuable suggestion. We fully agree that seasonal variations in bioaerosol concentration and community structure are of great importance for understanding the annual dynamics of atmospheric bioaerosols.

We carefully evaluated the possibility of conducting a seasonal analysis using the current dataset. However, such an analysis would not be sufficiently robust because none of the sampling sites was monitored continuously throughout an entire year (Fig. 2). Furthermore, bioaerosol characteristics exhibit substantial spatial heterogeneity across East Asia. Therefore, combining data from different sites to infer seasonal patterns could introduce considerable spatial bias and may lead to misleading conclusions.

Since the primary objective of this study is to present a high-quality, standardized dataset, we prefer not to include a seasonal analysis that is not adequately supported by the available observations. We agree that seasonal variability is an important topic and plan to address it in future studies based on more continuous and systematic observations.

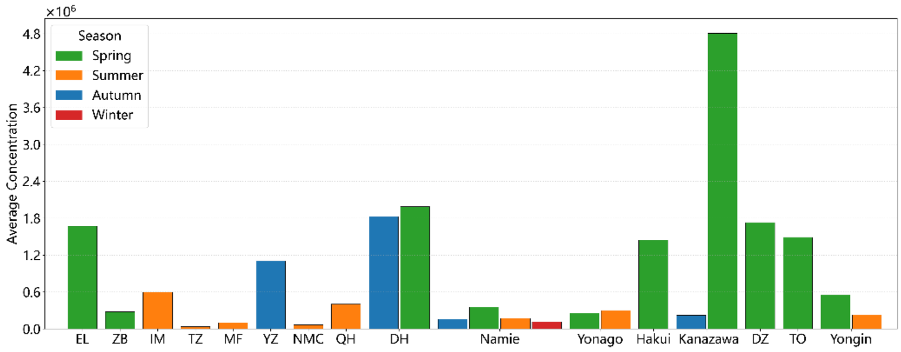

Figure 3: The average distribution of biological aerosol number concentrations at each site during different seasons in the DuBi field sampling experiment.

Comment 7:

One interesting finding of this study is that the concentration of biogenic aerosols and the α diversity index are significantly negatively correlated with NDVI. However, the present result comes mainly from descriptive correlation analysis, lacking quantitative interpretation of the underlying mechanisms. It is suggested that further mechanisms research should be carried out in future work. At least, this deficiency should be mentioned in the conclusion.

Response:

We greatly appreciate the referee's insightful observation regarding the negative correlation between biogenic aerosol concentrations and α diversity index with NDVI. This is indeed an interesting and counterintuitive finding from our dataset. We acknowledge the referee's point and have addressed it as follows:

The referee correctly identifies that our current analysis is primarily descriptive in nature, establishing the statistical correlation without providing detailed mechanistic interpretation. We agree that the underlying mechanisms driving this relationship remain open questions. Potential mechanisms could include differences in regional vegetation composition, land-use heterogeneity, atmospheric circulation patterns factors that cannot be fully disentangled from the present correlation analysis alone.

Following the referee's suggestion, we have added a paragraph to the Conclusions section explicitly acknowledging this limitation and highlighting it as an important avenue for future research. Thank you again for this constructive feedback, which has helped strengthen the scientific rigor and transparency of our manuscript.

Revision made:

Page 16, Line 324.

Revised:

Although significant correlations were identified between bioaerosol characteristics and environmental variables such as NDVI and temperature, the underlying mechanisms remain unresolved. The lack of year-round continuous observations at individual sites limits robust seasonal analysis, while the uneven spatial distribution of the network, particularly the underrepresentation of forested and other densely vegetated regions, constrains its ecosystem representativeness. Future studies should therefore combine longer-term monitoring, expanded coverage of vegetation-dominated environments, and more detailed process-based analyses to better resolve seasonal variability, vegetation-related emissions, and the mechanisms linking bioaerosols to environmental conditions.

Comment 8:

In conclusions, the author believes that this database can serve as a data foundation for climate models. Could you provide some examples to illustrate its potential application scenarios?

Response:

We thank the referee for this constructive suggestion. We agree that the original manuscript did not sufficiently illustrate how this dataset can be used in future research. As suggested, we have expanded the Conclusions by providing several representative application scenarios to better demonstrate the scientific and practical value of the database.

Specifically, because the dataset provides standardized observations of bioaerosol concentration, bacterial community structure, meteorological conditions, air quality, and NDVI across a wide range of environments in East Asia, it can serve as a valuable observational basis for atmospheric and climate studies. We have therefore clarified that its broad spatial coverage and standardized observations can provide valuable constraints for atmospheric and climate models, particularly by improving the representation of bioaerosol emissions, transport processes, and their potential interactions with cloud formation. In addition, we emphasize that the integration of biological and environmental variables enables the dataset to support evaluations of environmental exposure and associated public health risks across East Asia.

