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Atmospheric Microplastics and Nanoplastics: A Systematic Review of Sources, Transport, Chemical Transformation, Pollutant Interactions and Climate Implications

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ABSTRACT
Microplastics (MPs) and Nanoplastics (NPs) are plastic particles < 5mm and < 1µm, respectively, formed either through abrasion of bulk plastics or released as primary manufactured particles. Atmospheric MPs and NPs are now acknowledged as pervasive global environmental pollutants whose environmental role in atmospheric chemistry, pollution and climate change is progressively recognised. In this review we provide an integrated overview of current scientific understandings on sources, occurrences, transport, chemical evolution, pollutant interactions and environmental impacts of atmospheric plastic particles. Emissions primarily come from transport sector, industrial processes, man-made fibres and waste management system, whereas secondary emissions may come from fragmentation and re-suspension of plastic debris from land and sea surfaces. Once in the atmosphere, MPs and NPs can undergo long-range transport and both wet and dry deposition to pollute the remote ecosystems. Ultraviolet irradiation, ozone, hydroxyl radical and heterogeneous reactions in atmosphere can result in the weathering of plastic particles. The changes in particle morphology, surface functionalization and transformation from MP to NP have a profound effect on interaction of plastic with persistent organic pollutants, heavy metals, polycyclic aromatic hydrocarbons and per- and polyfluoroalkyl substances to function as a reactive pollutant carriers. Although, the study on atmospheric MPs/NPs has gained significant interest and rapid progresses, a substantial research gap still existed for detection of Nanoplastic, source apportionment and their atmospheric transport modelling and climatic feedback, therefore future study will need the development of standardized methodology, analytical technology and incorporating atmospheric plastic particles in environmental monitoring programs.

Keywords: Atmospheric Microplastics, Nanoplastics, Atmospheric Transport; Chemical Aging, Pollutant Interactions, Aerosols, Climate Change, Human Health, Atmospheric Deposition

INTRODUCTION

Plastic pollution is one of the ubiquitous environmental problems of the Anthropocene; the global production of plastic increased from approximately 2 million tonnes in 1950 to over 400 million tonnes in recent years (Geyer *et al.* 2017; Moruf *et al.*, 2020; United Nations Environment Programme [UNEP] 2023). Their durability, low cost and versatility contribute to their prevalent usage in a wide range of applications, from industrial to commercial, agricultural, domestic and even medical purposes. However, insufficient management of waste and increased levels of consumption have contributed to an exponential accumulation of plastic waste in terrestrial, freshwater, marine, and atmospheric environments (Jambeck *et al.* 2015; UNEP 2023).

For a long time, most plastic pollution studies have targeted aquatic ecosystems, where MPs (<5 mm) and NPs (<1 m) are documented widely in oceans, rivers, sediments and aquatic biota (Andrady 2011; Thompson *et al.* 2004). However, within the last decade more and more research has established the atmosphere as an under-researched and yet key compartment within the global plastic cycle (Allen *et al.* 2019; Brahney *et al.* 2021). Air transportation processes transport plastic particles away from the emission sources, and can result in regional, continental and trans-continental circulation of MPs and NPs, which are consequently identified as one of the emerging air contaminants.

Global Plastic Pollution and Atmospheric Emergence

Plastic pollution was initially recognized as a major environmental problem in marine ecosystems following the introduction of the term microplastics in the early 2000s. Subsequent research demonstrated that plastic particles are not confined to aquatic environments but are also widely distributed in soils, freshwater systems, and the atmosphere, indicating that plastic pollution is a global, interconnected environmental issue. Over the past decade, the atmosphere has emerged as an important environmental compartment because it facilitates the long-range transport and redistribution of microplastics (MPs) and nanoplastics (NPs) across terrestrial, aquatic, and remote ecosystems (Thompson *et al.*, 2004).

The first direct evidence of atmospheric microplastics was provided by Dris *et al.* (2016), who reported synthetic fibres in atmospheric fallout over the Paris metropolitan area, demonstrating that airborne plastic particles constitute an important pathway for environmental contamination. Subsequent investigations confirmed the occurrence of airborne microplastics in both indoor and outdoor environments, revealing higher concentrations indoors due to

textile abrasion and human activities (Dris *et al.,* 2017; Cai *et al.,* 2017; Gasperi *et al.,* 2018). These pioneering studies shifted scientific attention from the traditional focus on aquatic plastic pollution toward recognition of the atmosphere as an important transport medium for plastic particles. Since these early investigations, atmospheric microplastics have been detected in diverse environments, including densely populated cities, rural landscapes, mountain catchments, marine atmospheres, Arctic snow, Antarctic regions, and other remote wilderness areas where local anthropogenic sources are minimal (Allen *et al.,* 2019; Bergmann *et al.,* 2019; Brahney *et al.,* 2020). These findings fundamentally changed the perception of plastic pollution from a localized waste-management problem to a global atmospheric contaminant capable of crossing geographical and political boundaries through atmospheric circulation.

Atmospheric plastic particles originate from both primary and secondary sources. Primary emissions arise from synthetic textile fibres, tyre and brake wear, industrial activities, plastic manufacturing, and waste-handling operations, whereas secondary emissions result from the environmental weathering, fragmentation, and re-suspension of larger plastic debris from urban surfaces, agricultural soils, landfills, and coastal environments. Marine aerosols generated through sea-spray also contribute to atmospheric plastic loading by transferring buoyant particles from the ocean surface into the atmosphere (Dris *et al.,* 2016; Allen *et al.,* 2022; Brahney *et al.,* 2021; Ayoub *et al.,* 2025). Once airborne, plastic particles behave similarly to other atmospheric aerosols, such as mineral dust and black carbon with their transport governed by particle size, density, morphology, meteorological conditions, and large-scale atmospheric circulation. Fibrous particles, in particular, exhibit low settling velocities, allowing prolonged atmospheric residence times and transport over hundreds to thousands of kilometres.

Recent advances in atmospheric monitoring, remote sensing, and numerical modelling have further demonstrated that the atmosphere functions as a major pathway linking terrestrial, freshwater, marine, and cryospheric environments within the global plastic cycle. The detection of atmospheric microplastics in Arctic snow, alpine catchments, protected natural reserves, and marine atmospheres confirms that atmospheric transport is a dominant mechanism driving the global redistribution of plastic particles to distant and otherwise pristine ecosystems (Allen *et al.,* 2019; Bergmann *et al.,* 2019; Brahney *et al.,* 2020; Ayoub *et al.,* 2025).

Why Atmospheric Microplastics Matter

Scientific focus on atmospheric micro- and Nano plastics is increasing because of their diverse and far-reaching environmental, climatic and human health impacts. While larger pieces of plastic waste are more likely to stay confined to a single environment, airborne plastic particles are dispersed over vast geographical distances through atmospheric transport, contributing to widespread pollution in environments that have not previously been contaminated with plastic (Allen *et al.,* 2022; Ayoub *et al.,* 2025).

