Atmospheric Dust and Air Quality over large-cities and megacities of the World

This is a generally well-written paper on an important topic. I have only a few relatively minor suggested revisions.

The authors would like to thank the reviewer for his time, comments and suggestions. We did our best to incorporate the proposed changes and corrections in the revised manuscript, aiming at improving the presented paper. Following, you will find our responses, one by one to the comments addressed.

Kind regards,
Emmanouil Proestakis et al.

Reviewer's Comments

The text is somewhat wordy. It would benefit from a read-through to streamline and eliminate redundancies. For example, the beginning of Section 6 is redundant with the portion of Section 1 that describes the health impacts of coarse and fine particles.

The authors agree with the reviewer.
Following the reviewer's suggestion the beginning text of Section 6 has been removed and replaced as follows:

from: "To date, numerous epidemiological studies have reported associations between elevated levels of airborne dust and adverse health effects. According to the revealed outcomes, coarse mineral particles are considered to pose a low health risk, primarily causing mild skin irritation or allergic reactions, even under conditions of prolonged exposure and high concentrations (Sandstrom, 2008; Pérez García-Pando et al., 2014). However, finer dust particles, particularly those in the PM2.5 fraction, present a greater concern due to their ability to penetrate deep into the respiratory system and reach the alveolar region (Martinelli et al., 2013; Lazaridis, 2023). More specifically, exposure to fine-mode dust has been linked to a range of health outcomes, including, among others, cardiovascular (Kwon et al., 2002; Meng and Lu, 2007; Middleton et al., 2008; Prospero et al., 2008; Sandstrom and Forsberg, 2008; Pérez et al., 2012; De Longueville et al., 2010; Martinelli et al., 2013; Goudie, 2014; Zhang et al., 2016; Achakulwisut et al., 2018; Querol et al., 2019) and respiratory diseases (Kwon et al., 2002; Wiggs et al., 2003; Chen et al., 2004; Veranth et al., 2004; Park et al., 2005; Derbyshire, 2007; Meng and Lu, 2007; Cheng et al., 2008; Yoo et al., 2008; De Longueville et al., 2010; 2013; Leski et al., 2011; Goudie, 2014; Katra et al., 2014; Mueller et al., 2017; Middleton, 2020), as well as an increased risk of lung cancer (Giannadaki et al., 2014; Steenland and Ward, 2014).".

to: "To date, numerous epidemiological studies report on the adverse effects of airborne dust on human health, with more pronounced the impact of the fine-mode ($PM_{2.5}$) due to the deeper penetration into the respiratory system and the alveolar region (Martinelli et al., 2013; Lazaridis, 2023).".

Along the same lines, the portion of Section 1 that describes the importance of atmospheric dust in terms of its "effects on biogeochemistry, the radiation budget, weather, and climate" (lines 47-66) is too detailed. The study focuses on the health impacts of dust, so the importance of atmospheric dust's impacts on human health should be the focus. Briefly mentioning the important of dust in other fields would be sufficient.

The authors agree with the reviewer.
Following the reviewer's suggestion the beginning text of Section 6 has been removed and replaced as follows:

from: "Among the aerosol species resulting in degradation of air quality are mineral dust particles, especially over densely populated and heavily industrialized areas (Papachristopoulou et al., 2022; Proestakis et al., 2024). More specifically, atmospheric dust is recognized as one of the most important aerosol types, both in terms of mass and optical depth, and the dominant component of atmospheric aerosol over large areas of the Earth (Gliß et al., 2021; Kok et al., 2017; 2021; 2023). Once suspended in the atmosphere, dust exerts a multifaceted and complex role in the Earth's climate system, while simultaneously posing considerable challenges to anthropogenic activities. More specifically, upon entering the atmosphere, dust particles are subject to aeolian transport, in many cases over distances of thousands of kilometres downwind (e.g. Prospero, 1999a, 1999b;

Dey et al., 2004; Schepanski et al., 2009; Kanitz et al., 2014; Weinzierl et al., 2016; Marinou et al., 2017; Proestakis et al., 2018; 2024; Ramaswamy et al., 2018; Adebiyi and Kok, 2020; Aslanoğlu et al., 2022; Drakaki et al., 2022; Gkikas et al., 2022). While airborne, dust particles affect several atmospheric processes, spanning from short- (weather) to long- (climate) term temporal scales, via their interactions with the shortwave (SW) and longwave (LW) radiation. Dust aerosols serve as effective cloud condensation nuclei (CCN; Hatch et al., 2008) and/or ice-nucleating particles (INPs; DeMott et al., 2009). Atmospheric dust layers modify clouds' microphysical, macrophysical and optical properties, precipitation patterns, atmospheric stability, cloud formation, lifetime, and coverage (Twomey, 1977; Albrecht, 1989; Rosenfeld et al., 2008). Dust is considered a significant parameter related to aviation safety (Papagiannopoulos et al., 2020; Nickovic et al., 2021; Ryder et al., 2024) while, by reducing the amount of SW radiation reaching the Earth's surface, dust layers affect solar energy production (Kosmopoulos et al., 2018; Masoom et al., 2021; Fountoulakis et al., 2021). Eventually, upon their removal from the atmosphere, through wet or dry deposition (Gao et al., 2003; Hand et al., 2004; Prospero et al., 2010; Mahowald et al., 2011; Van der Does et al., 2018; 2021; Proestakis et al., 2025), dust particles enrich with micro nutrients the marine and terrestrial ecosystems (Okin et al., 2004; Jickells et al., 2005; Li et al., 2018).".