We believe that these additions provide clearer examples of the potential applications of the dataset and better highlight its value for future atmospheric, climate, and public health research.

Revision made:

Page 16, Line 324.

Revised:

Its broad spatial coverage and standardized observations provide valuable constraints for atmospheric and climate models, particularly in improving the representation of bioaerosol emissions, transport processes, and potential interactions with cloud formation. In addition, the dataset offers a basis for evaluating environmental exposure and associated public health risks across East Asia.

Once again, we sincerely appreciate your careful review and valuable comments, which have helped us improve the quality and completeness of our manuscript.

Sincerely,

The Authors

Response to Referee #2 Comments on ESSD-2026-338

Dear Referee,

We sincerely thank the referee for the careful evaluation of our manuscript and for the constructive comments regarding the scientific motivation, terminology, dataset description, figure presentation, and interpretation of the results. These comments helped us identify several aspects of the manuscript that required further clarification. In response, we have revised the Introduction and Methods sections, clarified the operational definition and scope of the measured bioaerosols, improved the presentation of the figures, expanded the site-level description of the dataset, and moderated several interpretations that were not sufficiently supported by the available observations. Our point-by-point responses are provided below.

Comment 1:

The motivation for conducting a dust–bioaerosol field campaign should be explained more clearly. The Introduction emphasizes the role of dust in bioaerosol transport, but meteorological conditions (e.g., wind) likely play an equally or even more important role. More background should be provided on why dust is specifically emphasized. In addition, there is an inconsistency: The Introduction states that bioaerosols are enhanced by dust-related transport, whereas Lines 194–195 state that the data were "analysed under non-special weather conditions (e.g., dust events)." This statement seems contradictory and should be clarified.

Response:

We thank the referee for this important comment. We agree that the original manuscript did not sufficiently distinguish the specific role of dust from the broader influence of meteorological conditions on bioaerosol emissions and transport.

The DuBi field observation program was not designed on the assumption that dust is the sole or dominant factor controlling bioaerosol variability. Meteorological conditions, including wind speed and direction, atmospheric stability, boundary-layer development, temperature, humidity, and precipitation, are controls on the release, transport, and removal of biological particles. Dust was specifically emphasized because East Asia contains extensive arid and semi-arid source regions and experiences frequent long-range dust transport from continental source areas toward densely populated downwind regions. During these events, biological particles originating from soil and other terrestrial surfaces may be aerosolized and transported together with dust. Therefore, the DuBi program was designed to investigate bioaerosols within a source–transport–receptor framework that includes dust-source regions, transitional areas, and downwind receptor sites, rather than to attribute all observed bioaerosol variability exclusively to dust.

We have revised the Introduction to explain this scientific rationale more clearly and to acknowledge the important role of meteorological processes. We now describe dust transport as one important regional pathway for the mobilization and long-range dispersal of biological particles, while wind and other meteorological variables regulate whether and how such transport occurs.

We also agree that the statement at Lines 194–195 was ambiguous. The phrase "non-special weather conditions" referred to the subset of observations used to characterize general spatial and temporal patterns and was not intended to describe the overall scope of the DuBi field program. It also did not mean that dust-related observations were irrelevant to the dataset. We have rewritten this sentence to clearly distinguish the general descriptive analysis from analyses specifically targeting dust-event conditions.

Revision made:

Page 3, Line 78.

Revised:

East Asia is one of the most densely populated and environmentally diverse regions worldwide (Su et al., 2015), characterized by frequent dust events driven by vast arid source regions in Central Asia and desert (Chen et al., 2026; Yu et al., 2023), rapid urbanization and industrialization (Tseng et al., 2024), intensive agricultural activities, and strong land – ocean interactions (Zhou et al., 2025; Lang et al., 2025). The abundance, dispersal, and community composition of atmospheric bioaerosols are influenced by meteorological conditions, including wind speed and direction, atmospheric stability, temperature, humidity, and precipitation (Uetake et al., 2019; Tignat-Perrier et al., 2019; Petersson Sjögren et al., 2023; Drautz-Moses et al., 2022). Under ongoing climate change, drought conditions are projected to intensify (Araujo et al., 2025; Xu et al., 2023), with East Asia expected to be particularly affected (Qi et al., 2024). Within this broad meteorological framework, dust events are of particular relevance in East Asia because the mobilization of mineral particles can simultaneously release soil-associated microorganisms and other biological materials into the atmosphere, while strong regional winds can transport these particles over long distances (Maki et al., 2019; Zhou et al., 2024; Tang et al., 2018). Thus, dust is an important mechanism linking terrestrial source areas with downwind environments. On this basis, the Dust – Bioaerosol (DuBi) field observation program adopted a source – transport – receptor perspective, incorporating observations in source regions, along transport pathways, and at downwind receptor sites. Given the extensive arid and semi-arid regions of East Asia and the large populations residing in downwind areas (Jin et al., 2022), the regional transport of dust-associated bioaerosols warrants particular attention because of its potential environmental and public health implications.