From an environmental standpoint, atmospheric deposition has become recognised as a key route for the translocation of plastics from the atmosphere to terrestrial and aquatic ecosystems. Through wet and dry deposition, atmospheric microplastics are delivered to forest systems, croplands, freshwaters, oceans and soils, thus causing pollution of terrestrial and aquatic ecosystems and extending the geographic reach of plastic pollution on a global scale (Brahney *et al.,* 2021). Atmospheric transport is also crucial in the context of interchanging between terrestrial and marine `systems and demonstrates the highly interlinked nature of the global plastic cycle. The presence of plastics in the atmosphere is also important because they undergo various physicochemical transformation processes while traveling. For example, exposure to UV radiation, O 3, •OH radicals and other oxidants leads to aging, which can result in changes in chemical composition, surface functionality, fragmentation to smaller particles including nanoplastics, and development of an oxidizing nature of plastics (Song *et al.,* 2026; Dodero *et al.,* 2025). These transformation processes impact upon the reactivity, capacity for adsorption, movement and toxicity of plastics in environmental systems.

Another major cause of concern arises from potential interactions of airborne plastics with contaminants. Adsorption onto plastics of large specific surface area and hydrophobic nature and with oxidizing surface reactivity after atmospheric aging leads to plastics binding and carrying pollutants such as persistent organic pollutants (POPs), polycyclic aromatic hydrocarbons (PAHs), heavy metals and per- and polyfluoroalkyl substances (PFAS) (Dhandapani *et al.,* 2025; Brenckman *et al.,* 2026). These interactions may facilitate transboundary movement of POPs, increase exposure potential to ecosystems and human health, and alter their fate. A new and important aspect of plastic pollution in the atmosphere involves the impact that this has on the climate. As aerosols, airborne plastics interact with incoming solar radiation and affect solar radiation budget, cloud condensation processes, and atmospheric chemistry (Revell *et al.,* 2021). Their influence on radiative forcing and climate feedbacks is still unknown but their nature as pollutants means they must be recognized as a potentially significant anthropogenic aerosol class (Joo, 2026).

Human exposure is also another significant concern. Humans can ingest or inhale plastics that become suspended in the atmosphere. Inhalation of such particles may have an influence on deep respiratory structures, and in vivo and in vitro evidence have shown that inhaled microplastics are associated with increased oxidative stress, inflammation and other damaging effects, and in particular when plastics are loaded with hazardous pollutants (Wang *et al.,* 2025). However, much uncertainty surrounds the actual levels of exposure, health mechanisms, and the actual extent to which human health effects occur.

Scope and Objectives of the Review

While the research into microplastics in the atmosphere has grown significantly over the last ten years, many gaps exist in our understanding of emission sources, transport, atmospheric transformations, interactions with other pollutants and links to climate change. Most studies carried out in the last ten years are specialized and cross-cutting the disciplines of atmospheric chemistry, aerosol science, pollution, toxicology and climate. Here a synthesis is made of our present understanding.

This review aims to offer a comprehensive and critical assessment of the nascent and evolving field of atmospheric micro- and nanoplastics. The review aims:

i. Examine the major sources and emission pathways of atmospheric microplastics and nanoplastics.
ii. Evaluate the occurrence, distribution, transport mechanisms, and deposition processes governing their atmospheric behaviour.
iii. Assess the chemical aging and atmospheric transformation processes that influence particle properties and environmental fate.

iv. Analyse interactions between airborne plastics and atmospheric pollutants, including organic contaminants, heavy metals, and emerging pollutants.
v. Explore the implications of atmospheric plastics for climate systems, atmospheric chemistry, ecosystem contamination, and human health.
vi. Identify current knowledge gaps, methodological limitations, and future research priorities required to advance understanding of atmospheric plastic pollution.

By integrating recent advances in atmospheric chemistry, environmental science, and climate research, this review seeks to provide a holistic perspective on the role of microplastics and nanoplastics in the atmosphere and their significance within the broader context of global environmental change.

MATERIALS AND METHODS

Review Methodology

This study uses a systematically structured literature review approach to aggregate state-of-the-art on atmospheric MPs and NPs including their sources, pathways, chemical transformation, pollutants interactions, and climatic impact. We employed the standard system of the literature review and PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure that the review is rigorous and reproducible (Peries et al., 2024; Zielli et al., 2026).

Literature Search Strategy

A systematic literature search was performed according to the PRISMA 2020 statement. Searches were made within Scopus, Web of Science, ScienceDirect, PubMed, SpringerLink, and Google Scholar using a combination of search terms with Boolean operators such as 'atmospheric microplastics', 'airborne microplastics', 'nanoplastics', 'atmospheric transport', 'atmospheric deposition', 'plastic aerosols', 'photochemical aging', 'pollutant interactions' and 'climate impacts'. This yielded paper published between January 2004 and March 2026. The number of records identified was 1300, with 312 duplicate results being removed. Upon title and abstract screening of the remaining 988 results, the full texts of 234 were reviewed against eligibility criteria. Following application of pre-defined inclusion and exclusion criteria, 92 papers were used in a qualitative synthesis.

PRISMA Screening Framework

The study selection process followed the PRISMA workflow, which includes four stages: identification, screening, eligibility, and inclusion.

i. ***Identification***
Relevant studies were retrieved using database searches and keyword combinations.

ii. ***Screening***
Duplicate records were removed, and titles and abstracts were screened for relevance to atmospheric microplastics and nanoplastics.

iii. ***Eligibility***
Full-text articles were assessed based on inclusion criteria, focusing on atmospheric processes and environmental transport mechanisms.

iv. ***Inclusion***
Final studies were included for qualitative synthesis based on relevance, methodological quality, and contribution to atmospheric microplastic science.

Recent PRISMA-based atmospheric microplastic reviews demonstrate that structured screening significantly improves transparency and reduces selection bias in emerging pollutant research domains (Peries *et al.*, 2024; Zielli *et al.*, 2026) as shown below.

