Improved microphysics modeling of clouds

May 11 2023

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Clouds are made up of individual, microscopic spheres of water, or hydrometeors, that change and interact with one another based on environmental conditions and the characteristics of the hydrometeor population, such as size and water phase: liquid, ice or vapor.

Improved modeling of the effects of environmental conditions on hydrometeor populations can enhance short- and longer-term weather forecasting and optimize solar energy capture. This review highlights understudied, yet promising areas of cloud microphysics and modeling and outlines the future challenges and directions of this emerging field.

The microscopic hydrometeors that make up clouds vary based on their size and water phase. Processes such as condensation and other, less obvious processes, like turbulence, radiative effect, lightning and chemical processes, interact with one another to regulate the hydrometeor population and the characteristics of a cloud at the microscopic level. Modeling the effects of processes on hydrometeors both individually and collectively with other processes is immensely challenging.

A team of leading atmospheric scientists, including researchers from Brookhaven National Laboratory, U.S.; McGill University, Canada; Nanjing University of Information Science and Technology, China; and the National Center for Atmospheric Research, U.S.), identified areas where more research is required to improve modeling equations and challenges that will need to be overcome to improve weather forecasting, climate prediction and solar energy harvesting to optimize the use of renewable energy sources.

The research team published their review in *Advances in Atmospheric Sciences*.

"We wanted to review some key aspects of explicit modeling and representation in various computer models of cloud microphysics, identify outstanding challenges, and discuss future research directions," said Yangang Liu, first author of the team's review and senior scientist in the Environmental and Climate Sciences Department at Brookhaven National Laboratory in Upton, New York, U.S..

"This review integrates different topics on which each of the co-authors have expertise into a cohesive unification, including different approaches for developing bulk microphysics parameterizations (approximate representations), … explicit modeling, and theoretical formulations. We believe that such an integrated approach is crucial for further advancing the field," said Liu.

"Cloud microphysics and their representation is becoming increasingly important as the resolutions of numerical weather prediction and climate models improve. Furthermore, significant knowledge gaps remain and need to be addressed in our physical understanding of cloud microphysical processes [such as] turbulence-microphysics interactions," said Liu.

Relatively little is known about the effects of small-scale turbulence on hydrometeors and other processes in the cloud. Turbulence-related processes, in particular, have not been included in most atmospheric modeling, despite the important role turbulence plays in the microphysics of clouds. Additional research in this area could significantly improve future modeling .

Liu and his colleagues identified several other challenges that, once overcome, will greatly advance the field's understanding of cloud processes and improve prediction. For example, comparing the different cloud microphysics modeling strategies to one another and understanding how and why they differ could enhance the accuracy of each platform. Additionally, seeking effective evaluation and integration of models and observations at different scales is needed to address cloud-related problems.

Increased computational power and use of artificial intelligence will also present new tools for researchers to improve the modeling of cloud microphysics in the future. Direct numerical simulations (DNSs), in particular, require a great deal of computing power to resolve individual hydrometeor particles, but have already significantly advanced modeling of warm cloud processes.

"We plan to further advance the specific areas each of us [has] been focusing on as well as go beyond our comfort zones to seek effective integration by capitalizing on advances in other disciplines such as computational technologies, machine learning and complex systems science, including development of bulk microphysics parameterizations, explicit modeling, and theoretical formulations," said Liu.

More information: Yangang Liu et al, Parameterization and Explicit Modeling of Cloud Microphysics: Approaches, Challenges, and Future Directions, *Advances in Atmospheric Sciences* (2023). DOI: 10.1007/s00376-022-2077-3

Provided by Chinese Academy of Sciences