Response letter

We thank the Editor and both referees for their careful assessment of our manuscript and their constructive comments and suggestions. We appreciate the opportunity to clarify the methodology, refine the interpretation of our findings, and improve the presentation of the study.

We provide point-by-point responses below. Each comment is reproduced and followed by our response and, where appropriate, the revised manuscript text. Line numbers in the reviewers' comments refer to the published preprint. Section and figure references identify the corresponding locations in the revised manuscript.

Reviewer comments are shown in black italics, our responses in blue, and quoted manuscript text in red.

Referee 1:

The manuscript is well written and presents important data on microplastic pollution connecting measurements between marine and air environments. I hope to see the manuscript accepted after one very minor revision:

We thank Reviewer 1 for the encouraging assessment of our manuscript and for recognising the value of combining marine and atmospheric microplastic observations. We appreciate the reviewer's careful reading and constructive suggestion, which we address below.

Comment on line 42: "MPs are generally defined as plastic particles smaller than 5 mm and typically larger than 100 nm (Kum et al., 2025)." I checked the paper on Kum et al. and rather than giving a definition for a microplastic I understood that their conclusion is that there is no consensus for the definition for microplastic. Therefore in my opinion the paper is incorrectly cited. In fact Kum et al. write: "We have also observed that there has been a multitude of opinions and recommendations regarding the definition of microplastics."

My suggestion to you is to leave out the lower limit, and simply write: "MPs are typically defined as plastic particles smaller than 5 mm." If you want to give a specific definition, then cite carefully the original source, however, in your case, I don't think you need to give the exact definition as it varies.

We thank the reviewer for this clarification and agree that Kum et al. (2025) was not an appropriate reference for the stated definition. Following the reviewer's suggestion, we have removed the lower size limit and the citation from this sentence.

Revised text: "MPs are typically defined as plastic particles smaller than 5 mm."

Then I have one optional revision:

I would really like to see some Raman spectra added to the manuscript. In the appendix you show representative microscope images. If you could add some representative Raman spectra, that would really be a valuable addition for scientist using Raman. Adding the spectra into the appendix would be enough. But as said, this is optional.

We thank the reviewer for this valuable suggestion. We have added Appendix C (Figs. C1–C9), presenting representative Raman spectra together with micrographs of the analysed airborne and marine particles. The accompanying descriptions identify the principal Raman bands and provide relevant literature assignments. The appendix also includes a cellulose fibre as a non-plastic comparison and

examples in which colourant signals dominate the spectrum. Assignments supported by diagnostic polymer bands are distinguished from tentative assignments and cases in which the substrate polymer remains unresolved.

Referee 2

General comment

The paper investigates airborne and marine microplastics in the Northern Indian Ocean discussing the differences and investigating possible transport paths. The topic is interesting and well timed. The dataset is good and the results are valuable for the scientific community. However, some aspects are not completely clear or discussed with the necessary detail, see my specific comments so that I suggest a revision step before considering the paper for publication.

We thank Reviewer 2 for the careful assessment of our manuscript and for recognising the relevance of the topic and the scientific value of our dataset and results. We appreciate the constructive comments and agree that several aspects require clarification and more detailed discussion. We address each comment below and describe the corresponding revisions to the manuscript.

Specific comments

Line 19. Do you mean that MPs are increasing or that the number of studies to detect them is increasing?

We thank the reviewer for pointing out this ambiguity. We have revised the sentence to refer to the documented occurrence of MPs, without implying an increase in their concentrations or in the number of studies.

Revised text: "Microplastics (MPs) have been detected in both marine and atmospheric particulate matter, but their sources, transport, and air–sea exchange remain poorly constrained in remote marine regions."

Line 92-100. It is quite difficult to say if MPs are acting as vector of eBC. There is also no need for this, the mobility in the atmosphere of fine eBC particles is likely larger than that of MPs. In addition, I do not agree that this eventual, but not clear in this dataset, interaction increases human health risks. I strongly suggest to modify these sentences providing evidences or remove these aspects.