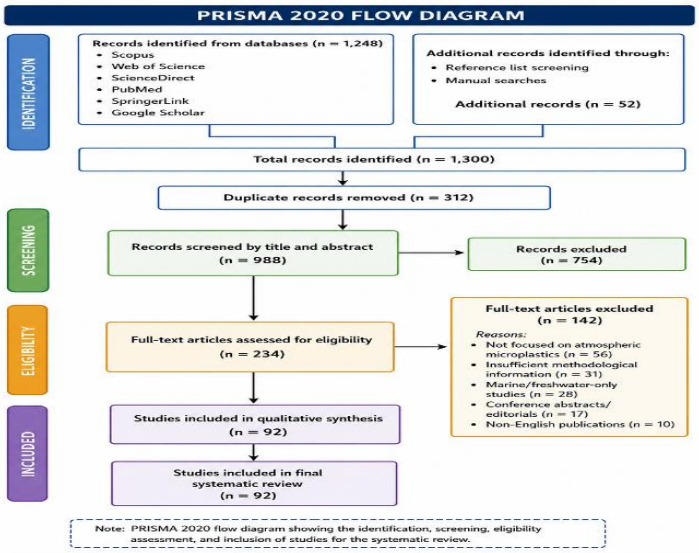

Figure 1: PRISMA 2020 flow Diagram Illustrating the Literature Identification, Screening, Eligibility Assessment, and Inclusion Process Used in this Systematic Review of Atmospheric Microplastics and Nanoplastics

Data Extraction and Synthesis

The data was extracted using a systematic framework. The parameters that were extracted were: geographic location, sampling media (air, deposition, snow or aerosol), type of polymer (PE, PP, PET, PVC), shape (fibre, fragment, film, bead), concentration (particle/m or flux), mechanisms of transport and deposition, mechanisms of chemical aging and transformation and the analytical method used (FTIR, Raman, py-GC/MS). Due to the diverse methodological approaches used, a narrative integrative synthesis of the extracted data was performed. This data was divided thematically into five categories: i) Sources and Emissions; ii) Transport and deposition; iii) Chemical aging and transformation; iv) Interactions with other pollutants; v) Climatic and health

impacts. Similar integrative narrative syntheses are present in recent literature reviews on atmospheric microplastics because of the variability in sampling methods, the limits of detection, and the reporting standards used (Mbachu *et al.,* 2020; Ayoub *et al.,* 2025; Peries *et al.,* 2024).

RESULTS AND DISCUSSION

Sources and Atmospheric Emissions of Microplastics and Nanoplastics

The source of airborne MPs and NPs is characterized by a heterogeneous blend of direct anthropogenic emission pathways and indirect emission pathways resulting from secondary re-emission to the atmosphere. This contrasts with well-defined sources of conventional atmospheric pollutants and involves trans-sectorial and secondary re-emission pathways from environmental processes. As a result, source apportionment is currently the most uncertain component of the atmospheric plastic cycle (Ayoub *et al.,* 2025; Peries *et al.,* 2024). The atmosphere acts as a receiving reservoir and a secondary reservoir, constantly re-distributing particles within atmospheric, terrestrial, and marine environments, leading to significant uncertainty associated with determining source strengths as well as making differentiation between primary emission and secondary re-emission pathways (Allen et al., 2022; Brahney *et al.,* 2021).

Primary and Secondary Atmospheric Sources

Primary atmospheric MPs are those emitted directly into the atmosphere as particles. Main sources are synthetic fibre particles released during production, use, and laundry of textiles; tire and brake wear particles derived from vehicles, industry production of plastic items, construction and the degradation of packaging (Dris *et al.,* 2016; Kole *et al.,* 2017). Road traffic emissions have gained recognition as important sources of MPs in urban environments. Repeated wearing of tires against the road produces fine PM strongly enriched in synthetic polymers and plastic additives. Fibres originating from synthetic textiles are also an important fraction of MPs in the atmosphere and their emission indoors and subsequent entry to the outdoor atmosphere may play an important role (Allen *et al.,* 2022).

Secondary MPs are those created in the environment by degradation of larger pieces of plastics. Breakdown of the materials is attributed to UV irradiation, temperature variation, physical wear or oxidative aging which will ultimately lead to the formation of successively smaller fragments and Nanoplastics (Song *et al.,* 2026; Dodero *et al.,* 2025). The creation of secondary particles is important because they introduce MPs into the nanoscale range, increasing their time of flight in the atmosphere and their movement.

Urban, Industrial and Transportation Emissions

In an urban setting this is where microplastic emissions are likely to be most intense. The high density of people and transport, coupled with an accumulation of industrial processes within city limits creates an environment where road dust resuspension, tire wear particle generation, dust from construction; waste handling and similar events lead to high atmospheric concentrations (Klein & Fischer, 2019). In an industrial environment plastic pellet production, the processing of polymers and mechanical processes of plastic items are responsible for the generation of both primary and secondary particle forms through the mechanisms of abrasion and thermal degradation. Traffic networks especially road traffic, contribute significantly to the microplastic burden of ambient air through the generation of TWP, tire wear and brake wear particles, and the abrasion of road surfaces, producing a constant and spatially distributed source category (Kole *et al.,* 2017). Weather effects play a role in urban atmospheric emissions too. Wind speed, and turbulence will lead to greater resuspension of particles from road surfaces and urban environments (From buildings, plants.).

Marine and Terrestrial Re-Emission Processes

Secondary re-emission can account for large amounts of atmospheric microplastic emissions. The surfaces of agricultural soils, landfills, road dust, and industrial sites represent long term storage sites for deposited plastic particles, which can be re-emitted to the atmosphere when the appropriate meteorological conditions are present (Brahney *et al.* 2021). Sea spray aerosolization of the ocean surface releases significant microplastic loads into the atmosphere; as bubbles burst, microplastics are incorporated into the sea-salt aerosol that can be transferred to the atmosphere and transported across oceans and continents (Allen *et al.* 2019; Brahney *et al.* 2020). It is these secondary re-emission mechanisms that account for microplastics detected in pristine locations such as alpine glaciers, polar ice and the open ocean where proximity to terrestrial human sources is extremely low; the atmospheric plastic cycle represents a form of recycling rather than a simple direct emission process.

Major Knowledge Gaps in Source Apportionment

Though considerable advancement has been made, there are still great uncertainties with regard to the quantitative description of and apportionments for each source for atmospheric microplastic pollution. First, the emission inventory values suffer from significant uncertainty attributed to variability in sampling approaches, polymer characterization methods, and inconsistent reporting units (Peries *et al.,* 2024). Second, discriminating primary emission and secondary resuspension remains a methodological difficulty. A significant number of atmospheric particles cannot be attributed to specific sources, because polymers might undergo degradation, mixing, and aging. Third, it's difficult to accurately describe nanoplastic emission due to analysis method limitations. Most of the monitoring strategies are optimized to analyse microplastic, thus lacking the capability to effectively capture and classify nanoscale particles; hence Nanoplastic loading is systematically underestimated (Song *et al.,* 2026). Fourth, geographic bias in monitoring (particularly poor representativeness from the sampling of data across South America, Africa, and portions of Asia) compromises the global validity of source estimates. Consequently, robust global emission models cannot be created; their results are not fully integrated into atmospheric transport models.