Despite increasing bioaerosol observations in East Asia, existing studies are often fragmented in terms of sampling protocols, temporal coverage, and analytical methodologies (Safatov et al., 2022). This methodological and observational heterogeneity limits regional comparisons and large-scale assessments and makes it difficult to distinguish genuine environmental variability from differences introduced by sampling and analytical procedures (Pogner et al., 2024a). Accurate assessment of bioaerosol-related effects therefore requires broader observational networks, longer and more continuous monitoring records, and greater methodological standardization to facilitate regional and transregional data integration and sharing (Huang et al., 2024a). Accordingly, the establishment of a bioaerosol dataset with broad geographical coverage and consistent sampling and analytical methodologies is essential for advancing regional-scale research and applications (Sajjad et al., 2023; Gashi et al., 2025; Boifot et al., 2024; Jiang et al., 2022). Such a dataset would enable a more comprehensive characterization of the geographic distribution, spatiotemporal variability, and environmental and health impacts of bioaerosols, while supporting the assessment of public health risks under climate change and providing a scientific basis for mitigation strategies and policy development.

Revision made:

Page 10, Line 194.

Revised:

To characterize the general relationships between bioaerosol concentration, NDVI, and air temperature across East Asia while minimizing the influence of dust transport, this analysis was restricted to samples collected under non-dust conditions.

Comment 2:

The definition of *bioaerosol* throughout the manuscript is unclear and should be better clarified. In general, bioaerosols, often referred to as primary biological aerosol particles (PBAPs), include bacteria, fungal spores, pollen, plant debris, and viruses. However, the fluorescence analysis in this study appears to recognize only cellular particles. Viruses therefore appear to be excluded from the measurements. Furthermore, the reported significant negative correlation between bioaerosol concentration and NDVI raises additional questions. Since NDVI is positively related to vegetation cover, one might expect higher concentrations of plant-derived particles (e.g., pollen or plant fragments) in regions with higher NDVI. The manuscript also switches to the term *microbial* (e.g., Line 199). Since *microbial bioaerosols* generally refer only to microorganisms (e.g., bacteria and fungi) and exclude pollen and plant fragments, the distinction between *bioaerosol* and *microbial bioaerosol* should be clearly defined and used consistently. Does this imply that the "bioaerosols" measured in this study do not include plant-derived particles? If so, this should be explicitly stated and the use of the term "bioaerosol" throughout the manuscript may not be appropriate.

Response:

We thank the referee for this important comment. We agree that the original manuscript did not sufficiently distinguish the broad definition of primary biological aerosol particles (PBAPs) from the operational definition applied in the present study. We have therefore clarified the scope of the fluorescence-based concentration measurements and standardized the use of the terms "bioaerosol," "microbial bioaerosol," and "bacterial community" throughout the manuscript.

In the broader atmospheric context, PBAPs include bacteria, fungal spores, pollen, plant debris, viruses, and other particles of biological origin. In the present study, however, bioaerosols were operationally defined as particles exhibiting cellular morphology and emitting blue-green fluorescence after DAPI staining. The reported concentrations therefore represent the subset of atmospheric biological particles that satisfied both the morphological and fluorescence-based identification criteria used in our microscopy analysis, rather than the complete spectrum of PBAPs.

The fluorescence analysis was not intended to identify only bacterial cells. Previous methodological work has shown that bacterial cells, fungal cells, and plant detritus can all exhibit detectable fluorescence after DAPI staining (Liu et al., 2023). Nevertheless, in our counting procedure, pollen and plant-derived fragments were not classified or quantified as separate particle categories. Such particles may have contributed to the reported concentrations only when they exhibited both the required morphology and characteristic fluorescence. Their specific contribution to the measured concentration cannot therefore be determined from the present data.

Viruses were not included in the reported concentration measurements because they were outside the size, optical resolution, and morphological identification range of the fluorescence microscopy procedure applied in this study. In addition, the DAPI method does not distinguish viable from non-viable biological particles. These methodological boundaries have now been stated explicitly in the revised Methods section.

We also agree that the terminology associated with the sequencing results required greater precision. The 16S rRNA gene sequencing data specifically characterize the bacterial communities associated with the collected aerosol samples. Accordingly, references to "microbial community," "microbial diversity," and "microbial composition" have been replaced with "bacterial community," "bacterial diversity," and "bacterial community composition," respectively, wherever the discussion is based on the 16S rRNA data. The term "bioaerosol concentration" is retained for the fluorescence microscopy measurements, but it is now explicitly defined as the concentration of particles satisfying the operational DAPI-based criteria described above.