We thank the referee for this helpful comment. We agree that our dataset does not establish physical interactions between AMPs and combustion-derived particles or increased health risks arising from such interactions. We have therefore removed the statements concerning MPs acting as vectors for BC and other pollutants, potential modifications to particle properties and atmospheric residence times, and enhanced human health risks. We have also revised the general discussion of inhalation exposure to avoid assigning fixed respiratory deposition regions solely from the stated particle-size ranges.

The revised paragraph focuses on documented airborne microplastic occurrence and transport, retaining the relevant supporting references. It also clarifies the purpose of the joint observations: eBC is used as a contextual indicator of combustion-derived aerosol influence, while aerosol light scattering provides complementary information on aerosol conditions.

Revised text: "Airborne fibres, including microplastics, have been documented in indoor and outdoor environments (Dris et al., 2017), while atmospheric transport and ocean–atmosphere exchange are recognised components of the plastic cycle (Brahney et al., 2021; Allen et al., 2022). Joint observations of AMPs and aerosol optical properties provide an opportunity to examine how AMP abundance varies with atmospheric aerosol conditions. In this study, equivalent black carbon (eBC) is used as a contextual indicator of combustion-derived aerosol influence, while aerosol light scattering provides complementary information on aerosol conditions. Relationships between AMP abundance and these aerosol indicators remain poorly constrained, particularly in remote island regions influenced by both marine aerosol production and combustion-derived particles."

Line 115. If the area has minimal direct local anthropogenic emissions, how it is possible to investigate the point (3) of the introduction using eBC as tracer of locale missions?

We thank the referee for pointing out this inconsistency. The reference to "local anthropogenic pollution sources" in objective (3) did not accurately describe the intended role of eBC in our analysis. We use eBC as a contextual indicator of combustion-derived aerosol influence, including aerosol transported from regional sources. The eBC measurements alone cannot distinguish local emissions from transported contributions.

We have therefore revised objective (3) to focus on the co-variability of AMPs with eBC and aerosol light scattering under different advection regimes. The description of limited direct local emissions has been retained because it explains the site's suitability for investigating the regional atmospheric background.

Revised text: "(3) assess the co-variability of AMPs with eBC and aerosol light scattering under different advection regimes, using eBC as a contextual indicator of combustion-derived aerosol influence."

It would be better to use eBC everywhere in the paper. Mixing BC and eBC is not clear and what is really measured is eBC.

We thank the referee for this suggestion and agree that the terminology should be consistent. We now use equivalent black carbon (eBC) when referring to the aethalometer-derived measurements. The Methods identify the 880 nm channel used for the reported eBC concentrations and explain the contextual role and limitations of this optical indicator. The general term black carbon is retained where it refers to the material or to findings from the literature rather than to our optical measurements.

The aerosol optical observations are retained as contextual descriptors of the conditions during AMP sampling. Their descriptive wind-sector differences are not used to establish corresponding differences in AMP concentrations or to assign common sources.

Line 155. There is a huge difference in sampling times. Why? How the sampling time was chosen, is there a criterion? In addition, all the averages and standard deviations for atmospheric particles have been calculated as weighted average taking into account the sampling duration?

We thank the referee for requesting this clarification. Exposure durations were deliberately varied to investigate possible effects of exposure time on microplastic accumulation on the collection slides. Slides were exposed in parallel and retrieved after different intervals, providing samples covering shorter and longer exposure periods, consistent with the experimental framework described by Ferrero et al. (2018).

Each sample concentration was normalised to its corresponding sampled air volume, determined from the volumetric airflow rate through the Deposition Box and the individual exposure duration, following the approach described by Ferrero et al. (2022). Sampling duration was therefore explicitly incorporated into the concentration calculation.

Overall mean concentrations and standard deviations were calculated across the 46 individual, volume-normalised environmental sample concentrations, excluding laboratory blanks 11 and 12. We now distinguish these descriptive summaries of all exposures from the exploratory wind-sector comparison, for which simultaneous and overlapping exposures require separate treatment.