Table 1: Major Atmospheric Sources of Microplastics and Nanoplastics (MPs/NPs)

Source Category	Specific Source	Mechanism of Emission	Polymer Types	Atmospheric Relevance
Textile Industry	Synthetic clothing fibres	Mechanical abrasion, washing, drying	Polyester, nylon, acrylic	High (urban + indoor-outdoor transfer)
Road Traffic	Tire and brake wear	Mechanical abrasion of rubber and composites	SBR, PE-based polymers	Very high (continuous emission)

Source Category	Specific Source	Mechanism of Emission	Polymer Types	Atmospheric Relevance
Construction	Building materials, dust	Cutting, grinding, weathering	PVC, PE, PP	High (urban hotspots)
Industrial Processes	Pellet loss, manufacturing	Handling, thermal processing	Virgin polymers	Moderate–high (localized)
Waste Management	Landfills, open burning	Mechanical disturbance, combustion	Mixed plastics	High (regional scale)
Terrestrial Re-emission	Soil and road dust	Wind resuspension	Fragmented plastics	High (secondary source)
Marine Aerosolization	Sea spray, wave action	Bubble bursting, sea-salt formation	Mixed aged polymers	Moderate–high (global transport)
Secondary Fragmentation	UV and oxidative degradation	Photochemical and mechanical breakdown	All polymers	Very high (nanoplastic formation pathway)

Atmospheric Occurrence, Transport, and Deposition of Microplastics and Nanoplastics

Atmospheric micro- and Nano plastics (MPs and NPs) are currently recognized as pervasive components of atmospheric particulate matter. Indeed, they have been identified in urban, rural, marine, alpine and even polar atmospheres. This broad distribution appears to be attributable to the long-range regional to global dispersal of atmospheric particulates via atmospheric transport (Allen *et al.,* 2022; Peries *et al.,* 2024). Furthermore, whereas emission-receptor gradients for traditional atmospheric pollutants are generally stable over time, the atmospheric plastic cycle appears to be much more dynamic in that emissions, re-suspension, atmospheric transport and deposition processes are on-going and pervasive. Data derived from recent observational studies and modelling results support the notion that the atmosphere serves as both a transporter and a temporary sink, forming an interface between the land, ocean and cryosphere, for plastic circulation on a global scale (Ayoub *et al.,* 2025; Wang & Good, 2024).

Global Distribution Patterns

A substantial body of evidence confirms the global presence of atmospheric microplastics in densely populated urban locations and in remote locations such as mountain catchments, polar ice, and open oceans (Brahney *et al.,* 2020; Bergmann *et al.,* 2019). The observed atmospheric microplastic concentrations often exhibit significant spatial variability with higher abundances observed in urban and industrial locations than remote locations. Their presence in remote environments demonstrates that microplastics can be transported large distances (hundreds or thousands of km) by long-range atmospheric transport (LRAT) (Allen *et al.,* 2019; Ayoub *et al.,* 2025). Global atmospheric microplastic emissions appear to be transported globally and redistributed by hemispheric atmospheric circulation patterns including westerlies and monsoons, enabling intercontinental transport and deposition (Long *et al.,* 2023). Reported literature atmospheric deposition flux concentrations vary significantly ranging from 10 to 10 particles m 3 in air samples to 50-700 particles m 2 day -1 in deposition samples.

Urban Versus Remote Environments

Atmospheric microplastic concentrations are generally higher in urban atmospheres, as cities represent the main emission hotspots for atmospheric MPs as they combine areas of heavy traffic, industrial facilities, construction activities and waste management, where resuspension of road dust particles and tire wear accounts for most of the transport mechanisms to the atmosphere (Kole *et al.,* 2017; Peries *et al.,* 2024). Lower, but detectable, microplastic concentrations are measured in remote environments such as Polar Regions, alpine sites or in marine atmospheres that evidence an efficient transport mechanism for MPs to remote areas, as testified by deposition analysis in sheltered natural sites and mountain catchments (Brahney et al., 2020; Allen *et al.,* 2019). A comparative study showed that while cities are emission hotspots in terms of emission density, natural sites could act as deposition sinks.

Particle Characteristics Governing Atmospheric Behaviour

Specific physical and chemical properties of micro-and Nano-plastic particles strongly control their atmospheric fate. The larger the particle size, the greater it's gravitational settling velocity, and the shorter its atmospheric residence time, resulting in increased long-range transport (Fox *et al.,* 2023). Fibrous shape may play a significant role in their ability for long-range transport. They are highly effective for transport, due to their shape which is associated with less efficient deposition compared to spherical fragments. Polymer type and density will determine atmospheric residence time, but aerodynamic diameter is found to be the most appropriate parameter predicting transport processes (Praetorius *et al.,* 2025). Aging causes changes to particle surface characteristics that contribute to alterations in the properties, for instance creating rough surfaces and the introduction of oxygen-containing groups which cause increased hygroscopicity (Song *et al.,* 2026; Dodero *et al.,* 2025).

Long-Range Transport Mechanisms

The transport of atmospheric microplastics over long distances is influenced by vertical mixing within the boundary layer of the planet, uplift to higher atmospheric layers, and horizontal advection by global atmospheric circulation systems. Particles that are transported to higher elevations can remain suspended for days to weeks, which allows for intercontinental transportation (Allen *et al.,* 2019; Ayoub *et al.,* 2025). It has been shown that modelled microplastic particles transport is very similar to coarse-mode aerosols and that the maximum range of particle transport is dependent on particle size distribution and meteorological conditions (Long *et al.,* 2023). Particles that transport far distances into remote regions are typically fibres or fragments and particles that have larger sizes are less likely to travel long distances. Observational studies of mountains, the Arctic and the marine atmosphere show that atmospheric transport is the key method for the global dispersal of plastic materials (Brahney *et al.,* 2021; Bergmann *et al.,* 2019).

Wet and Dry Deposition Processes

Microplastic removal from the atmosphere can happen via both dry deposition and wet deposition. Dry deposition involves gravitational settling, turbulent transfer and surface interception, and is more efficient for the bigger and denser particles, while wet deposition processes including rain-out and wash-out are the most important ones for fine particles and more efficient for removing from the atmosphere (Allen

et al., 2022). Meteorological parameters such as intensity of precipitation, humidity and wind speed are very influential on deposition rate, while seasonal differences in wet deposition flux have also been detected in many areas especially in monsoon and storm seasons (Ji *et al.,* 2025). Deposition processes play important roles as they transfer atmospheric plastic particles to terrestrial and aquatic environment and close the atmosphere section of global plastic cycle.

Monitoring Challenges and Data Uncertainties

In spite of remarkable progress made during the past few years in characterizing atmospheric microplastics, there still exists substantial uncertainty. Discrepancies in methods applied (active vs passive sampling), no consistent particle size thresholds and lack of standardized particle identification (FTIR and Raman Spectroscopy) make a comparison between findings of different studies impossible and contributes to the estimation uncertainties (Habibi *et al.,* 2022). Nanoplastics are almost entirely omitted since current analytical instruments cannot determine the presence of nanoplastics. It can thus be inferred that the atmospheric amount of plastics is systematically underestimated (Praetorius *et al.*, 2025). Additionally, the global database remains geographically imbalanced, and mainly relies on data from Europe, Asia and North America, with a conspicuous absence of Africa and South America. Mismatches between modelled and observed quantities reveal major uncertainties about both emission fluxes, particle size distributions, as well as about the atmospheric residence time of MPs and suggest a clear need for internationally accepted, standardized methodologies and monitoring networks (Ayoub *et al.* 2025).