Regarding the negative correlation between bioaerosol concentration and NDVI, we appreciate the reviewer's concern that greater vegetation cover may increase the abundance of plant-derived particles, such as pollen and plant fragments. However, the concentration reported in this study represents the total number of particles satisfying the operational DAPI-based identification criteria, rather than the concentration of any specific biological particle type. As discussed in the manuscript, regions with low NDVI are generally characterized by sparse vegetation cover and relatively dry and loose surface soils, which can facilitate the wind-driven entrainment of soil-associated microorganisms and other biological particles into the atmosphere (Qi et al., 2023). By contrast, denser vegetation in regions with high NDVI can enhance the interception of airborne particles and promote their dry deposition, thereby reducing their atmospheric concentrations (Zhai et al., 2022). These processes provide a plausible explanation for the observed regional-scale negative relationship. We acknowledge that vegetation may also act as a source of pollen and plant fragments. However, these particle types were not separately identified or quantified in the present study, and their individual contributions cannot be distinguished from those of other DAPI-defined biological particles. We have therefore revised the discussion to clarify that the negative correlation represents the overall relationship observed in this dataset and should not be interpreted as evidence that increasing vegetation cover universally reduces all categories of PBAPs. The proposed mechanisms remain an interpretation based on land-surface characteristics and require further particle-resolved observations for quantitative verification.

These revisions clarify that the fluorescence-based concentrations and the bacterial sequencing results represent two complementary but distinct components of the dataset and should not be interpreted as a complete characterization of all PBAP categories.

Revision made:

Page 7, Line 141.

Revised:

In this study, bioaerosols were operationally defined as particles exhibiting cellular morphology and emitting blue-green fluorescence after DAPI staining. Accordingly, the reported bioaerosol concentrations represent the fraction of atmospheric biological particles that met both the morphological and fluorescence-based identification criteria, rather than the full range of primary biological aerosol particles (PBAPs), Viruses were outside the detection scope of this method. Pollen and plant fragments were not separately identified or quantified and would only have been included when they met both identification criteria. Hereafter, "bioaerosol concentration" refers specifically to the particle concentration determined using this operational definition.

Revision made:

Page 10, Line 195.

Revised:

As shown in Fig. 4a, bioaerosol concentrations were significantly negatively correlated with NDVI. In regions with low NDVI, sparse vegetation cover and dry, loose surface soils may facilitate the wind-driven entrainment of soil-associated microorganisms and other biological particles into the atmosphere (Qi et al., 2023). In contrast, denser vegetation in regions with high NDVI may enhance the interception of airborne particles and promote dry deposition, thereby contributing to lower atmospheric bioaerosol concentrations (Zhai et al., 2022). Although vegetated surfaces may also emit pollen and plant fragments, these particle categories were not separately identified in the present study. The observed correlation therefore represents the net relationship between NDVI and the operationally defined DAPI-positive particle concentration rather than the response of individual PBAP categories.

Comment 3:

Why were these observation sites selected? Most sites appear to be located in or near dust source regions. Are these regions expected to have sufficiently high bioaerosol concentrations? If the primary objective is to characterize bioaerosols, why were regions with abundant vegetation (e.g., southwestern China or the forested regions of northeastern China) not included? The current site selection seems to emphasize dust source regions rather than regions with potentially strong biological aerosol emissions.

Response:

We thank the referee for this important comment. We agree that the rationale for site selection was not sufficiently explained in the original manuscript.

The observation network was established within the Dust–Bioaerosol (DuBi) field program and was designed primarily according to a source–transport–receptor framework. Accordingly, the selected sites included arid and semi-arid source regions, locations along potential atmospheric transport pathways, and downwind receptor areas. The relatively large number of sites associated with dust-affected regions reflects the original scientific objective of the DuBi program, namely, to investigate the mobilization and regional transport of biological particles associated with east Asian dust.

The sites were not selected on the assumption that dust source regions necessarily have uniformly higher bioaerosol concentrations. Rather, these regions were included because wind and dust emission can mobilize soil-associated microorganisms and other

biological material and transport them to distant receptor regions.
This network also includes sites with surface features such as urban, coastlines and forest. Nevertheless, we acknowledge that the spatial distribution is not balanced among all ecosystem types in East Asia. In particular, highly vegetated regions, including southwestern China and the forested areas of northeastern China, are underrepresented. The current dataset should therefore not be interpreted as a statistically representative sampling of all land-cover types or potential bioaerosol source regions across East Asia. We agree that vegetation-rich regions may represent important sources of pollen, fungal spores, plant fragments, and other biological particles. Their limited representation constrains the ability of the present dataset to characterize the full range of vegetation-related bioaerosol emissions. We have revised the manuscript to clarify the scientific basis and constraints of the site selection and have added this spatial imbalance as a limitation of the dataset. Future expansion of the observation network should include additional forested and densely vegetated regions to improve ecosystem representation and enable more systematic comparisons among dust-dominated, agricultural, urban, and forest environments.