to: "Among the aerosol species resulting in degradation of air quality are mineral dust particles, especially over densely populated and heavily industrialized areas (Papachristopoulou et al., 2022; Proestakis et al., 2024). Atmospheric dust is the dominant component of atmospheric aerosol over large areas of the Earth (Gliß et al., 2021; Kok et al., 2017; 2021; 2023). Transported over thousands of kilometres (e.g. Prospero, 1999a, 1999b; Dey et al., 2004; Schepanski et al., 2009; Kanitz et al., 2014; Weinzierl et al., 2016; Marinou et al., 2017; Proestakis et al., 2018; 2024; Ramaswamy et al., 2018; Adebiyi and Kok, 2020; Aslanoğlu et al., 2022; Drakaki et al., 2022; Gkikas et al., 2022), dust interacts with radiation, clouds, and precipitation (Twomey, 1977; Albrecht, 1989; Hatch et al., 2008; Rosenfeld et al., 2008; DeMott et al., 2009), affecting weather, climate, aviation safety, and solar energy production (Kosmopoulos et al., 2018; Papagiannopoulos et al., 2020; Fountoulakis et al., 2021; Masoom et al., 2021; Nickovic et al., 2021; Ryder et al., 2024). Ultimately, upon deposition (Gao et al., 2003; Hand et al., 2004; Prospero et al., 2010; Mahowald et al., 2011; Van der Does et al., 2018; 2021; Proestakis et al., 2025) dust particles enrich with nutrients marine and terrestrial ecosystems (Okin et al., 2004; Jickells et al., 2005; Li et al., 2018).".

The authors never address the fundamental question of why they used remote sensing data, i.e. CALIPSO and AERONET, to analyze the impacts of dust on surface air quality, instead of surface PM_{10} and $PM_{2.5}$ monitors. Do the 81 cities analyzed have PM monitor networks? Were PM monitor data used to, for example, validate the ESA-LIVAS atmospheric dust products? Using surface monitor data would counteract the shortcomings of the remote sensing dataset, such as the impacts of clouds and the coarse 1°x1° spatial resolution. I suspect I know the reasoning for the authors' focus on remote sensing data, but they need to clearly justify their choice in Section 1. This is a glaring omission that will puzzle any air quality experts reading the paper.

The authors appreciate the reviewer's observation and the opportunity given to clarify even more the rationale for using the CALIPSO-based LIVAS climate data record and remote sensing data, instead of surface PM10 and PM2.5 monitors. As such, towards clarifying the above conceptual approach of the authors and the motivation that lies behind the study, and following the reviewer's recommendation and valid comment the following text is included in the manuscript in the Section "Introduction":

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To date, in-situ measurements of particulate matter represent the most direct and reliable source of information on ambient air quality (including of the dust aerosol component), allowing for high temporal resolution measurement, low detection thresholds, and the capacity to distinguish between PM10, PM2.5 and even finer size fractions with high precision. Established under networks, such as OpenAQ (https://openaq.org/; last access: 16/09/2025), IQAir (https://www.iqair.com/air-quality-map; last access: 16/09/2025), and SPARTAN (https://www.spartan-network.org/; last access: 16/09/2025), in situ PM measurements are widely used for regulatory purposes, and are considered indispensable, among others, for health impact assessments, epidemiological studies, local air quality management and empowering evidence-based decision-making. More specifically, ground-based in situ monitoring stations provide unparalleled air quality measurements, enabling researchers, policymakers, and the public to track the aerosol load over time, to identify pollution hotspots, evaluate the effectiveness of environmental regulations, and allowing public health studies and air quality forecasting. In the case of the dust aerosol component in situ measurement have significantly contributed through shedding light on dust outbreaks over specific regions in terms of concentrations, phenomenology, and trends, and on dust relation with synoptic and mesoscale meteorology

(Querol et al., 2009; 2013), the contribution to daily PM10 concentrations (Stafoggia et al., 2016), and the broader impact on air quality (Querol et al., 2019).
Nevertheless, despite these significant advantages numerous challenges inherent to the complex nature of in situ measurements of ambient air quality hamper the feasibility of establishing and providing long-term and continuous measurements of high spatial and temporal coverage. More specifically, surface monitoring stations and networks of monitoring stations are not uniformly operational and available across the globe. Even in the case of large cities and megacities, particularly in the case of cities of Africa, parts of Asia, Middle East, and South America, monitoring stations are sparse or even completely absent, while even where networks exist, the provided aerosol load measurements are frequently characterized by non-continuity in terms of temporal coverage due to instrument operation, maintenance, malefactions, or resource limitations. Moreover, different types of instruments and measurement protocols introduce inconsistencies across regions, while spatial representativeness remains limited, as most stations are confined to specific urban environments and may not adequately capture variability within a metropolitan or larger city area.
Towards addressing these formidable challenges air quality monitoring frequently relies on satellite-based earth observations of the aerosol load, offering unique advantages in terms of spatial consistency, global coverage, and the ability to provide long-term, homogeneous datasets across large regions where monitoring networks are incomplete or even completely absent, though with lower accuracy than the accuracy offered by in-situ measurements. However, and despite the increasing number of scientific studies indicating that airborne mineral dust constitutes a significant environmental hazard and risk factor for human health, current knowledge on the dust health impacts, when it comes to incorporating EOs is still characterized by large uncertainties, primarily attributed to three key challenges.
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