Table 2: Global Atmospheric Concentrations and Deposition of Microplastics

Environment Type	Concentration Range	Deposition Flux	Dominant Particle Types	Key References
Urban Atmosphere	High variability (up to 10^1 particles m^{-3})	100–700 particles m^{-2} day^{-1}	Fibres, tire wear particles	Allen *et al.* (2022); Kole *et al*. (2017)
Rural Areas	Moderate	50–300 particles m^{-2} day^{-1}	Fibres, fragments	Ayoub *et al*. (2025)
Remote Mountain Regions	Low–moderate	10–200 particles m^{-2} day^{-1}	Fibres dominate	Brahney *et al*. (2020)
Polar Regions	Low but persistent	10–100 particles m^{-2} day^{-1}	Fibres, micro fragments	Bergmann *et al*. (2019)
Marine Atmosphere	Moderate variability	50–400 particles m^{-2} day^{-1}	Aged fragments, sea-spray MPs	Allen *et al*. (2019)

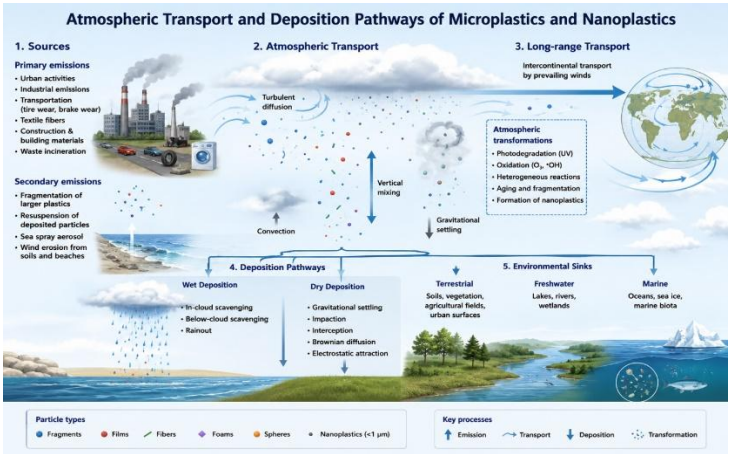

Figure 2: Schematic Representation of Atmospheric Transport and Deposition Pathways

Chemical Aging and Atmospheric Transformation of Microplastics and Nanoplastics

Atmospheric MPs and NPs are not inert during atmospheric transport. Rather, they evolve physiochemically throughout atmospheric transport as a result of solar irradiation and reacting atmospheric oxidants and heterogeneous interaction with the other particles and gases. These aging processes result in structural, chemical, and reactivity transformation of the plastic particles which has the implication for transport dynamics, pollutants interactions and toxicity (Song *et al.,* 2026; Dodero *et al.,* 2025).

Photochemical Weathering

The main mechanism for atmospheric plastics transformation is photochemical weathering. Solar UV irradiation initiates photolysis (polymer chain scission), oxidation and surface embrittlement. These are processes where integrity of the polymer chain becomes increasingly reduced, causing breakdown of polymer fragments into smaller ones and thus secondary particle formation. Degradation processes are a function of polymer type, colour pigment, and environment. Plasticizers, UV-stabilizing agents will retard the process, but the continuous weathering in atmosphere eventually weakens and destabilizes structure making particles easily break up (Dodero *et al.,* 2025). Smaller MP and NP are readily generated from atmospheric weathering.

UV-Induced Oxidation

Photooxidation of plastics in the air results in a change of surface chemistry, leading to the functionalization of the plastics surface with oxygen containing functional groups such as hydroxyl, carbonyl, and carboxyl groups (-OH, -C=O,

-COOH). This change in chemical composition leads to an increase in surface polarity, changing its adsorption properties. Oxidation not only leads to a roughened surface but also a reactive surface towards air. This results in aged microplastics with higher interaction with water vapour and polar pollutants than virgin microplastics and may lead to a greater probability of secondary fragmentation, generating nanoplastics (Song *et al.*, 2026).

Ozone and Hydroxyl Radical Reactions

The transformation of airborne plastic by atmospheric oxidants. O_3 (ozone) and OH (hydroxyl radicals) are extremely reactive species which can be found in the atmosphere. O and OH are able to attack the polymer backbones and therefore cause bond scission and oxidative degradations. OH is important in atmospheric self-cleaning processes; O and OH are initiating radical-mediated oxidative processes on plastic surfaces and contribute to forming oxygen rich functional groups such as carbonyls. Those processes increase their aging and drastically reduce the stability during their permanence (Dodero *et al.*, 2025).

Heterogeneous Atmospheric Chemistry

Aged MPs can be reactive surfaces in heterogeneous atmospheric chemistry. In such oxidation-induced reactive processes, their surfaces become reactive interfaces for gas-particle interactions with NOx, sulphur species, VOCs, and secondary organic aerosols. Those gas-particle reactions will then alter the particle's composition and atmospheric microenvironment. A high surface reactivity enhances an aged plastic's ability to be involved in secondary atmospheric processes, thus becoming a constituent of a larger aerosol chemistry system (Allen *et al.*, 2022).

Surface Functionalization

A surface functionalization is also another effect of atmospheric aging and it means that the surface chemistry of the particles evolves with the progression of the oxidation, adsorption and photodegradation reactions, leading to increasing surface polarity, roughness and hygroscopicity of particles. Functionalized surfaces have a higher affinity to atmospheric pollutants like POPs, PAHs and trace metals. Such a transformation will change fundamentally the role of microplastics in the environment. From merely inert detritus they can be transformed into active transporters of pollutants (Song *et al.*, 2026).

Formation of Nanoplastics

One of the great significance to atmospheric aging is the breakdown of microplastics into nanoplastics. Through exposure to UV radiation, oxidative stress and mechanical forces, polymers break down, continually into smaller particles, including nanoplastics. Nanoplastics show distinctly different behaviours in comparison to microplastics; the former has larger surface-area-to-volume ratio, greater reactivity and a larger probability of moving through the atmosphere and being assimilated into biota. They are difficult to quantify due to limitations in current detection methods; thus significant underestimate is apparent in atmospheric inventories (Praetorius *et al.*, 2025).

Effects of Aging on Mobility and Toxicity

Size, and surface characteristics (surface roughness, hydrophilicity) influence mobility and toxicity. At a physicochemical level, atmospheric aging of airborne plastic, such as decreasing plastic size and increased surface roughness, increased hydrophilicity, has led to increased atmospheric residence time and capacity for long-range transport. The increased capacity for adsorption of toxic species upon aging is thought to contribute to increased toxicity of aged versus fresh plastic, as aging of plastic has shown it can increase adsorption of various species (Revell *et al.*, 2021). There is strong evidence that inhalation of both microplastics and nanoplastics can cause cellular stress responses including inflammation, and potential damage (Song *et al.*, 2026), but especially when mixed with adsorbed pollutants (Revell *et al.*, 2021). Hygroscopicity, a property that changes upon atmospheric aging, will be important for condensation and ice nucleation on the plastic, thereby influencing the chemistry and climate impact of plastic in the atmosphere indirectly (Praetorius *et al.*, 2025).

