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Perspectives on the Desert dust Contribution to Ice Nucleation in Mixed-phase Clouds and Associated Radiative Forcing

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Wind-driven erosion of arid and semi-arid surfaces produces desert dust, the primary source of ice-nucleating particles (INP) in the atmosphere. These particles play a crucial role in the phase partitioning of mixed-phase clouds (MPCs) by influencing heterogeneous freezing processes. As global warming progresses, the shift from ice to liquid water in MPCs is anticipated to increase cloud reflectivity, potentially cooling the planet. However, the uncertainty surrounding this negative cloud-phase feedback is substantial, mainly due to uncertainties in the magnitude, spatiotemporal distribution, and trends of INP.

In dust-enriched environments, MPC glaciation is intricately linked to dust abundance and INP efficiency. Increased dust concentrations may enhance ice crystal formation, reducing overall cloud albedo and inducing a positive radiative effect, thereby diminishing the negative cloud-phase feedback. Currently, significant knowledge gaps impede the accurate representation of INP abundance, trends, and physical/chemical properties, hindering our understanding of its impact on ice formation in MPCs and climate.

This review assesses the current state-of-the-art in representing and quantifying the contribution of desert dust to ice nucleation in MPCs and its associated radiative forcing. Additionally, we offer a perspective on how new observational constraints, such as historical dust trends, satellite retrievals of quartz and feldspar surface abundances, recent measurements of mineral size distributions and mixing state at emission, and improved modeling with tailored ageing schemes, could help mitigate the existing uncertainties in estimating dust forcing via interactions with mixed-phase clouds.