During the revision, we regenerated the numerical summaries from the sample-level and particle-level source records, reconciling sample identifiers, exposure intervals, wind-sector assignments and particle eligibility within a common analysis workflow. The resulting updates concern both the numerical summaries and their statistical interpretation. Volume normalisation incorporates exposure duration into each concentration estimate, but does not remove temporal overlap between slides exposed simultaneously.

For the wind-sector concentration comparison, we used the short-exposure subset (approximately 25–55 h) and averaged parallel slides with identical sampling intervals. Where short exposures shared a start time, the longer window was retained to maximise coverage without overlap. The selection rule was based on exposure timing, rather than on the measured concentrations. This yielded ten non-overlapping sampling windows, five per sector. We used the two-sided Kolmogorov–Smirnov statistic, with exact permutation p values calculated from all 252 allocations of the sector labels.

Using a sampling window as the unit of comparison avoids counting parallel slides as separate temporal observations. Mean TSMP concentrations were 37.38 ± 12.50 m^{-3} under northerly flow and 46.46 ± 24.35 m^{-3} under easterly flow; corresponding AMP concentrations were 3.10 ± 2.95 and 2.53 ± 2.50 MP m^{-3}. Standard deviations describe variability among the sampling windows. Neither comparison resolved a systematic sectoral difference ($p = 0.87$ for TSMP and $p = 0.81$ for AMP). The revised analysis therefore does not support the previous statement of a statistically significant wind-sector difference in AMP concentration. Given the limited number of windows, non-significance should not be interpreted as evidence of equivalence.

For the TSMP and AMP analyses, Figures 8 and 9 and Table B1 retain the complete environmental dataset for descriptive purposes, including short and long exposures. Table B1 summarises concentrations across 26 northerly and 20 easterly slides, whereas Figure 9 pools individual particle properties. These descriptive values differ from the window-based statistics because they describe different, explicitly defined populations and levels of aggregation. The figures now use box plots showing the interquartile range, median, arithmetic mean and 1.5-IQR whiskers; the whiskers are not confidence intervals. The Table B1 note now identifies these descriptive populations and distinguishes them from the sampling-window units used for inference.

The particle-property summaries use 837 northerly and 657 easterly TSMP aspect ratios, 86 and 72 AMP aspect ratios, and 68 and 67 AMP aerodynamic-diameter estimates, respectively. Sector-specific polymer percentages have also been recalculated consistently relative to all AMPs within each sector, retaining unclassified plastics in the denominator. This gives PE contributions of 41.9 % under northerly flow and 62.5 % under easterly flow. These updates make the denominators and populations underlying the reported values explicit.

Revised text (Sect. 2.2.1): “In total, 48 samples were collected between 13 January and 4 February 2023, comprising 46 environmental samples and two laboratory blanks (samples 11 and 12). Exposure durations ranged from approximately 25 to 528 hours and were deliberately varied to investigate

possible effects of exposure time on microplastic accumulation on the collection slides. Slides were exposed in parallel and retrieved after different intervals, resulting in overlapping sampling periods covering shorter and longer exposures. Individual sampling intervals are listed in Table B2."

"For each sample, exposure duration was incorporated into the concentration calculation through the sampled air volume, determined as $V = Q \times \Delta t$, where Q is the volumetric airflow rate through the Deposition Box and Δt is the individual exposure duration. Concentration estimates were normalised using the corresponding sampled air volume, following the approach described by Ferrero et al. (2022). Overall mean concentrations and standard deviations for AMPs and TSMP were calculated from the 46 volume-normalised environmental sample concentrations, excluding laboratory blanks 11 and 12."

It is possible to identify a size range for TSMP? I believe that concentrations and percentages of AMP will strongly depend on the minimum size of particles measured.

We thank the reviewer for this helpful comment. We agree that AMP concentrations and their contribution to TSMP depend on the size range accessible to the sampling and analytical methods. We have added the observed length and width ranges for both TSMP and AMPs and clarified that these ranges describe the recorded particles rather than a validated lower detection limit. We have also clarified that the reported concentrations and percentages refer to the particle population detected using our workflow and that differences in lower size thresholds should be considered when comparing studies.