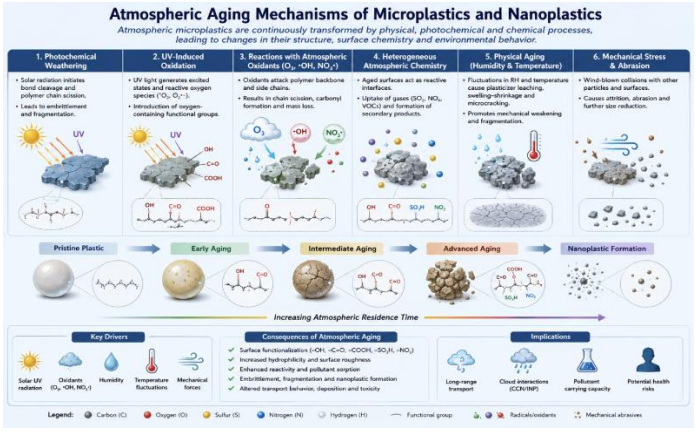

Figure 3: Schematic Representation of Atmospheric Aging Mechanisms

Interactions with Atmospheric Pollutants

The chemical reactive particulate substrate provided by atmospheric microplastics and nanoplastics (MNPs) can interact with diverse categories of air pollutants. Adsorption, accumulation, and transport of organic and inorganic pollutants to and from the hydrophobic polymer surface with large surface-area-to-volume ratio of plastic particles that are subject to oxidative weathering allows these atmospheric plastics to transition from inert debris to reactive components within the atmospheric chemical processes (Allen et al., 2022; Song et al., 2026). The characteristics and degree of interactions between pollutants and plastic depend on many factors such as the type of polymers and aging degree of the plastic, as well as the atmospheric conditions and physiochemical characteristics of the pollutants. It is concluded that the accumulation of MNPs is likely to play an

increasing significant role in the transport and fate of several groups of pollutants.

Persistent Organic Pollutants (POPs)

Since the most studied POPs (including PCBs, organochlorine pesticides and dioxins) are highly hydrophobic in nature, they can strongly associate with plastic surface by hydrophobic partitioning and van der Waals forces. Moreover, sorption capacities for POPs of aged microplastics were shown to be significantly higher than that of fresh microplastics, because oxidation of surfaces and increased roughness can introduce and provide more binding sites for POPs. Therefore, airborne plastics can serve as secondary vectors for the long-range transportation of POPs into the remote areas (Allen et al. 2022; Ayoub et al. 2025).

Heavy Metals

Atmospheric microplastics can also adsorb heavy metals such as lead (Pb), cadmium (Cd), mercury (Hg) and arsenic (As) due to electrostatic attraction, surface complexation and coordination by the oxygen containing functional groups formed in the atmospheric aging. The capacity of metal adsorption is greatly increased by the oxidation of the plastics. The adsorption of heavy metals increased markedly with the aging degree, and the aged particles treated with ozone and hydroxyl radicals can act as transport medium of the toxicity of trace metals in the atmosphere (Song et al., 2026; Dodero et al., 2025).

Polycyclic Aromatic Hydrocarbons (PAHs)

PAHs are also one of the most often found organically associated contaminates associated with airborne microplastics. PAH molecules' flat aromatic structures create stable pi electron interactions between PAH and polymer surface materials, especially with PE, PP, and polystyrene particles. PAH adsorption on MP surface increases after atmospheric ageing process because the increase of polarity of MP surface and the formation of microstructural defects for the sorption. Thus, MPAHs may increase exposure risk by inhalation, especially in urban air due to the abundant emission sources with combustion-derived PAHs (Allen et al., 2022).

PFAS and Emerging Contaminants

PFAS and other emergent contaminants have gained attention in research concerning microplastics in the atmosphere. PFAS are unique in terms of physicochemical properties and possess qualities that enable interaction with atmospheric particles such as their inherent persistent, surfactant, and refractory characteristics. Adsorption of PFAS to plastic particles was recently demonstrated by hydrophobic and electrostatic interactions, particularly within aged/oxidized plastics, potentially leading to enhanced long-range atmospheric transport and global dispersion of PFAS (Brenckman et al., 2026; Rahim et al., 2025). The prevalence of both contaminants co-occurring in the atmosphere calls attention to coupled exposure pathways and combined environmental impacts, although details are largely unknown.

Microplastics as Reactive Pollutant Carriers

However, atmospheric microplastics are moving beyond being merely inert carriers, to becoming reactive pollutants that are active in changing the atmospheric chemistry. They are capable of altering the fate, transport, and transformation of associated pollutants, through heterogeneous reactions and surface mediated processes. Due to their increased oxygenated functional groups and roughness (after aging), atmospheric microplastics can bind to other pollutants more strongly and participate in the atmospheric chemical cycles. They thus serve as a combination of pollutants transporter and a reactive surface, which may indicate they are growing players within atmospheric aerosol chemistry system (Song et al., 2026; Dodero et al., 2025).

Table 3: Pollutant–Microplastic Interactions in the Atmosphere

Pollutant Class	Representative Compounds	Interaction Mechanism	Role of Aging	Environmental Implication
Persistent Organic Pollutants (POPs)	PCBs, OCPs, dioxins	Hydrophobic partitioning, van der Waals forces	Increased sorption via surface oxidation	Long-range transport and persistence
Heavy Metals	Pb, Cd, Hg, As	Electrostatic attraction, complexation	Enhanced binding via oxygen functional groups	Toxic metal redistribution
PAHs	Benzo[a]pyrene, fluoranthene	π–π stacking, hydrophobic interaction	Increased adsorption via surface roughness	Elevated inhalation exposure risk
PFAS	PFOA, PFOS	Hydrophobic + electrostatic interactions	Stronger binding on aged polymers	Global transport of persistent chemicals
Emerging Contaminants	Pharmaceuticals, flame retardants	Mixed sorption mechanisms	Aging-dependent reactivity	Complex exposure mixtures
General Atmospheric Pollutants	VOCs, NO_x, SO_2	Heterogeneous surface reactions	Increased surface reactivity	Altered atmospheric chemistry pathways

Climate and Human Health Implications of Atmospheric Microplastics and Nanoplastics

The detection of atmospheric MPs and NPs is not just an indication that these materials are new environmental pollutants but also the development of important atmospheric processes including radiative effects, cloud microphysics, and impacts on human health. MPs and NPs behave in the atmosphere very similarly to traditional aerosol types like dust, black carbon, and organic carbon; however, they introduce a greater complexity due to their varied chemical properties, age-related surface transformations, and contaminant loading (Allen *et al.*, 2022; Revell *et al.*, 2021). It has been recently shown that Plastics in the atmosphere can remain in the atmospheric column, be transported over long distances, and interact with radiation, clouds, and the

respiratory system placing plastics at the boundary of climate and health sciences (Ayoub *et al.,* 2025; Le *et al.,* 2023).