Revision made:

Page 3, Line 78.

Revised:

East Asia is one of the most densely populated and environmentally diverse regions worldwide (Su et al., 2015), characterized by frequent dust events driven by vast arid source regions in Central Asia and desert (Chen et al., 2026; Yu et al., 2023), rapid urbanization and industrialization (Tseng et al., 2024), intensive agricultural activities, and strong land – ocean interactions (Zhou et al., 2025; Lang et al., 2025). The abundance, dispersal, and community composition of atmospheric bioaerosols are influenced by meteorological conditions, including wind speed and direction, atmospheric stability, temperature, humidity, and precipitation (Uetake et al., 2019; Tignat-Perrier et al., 2019; Petersson Sjögren et al., 2023; Drautz-Moses et al., 2022). Under ongoing climate change, drought conditions are projected to intensify (Araujo et al., 2025; Xu et al., 2023), with East Asia expected to be particularly affected (Qi et al., 2024). Within this broad meteorological framework, dust events are of particular relevance in East Asia because the mobilization of mineral particles can simultaneously release soil-associated microorganisms and other biological materials into the atmosphere, while strong regional winds can transport these particles over long distances (Maki et al., 2019; Zhou et al., 2024; Tang et al., 2018). Thus, dust is an important mechanism linking terrestrial source areas with downwind environments. On this basis, the Dust – Bioaerosol (DuBi) field observation program adopted a source –

transport－receptor perspective, incorporating observations in source regions, along transport pathways, and at downwind receptor sites. Given the extensive arid and semi-arid regions of East Asia and the large populations residing in downwind areas (Jin et al., 2022), the regional transport of dust-associated bioaerosols warrants particular attention because of its potential environmental and public health implications.

Revision made:

Page 16, Line 324.

Revised:

Although significant correlations were identified between bioaerosol characteristics and environmental variables such as NDVI and temperature, the underlying mechanisms remain unresolved. The lack of year-round continuous observations at individual sites limits robust seasonal analysis, while the uneven spatial distribution of the network, particularly the underrepresentation of forested and other densely vegetated regions, constrains its ecosystem representativeness. Future studies should therefore combine longer-term monitoring, expanded coverage of vegetation-dominated environments, and more detailed process-based analyses to better resolve seasonal variability, vegetation-related emissions, and the mechanisms linking bioaerosols to environmental conditions.

Comment 4:

The descriptions of mineral particles appear to be inconsistent. Line 137 states that mineral particles appear white, whereas Line 140 states that yellow-green particles represent mineral dust enriched with water-soluble salts or organic materials. Please clarify the relationship between these two particle categories and explain why mineral particles are represented by different colors.

Response:

We thank the referee for identifying this ambiguity. The two descriptions refer to different mixing states of mineral particles. Mineral particles were identified based on their characteristic morphology and color. Under fluorescence microscopy, they generally appeared white and optically transparent, often with recognizable geometric or crystalline shapes.

The yellow-green particles described in the manuscript represent mineral particles associated with or coated by water-soluble salts or organic matter. The yellow-green fluorescence originates from these attached materials rather than from the mineral components themselves. Particle classification was therefore not based solely on fluorescence color. Mineral particles exhibiting yellow-green fluorescence could still be identified from their characteristic transparent or crystalline morphology. Thus, the difference between the white and yellow-green appearances reflects the presence or absence of attached materials on the mineral particles, rather than an inconsistency in particle identification.

Comment 5:

Figures need to be improved:

- Please add the units of bioaerosol concentration to all figures where concentrations are presented.
- Please label all figure panels with identifiers such as (a), (b), and (c).
- Could the authors provide representative examples corresponding to each of the four particle colors shown in Figure 2? The distinction among the different particle categories in Figures 2e–g is currently not sufficiently clear.
- For the top panel of Figure 6, please clarify what the color scale of bioaerosol concentration represents.

Response:

We thank the referee for these constructive suggestions. All figures have been carefully revised to improve their clarity and consistency.