The updated TSMP concentration summaries and the separate wind-sector comparison are described in our response to the sampling-duration comment above. We have also distinguished pooled size distributions from morphology-specific summaries. The revised description explains that the right-skewed airborne length distribution reflects the combination of shorter fragments and less numerous but longer fibres, rather than a general enrichment in short fibres.

Revised text (Sect. 2.3):

For airborne samples, TSMP denotes the particle population collected on the glass slides and detected during microscopic inspection, with AMPs forming a subset of this population. Particle dimensions were characterised separately by length and width because of the contrasting geometries of fibres and fragments. The reported AMP concentrations and their contribution to TSMP therefore refer to the particle population detected using the present sampling and analytical workflow. These quantities may be affected by size-dependent collection, visual detection, and material identification, and comparisons with other studies should account for differences in the lower size threshold.

Revised text (Sect. 3.2):

Recorded TSMP lengths ranged from 18 to 7670 µm, and widths from 2 to 624 µm. Corresponding AMP lengths ranged from 32 to 6920 µm, and widths from 6 to 410 µm. These observed dimensional ranges do not, by themselves, establish a validated lower detection limit or demonstrate complete detection of particles at the smallest recorded sizes.

Figure 2. One error bar is missing for W20.

We thank the referee for noting this. The W20 value, 0.004 ± 0.006 MP m^{-3}, gives a negative lower mean-minus-SD endpoint, which cannot be represented on a logarithmic axis. Figure 2 now marks the lower SD whisker with a downward arrow at the plotting limit; this does not imply a negative physical concentration.

In revising the figure, we also standardised the statistical quantities used for the regional comparison. Error bars represent standard deviations where these could be established from the original studies. For Perera et al. (2022), reported standard errors were converted to standard deviations using the corresponding sample sizes. For Kaushik et al. (2024), the statistics were recalculated from the reported sample-level observations. Ghosh et al. (2025) is shown as means only because the accompanying dispersion measure could not be identified unambiguously. Thus, ranges and standard deviations are no longer presented as if they were the same quantity. The revised caption explains these distinctions, and the text acknowledges differences in sampling design and analytical size thresholds.

Revised caption excerpt: "Circles show means ± SD. P22 SDs were converted from SEs; K24 statistics were recalculated from four samples collected in 2016 and 2020. G25 diamonds show means only because the dispersion statistic is undefined. The arrow marks the truncated W20 lower SD whisker."

It would be useful to mention how the aerodynamic diameter was calculated.

We have expanded Sect. 2.3 to state the aerodynamic-diameter calculation explicitly, including the use of the full measured particle width d, the aspect ratio L/d, the reference density and the polymer-specific material densities. Particle-level estimates and their descriptive summaries in Figure 9 and Table B1 were regenerated using this formulation. These are model-derived estimates, rather than direct aerodynamic measurements, and depend on the stated assumptions concerning geometry, orientation and material density.

Revisited text: Equivalent aerodynamic diameters were estimated from microscopy-derived particle lengths and widths using the randomly oriented prolate-spheroid approximation described by Gonda and Abd El Khalik (1985), following Ferrero et al. (2022):

$$D_{ae} = \sqrt{\frac{3}{2}} \cdot d \cdot \sqrt{\frac{\frac{\rho}{\rho_0}}{\frac{0.385}{\ln(2\beta)-0.5}+\frac{1.230}{\ln(2\beta)+0.5}}}.$$

Here, (d) is the measured particle width, β=L/d is the aspect ratio, L is the measured particle length, and ρ is the material density. The reference density was ρ_0 =1000 kg m^{-3}. Material densities of 955, 905, 1350, and 1130 kg m^{-3} were assumed for PE, PP, PET, and PA, respectively. These values represent model-derived estimates dependent on the assumed density, geometry, and orientation. For irregular fragments, the prolate-spheroid representation constitutes a geometric approximation.