Microplastics as Atmospheric Aerosols

Once in the atmosphere, microplastics can be considered as aerosols, where the physical processes driving transport are dominated by the aerodynamic diameter, density, morphology and atmospheric turbulence. Fibres of a smaller size and the presence of low-density plastics result in an increased atmospheric residence time, which favours transportation at regional and intercontinental scales (Allen *et al.,* 2019; Brahney *et al.,* 2021). A study has also validated the way these anthropogenic plastics become part of the existing atmospheric aerosol composition and can be transported like any coarse-mode particle, as also identified in several modelling studies. The classification of plastic as anthropogenic aerosol has significant implications for atmospheric chemistry and climate modelling. High pollution zones such as cities and industrial areas are expected to be significant sources of atmospheric plastics (Ayoub *et al.,* 2025).

Radiative Forcing and Energy Balance

Microplastics in the atmosphere may impact the Earths radiative energy budget via scattering and absorption of incoming solar radiation and outgoing thermal radiation. Radiative forcing estimates from models, though highly uncertain, now suggest that MP can provide a net radiative forcing over the planet ranging from weak cooling to weak warming depending on size, optical properties and colour of the MP particles (Revell *et al.,* 2021; Goddard *et al.,* 2025). The role of more absorption-prone materials such as collared/dark and carbon-rich plastics compared with transparent/reflective particles may play a role at a localised warming or scattering-induced cooling capacity, respectively. The magnitude of global radiative forcing is minor in comparison with main aerosols; however, persistent emissions of plastics make their climatically relevant potential a consideration for future scenarios (Joo, 2026).

Cloud Condensation and Ice Nucleation Potential

A significant area of emerging research involves the role of microplastics as CCN and INPs. Laboratory and field studies demonstrate that particular polymer types such as polypropylene (PP) and polyethylene terephthalate (PET) are capable of nucleating ice within super cooled cloud droplets at atmospheric-relevant conditions for mixed-phase clouds (Seifried *et al.,* 2024). Ice-nucleating properties of polymers are affected by atmospheric aging (oxidation from ozone or UV), which changes the surface chemistry and functional groups. These effects have been observed to both increase and have little impact on nucleation ability and depend on the structure of the polymer and previous exposure (Seifried *et al.,* 2024). These studies suggest that microplastics could influence cloud microphysical properties, precipitation regimes and the atmospheric lifetime of aerosol particles but to what extent it impacts the climate is still being investigated (Aeschlimann *et al.,* 2022).

Secondary Organic Aerosol Formation

Atmospheric microplastics could indirectly influence Secondary Organic Aerosol (SOA) formation via heterogeneous reactions with VOCs and oxidants. Reactive surfaces are present on oxidized plastics, which allow the adsorption and conversion of organic vapours. The presence of microplastics could lead to enhanced SOA yields in polluted conditions (in an urban setting) and/or when VOC concentrations are high. Aged plastics could also provide a platform for multiphase chemistry with complicated kinetics. Such chemistry can change the composition of the aerosol and influence particle growth (Dodero *et al.,* 2025; Allen *et al.,* 2022). While largely unstudied, this pathway links microplastics with a well-established suite of atmospheric chemistry driven primarily by anthropogenic emissions and natural aerosol.

Human Inhalation Exposure and Toxicological Concerns

Humans are mainly exposed to atmospheric MPs and NPs through inhalation of the airborne particles. The highest concentrations of airborne MPs and NPs are found in indoor environments and cities. Because of their small size, NPs can deposit deep into the respiratory tract, and may even reach the alveoli. Even to the extent of NPs entering the bloodstream and being able to transfer to the circulatory system. Toxicological studies demonstrate that inhaled MPs may cause oxidative stress, inflammation, immunity, and damage of cells, especially when MPs have pollutants such as PAHs, heavy metals and POPs adsorbed on them (Wang *et al.,* 2025; Lamichhane *et al,* 2023). It is also emerging that chronic exposure to MPs may be linked with respiratory and cardiovascular diseases; although evidence based on human long-term epidemiological studies is currently lacking. NPs raise particular concern, as their greater surface-area-to-volume ratio and biological reactivity will enhance NPs interactions with cells and potential to cross the barriers (Le *et al.,* 2023). The risk of these hazards is increasing; however, there are major gaps concerning human exposure limits, dose-response relationships and long-term health consequences. Therefore, standardized analytical method and toxicology assessment guidelines need to be developed to establish human health risks accurately.

Knowledge Gaps and Future Research Priorities

Though research on atmospheric MPs and NPs has flourished in recent years, significant knowledge gaps remain in detection, quantification, and modelling and risk assessment of MPs/NPs in the atmosphere. This review, in accord with other literature, confirms that methodological variations, analytical limitations, and global insufficient data sets are key impediments in elucidating the atmospheric cycle of plastic (Zheng *et al.,* 2024; Song *et al.,* 2026).

Nanoplastic Detection Challenges

Detecting and quantifying nanoplastics (<1 μm) represents a major obstacle in atmospheric microplastic studies. Existing analytical techniques, such as FTIR and Raman spectroscopy, have detection limitations of >10-20 m and thus will always systematically underestimate the smallest sizes of microplastics (Yang *et al.,* 2021; Zheng *et al.,* 2024). Nanoplastics should be a primary concern given their larger surface area to volume ratio, increased reactivity, and capacity to cross biological membranes, but there are no standardized methods for detecting these materials and no verified references to ensure reproducibility between studies. Further analysis techniques like pyrolysis-GC/MS, thermal desorption, and high-resolution mass spectrometry are showing promise but are not yet adequate for regular atmospheric surveillance (Liu *et al.,* 2025).

Standardization of Sampling Protocols

A primary factor that hinders comparability of various studies is inconsistency in sampling methodology. Presently, atmospheric microplastic are sampled using two methods: active sampling (high volume air samplers) and passive

sampling (deposition collectors), where inconsistencies in terms of mesh sizes, sampling times and filter material are commonly found (Mbachu *et al.,* 2020; Zheng *et al.,* 2024). Additionally, the inconsistencies in sample pre-treatment methodology (density separation, digestion methods, contamination control) further contribute to variation in reported concentrations between different studies. It is agreed through recent scoping reviews that there is a critical need for globally harmonized methods to allow for meaningful comparison between studies, and accurate estimation of emission inventory (Rahim *et al.,* 2025).