1. **Units of bioaerosol concentration**
   The unit of bioaerosol concentration has been added to the relevant axes in all figures presenting concentration data. The concentration is now consistently reported in particles/m^3 throughout the manuscript and figures.
2. **Panel identifiers**
   (a), (b), (c) have been added to all multi-panel figures. The corresponding figure captions have also been revised to describe each panel explicitly and in the same order as presented in the figures.
3. **Representative examples of the four particle-colour categories in Fig. 2**
   We agree that the distinction among the four particle-colour categories in the original version of Fig. 2e–g was not sufficiently clear. To address this issue, we replaced these panels with three new representative images in which the four particle types can be more clearly distinguished. In addition, the different coloured particles have now been explicitly marked in the revised figure to facilitate visual identification. The corresponding figure caption has also been revised to clarify the interpretation of each particle category.
4. **Colour scale in the upper panel of Fig. 6**
   We thank the referee for pointing out this ambiguity. In the upper panel of Fig. 6, the different colours do not represent different bioaerosol concentration ranges. They are used only to distinguish samples collected in different months. Bioaerosol concentration is represented by the position of each data point on the

corresponding concentration axis. We have revised the figure legend and caption to clarify the meaning of the colours and avoid their interpretation as a concentration colour scale.

Revision made:

Page 8, Line 150.

Revised:

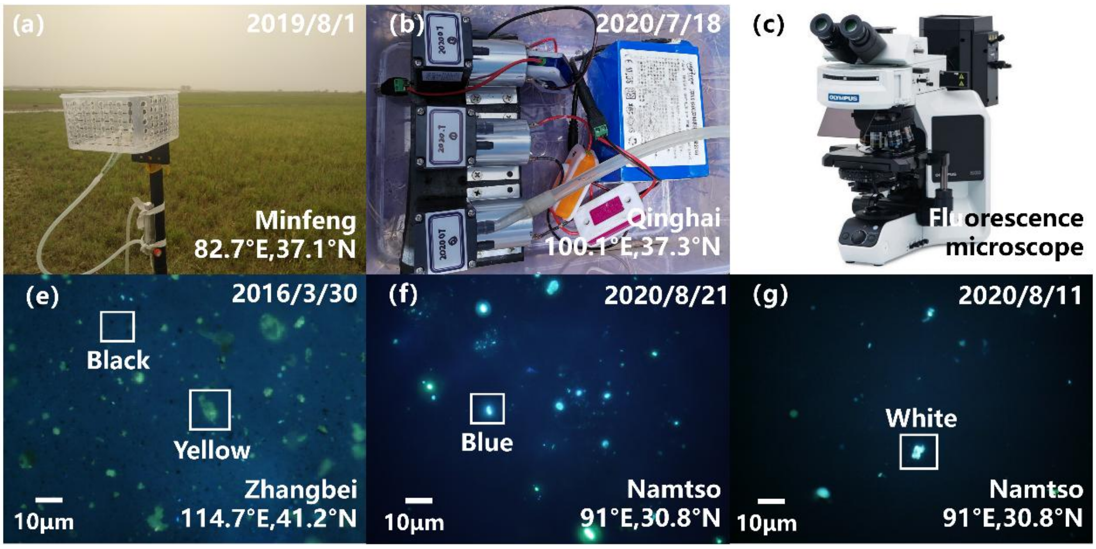

Figure 2: (a) Bioaerosols sampler used during the DuBi field sampling campaign; (b) power supply and sampling pump; (c) fluorescence microscope; (e–g) representative fluorescence micrographs of DAPI-stained samples, with the four particle-colour categories identified labels.

Revision made:

Page 11, Line 207.

Revised:

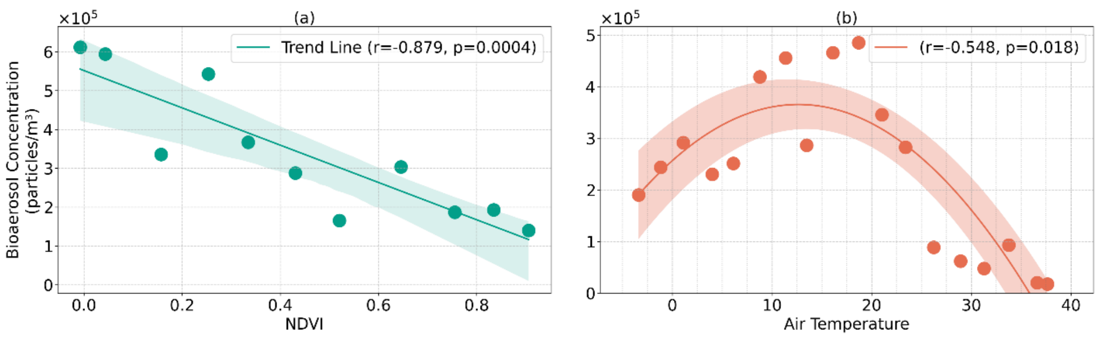

Figure 4: (a) Relationship between bioaerosol concentration and NDVI during the DuBi field sampling campaign. The green points represent mean bioaerosol concentrations calculated by binning NDVI into intervals of 0.1 and averaging all samples within each interval. (b) Relationship between bioaerosol concentration and air temperature. The orange points represent mean bioaerosol concentrations calculated by binning temperature into intervals of 2.5 °C and averaging all samples within each interval. The shaded areas indicate the 95 % confidence intervals.

