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EDITORIAL: PREFACE

Atmospheric and Earth System Modeling towards Coordinated Pollution Control and Climate Change Mitigation

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The intertwined challenges of air pollution and climate change represent a critical environmental dilemma of our time. These issues are inextricably linked through shared emission sources, coupled physical and chemical processes, and a common solution space in the transition to a sustainable future. Advanced atmospheric and Earth system modeling is therefore an indispensable tool for developing coordinated strategies that maximize co-benefits. This special issue, "Atmospheric and Earth System Modeling towards Coordinated Pollution Control and Climate Change Mitigation," showcases cutting-edge research that enhances our modeling capabilities to address this complex nexus. The contributions collectively advance model fidelity and integration across scales, from fundamental particle properties to regional pollution transport and climate impacts.

The journey towards effective mitigation begins with better diagnostics. The study "Data-driven machine learning quantifies ozone transport in the Hangzhou Bay urban cluster" demonstrates a paradigm shift, using machine learning to dissect complex pollutant transport patterns. This provides a granular understanding essential for designing targeted, regionally coordinated control measures. Complementing this, the perspective on the "Urgency and importance of local-scale modeling tools" argues for downscaling climate focus, bridging the gap between global projections and local adaptation needs for urban resilience.

A robust scientific foundation requires a deep understanding of fundamental processes. The comprehensive review, "Modeling the formation of aerosols and their interactions with weather and climate", sits at the heart of this nexus. It systematically dissects current knowledge and uncertainties regarding aerosols, which affect both human health and the Earth's radiative balance, providing a crucial roadmap for model improvement. Building on the need for higher fidelity, the research on "Advancing high-resolution modeling to unravel the interplay between extreme weather events and air pollution" tackles a key societal threat. It highlights how high-resolution simulations are vital for projecting compound hazards, such as pollution episodes during heatwaves and wildfires in a warming climate. Finally, refining core model physics is vital for predictive accuracy. The study on "Advanced modeling of the absorption enhancement of black carbon particles" addresses a critical detail with global significance. By refining the representation of black carbon aging in models, this work helps reduce major uncertainties in estimating its climate warming impact, directly informing the prioritization of mitigation efforts.

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Looking forward, the insights from this issue point to converging pathways for future modeling. The integration of data-driven machine learning with process-based physical models will create a new generation of efficient and powerful hybrid tools. The vision of high-resolution "Digital Twins" of the Earth system promises to revolutionize environmental prediction but will require unprecedented computational resources and data fusion. Furthermore, strengthening the coupling between atmospheric models and broader Earth system components, including human systems, is the next frontier for holistic assessment. The ultimate goal is to evolve our modeling frameworks into accessible, policy-relevant platforms that can quantitatively evaluate the co-benefits and trade-offs of intervention strategies. The research presented here represents significant strides toward this goal, affirming that in the face of interconnected challenges, our solutions must be equally integrated and guided by sophisticated science.