Atmospheric Modelling Uncertainties

In terms of atmospheric transport modelling, microplastic models are in their nascent stage relative to mature aerosol models. Current atmospheric transport models such as GEOS-Chem derived model utilize many oversimplifying assumptions in emissions, particle size distributions and deposition velocity (Ayoub *et al.,* 2025). The largest uncertainties are that of emission inventories (especially differences in emission sources: ocean vs. Land), size resolved emission parameters (poorly constrained), observations to validate models (lacking) and simulation of particle aging and fragmentation (underestimated) that are a direct result in the high uncertainties associated with the estimated global mass flux and long range transport (Song *et al.,* 2026; Long *et al.,* 2023). Enhancement of the incorporation of observations and/or the development of inverse modelling methods is necessary to decrease these uncertainties.

Climate Feedback Mechanisms

Little is known about the potential feedback of atmospheric microplastics (MPs) on the climate. Initial research suggests MPs may affect radiative forcing, cloud microphysics, and aerosol-radiation interactions but these have a large degree of uncertainty associated with them, and are largely not yet accounted for in most climate models (Revell *et al.,* 2021; Seifried *et al.,* 2024). Outstanding questions remain about how radiative forcing differs between polymer types, the interaction of aged and pristine particles with ice condensation and ice nucleation, and what the feedback could be for regional climate systems. A lack of standardized optical and physicochemical properties datasets is also a major gap in research, and the incorporation of MPs in Earth System Models.

Emerging Analytical Technologies

Advances in analytical chemistry and materials science are helping to overcome shortcomings in microplastic identification methods. These newer techniques including thermal extraction desorption GC/MS, hyperspectral imaging, nano-FTIR, and single particle mass spectrometry have begun to be utilized on samples collected from the atmosphere (Liu *et al.,* 2025). Automated classification of particles using artificial intelligence (AI) and machine learning shows significant potential to both increase particle identification accuracy and processing efficiency. These technologies are currently under development and are lacking in standardized calibration sets before large-scale implementation can be expected (Zheng *et al.,* 2024). Analytical approaches utilizing multi-technique analytical strategies that are simultaneously capable of resolving particle size, polymer type and chemical aging state need to be explored in the future.

Policy and Regulatory Priorities

Though increasingly accepted within the scientific community, there is yet to be a inclusion of atmospheric microplastics in mainstream environmental monitoring or regulations. This is considered a major governance gap especially since recent studies highlight their pervasive nature and health risks (Peries *et al.,* 2024). Policy should focus on: Creating a global monitoring network for atmospheric microplastics; Developing consistent sampling methods and analytical protocols; Integration of microplastics into air quality regulations, as well as implementing emission control policies to minimize microplastic sources from tire wear, textile fibre abrasion and waste management. Policy makers need a better understanding of exposure routes, toxicological limits and persistence of the environmental system before developing a useful policy.

Figure 4: Schematic Representation of Research Roadmap for Atmospheric Microplastic Science

CONCLUSION

Atmospheric microplastics (MPs) and nanoplastics (NPs) are emerging as a class of Anthropogenic Particles Pollutant, being globally distributed and showing complex Environmental, Chemical, Climatic and health implications. Synthesized herein, the evidence collected demonstrate that the atmosphere is indeed playing a crucial role within the global plastic cycle, being at once a transport medium, a transformation reactor and a depositional compartment that connects terrestrial, marine and cryospheric systems (Ayoub *et al.,* 2025; Allen *et al.,* 2022). From evidence shown the sources of atmospheric plastics can be diverse primary

sources (Urban emissions through traffic and industries, textile fibres) and secondary sources (re-suspension of MPs and NPs from terrestrial and marine reservoirs). Airborne plastic particles are transported over long distances being detected even in remote environments like Polar Regions, mountain catchment areas and Open Ocean (Brahney *et al.*, 2020; Bergmann *et al.*, 2019). Therefore, the plastic pollution is interconnected in a global net due to atmospheric pathways. The findings demonstrate also that atmospheric processing and aging change substantially the MPs and NPs physicochemical properties. The photochemical oxidation and heterogeneous atmospheric chemistry involved in aged plastic's transformations not only change their morphology, increase their surface reactivity and promote MPs fragmentation into NPs (Song *et al.*, 2026; Dodero *et al.*, 2025) but may also enhance their sorption ability toward many more co-occurring pollutants and influence their environmental and toxicological behaviour.

Added to their transport functions the atmospheric MPs and NPs may carry a multitude of contaminants. These latter encompass persistent organic pollutants, heavy metals and polycyclic aromatic hydrocarbons, as well as emerging contaminants such as PFAs. Through this association, plastic pollutants may be more mobile in the environment, leading to an increased environmental and human health risks (Brenckman *et al.*, 2026; Allen *et al.*, 2022). The capacity of plastic's aged products to adsorb and carry toxic compounds shows that MPs are more like a "vector" of secondary pollutants rather than a simply inert particle. Climatically, they may influence Earth's climate in term of radiative interactions, cloud microphysics and secondary aerosol formation processes. While their radiative forcing impact is highly uncertain at the current stage, evidence of MPs and NPs as CCN and IN is growing (Seifried *et al.*, 2024; Revell *et al.*, 2021) although they have not yet been implemented into Earth system models. From the health perspective inhalation exposure is a dominant pathway, especially for human populations living in urban environments. NPs show a greater health risk as they can penetrate the deep lung, potentially moving into the bloodstream and other systemic targets. They were already associated to several health outcomes like oxidative stress, inflammation and DNA damages (Wang *et al.*, 2025; Le *et al.*, 2023) especially when adsorbed with organic and inorganic contaminants; nevertheless epidemiological long term studies are still lacking.

In conclusion there are still many knowledge gaps related to NP detection methods, standard monitoring procedures, climate modelling and emission inventories of plastics, as well as insufficient data about un-monitored areas of the world, necessary to build up robust global assessments (Zheng *et al.*, 2024; Rahim *et al.*, 2025). It is then clear that further monitoring activities are required to increase knowledge on atmospheric plastic contamination and associated risks and impacts for the planet.

RECOMMENDATIONS

Based on the findings of this review, several priorities should be addressed to advance the understanding and management of atmospheric microplastics (MPs) and nanoplastics (NPs).

i. The development of standardized sampling, extraction, and analytical protocols is urgently needed to improve data comparability across studies and regions. Particular attention should be given to the detection and quantification of nanoplastics, which remain poorly characterized due to current methodological limitations.
ii. Future research should focus on refining atmospheric transport and deposition models by incorporating particle aging, fragmentation, and source-specific emission inventories. Such improvements will enhance predictions of long-range transport pathways and environmental fate.
iii. Finally, policymakers should integrate atmospheric microplastics into existing air quality monitoring and pollution control frameworks while promoting source-reduction strategies targeting tire wear, synthetic textile emissions, plastic waste mismanagement, and industrial releases. Coordinated international monitoring programs and regulatory initiatives will be essential for mitigating the growing burden of atmospheric plastic pollution.

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