Aspect-ratio summaries retain all dimensionally valid AMP records, including particles without an assigned polymer. Aerodynamic diameters are estimated only where a material density can be assigned, giving 135 estimates in the full dataset (68 northerly and 67 easterly particles). The corresponding descriptive means are 95.67 ± 88.52 and 103.07 ± 98.99 µm. Missing density assignments were not treated as zero aerodynamic diameters.

For the separate exploratory wind-sector comparison, aerodynamic diameters were first averaged within each slide, and parallel slide means were then averaged within each retained sampling window. Windows without eligible particles were omitted from this property comparison. This yielded four northerly and three easterly windows. The exact two-sided permutation comparison used the Kolmogorov–Smirnov statistic across all 35 allocations of sector labels and did not resolve a sectoral difference ($p = 0.97$). This p value concerns window means, not the pooled particle distributions shown in Figure 9.

Lines 683-694. It seems an overestimation of the results. Essentially the co-variation does not explain the source because correlation is not causation. So that I would revise these sentences. An equal caution should be applied on the conclusions (lines 711-716) reporting again these aspects.

We agree that co-variation cannot establish causation or identify AMP sources. In addition to revising the wording, we re-evaluated the wind-sector comparison using the non-overlapping sampling windows described above. This exploratory analysis did not resolve a systematic northerly–easterly difference in AMP concentration ($p = 0.81$). In the revised Discussion and Conclusions, we do not use this comparison as evidence of a systematic northerly enhancement in AMP concentration or of common sources with combustion-derived aerosol.

The eBC and aerosol scattering measurements characterise the atmospheric setting during AMP sampling. They do not establish common emission sources, determine AMP transport distances, or distinguish local emissions from regional and long-range contributions. Evidence for aged, transported aerosol provides context for the aerosol background but cannot be directly extrapolated to AMP origin. These limitations are made explicit in the revised Discussion and Conclusions.

Revised Discussion text: "The joint AMP and aerosol measurements characterise the conditions encountered during sampling. However, the AMP comparison based on non-overlapping sampling windows did not resolve a systematic wind-sector contrast. The chemical evidence for aged, transported aerosol provides context for the aerosol background but cannot be used directly to assign the origin or transport history of AMPs."

"Long-range atmospheric transport remains a plausible hypothesis, supported by observations of airborne microplastics in remote marine and Antarctic environments (Chen et al., 2023). Similarly, van der Does et al. (2018) reported that giant dust particles (>75 µm) can be transported surprisingly vast distances, suggesting that the same may be possible for large AMPs. Contributions from local or regional AMP emissions superimposed on a transported aerosol background also cannot be excluded. The present observations do not distinguish these possible contributions or quantify their relative importance. Further source-specific measurements and transport analyses are required to evaluate these hypotheses."

Revised Conclusions text: "Third, the joint eBC and aerosol scattering measurements characterised the atmospheric background during AMP sampling. The AMP comparison based on non-overlapping sampling windows did not resolve a systematic wind-sector contrast. These measurements provide context for interpreting AMP variability but do not establish common emission sources or a causal relationship between AMPs and combustion-derived aerosol. The relative contributions of local emissions, regional transport and long-range transport remain unresolved."

These revisions preserve the study's observational contribution: simultaneous characterisation of airborne and marine particle populations, documentation of their morphological and compositional variability, and measurements of the atmospheric context. They narrow the source-attribution claims to match what this dataset can establish.

Line 720. For the reasons above I would not say robust at maximum it can help.

We thank the referee for this suggestion and agree that the original wording was too strong. We have removed the term "robust" and revised the statement to describe the combined measurements as helping interpret MP variability and guide further investigation. This wording is consistent with the limitations on source attribution acknowledged in the revised Discussion and Conclusions.

Revisited text: More broadly, combining AMP and MMP observations with meteorological and aerosol optical measurements can help interpret MP variability and guide further investigation of potential sources, atmospheric transport, and air–sea exchange processes in island environments.

Figure B3. It is not a logarithmic axis.

We have removed the reference to a logarithmic axis from the Figure B3 caption. The caption now identifies the plotted concentrations and clarifies that laboratory blanks 11 and 12 are shown for context but excluded from the environmental statistics.