Revision made:

Page 12, Line 227.

Revised:

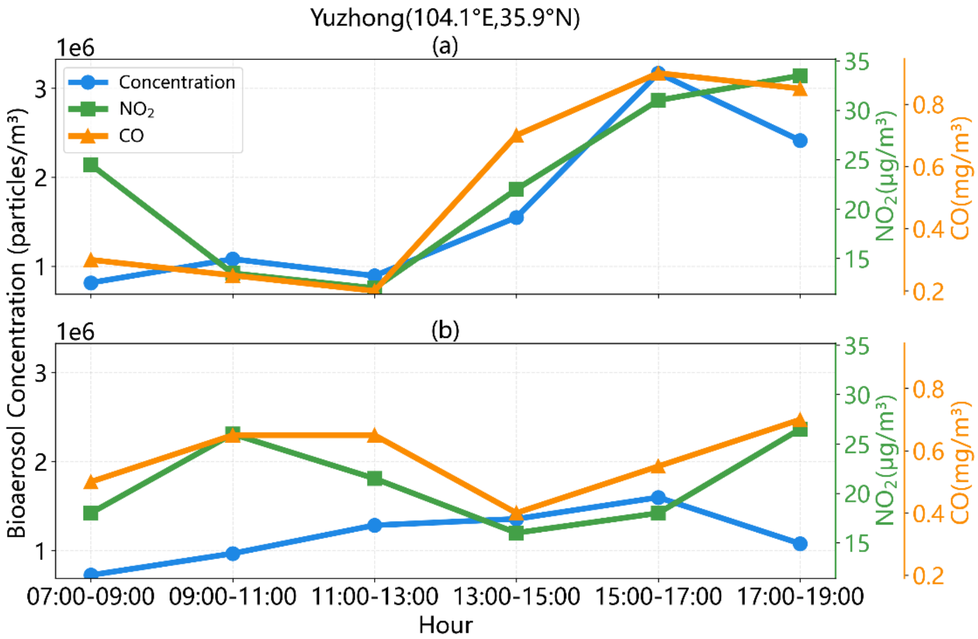

Figure 5: Temporal variations in bioaerosol, NO_2, and CO concentrations observed in Yuzhong on (a) 6 November and (b) 15 November 2020.

Revision made:

Page 13, Line 247.

Revised:

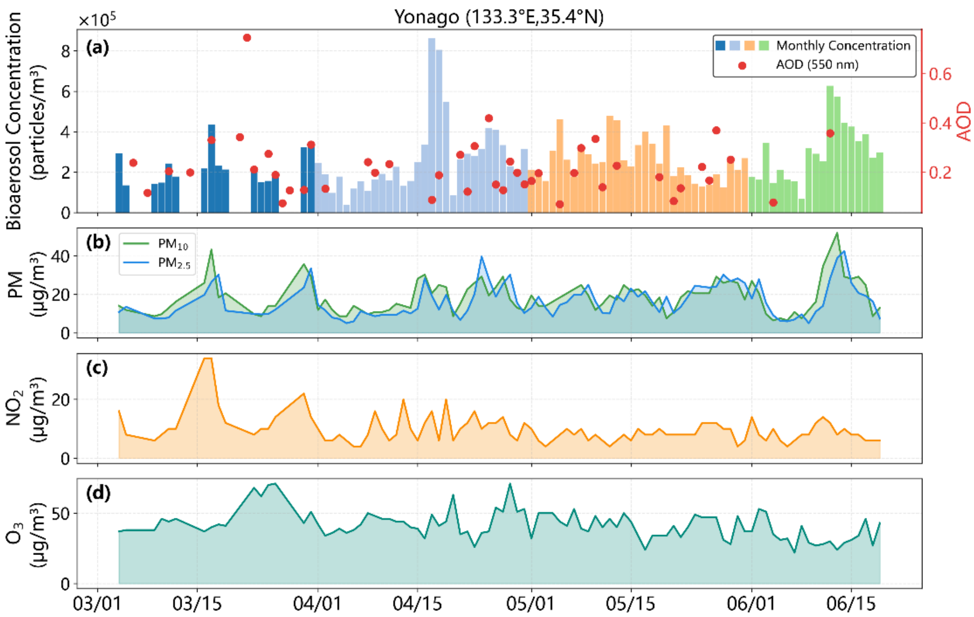

Figure 6: Daily variations in (a) bioaerosol concentration and aerosol optical depth (AOD), (b) $PM_{2.5}$ and PM_{10} concentrations, (c) NO_2 concentration, and (d) O_3 concentration in Yonago, Japan, during March–June 2015.

Comment 6:

As this is a *Scientific Data* paper, I would expect a more comprehensive description of the dataset itself before presenting downstream analyses. For example, it would be useful to first present the basic characteristics of bioaerosol concentrations and particle-type compositions at each observation site. For example, Section 3.3 and Figure 7 appear to analyze bacterial community composition using all samples combined. Would it be more informative to report the bacterial community composition separately for different sites, considering the large geographical differences among them?

Response:

We thank the referee for this important comment. We agree that, as a data paper, the manuscript should provide a more systematic description of the dataset itself before presenting subsequent analyses. In the original version, the site-level characteristics of bioaerosol concentrations, particle-type composition, and bacterial community structure were not presented in sufficient detail.

To address this concern, we have reorganized the Results section and expanded the description of the dataset at the observation-site level. The revised manuscript now first presents the distribution and variability of bioaerosol concentrations across the individual sites, together with the most abundant genera. This site-resolved presentation allows the spatial heterogeneity of the dataset to be assessed before the relationships with environmental variables are discussed.

We also agree that a site-resolved presentation can provide useful information on local bacterial community characteristics. However, the primary objective of Section 3.3 and Fig. 7 was to characterize the large-scale distribution of bacterial communities across East Asia and to examine their relationships with regional environmental gradients, rather than to establish a representative community profile for each individual site.

In particular, NDVI varies substantially among the observation sites because they encompass contrasting land-surface environments, ranging from arid and semi-arid regions to urban, coastal, and vegetated areas. By contrast, NDVI generally varies much less among samples collected at the same site over the relatively short observation periods available in this dataset. A site-by-site analysis would therefore provide insufficient within-site environmental variability for evaluating the relationship between bacterial community characteristics and NDVI. For these reasons, Fig. 7 was retained as a regional-scale overview of bacterial community composition across the dataset.

We also acknowledge that long-term, repeated observations at individual sites would be required to characterize site-specific community dynamics and evaluate their relationships with temporal changes in NDVI. This limitation and the need for future site-resolved analyses have now been noted in the revised manuscript.

Revision made:

Page 10, Line 193.

Revised:

Table 2 reports the Mean bioaerosol concentration and genus with highest mean relative abundance at each site. Concentrations span from 3.39 × 104 at Tazhong to 6.65 × 106 at Dalanzadgad. The three highest site means occur at Dalanzadgad, Kanazawa, and Dunhuang; the three lowest occur at Tazhong, Namtso, and Minfeng. These contrasts establish pronounced spatial heterogeneity in the reported site means. Lactococcus is the most frequently dominant genus, ranking first at 9 of 14 sites (64.3%); Ralstonia is reported at 2 sites.

Table 2: Mean bioaerosol concentrations and dominant genera at the sampling sites.

Site	**Mean bioaerosol concentration(particles/m^3)**	**Dominant genus**
Ali	–	*Lactococcus*
Dalanzadgad	6.646384×10^{6}	–
Dunhuang	3.177384×10^{6}	*Lactococcus*
Erenhot	1.666249×10^{6}	*Lactococcus*
Hakui	1.441260×10^{6}	–
Inner Mongolia	5.967343×10^{5}	*Corynebacterium*
Jinan	–	*Lactococcus*
Kanazawa	3.828780×10^{6}	–
Minfeng	9.869644×10^{4}	*Ralstonia*
Namie	1.994137×10^{5}	–
Namtso	6.523244×10^{4}	*Lactococcus*
Qinghai	4.025444×10^{5}	*Lactococcus*
Tazhong-Minfeng	–	*Muribaculaceae*
Tazhong	3.391558×10^{4}	*Lactococcus*
Tsogt-Ovoo	1.490235×10^{6}	–
Xigaze	–	*Kocuria*

Site	Mean bioaerosol concentration(particles/m^3)	Dominant genus
Yadong	–	*Lactococcus*
Yonago	2.661274×10^5	–
Yongin	4.247435×10^5	–
Yuzhong	1.058873×10^6	*Ralstonia*
Zhangbei	2.067384×10^5	*Lactococcus*

Revision made:

Page 16, Line 324.

Revised:

Although significant correlations were identified between bioaerosol characteristics and environmental variables such as NDVI and temperature, the underlying mechanisms remain unresolved. The lack of year-round continuous observations at individual sites limits robust seasonal analysis, while the uneven spatial distribution of the network, particularly the underrepresentation of forested and other densely vegetated regions, constrains its ecosystem representativeness. Future studies should therefore combine longer-term monitoring, expanded coverage of vegetation-dominated environments, and more detailed process-based analyses to better resolve seasonal variability, vegetation-related emissions, and the mechanisms linking bioaerosols to environmental conditions.

We sincerely thank the referee again for the careful evaluation of our manuscript and for the constructive comments and suggestions. We have addressed all comments and revised the manuscript accordingly. We believe that these revisions have improved the clarity, completeness, and scientific value of the manuscript and have strengthened its presentation as a data paper.

The Authors